Joost van Hoof
George Demiris
Eveline J.M. Wouters
Editors

Handbook of Smart Homes, Health Care and Well-Being

SpringerReference

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Handbook of Smart Homes, Health Care and Well-Being

With 172 Figures and 20 Tables

Springer Reference

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Preface

For centuries, home has been "where the heart is." Although vernacular architectures differ all over the world, the saying is familiar in all cultures. Housing and architecture are rooted in traditions, and often based on whatever building materials were locally available. After the Second World War, something changed in these traditional houses. We witnessed the emergence of the electronic age, during which numerous electric household appliances were introduced in the home environment all over the industrialized world, such as television sets, and some decades later, personal computers. Globalization and standardization in interior designs and the adoption of technologies emerged. The new machines provided people with the possibility to stay in touch with one another or assist in doing household tasks. The traditional home of the past from that moment on has turned into a hybrid dwelling that combines traditional building materials and architectural elements with modern technologies. So-called smart homes are an extrapolation of modern technologies entering the home environment. Smart homes can help people monitor their health status and overall mobility, can support occupants in controlling the indoor environment as they engage in activities of daily living, react to their presence, e.g., by adapting the light, connect residents with remote family members and health care providers, detect abnormal patterns in daily living over time, and in some cases even detect emergencies and notify others by generating alarms. Smart home technologies hold a great promise for the future of healthcare and well-being of older adults, people with disabilities, and the general population overall.

As a result of biomedical and technological advancements we all live longer, and, for the most part of our lives, in good health. In old age, many of us are confronted with frailty and health issues though, needing some kind of support. Technology can support us within our homes, but not unconditionally. In the *Handbook of Smart Homes, Health Care and Well-Being*, the complex field of smart home technology supporting autonomous living within the community is presented.

In the Handbook, an overview is offered that not only includes possibilities and best practices but also issues that touch aspects of social innovation that ideally go hand in hand with technological innovation. The book consists of three major parts. The first is directed toward demographic, human factor, medical, and health-related issues, including technology acceptance and adoption, legislation, and ethical aspects in using home technology. The second part is dedicated to technological solutions, standards, hardware and software, design, and implementation. The third part demonstrates several best practices from all over the world in the field of smart homes and discusses lessons learned.

The domain of smart homes is not static, but rather ever changing as it is subject to major changes and breakthroughs that will arise during the next decades. Developments in personal and mobile communication devices, the Internet of things, smart mobility, the ever increasing integration of ICT in daily lives in general, the need for energy conservation and decentralized power generation, changes in family patterns, and the wish to age independently in our societies are some of the trends that will impact the direction in which smart home technologies develop. The book presents the state of the art of smart home technologies of the year 2016, realizing that the domain itself is a dynamic transition towards an ever-increasingly connected society.

March 2016

Joost van Hoof
George Demiris
Eveline J. M. Wouters

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Part I

The Use of Technology in Health Care and Social Innovation. Challenges and Opportunities

Persuasive Technology

Janienke Sturm

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Abstract

Since long, persuasion, or exerting influence, has been associated with certain professions such as sales people, therapists, coaches, and teachers. Recent technological developments create the possibility of using computers as persuasive instruments, as a means to elicit specific (desired) behavior, which paves the way for novel, intelligent systems that support the empowerment of seniors.

Behavior is explained as a combination of motivation, ability, and opportunity. A number of persuasive strategies can be applied to entice people to perform specific behavior, for instance commitment, social proof, and authority.

Smart homes are equipped with various kinds of sensors, actuators, and intelligent software, integrated in furniture, walls, and everyday objects. This enables people to be interconnected always and everywhere. Computers are able

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to recognize what people are doing, and in case the observed behavior deviates from the normal pattern, family members or an emergency service can automatically be warned. In this way, smart homes are excellent contexts for persuasive technology.

Energy saving and health are the two dominant application domains for persuasive systems in smart home environments. Current research and development projects are often in the experimental phase, implementing and evaluating only prototype systems. Extensive user studies providing a detailed account of the effect of an implemented persuasive system on people's behavior are therefore scarce. Challenges to be addressed in future research on persuasive technology in smart home contexts are related to the evaluation of the effectiveness of persuasive systems, the acceptance and adoption of these systems, and the ethical considerations.

Keywords
Persuasion • Motivation • Behavior change • Persuasive technology • Smart homes

Introduction

Since long, persuasion, or exerting influence, has been associated with certain professions such as sales people, therapists, coaches, and teachers. Recent technological developments create the possibility of using computers as persuasive instruments, as a means to elicit specific (desired) behavior. Smart homes are equipped with sensors that can record the behavior of people, with smart algorithms that can analyze and interpret sensor data, and with intelligent everyday objects that are wirelessly connected. These technical capabilities provide excellent opportunities to influence the behavior and attitude of people. In this way, technology can play an important part in encouraging healthy behavior (e.g., getting sufficient physical activity, taking medicine on time, training cognitive skills) or other desired behavior (social participation, energy saving). From a societal perspective, persuasive technology supports the empowerment of seniors, enabling them to live independently for as long as possible. From an economic perspective, persuasive technology holds the promise of reducing the costs of the healthcare system.

The Basics of Persuasion

Persuasion can be defined as an attempt to change attitudes or behaviors or both (without using coercion or deception) (Fogg 2002). Persuasion is different from conviction: where conviction relies on strategies rooted in logical proof and therefore appeals to people's reason and intelligence, persuasion relies primarily on strategies that trigger people's emotions (Oinas-Kukkonen and Harjumaa 2008).

In this chapter we focus on behavior change (i.e., changing how people act) rather than attitude change (i.e., changing the way people feel about something). Attitude may be really hard to change as it has to do with values and emotions. Moreover, attitudes do not always predict behavior. And, the other way around, behavior change does not always require an attitude change. Finally, it is easier to change attitude when the behavior change occurs first (Oinas-Kukkonen and Harjumaa 2009). In order to understand behavior change, we first need to understand behavior.

A Model of Behavior

Researchers in various disciplines (for instance from psychology, marketing, consumer behavior, information systems, etc.) have addressed the question which factors determine behavior. Most of the theories about behavior agree that whether or not certain behavior is performed is determined by three factors (see Fig. 1): motivation or intention, ability, and opportunity (Hughes 2007; Ölander and Thøgersen 1995; Fogg 2002; Deterding 2012). Ability and opportunity can be considered moderating factors on the connection between motivation and behavior: ability and opportunity influence how motivation leads to certain behavior.

Motivation (Does a person want to do it?) is a result of the fulfillment of various sorts of human needs: physiological needs (such as basic needs for food, water, and safety), social needs (such as power, belonging, and recognition), and psychological needs (such as needs for relatedness, autonomy, and competence (Ryan and Deci 2000)).

Fig. 1 Behavior is influenced by motivation, ability, and opportunity (From NBS.net)

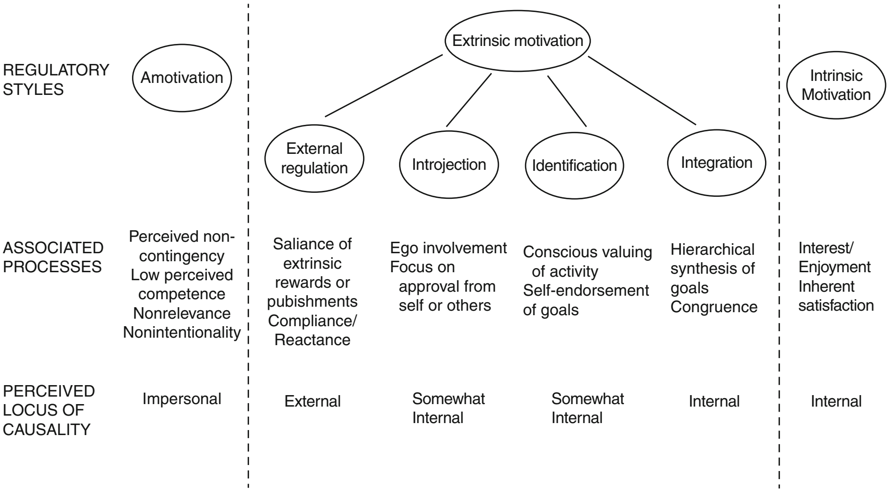

Fig. 2 A taxonomy of human motivation (From Ryan and Deci 2000)

Two types of motivation can be distinguished: intrinsic and extrinsic motivation; see Fig. 2 (Ryan and Deci 2000). Intrinsic motivation entails doing something because it is inherently enjoying or interesting. Intrinsic motivation is very closely related to the values that a person has and the things that he/she likes. Extrinsic motivation refers to doing something because it leads to a specific outcome; in other words, a person is doing something for its instrumental value. There are multiple levels of external motivation, differing in the extent to which a person has internalized the reasons for performing the behavior. External motivation ranges from unwillingness (low motivation) to active personal commitment (high motivation). Intrinsic motivation increases if internal human needs (for instance for autonomy or competence) are satisfied. External motivators, such as rewards or other less tangible things such as deadlines or fines, should be used carefully because they may undermine intrinsic motivation (Ryan and Deci 2000).

Ability (Is a person capable of doing it?). To be able to perform behavior, people need to know how to do it, they must have the right skills, and they have to believe that they are able to perform the behavior (self-efficacy, confidence). Also, they have to have willpower. They must be capable of taking the decision to perform the behavior. Habits and the presence of social support are important prerequisites for certain behavior to occur as well. And they have to get the right social support for doing so. Finally, they must be able to afford performing the behavior if costs are involved.

Opportunity (Does a person have the chance to do it?). People should have sufficient resources and relationships and the right environmental conditions to be able to perform the desired behavior. Moreover, opportune moments need to occur for the behavior to actually take place. If motivation is high and ability is provided for, creating an opportunity will make people really take the step to perform the behavior.

In sum, certain behavior occurs when people are motivated and able to perform the behavior and when they have the opportunity. If one of these conditions is lacking, the desired behavior may not occur. For instance, someone who wants to run every day, knows how to run, but doesn't have access to running shoes will find it hard to start running. Or someone who wants to reduce her energy consumption, has an intelligent thermostat, but doesn't know how to use it will have difficulty achieving his or her goals. Changing behavior thus entails increasing motivation, improving ability, and/or creating opportunities. Improving ability and creating opportunities are rather straightforward. Increasing motivation is much harder to accomplish. One way is to provide people with information to convince them of the necessity and benefits of the target behavior (or the negative effects in case of bad behavior need to be reduced). Another way is to make the behavior itself more fun, more interesting, or more challenging. This may be more effective, because it increases the intrinsic motivation of people to perform the behavior. Finally, motivation can be increased by using principles of persuasion that have long been used in many disciplines, such as marketing, therapy, education, etc.

Persuasive Strategies

Cialdini (2009) describes six persuasive principles that are commonly used (by for instance marketers, therapists, or teachers) to persuade people to start, increase, or decrease certain behavior.

Reciprocation: People are inclined (or even feel obliged) to repay, in kind, what a person has given them. If someone (or even a computer) does something for you, you feel obliged to repay. Reciprocity is a very powerful principle and one that is hard to resist.

Commitment and Consistency: Once we have taken a certain decision or standpoint, we will commit to this as much as possible, so as to maintain consistency. The commitment strategy is often applied in the form of goal setting. When people set their own goals, for instance in terms of the number of steps they aim to take every day, and personally write their goals down, they will most likely commit themselves to these goals and actually try to reach them. This effect is even larger if the goals are effortful and publicly visible.

Social Proof: What people determine to be correct behavior is dependent on what other people consider to be correct behavior. Even more powerful is the notion of similarity: people are inclined to follow the behavior of similar other people or people they like or admire. The principle of social proof can be observed in persuasive systems showing for instance who else is using the system and how they perform. The use of social proof as a persuasive technique has taken off since the rise of social media.

Liking: People are more inclined to follow the request of someone they know and like (on the basis of physical attractiveness, similarity, compliments, familiarity, cooperation). This principle can be observed in persuasive systems using a personalized avatar that shows resemblance to the person using the system.

Authority: People tend to follow a request if the request comes from authorities. This principle can be observed on many websites that have a quality label and in advertisements in which medical doctors or scientists recommend a particular health-related product.

Scarcity: Opportunities seem more valuable to people when their availability is limited. The notion of competition is important in relation to scarcity: the feeling of being in competition for some scarce good has large motivating capabilities.

Persuasive Technology

Recent technological advancements, such as the miniaturization of computer chips and the widespread availability of wireless connectivity, ensure that smart technology is becoming increasingly integrated in people's everyday life. Today a large proportion of the population (including elderly) uses a smartphone or tablet computer. In addition, many household appliances have become intelligent (for instance, the washing machine and the thermostat). Smart homes are equipped with all kinds of sensors, actuators, and intelligent software, integrated in furniture, walls, and everyday objects. Modern technology enables people to be interconnected always and everywhere. Computers are able to recognize what people are doing, and in case the observed behavior deviates from the normal pattern, family members or an emergency service can automatically be warned. In this way, computers have become excellent instruments for persuading people to perform specific behavior. Using computers to exert influence is called persuasive technology (see Fig. 3).

Using technology for persuasion has several advantages. In smart homes technology is omnipresent and can always be on, so that persuasive feedback can be provided at the most opportune moment (e.g., when people have been sitting in their chair for a couple of hours, but not when they have just received visitors). Moreover, the persuasive message can be given using the most appropriate modality (voice, sound, a movie, a simulation, etc.). Also, unlike humans, computers do not become frustrated or impatient when somebody needs to be reminded of the desired behavior several times a day. Finally, technology is anonymous, which makes it easier for people to ask for help and to try out new, unfamiliar behavior.

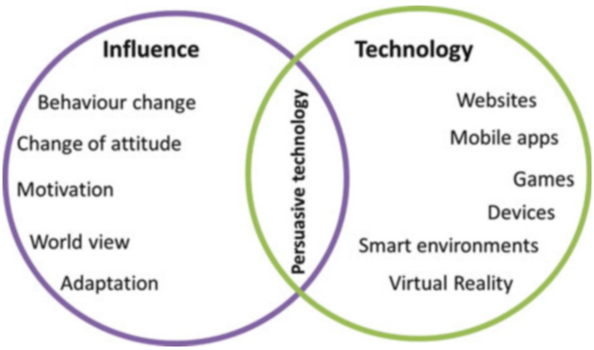

Fig. 3 Persuasive technology as a combination of influence strategies and technology (Adapted from Fogg 2002)

Roles

Persuasive technology can take on different roles. First of all, technology can be used as a persuasive *tool*, making certain behavior easier, more efficient, or more feasible to do. Examples of persuasive tools are a personal device that reminds people at the right moment to take their medication or a step counter that provides people with motivating measurements of their performance. Technology can also take on the role of persuasive *medium*, an instrument that provides a persuasive message in such a way that it motivates people: for instance, simulations and interactive experiences, which give people the opportunity to practice and to experience the effect of their behavior. Finally, technology can be used as a *social actor*, someone who gives compliments or motivational feedback, who provides reminders, who does suggestions, etc. In the role of a social actor, technology can have an animate appearance (e.g., an avatar), play an animated role (e.g., as a coach), or follow social rules such as politeness and turn-taking. In practice, persuasive systems will usually have more than one role (for instance a coaching system that provides insight into the user's performance, but also gives motivating feedback at opportune moments and connects the user with other users for social support).

Design Considerations

When designing persuasive systems the following issues need to be taken into consideration. Influence is not a single action, but an incremental process. Therefore, persuasive systems should support small, achievable, incremental steps, rather than trying to reach the target behavior in one giant leap. It is important that the ultimate goal should always remain clear to the user. Commitment is a very effective and powerful persuasive instrument, which should be designed for, for instance by making people set their goals and make them public. Persuasive systems should be as unobtrusive as possible and take action only at opportune moments. Finally, like interactive systems in general, persuasive systems should be useful and easy to use (e.g., error-free, providing adequate help, creating a nice user experience) (Oinas-Kukkonen and Harjumaa 2008; Fogg 2009a, b).

Persuasive Systems in Smart Homes

State of the Art

The advanced technology that is integrated in smart homes offers excellent opportunities for deploying persuasive systems. For instance, small, pervasive sensors, that are placed throughout the home, in walls, furniture, and daily objects, are able to monitor people throughout the day in an unobtrusive way. Intelligent algorithms are able to interpret the data coming from this sensor network in order to deduce a person's activities. By looking for patterns and recognizing deviations from these patterns, smart devices can adapt to the user's changing capabilities and changing stages of behavior change. Context awareness and real-time information exchange enable delivery of the right persuasive message at the most opportune moment and in an appropriate form (Chatterjee and Price 2009).

Persuasive technology is a relatively new phenomenon, especially in the context of smart homes. As a consequence, research and development projects are often in the experimental phase, implementing and evaluating only prototype systems. Extensive user studies providing a detailed account of the effect of an implemented persuasive system on people's behavior are scarce. To date, energy saving and health are the two dominant application domains for persuasive systems in smart home environments. Most health-related projects are aimed at supporting people to live independently for as long as possible. Applications in this domain include systems for self-management of diseases, for instance dealing with diabetes (Chatterjee et al. 2012) and medication compliance (De Oliveira et al. 2010). In addition, quite a large number of applications focus on stimulating physical activity, for instance by means of accelerometers that are linked to an app or in the form of exercise games (Vankipuram et al. 2012; Albaina et al. 2009). Finally, social interaction and the prevention of isolation and loneliness are frequently addressed (Romero et al. 2010; Vargheese et al. 2013).

In general, existing projects often use relatively simple technology, such as mobile phones, accelerometers, single sensors, etc. Few projects make use of complex sensor networks in combination with intelligent data processing algorithms. Overall, the technological capabilities that the smart home context offers are not yet fully exploited. In some projects existing hardware is used (for instance, a tablet computer or television set), whereas in other projects dedicated hardware is developed that fits more easily into people's daily life, without becoming obtrusive. In current systems persuasive technology takes on different roles, both as a social actor (for instance virtual coaches or socially assistive robots) and as a tool (for instance a reminder of medication). Persuasive principles that are commonly observed in current persuasive systems for smart homes are principles of social proof, commitment (personal goal setting), and liking.

Research Challenges

There are a number of challenges that have not received sufficient attention in current projects on persuasive systems in smart homes, although they are vital for the successful deployment of these systems. As mentioned before, most projects about persuasive technology in smart homes are in the experimental phase; the system itself is often not more than a prototype. In order to assess whether a persuasive system has the desired effect (i.e., whether the behavior of the user actually changes as a result of using the system), large-scale, long-term user evaluations with working systems are required. Central questions in such evaluations should be: what is the attitude of people toward the system? How persuasive is the system considered to be? What is the effectiveness of the system? Does it really change users' behavior, also on the long term? An important challenge in this respect is to determine which outcome measures can be used to quantify how persuadable and effective a system is.

One of the key factors determining the effectiveness of a persuasive system is the acceptance or adoption of the system by its users. Whether or not people intend to use the technology depends on a variety of factors, including to what extent the system meets the needs and demands of the users. Involving end users in the design process ensures that the product solves an actual and relevant problem and that the product reaches its target group. Paradoxically, people who are most easy to reach and most eager to adopt a system usually are the people who least need such a system. For instance, applications showing performance data about physical activity usually appeal to people who like to be active anyway, whereas the people who need this type of application the most, the inactive people, are usually the least interested. Other important factors for the adoption of persuasive systems are to avoid patronizing and stigmatization, to make interaction fun and challenging (thus appealing to people's intrinsic motivation), and to support autonomy. More research is needed to understand how these rather abstract notions can be translated into practical guidelines for the design of persuasive systems.

Finally in the design and implementation of persuasive systems, ethical aspects should be carefully considered. Important issues to consider are related to control, trust, privacy, and transparency. Especially when sensors are used to collect information, it is important that the user is aware of what information is collected and what it is used for. Also, persuasive systems should always be transparent about their persuasive intent. Now that smart home systems are increasingly able to act autonomously and adapt on the basis of knowledge about the user and the use context, it is important that the user always remains in control. Influence should be done openly, and no coercion should take place. To date, ethical issues like these have largely remained unaddressed in research related to persuasive technology (Oinas-Kukkonen and Harjumaa 2009).

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Demographic Trends: Why We Need Smart Solutions

Eveline J. M. Wouters

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Abstract

One of the most fascinating trends of the twenty-first century is the fact that most of us will live a long and mostly healthy and active life. Since 1840, life expectancy in the world has increased by an extra 3 months per year, a linear trend that has not reached its maximum. This trend is seen worldwide: both the increasing proportion of older people and the individual increase in duration are offering us several challenges and opportunities. Aging, especially the years of very old age, poses key questions as to how to manage health care, well-being, social engagement, dependency, and disability. In many developed countries, there has been a tremendous rise in health-care costs, unfavorably influenced by this trend of aging.

Technology can support opportunities and challenges resulting from this trend: with the help of technology, social connectedness can be preserved and also resources, skills, and health-care needs can be supplied.

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In this chapter, an overview of recent demographic (and other) trends and the underlying causes of these trends and their relationship with accompanying technological developments is given.

Keywords
Demographic transition • Longevity • Technological expansion • Chronic illness • e-health acceptance

Introduction

Although life expectancy has increased dramatically in the twentieth century (Oeppen and Vaupel 2002), retirement from work has dropped at the same time. For instance, in the Netherlands, after World War II, during the preparation of a mandatory pension program in 1947 (Cox 1993), the average life expectancy was about 70 years. The retirement age (65 years) seemed in proportion to this life expectancy. In recent decades, life expectancy has increased substantially, and many persons (especially women) live over 80 years, while the retirement age in the Netherlands has only very recently been postponed up to the age of 67 years. People nowadays spend many years out of the workforce. In the OECD countries, women spend about 22 years as pensioners, whereas for men, this period is on average 18 years (OECD 2007).

Growing older is one of the greatest achievements of the past century (Oeppen and Vaupel 2002). At the same time, aging of the world offers several challenges to society. Health care is one of these challenges as is illustrated by the following case history, representing an average person in a general practitioner's practice.

> Jonathan Fraser is 74 years of age. His body mass index (BMI) is 32, although he does not really appear obese at first glance. He smokes about 20 cigarettes a day and drinks a few beers. Eight years ago, he survived a heart attack. Although he recovered reasonably well, he is not in the same condition as he used to be in: using stairs and cycling has become rather difficult. Apart from that, Jonathan suffers from chronic obstructive pulmonary disease (COPD). Jonathan is on antihypertensive drugs, cholesterol medication (statins), bronchodilators, and anti-inflammatory drugs. One year ago, his health problems increased by development of diabetes. He is on insulin and diet as well. Altogether, Jonathan is taking ten different drugs, which he has to take five times a day in different doses.

Jonathan is a typical case. Noncommunicable diseases, such as Jonathan is suffering from, are one of the frequently met consequences of longevity (Gijsen et al. 2001). The older age group is more susceptible to diseases and disabilities, and this group will have a significant effect on society. But there is more to be said about trends in society, apart from aging. In the following paragraphs, firstly, trends in aging, social economic globalization, and technological developments will be described. Secondly, causes of longevity will be outlined, followed by the consequences. Finally, the role of technology in coping with challenges related to longevity will be introduced.

The Rise of a Global Aging Population and Other Trends

Both in developed but even much more in developing countries, the demographic transition is huge. As a result of the rise in life expectancy and a decline in fertility rate, the average age is rising, resulting in a higher proportion of older persons. In 2050, the number of persons over 60 years of age is expected to be between 1.5 and 2 billion (UN 2013; WHO 2011). At the same time, the proportion of persons over 80 is rising disproportionately: in 2050, over 400 million people will have reached this age (UN 2013). This trend is a historical breakthrough: since the beginning of history, young children have outnumbered their elders. In a few years from now, persons over 65 will outnumber children under the age of 5 years (WHO 2011). Moreover, most of the babies born in 2000 in countries with high life expectancy (such as Sweden, Italy, Spain, and Japan) will live up to become 100 years (Oeppen and Vaupel 2002).

Aging is not the only trend in society. Economies are globalizing, and there is a societal shift from rural to urban environments. Because life in the city is more expensive and children are less useful as laborers, and because parents are higher educated families became smaller. Also, more nontraditional family forms and new types of households have evolved (Buzar et al. 2005). As a result of this social trend, families tend to be smaller, not living together in a traditional way. This results in fewer opportunities for older persons to be living with younger people or, when needed, to be taken care of by relatives. With these sources of support declining, other tools will be needed to cope with the trend of aging.

Aging and globalizing societies are accompanied by technological expansion. Technology in health care, partly responsible for longevity, is not at all a new trend in itself. The difference between past times and current time is the exponential growth rate of evolving technology. In health care, as in other domains, technology will be of major importance. Examples are developments in information and communication technology, biotechnology (such as personalized medicine and nanotechnology), and social robotics.

Why Do We Grow Older?

For centuries, causes of death have not changed substantially. Until the start of human life, until about 8000 BCE, major reasons to die were famine, violence, and accidents. After that, until World War II, infectious diseases were the most important causes of death (WHO 2011). The first important changes in life expectancy can be seen in the eighteenth century in Western countries as a result of hygiene, the availability and improved quality of water and the introduction of sewage systems.

Even before bacteria were discovered, death rates dropped substantially as a result of extinction of infectious diseases such as cholera.

Technological innovations were not the only causes of improvement. As a result of industrialization, more people moved to cities, which obliged social innovation: improvements in housing and hygiene were the result, as was population growth. In addition, globalization as a result of colonization of tropical countries resulted in a wider variety and accessibility to food supplies, in order to tackle this growth.

Moreover, a change in views about health occurred: mythical opinions were changed for scientific views. Rational and objective (evidence based) causes of health and disease overruled supernatural causes. Human interventions started to be accepted, and diseases were allowed to be studied and cures were developed.

This human interest in health and diseases tremendously accelerated developments in health care and medical science. As a result, health care was not exclusively accessible for the rich. At the same time institutions changed: whereas in former times, nursing took place at home (the rich) and in poor relief of convents and monasteries (the poor), in the nineteenth centuries the first hospitals were founded. These hospitals also provided for the education of doctors. Diseases, like the taxonomy of plants by Linnaeus in the eighteenth century, were classified for the first time, resulting in the first edition of the well-known International Classification of Diseases (ICD) in 1900. ICD in its first form was developed to classify causes of death in a comparable (statistical) manner (Israel 1978). The ICD has since evaluated into the standard diagnostic tool for epidemiology, health management, and clinical purposes (WHO 2014). The tenth version is used at the moment, and the eleventh is expected to be released in 2015.

Great medical discoveries like vaccination against diseases such as poliomyelitis, tetanus, diphtheria, and pertussis have resulted in a drop in childhood mortality. From the nineteenth century, global vaccination programs have eventually resulted in eradication of smallpox in 1977.

But also wars have given impetus to medical improvements. Serious injuries in World War I in Europe required huge surgical procedures. Better instruments (steel industry) and the evolution of anesthesia enabled surgery which was previously unimaginable. Even chemotherapy in cancer treatment originates in World War I. Mustard gas, used as chemical weapon for mass destruction, appeared to be able to destroy cancer cells in several affected tissues and organs (Adair and Bagg 1931). After postmortal examination of soldiers, fast-growing tissues like lymphoid tissue and bone marrow had shrunk substantially (Krumbhaar and Krumbhaar 1919). In World War II, penicillin was, as a result of better isolation methods, for the first time used on a large scale (Clayton et al.1944). Currently, it is still a frontline antibiotic. More recently (2004), teleconsultation programs for physicians in austere and inaccessible environments were set up in the army for remote teledermatology consultations from health-care providers in Iraq, Kuwait, and Afghanistan to medical subspecialists in the United States of America. These programs were proven to be valuable and successful and have been expanded to several other subspecialisms, such as cardiology, burn trauma, and infectious diseases (McManus et al. 2008).

Progress in health care has increased excessively in the second half of the twentieth century. This can be attributed to the exponential growth in technological possibilities.

Advanced surgery, for instance, developments in transplantation surgery, laparoscopic surgery, and microsurgery, offers possibilities unthinkable in earlier times. Together with improvements in radiology and pharmacology, many previously incurable diseases can be cured. The effect is, among others, that people no longer die from these diseases, but, at the same time, will live longer with chronic diseases. More children survive their first years, in which they are exposed to most dangers. Most of the improvement in life expectancy is attributable to the fact that less children and women die. The result is that infectious and acute diseases decrease, and chronic and degenerative diseases increase: the so-called epidemiologic transition (Omran 1971).

Other developments in the twentieth century have further contributed to the improved health and longevity. Public health education programs, for example, for the prevention of tobacco smoking, sexually transmitted diseases, burn injuries, intoxication, and drugs, have saved many lives, but also medical interventions such as administration of statins that decrease cardiovascular risk by decreasing the levels of low-density lipoprotein cholesterol and, as a consequence, improving dyslipidemia as well as prenatal diagnosis of congenital anomalies and newborn screening to identify serious disorders that are relatively prevalent and treatable or controllable, like phenylketonuria. Other examples of successful population secondary prevention programs are population screening on breast cancer and cervical cancer. Not only medical precautionary measures have been successful. Examples of successful nonmedical interventions are the decline in fatal traffic accidents, as a result of the compulsory use of seat belts. Furthermore, the widespread introduction of roundabouts (instead of intersections) has been very successful in this respect (Retting et al. 2001). Another recent example of an efficacious preventive measure against sudden infant death syndrome (SIDS) was the advice to parents not to use the prone position for their babies, which is associated with higher risk for SIDS (Dwyer et al. 1991).

In summary, mortality has fallen down substantially throughout the past centuries but mostly in the twentieth century. Mean life expectancy has risen to about 80 years, and mortality causes have changed. From famine, accidents, violence, and infectious diseases, most of us will eventually die from chronic and degenerative diseases.

Consequences of Aging Societies

One of the consequences of longer life expectancy is the increasing number of older persons and persons with chronic morbidities and disabilities (Murray et al. 2013; The state of US health 1990–2010: burden of diseases, injuries, and risk factors 2013). Deaths from noncommunicable diseases rose substantially in the last two decades, accounting for two thirds of all deaths worldwide in 2010 (Lozano et al. 2012). Most of all deaths in the world are now attributable to ischemic heart disease, stroke, chronic obstructive pulmonary disease (COPD), lower respiratory infections, lung cancer, and HIV/AIDS (Lozano et al. 2012). For the loss of quality of life and the strain on health care, not only causes of mortality but especially chronic morbidity are important. In the last 20 years, morbidity as a result of, for example, lower respiratory infections, stroke (Murray et al. 2012), and diabetes (Tamayo et al. 2013) has increased significantly. But also health problems, such as chronic arthritis (Hawkins et al. 2013) and depression (Jeste et al. 2013), can generate a high impact on quality of life and activities of daily living (Johannes et al. 2010).

Successful aging (i.e., in an active and healthy manner) is diminished most alarmingly by the onset of dementia (Alzheimer disease). Dementia in the later phases of the syndrome needs contact care in activities of daily living. Not only for patients but also for family members, professional carers, and societies, dementia is a severe burden. The risk to develop dementia is strongly related to age; in people 85 years and older, the estimated risk is between 20 % and 30 % (Lobo et al. 2011; WHO 2011). As a result of the aging trend, the social and economic burden of dementia is huge (Prince et al. 2013) and, unless prevention or treatment will be successful, will increase in the years to come.

Currently, there is still a discussion among researchers whether we actually live more years in poor health compared to former times: do we really acquire more disabilities during a life time (Christensen et al. 2009)? Whatever the outcome of the debate, the aging society offers important challenges in order to stay healthy or, alternately, to be able to live independently and participatory in society as long as possible.

Challenges are not only the result of chronic diseases and disability in (very) old age. The global trend toward having fewer children implies that there will be less potential support for older persons from their families. This trend is also called “beanpole families,” meaning that there is a vertical expansion of family structure (more generations living at the same time) but smaller generations (Laslett 1997). As a result, the proportion of older persons, especially older women, living alone has risen dramatically in past decades in most countries (Kramarow 1995). Loneliness, although in old age not only related to quantity but also to quality of relationships and physical health, is a major factor associated with quality of life (Victor and Bowling 2012; Victor and Yang 2012).

Growing older and needing more (professional) care has major consequences for the economy. In most European countries, health expenditure per person is huge. For example, in the Netherlands, it is, as compared to other European countries, among the highest (Health Expenditure Per Capita 2012). Although there seems to be some slowing in health-care spending, related to the growth of the GDP (Fuchs 2013), the absolute expenditure in most developed countries is still over 10 % of the GDP. This implies that a paradigm shift in health care is needed and health care has to shift into the direction of self-management and informal care as opposed to mostly formal care. Technology might play an important supportive role in this development.

The Role of Technology in an Aging Society

Technology is often considered to be one of the solutions for the challenges, e.g., the financial challenges, in health care. Before considering some of the possibilities, it should be said that technology, on the other hand, is also one of the *causes* of high costs. As a result of technology, expensive interventions have been made possible, and the purchase of expensive equipment and instruments is also related to high health-care expenditure.

At the same time, technology can help to reduce costs in several manners. (Nevertheless, information technology has been taken up slowly in health care, and the electronic health record (EHR) has not been adopted until recently in developed countries and in some, to date, not entirely.) Other promising developments in information technology and the ones this book is specifically focused upon are related to share information without being hindered by distance. IC technology – telemedicine, e-health, e-care, remote monitoring, and smart homes have in common that they offer the opportunity to share information between health-care professionals (informal carers) and patients. The combination with smart sensor technology makes it possible to support persons with health-care problems at home. These developments have several consequences. For instance, older persons and persons with chronic health-care problems will be able to stay in their own homes and communities while being monitored and receiving feedback on health-care indicators and activities of daily living, depending on the support they need. Immobile patients can visit their health-care professionals without leaving home, and simple medical achievements, like taking blood pressure or simple blood samples, can be performed by patients themselves. But also in institutional care, by using surveillance technology, for instance, persons with cognitive impairments can be monitored and offered more freedom. Moreover, not only formal health care can benefit from e-health, but also informal care. There are several initiatives supporting community care with IC technology. IC technology can be used for persons to be in contact with other persons, with informal carers, and with volunteers and several other members of communities, without the need of being mobile.

Currently, there are not yet many randomized controlled trials available to support the clinical effectiveness of e-health at this moment (Merriel et al. 2014; Redfern et al. 2014), but several smaller studies indicate that e-health is potentially beneficial in a wide variety of health-care issues, for instance, in diabetes care (Harno et al. 2006), breast feeding advice (Giglia and Binns 2014), COPD (Cruz et al. 2014), and cardiovascular care (Purcell et al. 2014).

Conclusions

In conclusion, although promising, at this moment the implementation of IT solutions is not as big as expected or hoped for. The reasons for this are many. Examples are usability and acceptance of technology by older persons (Peek et al. 2014) and health-care providers (Pols 2010; Pols and Moser 2009; Toofany 2006) and ethical issues (Niemeijer et al. 2013). Also, many technological solutions have been developed without involving the "stakeholders" properly, accounting for a substantial portion of non-adoption.

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Coping with Complexity: Designing Homes and Facilities for Frail and Dependent Elderly in a Changing Society

Maarten J. Verkerk

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Abstract

Demographic changes, technological innovations, and plurality in values place architects and consulting engineers for large challenges. This chapter unravels the different types of complexity that play a role in designing homes for frail elderly and facilities for adults with dementia. Five types of complexity are identified as follows: aspectual complexity, contextual complexity, stakeholder-related complexity, value-based complexity, and technological complexity. It is shown that this model guides architects and consulting engineers in analyzing and designing complex homes and facilities.

Keywords

Design • Complexity • Values • Demographic changes

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Introduction

In 1964 Bob Dylan sang his famous "The times they are a-changin." This 50-year-old song is still very topical. The developments in science and technology are amazing, the financial crisis has left deep marks in our economy, and demographic developments will change the face of our society considerably. Additionally, individuals shape more and more their own life, social relationships become "thinner," and long-life companionships cannot anymore be taken for granted.

Demographic developments will give society a new look. I would like to illustrate these changes with some data from the Netherlands. In the period 2010–2040, the number of people over 65 will increase from 2.6 to 4.6 million and the number of people over 80 from 0.65 to 1.5 million. The societal impact of this growth is reflected in the so-called gray pressure that presents the ratio between the number of people over 65 and the potential working population. This ratio will increase from about 25 % to 50 % (Van Duin and Stoeldraijer 2012). Another important development is the growth in the number of single person households: from about 2.7 million in 2010 to about 3.8 million in 2040. The elderly account mainly for this growth: the number of single person households of people with the age of 65–79 will grow from 0.5 to 1.0 million and of people with the age over 80 from 0.3 to 0.7 million (Van Duin et al. 2013). In the same period, the number of people with dementia will increase from about 240,000 to 540,000 (Alzheimer Nederland 2013). These developments place Dutch society for a double assignment: how to deliver care and how to finance care.

Innovation is one of the answers on the burden of the graying society. New technologies are developed to support independent living at an old age. Self-management systems are already on the market to support (old) citizens to manage their chronic illnesses. Finally, family care and volunteers are expected to give informal care. It goes without saying that many promises of innovation are not yet redeemed.

At the same time, the philosophy of life of citizens is also strongly changing. The mediaeval idea of *cuius regio, eius religio* lies far behind us and has given way to a plurality in basic beliefs. In most Western countries, Christian, modern and post-modern views on the good life are simultaneously present (Ferry 2010). Additionally, Islamic values have secured a position in non-Islamic countries. On the one hand, elderly people stress the value of autonomy. On the other hand, the limits of this value come the fore when elderly become frail and dependent on daily care.

Demographic changes, technological innovations, and plurality in values place architects and consulting engineers for large challenges. The design of homes and buildings is already a complex and dynamic process. However, the overall complexity is strongly increased when the design process concerns home buildings for specific user groups with nonstandard requirements. For example, the design of a smart home for frail elderly or a long-term facility for older adults with dementia requires interdisciplinary dialogues involving many disciplines like social workers, care professionals, senior citizens' associations, and patient associations. In addition, the design of the building should also take into account the standard requirements of an adequate operation and cost-effective maintenance. Technological innovations will increase the complexity and dynamics of the designing process further. Interdisciplinary design teams that cover all (new) technologies are of utmost importance. Finally, architects and consulting engineers are not used to take a plurality in values into account. Additionally, they are often not aware of their own hidden values that determine their designing process.

The complexity of the built environment becomes particularly evident when concerning the evidence-based design of health-care facilities (Ulrich et al. 2008; Huisman et al. 2012). Various researchers have proposed theoretical or conceptual frameworks linking different built environment characteristics to health outcomes or to capture the current domain of evidence-based design in health care. However, these models all capture a different part of the complexity and, thus, reflect a part of reality (Van Hoof and Verkerk 2013).

The aim of this chapter is to unravel the complexity of the design process of homes and facilities for frail and dependent elderly. I distinguish five different types of complexity: contextual, stakeholder related, value based, aspectual, and technological. I will show that architects and consulting engineers have to analyze every type of complexity and its influence on the design process (Ribeiro et al. 2012; Van Hoof and Verkerk 2013; Verkerk 2014).

Unraveling Complexity

It is of utmost importance to develop models that cover the full complexity of designing homes for frail elderly and facilities for older adults with dementia. One route to develop such models is to combine health-care models with construction models (Van Hoof 2010). This route presupposes that both models can be combined and that the combined model is complete. However, both presuppositions are problematic. Another route is to use philosophical theories that address complexity and to elaborate these theories for the topic under investigation (Van Hoof and Verkerk 2013). If necessary, disciplinary theories or tools can be used to bridge the gap to reality. Basically, this route is more promising because philosophy as “discipline of the disciplines” has the best “credits” to investigate the complexity of reality (Strauss 2009).

In this chapter, the route of philosophical theories will be taken to investigate complexity in designing homes for frail elderly and facilities for adults with dementia. Five different types of complexity are distinguished:

(a) Aspectual complexity
(b) Contextual complexity
(c) Stakeholder-related complexity
(d) Value-based complexity
(e) Technological complexity

For each type of complexity, the philosophical roots will be given.

Aspectual Complexity. In philosophy a distinction is made between "wholes" and "aspects" (Dooyeweerd 1969). A "whole" is a totality with an own identity. Examples of wholes are human beings and animals, trees and bushes, and stones and grains of sand. All these wholes have an own identity. Humans, animals, trees, and bushes are a part of the living world and stones and grains of sand not. Humans can enjoy art and think rationally, and animals cannot. Animals have emotions and actively perceive their environment, and trees and bushes do not. Each whole functions in a number of different aspects or dimensions. For example, a human being needs food (biological aspect), has feelings (psychical aspect), interacts with other people (social aspect), exchanges goods with another person (economical aspect), enjoys art (aesthetical aspect), shows ethical behavior (moral aspect), and does or does not believe in God (spiritual or religious aspect). All these aspects have an own nature or character, show their own dynamics and mechanisms, and can be described with specific laws or norms. For example, the dynamics of social interaction are quite different from the dynamics of enjoying art. The biological laws that determine the digestion of food are quite different from the norms for moral behavior. In other words, every aspect has its own core that cannot be reduced to another one. Technological artifacts like homes for frail elderly and facilities for adults with dementia are also wholes. They function also in different aspects or dimensions. For example, a facility for adults with dementia functions in the spatial aspect (it has a specific shape) and in the physical aspect (it consists of materials with specific properties). It also functions in the economic aspect (investment money, operating costs) and in the aesthetic aspect (its beauty). Finally, it functions in the juridical aspect (a facility has an owner) and in the spiritual aspect (giving hope and trust). In total 15 different aspects are distinguished as follows: numerical, spatial, kinematic, physical, biotic (biological), psychic, logical (analytical), formative, lingual, social, economic, aesthetic, juridical, ethical (moral), and spiritual (pistical). The idea of aspectual complexity is based on the theory of modal aspects developed by Dooyeweerd (1969, Vol. II). The idea of aspectual complexity prevents that architects or consulting engineers focus themselves on the most well-known aspects and "forget" the other ones.

Contextual Complexity. The idea of contextual complexity acknowledges that the context of design has a strong influence on the design itself. For example, the context of a church is quite different from the context of a showroom of cars. In a church people are invited to give oneself up in God's hands, whereas in a showroom customers are seduced to buy a new car. In the same way, the context of a home for frail elderly is different from the context of a facility for adults with dementia. Homes for frail elderly have to be designed in such a way that they can live as autonomous as possible and can participate in society, i.e., the design has to support social functioning of the frail elder. Facilities for adults with dementia have to be designed so that the environment is healing and optimal care will be given to patients, i.e., the design has to support healing and care. The idea of contextual complexity is very important: it highlights the intrinsic nature, dynamics, and normativity of a design. The idea of contextual complexity can be sharpened by using the theory of modal aspects: the design of a home for frail elderly is led by the social aspect and the design of a facility for adults with dementia by the moral aspect. It has to be noted that the core of morality is "caring for." The idea of contextual complexity is based on the analysis of societal plurality by Mouw and Griffioen (1993), the idea of internal values as developed by MacIntyre (1981), and the theory of individuality structures of Dooyeweerd (1969, Vol. III).

Stakeholder Complexity. The idea of stakeholder complexity stresses that stakeholders have to be involved in the design process and that different stakeholders have different types of justified interests. For example, in designing facilities for adults with dementia, many stakeholders play a role: patients, families, associations for people with dementia, health-care professionals, owners, government, local authorities, insurance companies, architects, constructors, and so on. All these stakeholders have justified interests. The justified interests of patients are a healing environment, good care, and financially affordability. The justified interests of owners are return on investment and long-term occupancy. The idea of "justified" interests on the one hand opens the eyes of engineers for the diversity of stakeholders and their different interests, and on the other hand supports them in critically reviewing existing practices. For example, in architecture the judgments of peers about the design and the beauty of the building are considered as very important. However, from a philosophical point of view, their judgment is not a justified interest. The idea of stakeholders and justified interests is based on the theory of individuality structures of Dooyeweerd (1969, Vol. III) and the theory of stakeholders as developed by Freeman (2001).

Value-Based Complexity. The idea of value-based complexity highlights that values, ideals, or dreams play a role in the design of homes of frail elderly and facilities for adults with dementia. Firstly, values can have a cultural source. For example, the values "freedom" and "individual responsibility" underlay the health-care practices in the United States of America, whereas the values "solidarity" and "dignity" underlay the health-care practices in the Netherlands. Secondly, values can have an institutional background. For example, one health-care institution for elderly with dementia is driven by the values "safety" and "excellent care," another one is driven by "feeling at home" and "closeness," and again another one by "dignity" and "living in the sight of God." Finally, values can have a personal background. For example, a client can have a Buddhist, Christian, Humanist, or Islamite principles or an investor can be driven by "social return on investment" or by "financial return on investment." The idea of value-based complexity discloses the whole field of the good life. It supports the engineer in making explicit the various values that influence the design and invites him or her "to translate" values or ideals in a design. The idea of value-based complexity is based on the practice model developed by Jochemsen, Glas, Hoogland, Verkerk, and others (Jochemsen and Glas 1997; Hoogland and Jochemsen 2000; Jochemsen 2006, and Verkerk et al. 2007) and the theory of ground motives of Dooyeweerd (1969, Vol. I).

Technological Complexity. The idea of technological complexity emphasizes that different types of technology are used. Brand (1994) presents six systems: stuff, space plan, services, skin, structure, and site. Each system has a specific set of functions (which can be seen as solutions) that contribute to the optimization of a certain value for (different) stakeholders. It has to be remarked that the six systems are differently qualified in view of the theory of modal aspects. For example, the stuff is physically qualified, the space plan spatially, the social media services socially, and the security services morally.

Heuristics for Complex Designs

In the foregoing section, we have introduced five types of complexity. It could be remarked that these distinctions do not simplify the design process but makes it more complex "than it was." This remark has a grain of truth in it: we are dealing with five types of complexity and every type has its own complexity. However, it is well known that complex realities never can be understood by means of simple models. That means, the complexity of designs only can be understood by models that do justice to that complexity. The different types of complexity order reality and support the architects and engineers in ordering information, in asking questions, and in finding answers on these questions.

In this section I will show that the different types of complexity offer a heuristic to define the specification and to support the creative design process. I would like to illustrate this heuristic by the design process of facilities for adults with dementia.

The design process can be schematized in five steps. Basically, for every technology (technological complexity), a specification has to be made and a (draft) design proposed. This specification and design is multi-aspectual (aspectual complexity) and has to be developed from three perspectives:

1. The requirements of the specific context (contextual complexity)
2. The values that underlay or have to underlay the design (value-based complexity)
3. The justified interest of different stakeholders (stakeholder complexity)

It must be noted that in designing complex systems, the phases "analysis" and "creative design" are not successive steps but are strongly interwoven:

Step 1: Determine the technological complexity of the design. For example, the systematic of Brand (1994) can be used to understand the technological complexity of a new facility. Especially, the services have to be elaborated in more detail: communication, recreation, safety, care, and so on. A further qualification of the different technologies by using the theory of modal aspects can be very helpful to understand their function more fundamentally and to stimulate innovative solutions.

Step 2: Determine the intrinsic dynamics and normativity of the context of the design. Every context has its own dynamics and normativity. The context of a facility for elderly with dementia is determined by the fact that these patients cannot anymore live independently but that they need care, 7 days a week and 24 h a day. The care for elderly with dementia is not "just care" but is care for elderly whose cognitive and noncognitive functions are deteriorating. Architects and consulting engineers have to understand the nature of the deterioration in order to design a facility that supports care for this specific type of patients.

Step 3: Specify the requirements of every technological system from the perspective of the patient and check all 15 aspects. In step 2 we have determined the nature of the facility: care for elderly with dementia. In this step the requirements of every technological system are determined from the perspective of the patient. For example, the design of the space plan also has to support the care for patients with dementia. This requirement leads to a number of questions that have to be answered during the design process. How to design the space plan that the patients will not lose their way? How to design the living room to prevent that social interaction will result in too much stimuli for the patient? How to design the dining room that the patients "know" that they have to eat? How to design the garden that elderly with dementia can experience the beauty of flowers and trees? How to design the chapel or a spiritual nook that stimulate religious and spiritual experiences? This step is the most fundamental step in the whole design. Basically, for every technological system, these types of questions have to be asked.

Step 4: Specify the requirements of technological system from the perspective of values or basic beliefs. In step 3 we have defined the specification of the technological systems from the perspective of the (care for the) patient. In this step the specification will be refined from the perspective of the (shared) values that have to underlay the design. As shown above, values can have different sources or backgrounds. Especially, shared values can evolve in dialogues between different stakeholders, e.g., patients, families, health-care professionals, and so on. The basic question in this step is: What does this value mean for every technological system? For example, what do the values 'feeling at home' and 'closeness' mean for the designing the space plan fo the facility? Or for the different materials that are used? If necessary, all 15 aspects can be checked off.

Step 5: Specify the requirements of the technological system from the perspective of the justified interests of different stakeholders. In step 3 we have defined the specification of the technological systems from the perspective of the (care for the) patient and in step 4 from the perspective of (shared) values that have to underlay the design. In this step the specification for the technological systems will be further refined from the perspective of the justified interests of different stakeholders. Above we have shown that most stakeholders have one or two justified interests and that these interests can be qualified by using the theory of modal aspects. For every stakeholder the question is: What is the influence of his or her justified interests on the design?

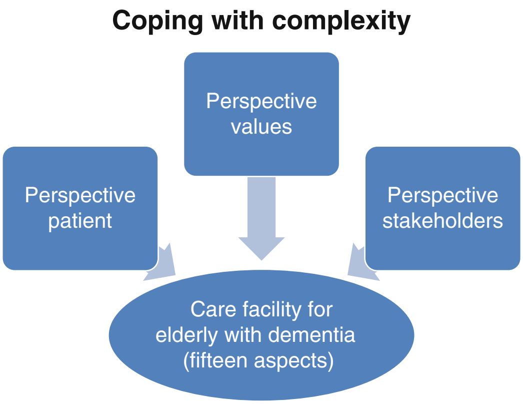

Fig. 1 Coping with complexity in designing homes and facilities for frail and dependent elderly

The design process is summarized in Fig. 1. It goes without saying that in the steps 3, 4, and 5, the process of specification and the process of creative design are strongly intertwined. Additionally, the steps 3, 4, and 5 will easily get mixed up.

Conclusions

Demographic changes, technological innovations, and plurality in values place architects and consulting engineers for large challenges. This chapter illustrates the need for a philosophical model that unravels complexity in designing homes for frail elderly and facilities for adults with dementia. Five types of complexity are identified as follows: aspectual complexity, contextual complexity, stakeholder-related complexity, value-based complexity, and technological complexity. These types of complexity function as a pair of glasses: they highlight specific topics of the design. One pair of glasses is not enough: we need all five pairs of glasses to understand the full complexity of the design.

The first conclusion is that this model guides architects and consulting engineers in understanding the different aspects involved, the nature of the context, the justified interests of stakeholders, the values that shape the design, and the different technologies involved.

The second conclusion is that the technical systems (technological complexity) have to be developed successively by the requirement of the specific context, the values involved, and the justified interests of the different stakeholders.

The last conclusion is that this model does not only support the design of homes and facilities for frail and dependent elderly but also other complex designs like the electrical infrastructure of the future.

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A Framework for the Acceptance of Gerontechnology in Relation to Smart Living

Don G. Bouwhuis

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Abstract

Despite the wide availability of telecare devices, the economic pressures, and the claimed benefits, the uptake of telecare services by older people is disappointingly limited. Much research is spent on finding out why the telecare acceptance is so much less than expected.

Ease of use, or rather lack of it – a seemingly likely cause – is difficult to assess since the traditional usability criteria do not apply well to the daily life of older people. Acceptance in the social environment plays an important role, sometimes

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in a positive sense, but mostly in a negative one; however, social environment is all but impossible to manipulate.

What does delay acceptance is the lack of standardization, which, in turn is also due to the fact that the impressive technological progress of the past decades has largely bypassed the field of assistive technology and health care. Another negative factor is cost. Though the price of devices has come down appreciably in recent years, system architecture and installation are getting more expensive and increased functionality goes hand in hand with higher cost. Next, during the actual running of telecare systems, successful operation has to compete with inherent difficulties of decision making in a noisy context. Making correct diagnoses is necessarily connected with false alarms, which may render the telecare system unusable. This is exacerbated by sources of unreliability in the system as a whole, like falling sensors, disconnected leads, empty batteries, and erased memories.

In the light of these difficulties, traditional Technology Acceptance Models (TAMs) are focusing on a very small part and then probably the wrong one of the whole complex multistage decision process in implementing a telecare system.

As it is, the comparatively immature state of telecare systems is up to now a multisectoral issue, in which stakeholders of different economic sectors operate mostly independently. Early stakeholders take decisions which later ones have to accept, up to the client as the end user, who also has to accept, but often does not. In a confusing situation like this, where the client is confronted with a system he or she has not chosen, it is doubtful that models based on a theory of rational behavior like the TAMs or Innovation Theory are valid at all.

What should be minimally done on the basis of these observations are three things.

First, an effective business case should be developed to run a telecare system – currently absent. Second, in addition to regulation, there should be a strong effort in the area of standardization. Finally, telecare should become a product that older people want, not one they have to accept.

Keywords

Telecare • Usability • Rationality • Technology acceptance • Business model • Standardization • Reliability

Introduction

When Oedipus encountered the Sphynx at the gates of the Greek city of Thebes, an apocryphal event that may be dated around 1000 BC, he had to solve a riddle in order to enter the town. The Sphynx asked: What creature goes on four feet in the morning, on two on midday, and on three in the evening? Oedipus answered: It is man; as a baby it crawls on all four, as an adult he walks on two legs, and when old he needs a stick as a third foot. This observation qualifies the walking stick as the earliest assistive technology for older people. In the 3,000 years since then, only very few

Fig. 1 An older man sitting in a wheelchair, depicted in the London Illustrated News of 1894. In the background another old man is walking with difficulty, holding a cane. Note the strange coincidence with the Sphynx riddle that the baby pram has four wheels and the wheelchair three

other assistive products were introduced: dentures, lenses for reading glasses, and ear trumpets. Pictures of wheeled chairs in China date from as early as 525 AD, but practical wheelchairs were only introduced around 1900 and were primarily intended for disabled people rather than for older people with mobility problems (Sawatzky 2002), who used them if they could anyhow (Fig. 1). The earliest use of eyeglasses, mostly to correct for farsightedness, dates from the thirteenth century (Ilardi 2007). The first foldable tubular steel wheelchair, similar to current ones, was designed in 1932 by Jennings and Everest in the USA (Sawatzky 2002). One other example, the first stairlift was created by C. Crispen in the 1920s, who called it the Inclinator, but practical devices of this kind came on the market from the mid 1970s (Baker 2006). While practically all of these products were passive physical devices, one of the first applications of electronics was in the area of hearing aids. Alexander Graham Bell, in 1876, had intended his speech transmission system in first instance as an aid for the deaf. Though the telephone application overtook other interests, his invention was turned by Miller Hutchison into the electric hearing aid in 1898, called the Akouphone. Electronic amplification was introduced in the 1920s, and in the course of the twentieth century, even more improvements like miniaturization and noise suppression were introduced. Yet, also considering this one product, it is remarkable that while technology, including electronic technology and specifically medical technology, made such giant strides in the twentieth century, so few assistive products for older people were proposed or developed until the 1990s. It is telling that the wheeled walker, mostly known as rollator, invented by Aina

Wifalk in 1978 is considered by many users as the best invention of the century, or, since the wheel.

Forms of Technology Acceptance

All of the products mentioned have in common that they were meant to cope with disabilities, not specifically in relation with aging. That they were often seen as a sign of old age is caused by the fact that perceptual functioning and mobility are negatively correlated with age. So, as aging progresses, the proportion of older persons needing assistive devices will increase. Because in many countries the population is aging, the majority of assistive devices will ultimately be used by older persons. Another aspect is that the assistive products satisfy a personally felt need; they are, in fact, required. In the case of a dysfunction, e.g., low vision, magnifying glasses are not a product that is accepted or not, they are demanded or required, as otherwise the intended activity of the affected person just cannot be executed. Acceptance in such a case is a default. Even if a person who needs perceptual or mobility assistance is averse to the assistive product, the need to use it anyway will overcome the felt objection. This held, for example, for the early ear trumpets that could be very bulky and expose the deafness of the person spoken to an unwanted degree. Up to this day, much value is attached to the near invisibility of a hearing aid, as showing a dysfunction is considered to be embarrassing for the person, whether this is justified or not. The high popularity of contact lenses can also partly be explained by the desire not to wear glasses that give away some sort of a vision problem. Personal choice for an assistive device, then, is a balance between acceptability and need, where usage that is considered unacceptable will be enforced by sheer need.

Acceptability has two extremes, rejection on the negative side and attraction on the positive side. So any product will be situated on this subjective acceptability scale, on which there may be unwanted products, indifferent ones but also products that are highly attractive. Inasmuch as this is a subjective scale, the attraction value may not be dependent on objective or formal criteria at all. To some extent this scale can be called irrational (Tversky and Kahneman 1981) which is not to say that it cannot be rational and supported by formal argument, but it need not be, and frequently is not rational.

Usability and Acceptance

Usability is commonly seen as an important determinant of acceptance. Although the concept of usability, that has been standardized by the ISO (1993), originally was focusing on Video Display Terminals, it has since then adopted a much broader field of application and is currently the most important set of guidelines on product usability extant. Still, the guidelines are typically suitable for a work situation in which product users are controlling systems that produce useful output. In this way the guidelines are less applicable to leisure activities, like watching TV, where the users do not have to produce useful output and where control is mostly limited to switching the set on and off. The main three properties of usability are:

1. Effectiveness
2. Efficiency
3. Satisfaction

Next there are two other requirements that have not yet been formally standardized, but intuitively are sufficiently important to take into account

4. Memorability
5. Learnability

If a task situation in which products have to be controlled satisfies the three main criteria, they have a high usability, but products may also be lacking in one or more of the three, leading to lower usability. Pitting these criteria against assistive devices leads to unexpected conclusions.

Effectiveness cannot be expressed in a measure of output, but only in the extent to which the user can execute tasks with the assistive device that he could not without them. As a rule, this effectiveness is lower than that attained by people without a dysfunction. People who have to walk with a stick are invariably slower than people who do not need one. People who have their vision "restored" by glasses that bring their vision onto a nominally good level do still read considerably slower than people with normal vision (Aberson and Bouwhuis 1997). Measuring effectiveness is easy in the case of observable output, but much more difficult when it is individual functional effectiveness. Moreover, effectiveness is not only assessed by the person; a nurse, doctor, or other carer can judge the effectiveness differently than the challenged person.

Efficiency is determined by the resources expended in relation to the accuracy and completeness of goals achieved. As for effectiveness, it is not easy to assess the efficiency of the use of assistive devices. Assistive devices are resources and have to be used in order to perform a task or function. In this way their control, if any, requires more mental or physical effort than not having to use them. Hearing aids and glasses require hardly any control, but many interactive devices, like video communication require pressing buttons, touching screens, making choices, and dealing with waiting times. So the usability component "efficiency" is more suited to comparison between similar products that may vary in efficiency, whereas an assistive device is usually the only option offered.

Satisfaction is described as the comfort and acceptability of the **work system** to its users and other people affected by its use. Especially in the area of assistive technology satisfaction is not independent of effectiveness and efficiency. Suppose that a person with serious hearing loss employs a speech recognition system that presents speech in the form of readable text. If the effectiveness of the system is low, it will lead to dissatisfaction of the user, while the speaker may be annoyed by the low success rate of his communication, exactly the situation of low satisfaction. Generally this holds for all assistive technology; if its success rate is low, its effectiveness is low and correspondingly user satisfaction will be low. If the effectiveness is low, this may induce the user to spend more effort in making the technology work, which, in turn, will decrease the efficiency.

Memorability becomes important when devices become more interactive. There is nothing to remember for a walking stick or reading glasses, but adjusting a hearing aid may be so complex that often a specialist has to be called in. Battery changes, which almost all mobile devices require, may involve a number of actions that have to be remembered from the previous change, if only to remember how to insert the batteries. Despite being not yet standardized, memorability is relatively easy to measure; as soon as users forget necessary control actions or device properties they may need, memorability is undesirably low. If users intuitively pick invariably the right control actions, memorability is high. Memorability, therefore, stands as an important and reliable measure of usability of assistive technology.

Learnability is a slightly more complex issue. If interaction patterns have to be learned, they also have to be remembered, which taxes memory and will affect memorability. With the current state of assistive technology, it will consistently be required to perform some control actions to make it operate successfully, and these will have to be learned. Learnability is also relatively easy to measure by the amount and frequency of training that the users get. In many "work systems," this is less easy, as learnability may affect effectiveness and efficiency, as work systems are usually more complex than a single-purpose assistive device.

In contrast to the technical specifications of a device, which is a product-oriented approach, usability is a user-oriented approach. While effectiveness can to some extent be described by technical specifications, this becomes more difficult, especially for more complex devices for efficiency. Satisfaction cannot be specified in a technical sense. Memorability and learnability largely evade technical specification.

As argued before, acceptability is not merely the sum of technical capability and usability (Melenhorst 2002). For human choice, more aspects and more subjective considerations enter into establishing a preference. Norman (2004) has proposed a different type of assessment of products, which he termed "three levels of experience."

Three Levels of Experience

Apart from technological and usability aspects, products are also evaluated in terms of how they are experienced, in which the design aspects (1) visceral, (2) behavioral, and (3) reflective are distinguished.

Visceral design concerns itself with appearances, and the term "visceral" already implies that the design of a product leads to a purely subjective and emotional experience. As the looks of a product are mostly unrelated to its purpose (see also Michl (2009) on "form follows function"), there are a wide variety of designs for the

Fig. 2 The antique can opener (*left*) is much inferior in handling and result to the modern one (*right*), which also requires less force, all of which lead to a positive behavioral experience

same product type and a correspondingly great variety of opinions about those. Many devices, e.g., those providing telecare, that are installed in the home of older people are seen as an eyesore, which have to be hidden from view as much as possible. Worse even, most of these devices have to be connected to other ones, which leads to a seemingly random mess of wires against the walls of the room, generally strongly abhorred by the tenants. In the course of their life, older persons have developed their own preferences and have created a living environment to their own taste. Logically, assistive technology is new, and alien in shape and design in comparison with their daily environment, and will generally not be positively appreciated.

Behavioral design serves to create a high effectiveness of use that, in turn, leads to satisfaction with the product. A good example is the difference between antique and modern can openers illustrated in Fig. 2. The old-fashioned can opener required considerable force, adroitness in moving the handle around the rim of the can, which then raised the lid with jagged and sharp edges. In contrast the modern can opener requires little force and no complex movement and does result in a relatively smooth and much less dangerous lid. Older people, accustomed to the antique can opener, are without exception pleasantly surprised by the ease and pleasantness of use of the new version. Basically, behavioral design, and concomitant experience, combines effectiveness, satisfaction, and efficiency in a single concept.

Reflective design already refers to reflection, a personal cognitive experience. Norman (2004) calls it the rationalization and intellectualization of a product. The product becomes a statement of the person who owns it. Norman (2004) gives the Mini, the restyled version of the original BMC Mini car as an example, but it can also be exemplified by a large screen HDTV, design furniture, or luxury kitchens. Ownership of such products is a source of pride, which definitely moves this concept out of the work situation from which the usability standards evolved. Interestingly, the usage properties of such products seem not to be particularly relevant. It is a well-known fact among kitchen suppliers that sophisticated luxury kitchens are hardly ever used. Maserati and vintage cars only hit the road on special occasions and in favorable conditions, and TV shows recorded by multifunctional video-recording systems are almost never watched afterwards. More recent technological products, like smart phones, are a prominent example of reflective design. Rather than being only a communication device, they also often function as personal decoration, as a contemporary version of jewelry with which one can show off (Juhlin and Zhang 2011; Fortunati 2013).

So for assistive technology, it would be optimal if indeed the users would really be proud of it, but at the same time use it extensively to their own advantage.

Social Conformance

There are, of course, many other factors that determine or affect choice of products, but not all of those seem to be relevant for assistive technology. Fashion is one example, which is of almost overriding importance for clothing and interior design, but hardly affects the design of technology per se. There are, however, two factors that, in combination, may play an important role in dealing with assistive technology.

These are "custom" and "social conformance." Both relate to the perception of what other people do and want, especially in the broad social circle of people. This is an old phenomenon. At the occasion of the opening of the railway between Bakewell and Buxton in 1835, the Duke of Wellington is quoted as saying: "Every fool in Bakewell wants to be in Buxton, and every fool in Buxton wants to be in Bakewell," adding that ". . .railways are to be opposed as they will encourage the lower classes to move about. . .." Around 1890 high-ranking ladies were complaining about their maid servants who were driving a bicycle on Sundays, quite likely with their lovers, which until then was only relegated to the higher classes due to the high price of bicycles.

While class differences petered out in the twentieth century, owning a personal computer in 1980 was seen by many as frivolous uselessness, somewhat later the mouse was derided as silly, and 10 years later the same was claimed about the mobile phone. When no one in one's social circle has any form of telecare installed in the home, and its function is largely alien to the older person, having such a system installed will, in a sense, have to compete with the felt social pressure not to have one. Additionally, it will expose the vulnerability of the person, which is not seen as anything to be proud of, leave alone that it will be intellectualized as reflective design.

Regulation and Standardization

One factor that is completely unrelated to any of the above is still one of the most powerful to introduce products into society as a whole, which is legal regulation. The variety of products and systems which it covers is very large, and practically always for good reasons. The safety regulation for installing electricity in homes is one early example; driving on only one side of the road is another. More recent examples include helmets for motorcyclists and safety belts for motorists, and in many countries, there are legal obligations to supply medical aids, like crutches, wheelchairs, and other products to persons who need them.

As a rule standardization does not originate from the government, but it can play an important role to enforce it, while industry, professional, and consumer organizations will draft the standards for a product area. Standardization is of inestimable value for installing effective and affordable technology. Regulation and standardization essentially take away many of the subjective barriers that exist to adopt technology and not only assistive technology. It will appear in the following sections that it is in fact the lack of standardization that has been one of the most important barriers in the take-up of telecare and related assistive technology.

Cost and Pricing

Cost and pricing have to be differentiated as cost of technology is not always reflected in the price. This holds especially for medical technology and for other professional products. The reason is that those standardly have to conform to specifications that are mostly irrelevant or unnecessary for consumer products. Medical technology has to conform to strict regulations, i.e.:

- European Union laws – the Medical Devices Directives and Regulations
- UK laws – the Medical Devices Regulations

As an example a small section is presented here outlining one of the many procedures (note the number 39!) to be followed for biological safety, as prescribed by the Medicines and Healthcare Products Regulatory Agency (MHRA) of the British Government (2013)

> **39. Detailed information on the device**
> Detailed description of how biocompatibility and biological safety have been addressed. The risk assessment should cover the rationale for the decisions adopted. It should be apparent from the risk assessment, how hazards were identified and characterised and how the risks arising from the identified hazards were estimated and justified in relation to anticipated benefits. Particular attention should be paid to biological safety issues, especially for devices containing new materials that will come into contact with patients or where materials are used in a situation involving a greater degree of patient contact.

Often the investment in making the product conform to regulations is higher than developing the product itself, which drives up the price to a considerable amount. Likewise, specifications for professional use also increase the price of product development; military specifications are a case in point. Another reason for a high cost is the mostly limited production runs; minimal production runs for consumer products are 10,000 but can easily exceed millions.

Even so, this does not necessarily imply that consumer products are by definition less reliable than professional products. The sheer number of products allows carrying out extensive reliability testing such that consumer products may be appreciably more reliable than some professional products. At the time when devices for home automation became available for disabled and older people, the price of these devices was a considerable barrier for installation. One example is automatic door openers that technically were not very complex and well affordable. When they were installed, there was a regulation that the opener must include a protective system that prevented someone to be crushed between an opening door and a wall. This pushed up the price to almost four times the device cost itself. At the same time, however, automatic garage door openers, commercial products, had featured such a provision for years and carried a purchase price of less than one tenth of the automatic door opener.

Usefulness and Effectiveness

As mentioned before the effectiveness as described in the ISO usability standard cannot be directly transferred to an assistive technology situation, as there is no measurable production by the system. However, when the system, e.g., a medical alarm system, has to function and indeed does function, it does what it is expected to do and thereby is very useful for the client. Usefulness seems, therefore, a better term than “effectiveness” in this context. It is, however, not the case that clients having such an alarm system installed perceive its functionality as useful. First, in general, the alarm has been installed more as a precaution as the client has a raised likelihood of developing a serious medical incident. Still, as long as the client is deemed to be able to be living in his own home, such incidents are rare, and the system has only to be activated rather infrequently, or not at all. As long as the system is not activated, the client does not intrinsically perceive the system as effective and essentially cannot perceive its usefulness.

Second, the current state of technology cannot prevent false alarms to occur. False alarms in this situation occur on two levels rather than one. All diagnostic systems have a sensitivity that is limited to some extent; no system is infinitely sensitive. Consequently, there will occur hits, misses, false alarms, and correct inaction. A quantitative example may illustrate the behavior of an alarm system with its consequences.

Suppose that the sensitivity of a diagnostic system has a discrimination power of $d' = 2.5$, which is a pretty good performance (see for an explanation of d': Peterson et al. 1954, and note that null sensitivity has a d' of 0). The sensitivity is system bound, the user cannot adjust it, but the criterion level, above which the system produces an alarm, can be set relatively arbitrarily, though extreme high and low values should be avoided. Setting the criterion low means that an alarm will already be produced when there is a little evidence for a health incident, and a high criterion will trip only the alarm when there is strong evidence. In the first case, there will be a lot of false alarms but also a high hit rate; in the second case, there will hardly be any false alarms, but also many incidents will be missed – a low hit rate. Now with a sensitivity of $d' = 2.5$ and using a moderately low criterion of 1.65 (the criterion is expressed in the same units as d'), we obtain the following results:

	System response		
State of health	Alarm	No action	Sum
Real incident	0.80	0.20	1.00
Everything normal	0.05	0.95	1.00

Obviously, one wants to optimize the number of desired outcomes, which consists of the sum of the hit rate and the correct rejection. In the above example, this would be 0.80 + 0.95 = 1.75. This is, however, not the highest possible value of desired outcomes. The highest value that can be attained is by setting the criterion somewhat lower, to 1.25, leading to the following outcomes:

	System response		
State of health	Alarm	No action	Sum
Real incident	0.89	0.11	1.00
Everything normal	0.11	0.89	1.00

In this example the false alarm rate (11 %) has more than doubled, which is why the previous criterion setting is preferable. It is useful to see what would happen if we try to reduce the false alarm rate even more, say to 1 %. This leads to the next outcomes:

	System response		
State of health	Alarm	No action	Sum
Real incident	0.56	0.44	1.00
Everything normal	0.01	0.99	1.00

While the false alarm rate has been reduced now to only 1 %, almost half of the real incident occurrences (44 %) will be missed; clearly an undesirable criterion setting.

The Base Rate Problem

Now the health state of a client is not a series of discrete events, each with its associated probability, but rather a continuous variable, which is why some approximations are needed to clarify the analysis given here. This relates to what the likelihood is of an incident and of a normal state of health, which is hard to define on a continuous variable. A helpful approximation is to express the likelihood as number of occurrences per time unit, say incidents per week. Now suppose that a health crisis occurs once a year, then there are 51 weeks without an incident: in other words the “everything normal” situation is 51 times as likely as a health incident. The probability of occurrence of a health incident would then be 1/52, or less than

2 %, which is called the base rate. If the base rate is low, the criterion at which an alarm has to be produced has to move up, as otherwise too many false alarms will occur. If the criterion is now set so high as to produce an equal number of "hits" as "false alarms," the probability of a "hit" – a real health incident correctly detected – has come down to 1.2 %, and it is a small consolation that the chance of a "false alarm" is then also 1.2 %. This is because the quantity of time slots without an incident is counting so heavily in the monitoring process. The rarer the incident occurrences are, the higher the sensitivity of the system has to be, which is often not easy to realize. Of course, there are obvious situations where the physiological status is evident, like a heart that stops beating, or no detectable breathing. Many physiological indicators can, however, be rather variable, which makes correct identification of a serious incident uncertain.

The Reliability Problem

The second level of false alarms has nothing to do with sensitivity, but with the reliability of the system as a whole. The growing amount of wireless signals, especially in areas with a high population density may emit interfering signals that may intrude on the correct functioning of the system. System-born software glitches may also cause interference with functioning, and so there may be several sources of harmful interference that can give rise to an alarm. It may be that a sensor gets detached without being noticed by the wearer, or leads are disconnected accidentally by house cleaning. In that case the output of the diagnostic system is bypassed, and whatever its output is, the alarm state is always produced: there is no decision matrix involved. In actual practice this does not happen often, but its likelihood may be of the same order as that of a real health incident, but may also be higher. Again a quantitative example may be useful.

Suppose that a true health incident occurs on average once a year, and a system glitch leading to an alarm also once a year, where the true hit rate is 80 % and the false alarm rate 5 % as before. Again we take as quantification of the likelihood the number of weeks in which an incident occurs. Leaving out the computational details, it can be found, with the given sensitivity of the diagnostic device, that when an alarm is given, it is justified in 25 % of the cases, and therefore, 75 % consists of false alarms. Now if a fluke false alarm occurs only once a year, then the probability of notifying a valid health incident drops to 18.5 %, so that false alarms are more than five times as likely than valid alarms.

Understandably, prospective clients, hardly aware of the possibility and frequency of occurrence of false alarms, both of the first and the second kind, may find the system useful and reassuring. However, as soon as the installed system is operational, false alarms may occur, and observing the associated consequences, clients rate its usefulness much lower and lose trust in the system, which, in turn, may lead to discontinuation of the service. This phenomenon of shifting attitudes as a result of experience is not new; it was already found by Ehrlich et al. 1957. Consequently, the rating of usefulness is first based on insufficient information and subsequently will change into a negative direction as soon as the daily operation with its associated false alarms is experienced. Usefulness, therefore, appears not to be a reliable predictor of use of telecare systems.

Technology Acceptance

Two approaches to describe the adoption of new technology in the population have received widespread attention. The first, the Innovation Theory, was proposed by Everett Rogers in 1962 and has become quite influential. The main idea is that the adoption process of a particular novel product, like an electric motor, an electric shaver, or refrigerator is following a fixed sequence of stages. The first is *knowledge acquisition*, next follows *persuasion*, e.g., by social peers, after which a *decision* is taken to purchase the product. The next step then is *implementation*, which is concluded by *confirmation*. An expanded model was presented 20 years later (Rogers 1983), the schematic representation of which is shown in Fig. 3. In this scheme there are two problematic components in the case of assistive technology and telecare. First, older people do not actively try to acquire knowledge about assistive technology; mostly they are confronted by it by external parties. Due to the rapid technology advances, older people usually have no knowledge about the existence of assistive technology and have little or no knowledge at all about the control of such technology and about its exact function (Docampo Rama 2001). The second problem is the decision stage, where it is assumed – as a default – that the user takes the decision to adopt an innovation. In telecare this is not nearly always the case, as it is often the caretaker, the care organization, or the relatives who take the actual decision.

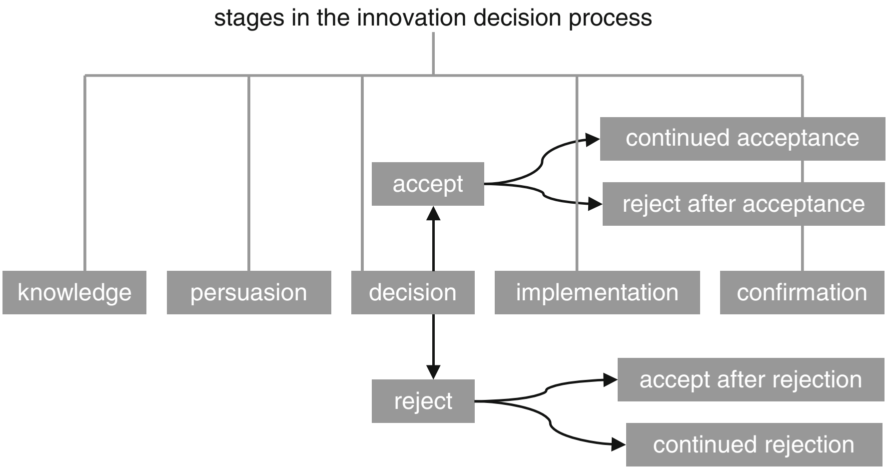

Fig. 3 The expanded innovation model by Rogers (1983), showing the five basic stages and a more detailed decision process than the earlier model (1962)

Also, if the innovation is rejected, the confirmation state is not attained at all. The question is therefore whether the linear sequence of stages is valid. Beal and Rogers (1960) found that innovation adopters often skipped stages or changed the order, suggesting that the model is not universally applicable. Rogers himself stated that the sequential model was not based on empirical research, but seemed a logical and rational description of the stages of innovation adoption. However, in recent decades, strong doubt has been shed on the assumption that human choice behavior is indeed rational. Criticism of such an assumption has come from social philosophy, economics, and most strongly from psychology. Bourdieu (2005) states that social agents do not continuously calculate according to explicit rational and economic criteria. Rather, social agents operate according to an implicit practical logic – a practical sense – and bodily dispositions. In psychology the doubt about logical decision making goes as far back as the research of Narziss Ach (1905). In recent years most empirical research on the irrational aspects of decision and choice has been published by Kahneman (2011) and Ariely (2008). On the basis of such research, the sequential stage model by Rogers (1962, 1983) is untenable; it appears that buyers behave very differently from following a logical and predictable decision and usage process.

This state of affairs has consequences for other theories as well, notably attitude theories, of which the Technology Acceptance Model (TAM; Davis 1989) is the most relevant here. Like its follow-up, the UTAUT model (Venkatesh et al. 2003), it is based on the Theory of Reasoned Action (Fishbein and Ajzen 1975), where the word "reasoned" refers to a rational and logical sequence of processes that lead to a decision or an action. Central in attitude theories is the concept of "intention" that is taken to lead automatically to a choice or action. This assumption is so strong that quite often "intention" is taken to be almost equivalent to the choice or action. In reality this is hardly the case in choice for assistive technology or telecare (Sponselee 2013). Generally speaking, the factors that according to TAM and similar models lead to "intention" need not to be involved in the choice process, or in a different order, or with a different chain of causation. A final argument to treat the predictive value of Technology Acceptance Models with caution is that the proportion of explained variance for applications in telecare and assistive technology rarely exceeds 50 %, whereas the highest values overall hover around 60 %. Inasmuch as this holds only for the prediction of intention (to buy), the actual predictive value for actual usage must be still lower.

Choice and Stakeholders

Most Technology Acceptance Models consider the telecare client by default as the sole agent who makes the choice to acquire a telecare system. Though the consent of the client is usually taken seriously by care organizations, the installation of telecare comprises a great many stakeholders with their own interest at heart, which may separately or collectively block delivery and/or installation, irrespective of the intentions of the client. Alternatively, the client can be asked to allow telecare installation in the home, where the client's consent is seen as a default. Mahoney (2010) gives a sometimes startling rendering of the events that may take place during the introduction of a telecare service. A number of quotes from this paper:

> The project had been formally blackballed by the union representatives for the case managers because they perceived the technology to be a threat to their jobs.
>
> [..] Friedman and Wyatt (1997), [..] note that completely different questions arise when an information resource is still in the lab, versus when it is in the field, and it can take *many years* (Mahoney's italics) for an installed resource to stabilize within an environment.
>
> The greatest barrier, however, was the pharmaceutical company's ban prohibiting caregivers from participating in another Alzheimer's disease-related study, even non-drug interventions.
>
> Several [gatekeepers] deemed the technology as a-humanistic and of no-value to their members, without letting the members even learn about the project.
>
> Findings revealed that the main reasons study participants declined use of the home monitoring technology related to concerns about the care-recipient's home environment and loss of familial privacy.

Observations like these reveal the older client as an accidental stakeholder somewhere at the end of the process. Seen in this sense, it is less important to what extent the older client accepts the technology, but rather how all stakeholders do so.

Telecare: A Multisectoral System

An interesting if not dramatic example of a failed business case is supplied by the bankruptcy in 2009 of the care organization Meavita in the Netherlands. Meavita had 100,000 care clients, 20,000 employees, and, in an attempt to lower the care costs, ordered 30,000 TV-phones. These video devices enabled video communication between nurses and clients and would also transmit clients' blood pressure values and glucose levels. This order was the main cause of insolvency of the care organization in the wake of production problems in China, inability of the technology developer to attain reliable operation, installation difficulties, and lack of cooperation by the network provider (and many other troubles). Ultimately only 1,500 clients received a TV-phone, short-lived as it was, due to the bankruptcy.

Apparently, assuming that technology with suitable specified capabilities can directly be plugged in into a telecare system is mere wishful thinking. The reasons are multiple, but the most striking property of assistive technology and telecare provisions is that they are multisectoral products. Without going into the details of economic sector theory, we may note that assistive technology is associated with the industrial sector, running the operation is part of the care sector, processing client data is part of the medical sector, and doing the investments is the area of the financial sector. Too much telecare and assistive technology is seen as a product that you can buy, install, and enjoy, while it is a system consisting of many components of widely differing kinds, not controllable by the user.

In fact, all products lie on a dimension of dependency of infrastructure. A chair does not depend on infrastructure, if one disregards the means to manufacture it. A radio, however, depends on a whole system of program providers and transmission stations. The situation for the telephone is even more complex. More physical products, like automobiles, seem to be separate products, but rely heavily on the existence of paved roads, an extensive network of fuel providers, a well-organized service network, and state-run traffic safety provisions as well as a legal system for traffic regulation. It is the existence of the traffic infrastructure that makes it possible for the individual to consider and use the car as a separate and (almost) fully controllable device. The car does not need a business case: to most users car usage is transparent and affordable, fitting in, and often enabling the lifestyle and/or professional life of the owner.

Nothing of this holds for assistive systems and telecare. Assistive systems often do not have to be controlled by the user, e.g., automatic ventilation, fall detection, and remote monitoring of vital signs. In most cases they are not purchased by the client as consumer, but installed on the recommendation of care organization or medics.

For assistive systems and telecare, the client is not the only user, since the care organization can monitor the vital signs or entertain communication and so is using the system as well.

But the care organization is certainly not equipped to take care of the technological components and installation requirements, and this is where assistive technology and telecare are fundamentally different from other, common, products.

Six different parties can be distinguished

1. The equipment manufacturer
2. The software developer
3. The program provider (which may be the care organization)
4. The communication network provider
5. The installation firm
6. Financial services for the investment

The agreements, authorizations, and dependencies between the six parties for the new products in a novel type of application have not yet been consolidated to a degree where dependable service is possible.

Suppose that a home-installed device is defective. The interesting question that arises is who is going to take care of the repair and who is going to pay for it. In fact, the situation is even more convoluted, as it is often not clear why an installed system is not operational. The cause may be located in a device, in the Home Area Network, there may be interference by nearby powerful routers, there may be a glitch in the communication network, and there may be a software error. In actual practice it appears (Sponselee 2013) that repeated visits by technicians, whether for installation difficulties or for repair, are a main source of discontent from the part of the clients, who often discontinue the teleservice for that reason.

Seen in this perspective, it is clear that the regular questions concerning the experience with the system, as there are "perceived usefulness" and "perceived ease of use," are mostly not applicable, but also miss a multitude of factors that make their presence felt in a multitude of stakeholders. Inasmuch as TAM (Davis 1989) was applied to finished and operational products within a stabilized application environment, it is certainly totally inadequate to make even approximate predictions about usage, leave alone by what party.

Conclusions

Recent developments in technology are not all a bad sign for assistive technology and telecare. What can be seen is that a large group of products has moved from professional deployment to consumer usage. One of the most telling products is that of video cameras that, once only affordable for broadcast agencies, now are featured in the cheapest products and even toys. Successful deployment of assistive systems and telecare will therefore be dependent on devices that will be produced for the consumer market, not for the professional market. These consumer products will be more reliable and far less expensive than professional products.

While around 1995 device communication in the home was planned for wired home networks, like the ill-fated European Home System (EHSA 1997), and many more, currently the Internet protocol (2013) abbreviated to IP is almost universally employed for wireless communication between devices in the home. Two striking advantages come with this adoption: no expensive cabling in the home and interoperability between devices equipped with IP.

These two developments alone will not create a stable platform for assistive technology and telecare, as there are still too many unrelated parties involved in implementation.

This essentially means that a business model has to be developed that includes the activities necessary to pay, implement, install, and run such systems.

So far extremely few successful telecare systems of any reasonable size have come to light, and even here, if the client moves from one area to another, it is impossible to take the telecare system with them, as they do with a car, their glasses, and their hearing aid. The largest system extant, the CCHT system of the Veteran Health Administration (Darkins et al. 2008), is an attempt to incorporate the maximal number of specialized services, medical and technical, in the telecare system. Though it is difficult to get information concerning the current number of clients, there were more than 30,000 in 2007, with numbers growing. Yet the CCHT system shows many unresolved problems (Hopp et al. 2007) that demonstrate that the chosen business model is not optimal.

It is unlikely that as long as a stable telehealth infrastructure does not evolve, a successful business model can be maintained. So far, the absence of resilient business models in telecare and assistive technology is a well-established fact.

Where does this leave the most important end user, the client, who receives some form of care or assistance? Most often the client has to take whatever is offered, and there is no choice between alternatives. This makes perceived usefulness (PU) and the perceived ease of use (PEoU) rather academic, especially as almost always the client has no prior experience with the devices.

Even armed with full documentation and extensively briefed in meetings, older people with some form of assistive technology are normally unable to operate successfully more than one device, while maintaining that all devices are easy to use (Eyck 2004). Here the critical issue is that enquiries and surveys are taken in a different context than when operating the systems. Older people may well have the feeling that their devices are easy to operate, but whenever they have to control those in experimentally controlled conditions, it appears standardly to be much harder than they anticipated, (Eyck 2004; Ebeli 2005). This phenomenon is another reason for the insufficiency of the TAM framework in predicting technology acceptance.

Finally, it should be noted that considering the state of the art in telecare and assistive technology, the diffusion model of Rogers (1962, 1983) appears to be unsuitable for any prediction of usage and consequently diffusion. Apparently, in order to make even approximate predictions, much more detail of the type of technology and its usage should be included. For the time being, the Technology Diffusion Model will not have any use for the technology acceptance in telecare and assistive technology.

All of this, with admittedly some pessimistic overtones, does not take away that for a number of care activities, telecare can be particularly effective and actually is effective in quite a number of cases (Darkins et al. 2008). Glucose measurement for diabetics seems currently both one of the more popular and more effective telecare applications. This will undoubtedly grow, only we do not know how fast this will be.

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Acceptance and Effectiveness of Smart Home Solutions

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Abstract

Despite current developments in health care, demographics, and technology, the implementation and use of smart home technologies has so far not been as effective as possible. Possible barriers are a lack of incentives and vision on technology application, the complexity of technology and the financing structure, the multidisciplinary collaboration, and the user-technology interaction. This chapter describes recommendations to increase the effectiveness of smart home technology, which relate to a better user-fit, evidence-based practice, technological improvements, project organization, and the financing structure.

Keywords

Acceptance • Smart homes • Needs • Stakeholders • Organization

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Introduction

The positive effects of adequately implementing current and future smart home technologies in health-care situations are stated to be promising. However, despite the driving factors, such as developments in health care, demographics, and technology, the implementation and use of smart home technologies has so far not been as effective as possible. Technologies did not bring the expected benefits for the end-users or have been disused by them (e.g., Cartwright et al. 2013; Steventon et al. 2013; Sponselee 2013). Also, the care process appeared not to be as effective as expected and even more expensive than anticipated (e.g., Henderson et al. 2013, 2014). As a result, many projects have been canceled or postponed.

This chapter describes recommendations to increase the effectiveness of smart home technology, which highly depends on the acceptance and use of the technology and the benefits perceived by its users and end-users.

Hindering Factors for Smart Home Effectiveness

In order to increase acceptance and effectiveness of smart home solutions, it is important to define and understand which barriers hinder effective implementation and use. Although barriers may vary between projects, hindering factors often mentioned in the context of smart home technology involve a lack of incentives and vision on technology application in the care sector, as well as the complexity of the technology and the financing structure (Sanders et al. 2012; Sponselee 2013). Smart home solutions come along with investment, maintenance, and operation costs. While these costs are often covered by subsidy in the early stages of implementation, for (large-scale) implementation and use, there is a lack of financing structure. Additional hindering factors are the diverse stakeholders that have to cooperate in the field of smart home solutions and the, mostly older, end-users who have to interact with this new technology. The multi-sectoral nature of smart home technology disturbs the – financial – responsibilities, as well as the individual financial obligations.

Multidisciplinary Stakeholders

Problems with smart home technology can be partially ascribed to the fact that many stakeholders are involved (Bierhoff et al. 2008). Although the technology mainly originates from the information and communication (ICT) sector, the implementation process of this technology also involves the industry, security, care, and telecom sector. For further development of smart home technology, the educational, government, and care sectors are involved, while for exploitation of smart home solutions, government, finance (insurance companies), trade, and recreational sectors are involved. These sectors are not always used to working in a multidisciplinary fashion, and they may have different goals and aspirations regarding smart home technology. However, due to future ICT developments, trans-sectoral innovation is needed, especially in the area of smart living (Baken 2010).

The multidisciplinary collaboration results in organizational, financial, as well as cultural issues. To decrease the perception differences between the stakeholders involved, an analysis of the expected and experienced effects of smart home technology for each stakeholder can be made (Sponselee 2013). The outcomes can then be communicated among stakeholders to increase awareness. For designers, for example, the effects may involve effective goals, whereas caregivers are mainly interested in effects on workload and quality of care, while care receivers are influenced by usability effects.

Technology and Its Users

An insufficient supply of technologies to solve the problems with smart home solutions in care situations is not the main issue. Actually, at a technological level even more is possible than yet applied in the so-called "smart" technology. There is however a technological need for a platform that enables communication between smart home services, devices, and applications (Brink 2013). The problem also relates to the usability and functionalities of smart home technology that do not sufficiently correspond to the actual needs of the care receivers and caregivers. Even though many researchers have stated that user requirements should be better taken into account in smart home projects, many tangible improvements are driven by improved technology (technology push). The actual users obviously need to get better involved in the development and implementation process of smart home technology. By involving the care receiver and the caregiver in the process, the designer gains more insight into the true perceptions of the stakeholders he or she is designing for. As a result, the list of functional requirements for a smart home system or a smart home project consists of more than just technological functionalities and should comprise all stakeholders' attributes, consequences, and values. In the implementation process of smart home technology, by taking a gerontechnological approach, the older end-users can be better understood. However, the design process must be considered as an ongoing cycle. After use, the stakeholders' expected effects change into actual experienced effects, which may be different and may modify the list of requirements.

Low acceptance and adoption of smart home solutions by end-users can thus partially be ascribed to the "gap" between what the technology can do or bring to the people and the actual need that these people have. This "gap" is actually the result of the "driving factors" for smart home solutions. Nowadays, society as well as government, industry, and care organizations feels the pressure of a society that is growing older. The "dependency ratio" is increasing, which means fewer people will be available in the near future to handle the growing amount of older people who are in need of care. To reduce the growing call for caregiving by professionals, people are encouraged to prevent or reduce the need for professional care, by self-management and self-care, and support by informal caregivers. Their autonomy and independence can be supported by technology, for example, by smart home solutions. Unfortunately, the technology has often been developed from a care perspective, while it may also have other potential benefits related to welfare, well-being, or entertainment. Current smart home platforms however are found to support only 20 % of the desired applications for aging in place (Brink 2013). As long as platforms are not suitable, the needed applications and functionalities are less likely to be developed. The challenge for the industry, service providers, care organizations, and government is to articulate the needs of potential users, then develop and introduce technology that supports those needs or enhances them, and then – later on – add useful smart home functionalities to the accepted technology.

Although many researchers claim to know the needs of older people and many smart home technology projects state they have introduced technology that fits the needs of older end-users, the adoption of smart home technology on a large scale is lacking. Mohammadi (2010) found that producers of smart home technology think that older people do not know which technology is available and what the possibilities are, while the older people in her study were familiar with the technology but stated that the current functionalities did not fit their needs.

Now that we have clarified the possible hindering factors for the acceptance and effectiveness of smart home solutions, the following recommendations are proposed.

Smart Home Solutions Must Fit to Needs

The expectations of smart home technology being useful for home (health-care) situations are increasing, and the application is growing constantly. Meanwhile, it is still often unknown what the exact needs of the end-users are and therefore in what way the technology can be supportive. Acceptance of smart home technology is positively influenced by the compatibility between needs and the expected and experienced benefits (Sponselee 2013; Peeters et al. 2012). In a study by Sponselee (2013), a lack of fit was the main reason for rather low experienced benefits: participants were not yet in need of "distant care," while people with a certain need for care (e.g., dependent upon care by others/professionals) or support (e.g., being widowed) benefited the most from smart home solutions. To increase the effectiveness of smart home technology, beneficial functionalities for end-users with specified needs must be denoted. However, the translation of needs to system functionalities and applications requires further research and documentation.

At the same time, it is difficult to make a business case based on the promising effect of smart home solutions on *prevention*, i.e., on postponing the need for care by implementing smart home technology (while in fact, many smart home projects are based on this principle). On the one hand, a financial compensation for smart home solutions for people who are not yet in need of care is lacking. On the other hand, the (preventive) benefits are difficult to prove, as it involves long-term benefits (e.g., postponed appeal on welfare or care resources).

To increase the effectiveness of smart home solutions, it is important to define the envisioned target group. For technology designers it is relevant to understand who the target group is. What goals are important for them, what are their needs, and thus, what benefits are expected from the technology? Also care organizations in telecare projects must be aware of the group of people they want to support with technology. For certain patient groups, technology can become part of the health-care provision process. However, not all technologies are useful for every group or individual. Based on the needs of the end-users and those of other users (e.g., (in) formal caregivers), a selection of technological functionalities should be made. Despite several attempts, no globally accepted overview of smart home solutions in relation to needs is available (e.g., an “availability matrix” (see World Health Organization 2010)). A possible tool to select smart home or e-health technologies is the WHO Compendium of innovative health technologies (World Health Organization 2014) in which health problems as well as corresponding solutions are described. A Dutch tool to select these functionalities is a model presented by Nictiz, in which IT platforms for distant care and welfare services are described along three layers: network services (bottom), platform services, and application services (top layer) (Krijgsman et al. 2012). The application layer consists of four categories of services, namely, comfort, welfare, safety and security, and cure and care. Such a model can be used as a means for discussion in the orientation phase of the implementation process and as a tool for so-called use cases. The technology can, therefore, better be implemented – first – for specific patient groups, with a specific need for care, like COPD, diabetes, or CVA patients, who already receive long-term care (Peeters et al. 2012) and have certain financial resources and who may already experience some benefits brought by the technology (better physical control, information availability, and less travel time for doctor or hospital visits (see, e.g., Evers et al. 2009; KNMG, NCPF and ZN 2012)). Dutch policymakers, for example, are focusing specifically on telemonitoring for patients with diabetes mellitus and chronic heart failure, as well as teleconsultation for dermatology, as the best effects are found for these target groups (KNMG, NCPF and ZN 2012; Schippers 2012). With the current amount of older people suffering from these diseases and the expected growth of people with these diagnoses, the technology may help to reduce the pressure on care organizations by focusing on these specific patient groups.

To increase the acceptance and use of smart home solutions, we thus need to understand what the needs of people are and how technology might substitute or support these needs. It is therefore important to accord the end-user a central role in the development and implementation process. By assessing the end-user’s needs, smart home functionalities can be defined that fit those needs, in order to increase technology acceptance. Different methods can be used to assess the end-user’s needs in relation to smart home solutions, ranging from workshops, role-play, and demonstration facilities to in-home experience. Although these methods differ in their usefulness to obtain the end-user’s needs (Sponselee 2013), it will help to define people’s needs in relation to smart home solutions. For some researchers in smart home projects, it might be surprising to find that people’s needs are not merely care related. People in their third age, for example, who may have minor physical restrictions, are still (socially) active and want to participate in society (Sponselee 2013). Besides medical or care-related needs (possibly for the future), safety and security needs may be expressed, e.g., in the scope of social support and surveillance. As a result, social networks appear to be important. On the other hand, despite the need for (social, mental, or physical) support, older people want to stay in control, by selecting their own support, facilitated by accessible information and proper communication. Technology is considered as a means to achieve this, although specific technology requirements have to be taken into account in order to benefit from the technological potential.

More Benefit Evidences Are Needed

There is a lack of evidence of the (beneficial) effects of technology use for specific groups. It is, for example, still rather unclear what the effectiveness of smart home functionalities is for older people, patients, (in)formal caregivers, and care organizations (see also Black et al. 2011; Peeters and de Bie 2012). Without a defined fit between functionalities and benefits, a paucity of empirically demonstrated evidence of benefits, and a lack of evidence of cost-effectiveness (Black et al. 2011), there is no chance of a feasible business case.

In a study along 75 older users, a screen-to-screen telecare system was found to have beneficial effects on the well-being, feeling of safety, feeling of independence, and independent living (Sponselee 2013). However, these benefits differed along persons, depending on their needs and depending on the functionalities of the system. This demonstrates that personal needs should be collected as identifiers for smart home solutions to achieve eventual benefits of the technology interaction. The telecare system under study, for example, was most beneficial for people suffering from lung diseases, from rheumatoid diseases, and with mobility and hip, leg, or back problems, while people who were divorced or widowed benefited more than singles and married couples. Despite the multiple functionalities provided by the telecare system, the personal alarm was mentioned to be the most important functionality of the system, in parallel with the fact that people could immediately and directly come in contact with the care center.

More tests of beneficial effects are required to test whether goals are met at the end of a smart home technology implementation, preferably in a randomized controlled trial (Evers et al. 2009; Black et al. 2011). Therefore one should define at the beginning of such trial or project what effects are expected, and how this can best be measured. This also includes selecting the target group in which best effects are expected. A helpful tool is offered by Nictiz, who published a white paper on the arrangement of e-health applications, considering the users, the technology, and the care process (Krijgsman and Klein Wolterink 2012, see Fig. 1).

The second problem of a lack of evidence is that much knowledge on the effects of smart home solutions is not sufficiently available to others (see also Peeters and de Bie 2012). The knowledge on technologies and functionalities in home care is increasing but still fragmented. This knowledge needs to be collected, made available, and distributed – in a tangible way, beyond scientific conferences – to all stakeholders interested in implementing smart home technology. It is necessary to

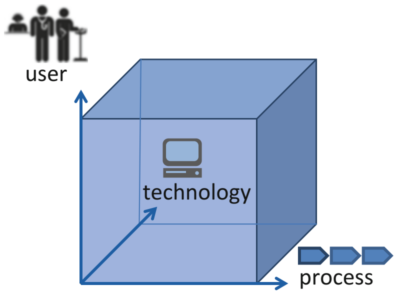

Fig. 1 Three dimensions along which e-health application can be classified (Krijgsman and Klein Wolterink 2012)

educate people for a new profession, both technology and care oriented, being able to bring this knowledge to whom it may concern (e.g., the development of a telecare wiki by J. Grin and P. Stevens (2012) and an eHealth Guide under development by the Dutch Patient Consumer Federation (NCPF) (KNMG, NCPF and ZN 2012)).

The Technological Challenge

Despite the innovation initiatives, technical problems are still a major barrier for successful implementation of smart home solutions. The technology to be implemented must function at all times and, moreover, should be accessible. The technology must be tailored to the situation and skills of the users, involving user-friendly interfaces, comfortable technology interaction, and non-stigmatizing design. Daily constraints such as memory loss, low vision, and hearing difficulties (common constraints coming with age) might also obstruct the effectiveness of the functionalities of the smart home technology.

For increased acceptance and effectiveness, technical problems, such as malfunctioning devices, power loss, and connection failures, should be avoided. Regarding accessibility, the smart home interface must fit the technology generation it is designed for. When the envisioned users were in the third age (active retired), the system should be designed according to the electromechanical technology generation (Docampo Rama 2001). A Windows-menu-layered interface design thus does not meet this requirement. In addition, interfaces are often not designed for people who have hearing loss, have low vision, or are somewhat forgetful. As a result, many functionalities may not be known and used, as it does not exist in the mental representation of the interface of its user.

To overcome the problems illustrated above, technology providers must be aware of and communicate the limitations and possible (connection) problems of their technology at the beginning of the implementation. Extensive user testing by the technology providers – to increase awareness – as well as the development of a flexible interface design is required. Smart home system design also needs accessibility requirements for the hearing impaired and for the mentally impaired: synchronization of sound and picture, subtitles, and visual feedback can help the hearing impaired, while people with dementia or mild cognitive impairments need as less interaction with the technology as possible and otherwise as intuitively as possible.

While the technology is not working without problems and interfaces cannot be used solely on intuition, it is important to provide support and training. Without support, problem situations during the use of the smart home solution lead to de-motivation and a high probability of abandoning the system. Training on how to use the technology is needed at all levels: people who interact with the system at home, family members who remotely receive information, and nurses who interpret incoming data. One should realize that older users need more guidance during pilot tests than younger people, while caregivers need to be motivated to use technology in the care process. The best way to increase the acceptance among caregivers is to include the use and implications of smart home technology in the curricula of social and nursing studies. Eventually, there must be an educational specialization in the field of care and technology for this envisioned profession.

Smart Home Technology Organization

The project organization around the implementation of smart home solutions is complex. One of the problems of implementing smart home technology is the idea of stakeholders that innovation solely involves the implementation of these new technologies. Implementing smart home technology is more than a technological innovation. It particularly involves a process innovation. The introduction of smart home technology in (home) care influences the structure of the individual care and welfare organizations, while it often leads to new collaborations between healthcare, welfare, and service organizations. New working protocols need to be developed that fit the new processes.

An implementation process, in theory, proceeds with the following steps: (1) technology testing, (2) pilot (focusing on acceptance), (3) organizing underlying processes, (4) implementation, (5) and use. However, effective testing of technology and technology acceptance in practice are only useful in case the technology is on a process level already partially organized. People comment or react negatively on "the smart home solution" when the organization of processes is not properly organized, although the technology might be acceptable. In this case, the technology is not accepted, while it might have been accepted in case the processes were experienced positively.

For a successful implementation, cooperation of multiple partners is necessary (e.g., KNMG, NPCF and ZN 2012; Schippers 2012). When a company, housing corporation, or welfare or care organization decides to implement smart home technology in their business, the first thing to do is to bring together all other stakeholders involved. The innovation is not the implementation of technology alone; it involves cooperation with other businesses to provide new or other services. It is important to innovate through a multidisciplinary, and preferably interdisciplinary, project team (cocreation). As stakeholders may have different goals and interests, it is important to communicate these expectations in workshops or other meetings in which project goals are defined. It should be clear what effects each stakeholder wants to achieve by implementing new technology. Setting goals and knowing what benefits are expected are necessary to make decisions later on regarding functionalities of technologies and also to evaluate whether project goals are reached at the end.

The implementation and design route should also be more iterative. The stakeholders involved must be aware of the fact that (Sponselee and Schouten 2012):

– Choosing technology is not the only (important) step toward innovation.
– Implementation is a process that takes time and involves a change in care processes as well.
– In parallel with the technological innovation, the process innovation involves revising processes and informing and training care professionals, in order to increase acceptance in the workplace.
– End-users need to be well informed about and supported in the implementation process.
– The process needs a proper overarching coordination.

The implementation of smart home solutions thus involves a range of steps to be taken, related to the multiple stakeholders. In Table 1 an example is given of the implementation steps and corresponding responsible stakeholders. The implementation steps on the left are partially based on earlier studies (e.g., the importance of articulating and communicating the goals of stakeholders at the beginning of a project; Sponselee 2013). Table 1 serves as an example of a tool that can be used in projects to determine steps and responsibilities of stakeholders involved and discuss, communicate, and agree upon these. The stakeholders will vary depending on the project.

For Example As aging in place is a current trend/development, a local care organization may want to extend their services, by connecting to older people living independently at home, offering remote care on demand. They seek for partners that offer welfare services (to support independent living). A housing corporation may also want to extend their services, as their tenants become older and more care dependent. These three partners should start their collaboration by communicating each individual vision on implementing smart home technology (1). In a successive step other stakeholders involved should communicate their goals, from their own perspective and for whom, as all partners may have different goals (2). The needs (of clients and formal and informal caregivers) that are expected to be supported by means of the intervention should be determined (3), as well as the expectations (4) and the possible role technology may play in this intervention (5). Next, the technology should be considered as part of the services, processes, and protocols that may need revision (6). Then, an implementation plan can be developed by several stakeholders (7). As a result, new responsibilities and roles of the partners should be considered (8). Providing information and training to professionals and end-users is part of the implementation process (9). Several partners should take responsibility

Table 1 Checklist for telecare implementation: implementation steps and stakeholders' responsibilities

	1. Care organization	2. Welfare organization	3. Government	4. Research	5. Developer	6. End-user	7. Family	8. Housing corporation	9. Insurance company	10. Local government	11. Informal caregiver	12. System integrator	13. . . .
1. Vision	X	X						X					
2. Goals	X	X			X	X	X	X	X	X	X		
3. Needs	X	X		X				X					
4. Expectations	X	X			X	X	X	X			X		
5. Role of technology	X	X				X	X				X		
6. Telecare as part of care process	X	X				X	X				X		
7. Implementation plan	X	X			X			X					
8. Organization/ roles?	X	X				X	X	X		X	X		
9. Information/ training	X	X	X	X	X								
10. Service/help desk	X	X			X			X				X	
11. Costs	X	X	X	X	X	X	X	X	X	X	X		
12. User-friendliness	X	X		X	X	X						X	
13. Personal preferences/ needs	X	X			X	X					X	X	
14. . . .													

for information and help desk services (10). In addition to the implementation plan, stakeholders should calculate internal costs/benefits in a business case, resulting in costs for individual end-users as well (11). The user-friendliness of the interfaces should be tested and preferably adjusted to the user group (12), providing variations according to personal preferences and needs (13). For each step, it should be clear which stakeholders take responsibility.

A Financing Structure Is Required

Costs associated with smart home technology implementation are related to investments, maintenance, and operation. These costs are often borne by funding agencies only in the early stages of implementation. However, for continuation of implementation and use, there is a lack of financing structure. Also for large-scale implementation of smart home technology, a transparent and comprehensive structure is needed, to answer all questions individuals have, concerning their financial obligations.

An additional financial problem is that investments and financial benefits often do not appear in the same economic sector. While care organizations invest in telecare, hospitalization, medication, or other health-care needs may be prevented, resulting in reduced costs for insurance companies and local and national government.

National and local government as well as health-care insurance companies must consider their role in the structure and take their responsibility.[1] The financial system in the Netherlands, for example, is currently under construction to make the technology better accessible for everyone (screen-to-screen care for long-term care is structurally financed from January 2012 on; telemonitoring for people with chronic heart failures, telehealth for persons with diabetes, and teleconsultation will be financed structurally in the near future (KNMG, NCPF and ZN 2012); video consultation will be financed likewise physical consult with medical specialists (Dorresteijn 2012)).

Another solution involves a paradigm shift, which will probably take longer, but is inevitable. Especially Dutch citizens are accustomed to the so-called welfare state: the government will take care of you whenever you are in need of something. Due to the enormously increasing care expenditures, this welfare state can no longer be preserved. The Dutch government is already economizing the long-term care, and also domestic help is no longer be compensated for (Ministerie van Volksgezondheid 2012; Rutte and Samsom 2012). People will have to realize that they are responsible themselves for more and more services that were previously provided by the government.

[1]In the National Implementation Agenda (NIA) eHealth, the Dutch health insurance companies (ZN) state that e-health will become part of the contract policies (and thus financial structure) with care organizations (KNMG, NPCF, and and ZN 2012).

Overall Conclusions

The recommendations presented here correspond highly with other current research (e.g., Sol 2012; van Ginkel et al. 2012; Claassen and Willems 2011): involve the older end-user or patient to come to needs-driven innovation, develop a thorough plan beforehand with all stakeholders involved, write a business case, test the concept before implementation, and include and take care of the implementation process. Another important conclusion is the need for support and training of care professionals, including the latest technology in care education, in order to get potential care workers acquainted with smart home solutions, as well as including the care application field into technical studies, in order to slightly bridge the gap between developers and users of smart home technology.

Smart home solutions appear to be beneficial depending on personal situations or for specific user groups, e.g., for people who are mobility impaired, who need medication on a daily basis, or who receive specific therapy. Care organizations as well as researchers have to invest more in defining user needs and effect studies. Effects to further study in randomized controlled trials, for example, are increased well-being, increased quality of care, and elongation of independent living, from an end-user perspective. Beneficial effects for caregivers or care organizations may be related to quality of care, reduced pressure on care, financial profits, or adequate reply to care demand. What smart home solutions are best to achieve these benefits should be considered thoroughly in advance.

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Smart Home Solutions: Privacy Issues

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Abstract

Smart home solutions enable access to health-care services to patients by the use of ubiquitous, smart devices or sensors, at the convenience of their home. As in any health-care IT infrastructure, sensitive health information of a patient is processed and transmitted to third parties, increasing the risk of a privacy breach. The smart home environment, due to its pervasive nature, augments such privacy challenges and poses requirements for the devices and software designed. In this chapter, we identify privacy requirements for this environment, and we map requirements to existing solutions. The chapter concludes with identified priorities and challenges for future work.

Keywords

Health-care • Smart home • Privacy • Privacy requirement

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Introduction

Health-care information technology (IT) enables access to health-care services for patients and medical staff. Smart homes (or places) enable patient self-treatment and monitoring by using simple devices, which provide standardized outputs for specific physiological conditions, intelligent applications or software capable of analyzing and processing body signals, sensor-integrated smart devices, wearable sensors, and other devices exclusively manufactured for the purpose of body signal monitoring and processing (Athavale 2011). Whether at home or in typical settings (physician's office, hospital), health-care IT infrastructures process sensitive patient health information and, thus, face several information security and privacy threats. Such threats, as well as their corresponding impact, have been presented in the past (Gritzalis 1998) (see Table 1).

Smart homes fall into the pervasive computing paradigm. They utilize components (e.g., sensors), which may be invisible and transparent to the user. Their increasing storage and communication capabilities, coupled with their small size, enable collection, processing, and potential disclosure of personal health information (PHI), thus posing significant privacy risks (Dritsas et al. 2006). A comprehensive view of privacy challenges is depicted in a 2011 study on "Patient Privacy and Data Security" (see Fig. 1). Also, existing health-care solutions have focused on information security. For example, Gritzalis and Lambrinoudakis (2004) propose an architecture that preserves authentication and authorization in Web-based distributed systems. Such architecture includes a role-based access scheme and an intelligent security agent, which can be applied in health-care environments. Lekkas and Gritzalis (2006) cover the authenticity requirement for electronic health records (EHR) in a long-term basis. Another approach (Gritzalis 1997) focuses on the issue of protecting health information systems (HIS) by proposing a methodology and a decision-support roadmap for the development of the security profile of a specific information system. Relevant standards regarding health care are also

Table 1 Threats and corresponding impacts (Adapted by Gritzalis 1998)

Security concern/threat	Impact
Information disclosure (loss of confidentiality)	Patient embarrassment, loss of trust, legal consequences, loss of reputation
Withholding information or services (loss of availability)	Poor quality of services, insufficient patient treatment, legal claims, financial impact
Modification of information (loss of integrity)	Insufficient or inappropriate patient treatment, poor management, financial loss
Repudiation	Financial loss, lack of accountability, loss of reputation
Non-auditability	Poor management, inability to claim penalties and take legal action
Loss of authenticity/validity	Insufficient patient treatment

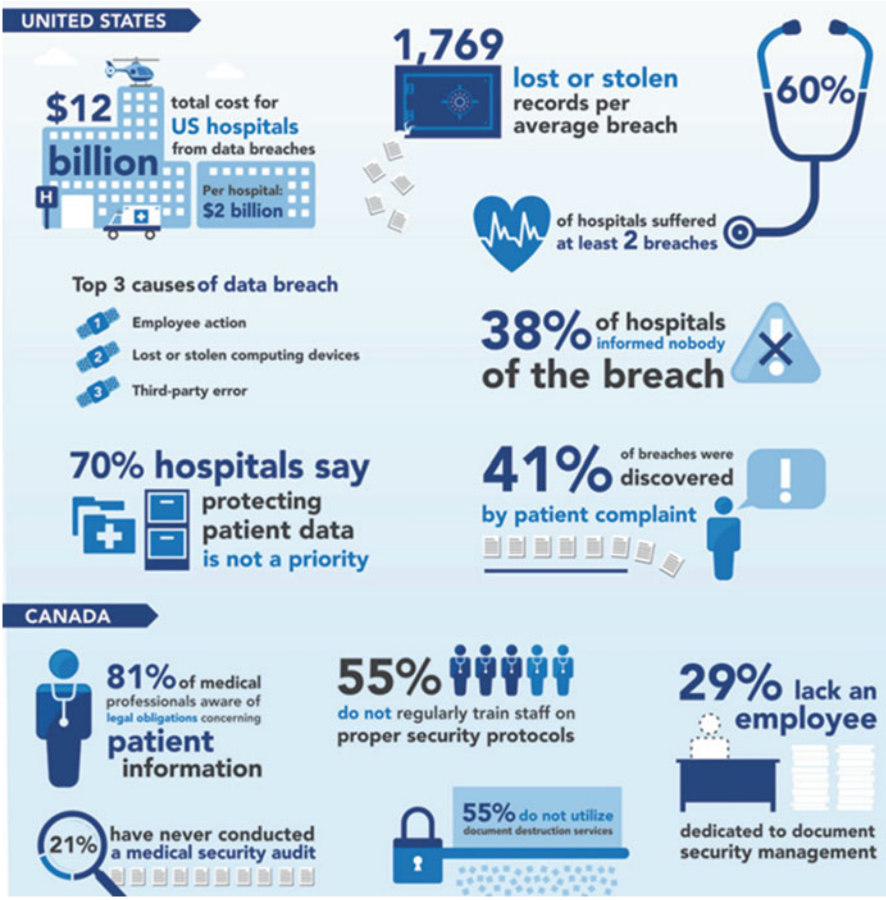

Fig. 1 Privacy in health care in numbers (Adapted by IHTT (http://ihealthtran.com/wordpress/2013/06/infographic-protecting-patient-privacy-how-important-is-it/)

reviewed through the use of a framework that identifies existing gaps and inconsistencies (Gritzalis 1998).

The main focus of this chapter is to review and evaluate privacy challenges introduced by a smart home health-care environment. To this purpose, both privacy requirements and available solutions are reviewed. In section "Privacy Requirements for Smart Home Healthcare Solutions," we review privacy requirements for health care and, then, we propose requirements for smart home health-care solutions. In section "Privacy Solutions for Smart Homes," we discuss existing privacy mechanisms (e.g., architectures, frameworks, models, systems). In section "Evaluation of Privacy in Smart Home Healthcare Solutions," we map requirements to solutions and identify priorities posed by each solution. The chapter concludes with key findings, research challenges, and future work.

Privacy Requirements for Smart Home Health-Care Solutions

Privacy Principles

The US Health Insurance Portability and Accountability Act (HIPAA), passed in 1996 and revised by the American Recovery and Reinvestment Act (ARRA 2009), identifies privacy rights for patients and required policies for health-care information systems (HIS) (HHS 1996). HIPAA includes the following privacy guidelines for privacy compliance and awareness (AMA 2006; CDT 2009):

1. Appoint a HIPAA privacy officer.
2. Develop "minimum necessary" policies for the following: uses, routine disclosures, non-routine disclosures, limit request to minimum necessary, and ability to rely on request for minimum necessary.
3. Develop policies for access to designated record set: providing access and denying access.
4. Develop policies for accounting of disclosures.
5. Develop policies for amendment requests: accepting or denying an amendment, actions on notice of an amendment, and documentation.
6. Develop policies for business associate (BA) relationships and amend business associate contracts or agreements: obtain satisfactory assurances in contract and document sanctions for noncompliance.
7. Develop verification policies.
8. Develop policies for alternative means of communication request.
9. Develop policies for restricted use request.
10. Develop complaint policies.
11. Develop anti-retaliation policies.
12. Develop appropriate administrative, technical, and physical safeguards.
13. Train workforce: train staff and develop sanctions for noncompliance.
14. Develop and disseminate privacy notice.
15. Limit disclosure to those authorized by the client or that are required or allowed by the privacy regulations.

Kotz et al. (2009) studied several available frameworks (see Table 2): ONC National Framework (HHS 2008), Health Privacy Project – Best Practices (HPP 2007), Markle Foundation's "Common Framework" (Markle 2008), and CCHIT's Certification Criteria (CCHIT 2008).

Avancha et al. (2012) extended the work of Kotz et al. (2009) and propose a comprehensive list of ten principles and respective properties:

Table 2 Privacy requirements for health care

ONCNF	HPPBP	MFCF	CCHIT	Requirements
Individual access	Transparency and notice	Openness and transparency	Consent	*Openness and transparency*
Correction	Education	Purpose specification	Controlling access to your information	*Purpose specification*
Openness and transparency	Employees can choose which content is included in the PHR	Collection limitation and data minimization	Conditions of use	*Collection limitation and data minimization*
Individual choice	Employees control access to and use of the PHR	Use limitation	Amending the record	*Use limitation*
Collection, use, and disclosure limitation	Employees can designate proxies to act on their behalf	Individual participation and control	Account management	*Individual participation and control*
Data quality and integrity	"Chain of trust": information policies extend to business partners	Data quality and integrity	Document import	*Data quality and integrity*
Safeguards	Data security	Security safeguards and controls	Data availability	*Security safeguards and controls*
Accountability	Data management	Accountability and oversight	–	*Accountability and remedies*
–	Enforcement and remedies	Remedies	–	*Patient access to data*
–	Portability	–	–	*Anonymity of presence*

1. **Openness and transparency**: Inform patients, enable patients to review storage and use of their PHI, and enable patients to control, through informed consent.
2. **Purpose specification**: Inform patients, limit collection and storage of PHI, and limit use and disclosure of PHI to those purposes previously specified and consented.
3. **Collection limitation and data minimization**: Enable patients to control, through informed consent; limit collection and storage of PHI; and limit use and disclosure of PHI to those purposes previously specified and consented.
4. **Use limitation**: Limit use and disclosure of PHI to those purposes previously specified and consented.
5. **Individual participation and control**: Enable patients to review storage and use of their PHI and enable patients to control, through informed consent.
6. **Data quality and integrity**: Provide access to PHI and ensure quality of PHI.

7. **Security safeguards and controls**: Apply suitable technical and managerial countermeasures.
8. **Accountability and remedies**: Support accountability through robust mechanisms and support mechanisms to remedy effects of security breaches or privacy violations.
9. **Patient access to data**: Provide access to PHI.
10. **Anonymity of presence**: Hide patient identity and sensor presence and data-collection activity from unauthorized observers.

In addition, several authors outline other or similar privacy requirements in the context of health care, based on the type of information transmitted and the available solutions used for that purpose (e.g., frameworks, devices, models). Both Deng et al. (2011) and Fang and Zhu (2010) focus on the preservation of the unlinkability and anonymity of the transmitted and stored data and the content awareness of the patient, while the former also points out the policy and consent compliance of the whole system used, in parallel with security and privacy requirements regarding home health-care applications in the cloud. In a more descriptive approach, Gates and Bishop (2010) result in the following requirements when combining health-care deliverance via social networks: (a) information (e.g., name, address, social security number,) should uniquely be associated with each specific individual (i.e., data sanitization problem); (b) information should not be disseminated without the consent of the patient; and (c) governance issues (e.g., laws, customs, and other matters) may override the previous control.

Regarding privacy in a Ubicomp system, Dritsas et al. (2006) suggest baseline privacy protection principles, originated from Langheinrich (2001, 2002). Such principles are outlined as follows:

1. **Notice**: Users should always be aware of the collection of their personal data.
2. **Choice and consent**: Users should have the choice of carrying out, or not, of their personal data.
3. **Proximity**: The collection of data from a user device should only occur when the user is present.
4. **Locality**: Processing and access to data should only be done within the space they were collected.
5. **Anonymity and pseudonymity**: Whenever the user's identity is not required or whenever the user does not consent, anonymity or pseudonymity services should be provided for.
6. **Security**: There should be security mechanisms, which provide adequate protection for collected data.
7. **Access and resource**: Access to user data should only be allowed to authorized persons. There should be regulatory means for the protection of a user against noncompliance.

Similarly, Rui and Liu (2010) examined the privacy perceptions of both patients and clinicians/practitioners. They examined how access to the data in an EHR system should be managed and controlled. For example, a patient should be able to restrict access to EHR if he or she does not want to reveal such information to family members or health-care providers, and, at the same time, the authenticity of EHR with respect to content authentication and source verifiability should be addressed. On the other hand, clinicians should apply mechanisms to obtain patients' information from multiple EHR repositories accurately, securely, and timely. Furthermore, access to historical medical records should be, in general, granted to a practitioner if both the patient's consent and authorization from the respective care delivery organization (CDO) are granted.

Giannetsos et al. (2011) distinguish privacy, integrity, and policy issues. They describe **privacy** requirements in the form of questions: W*ho is asking for the data* (identity)? *How much does the data reveal about me* (granularity)? How *long will the data be retained* (time)? Regarding **integrity**, they point out that the adversary can be both an outsider and an insider. The personal nature of information increases the motive to launch an attack (i.e., data authentication problem); such data should be delivered under the assurance that no intermediate has tampered with them. Regarding **policy**, synergy between policies and technologies entails all of the challenges of interdisciplinary cooperation, the included parties should determine which issues are best addressed by policy or technology, while policy language can be used in order to express users preferences in a readable format, in case of a complex environment.

In a similar approach (Oladimeji et al. 2011), privacy is achieved when (a) the involved applications confer the ownership and control over disclosure to the principal of that information (Venkatasubramanian and Gupta 2006), and (b) individual patients have high level of control in deciding who accesses their health information, for what purpose, and under what conditions, while (c) the need for information by health-care personnel, whose identities may not be known in advance, can potentially conflict with privacy, in an emergency response situation. Regarding integrity, data transmission potentially increases integrity vulnerability in this domain (Stajano 2010), because Ubicomp introduces nontraditional data communication interfaces (e.g., touch-screen icons, voice, infrared signals, direct electrical signals, ad hoc wireless networks,). Thus, the interchange of the EHR over ad hoc and pervasive communication channels is susceptible to data harvesting by malicious (passive) attackers, while data can be distorted by spurious signals from a malicious (active) attacker.

It is equally important to outline which challenges a patient faces regarding health identity and anonymity. Mohammed et al. (2009) argue that if a record is so specific that not many patients match it, then releasing the data may lead to linking the anonymous EHR to a patient. If a sensitive value occurs together with some quasi-identifier attributes frequently, then sensitive information can be inferred from such attributes even though the exact record of the patient cannot be identified. Ahamed et al. (2007) provide two indicative scenarios regarding privacy violation and information leakage in a health-care context from which they induce the following challenges: (a) patient authorization is needed to access his/her EHR, but only on a need-to-know basis, while (b) doctors/health-care service providers hold the right to restrict access to prediction information, which may be kept secret for the sake of analysis and can only be revealed to the patient, upon request, after the end of treatment.

The abovementioned elements of the privacy issue are generally depicted for health-care systems, but they can be applied to a health-care environment as well. A corresponding list of requirements for health care in a smart home would include the following requirements (extends Avancha et al. 2012):

R1 – Openness and transparency: *Patients should have knowledge about PHI collected, purpose of use, identity of persons who can access/use it, PHI location, duration of preservation, and how to obtain access and control to it.*

R2 – Purpose specification: *The purpose of PHI collection should be specified at the time of collection, while the subsequent use should be limited to those purposes.*

R3 – Collection limitation and data minimization: *Lawful and fair means should be used for PHI collection; collection should be limited to the PHI necessary to carry out the specified purpose. A patient must authorize such an activity and decide on its approval or rejection, while maintaining knowledge of the included parties.*

R4 – Use limitation: *Information policies and practices should maintain compliance of the involved activities to the initial specified purposes.*

R5 – Individual participation and control: *Patients should control access to their PHI. They need to know who is storing what information on them, how that information is being used, and to whom it is disclosed.*

R6 – Data quality and integrity: *PHI should be collected in correlation with the intended use purposes and be accurate, complete, and up-to-date. Transmitted data must be protected* (e.g., *vulnerability protection of the used machines*) *for integrity preservation.*

R7 – Security safeguards and controls: *Adequate safeguards should be in use for the protection of PHI against existing threats* (e.g., *modification*, *disclosure*, etc.).

R8 – Accountability and remedies: *Accountability should be retained among the parties responsible for PHI, while remedies should also exist to address security breaches or privacy violations.*

R9 – Patient access to data: *Patients should obtain access to their PHI in a readable electronic format and be able to modify them, while annotating records submitted by others.*

R10 – Patient's location: *The location of the monitored patient should be private and protected against disclosure, deliberate or not.*

R11 – Anonymity of the patient's data: *PHI should be collected and processed in an anonymous way.*

R12 – Unlinkability of the patient's data: *PHI should preserve unlinkability to the patient. A party should not be able to trace back to the patient based on intercepted data. Such a requirement is opposed to the unique records problem, where a patient is easily identified due to the uniqueness of his/her data* (e.g., *a record is so specific that not many patients match it*).

R13 – Law and policy compliance: *Relevant laws*, *acts*, *initiatives*, etc. (e.g., *HIPAA*, *ARRA*), *as well as the defined policies should preserve their compliance among all the available elements of the environment* (e.g., *roles*, *information*, *solutions*, *frameworks*, etc.).

These requirements can be grouped in four main classes: anonymity and unlinkability (R11 and R12), policy and law compliance (R2, R3, R4, R13), patient's control over the data (R1, R5, R9, R10), and security countermeasures (R6, R7, R8).

Privacy Solutions for Smart Homes

While the literature presents few privacy approaches for smart home solutions, some approaches do exist. For example, Park (2011) proposes a Privacy Protection Framework regarding RFID (radio-frequency identification) services that are currently used in smart homes. The goal of the framework is to allow patients to control the personal information transmitted via such a service, and the following privacy-related safeguards are outlined for mobile RFID application and contents provision systems:

1. Preserve **confidentiality**, **integrity** and **entity's authorization** through privacy protection systems.
2. Provide detailed **access control mechanisms** that can manage object information, log data, and personal information by user group.
3. Communicate through **secure communication paths**.
4. Provide **auditing functions** with stronger privacy based on the privacy protection policy that each individual user defined.
5. Manage **personal privacy information** based on the rules that individual users defined.
6. Have mechanisms to **negotiate privacy policies** with mobile RFID terminals to prevent them from gathering personal information.

A classification of the privacy levels is also proposed. The privacy level ranges from no provided privacy protection (level 0) to full privacy protection (level 10). Levels 1–9 are separated into **low level** (1–3) where most information is disclosed; **medium level** (4–6), where object information and history are disclosed; and **high level** (7–9), where only part of the object information and object category are disclosed).

Regarding cloud-oriented health-care systems, Rui and Liu (2010) propose an EHR security reference model that includes privacy-preserving solutions on behalf of the patient. The model consists of three core components, i.e., **secure collection and integration**, **secure storage and access management**, and **secure usage**. Any transmitted information between two parties should be encrypted via established security protocols (e.g., SSL, TLS, IPSec, etc.), while:

- EHR **authenticity and integrity** must be verified through validating the signature of the EHR owner.
- The **structure and format of composite EHR** should be defined in a way that EHR of different formats from different CDOs can be easily and correctly integrated into a composite EHR, but also data encryption and access control of individual EHRs can be incorporated without compromises.

The conflict between privacy and the need for immediate access to EHR in emergency situations is still an open issue. Liang et al. (2011) proposed a **privacy-preserving scheme**, called PEC, which transmits patient's data to nearby helpers in emergency situations via the use of mobile health-care social networks. More specifically, it collects all the emergency data (e.g., location, health record, physiological condition, etc.) and establishes a call to the nearby physician by transmitting the gathered information. The security benefits of such approach focus on the guarantee of the availability of the patient's PHI in parallel with the preservation of his/her privacy. PEC uses encryption to hide transmitted information (generation phase) on the patient's side, while a decryption operation (verification phase) on the PHI by itself is performed on the physician's side.

A similar solution for emergency situations is proposed by Fang and Zhu (2010) and is based on **anonymous credentia**l, **pseudorandom number generator (PRNG**), and **proof of knowledge**. A commitment phase, a signature phase, and a credential derivation phase are used to create anonymous credentials. PRNG reduces the extra communication and storage overhead incurred in encrypting the entire data, while proof of knowledge provides assistance when it is necessary to retrieve data regarding the patient's condition from the PRNG (emergencies).

Gritzalis (2004 proposes **privacy protector (PP)** for HIT systems, which can be used to embed privacy-enhancing technologies (PET) in the development process of an application. The approach includes (a) mediation of a privacy protection conceptual entity, which renders the user capable of withholding his/her real identity; (b) simplicity of the underlying infrastructure, provided that PP services are embedded within the IT application development process; (c) limitation in the number of trusted entities; (d) limited exposure of personal data to unprotected communication lines; (e) control and responsibility of protecting personal data lying with the user; and (f) an easy-to-apply legal framework.

Tentori et al. (2006) focus on privacy through the use of ubiquitous computing within a hospital environment, an approach that could be transferred in a ubiquitous smart home as well. An architecture is proposed which allows the identification of different levels of the **quality of privacy (QoP**), similarly to the quality of service (QoS) concept. More specifically, the user demands a certain level of QoP, which is based on contextual variables and the degree of privacy desired while using the ubiquitous application. The architecture is supported by:

- An **ontology** to manage QoP consisting of events, conditions, and actions
- An **agent**, called broker, which handles the communication between the users

- A context-aware privacy **c-filter**, which filters the communication between the user and the broker
- A context-aware privacy **s-filter**, which filters the communication between the broker and other agents (e.g., services, devices, etc.)
- A **protocol** to preserve privacy, based on the extension of the SALSA framework (Rodriguez et al. 2005)
- A **location-aware migration component**, based on Amaya et al. (2005), which allows users to seamlessly transfer information to any device in the vicinity (e.g., PC)

Bhatti and Grandison (2007) propose a privacy management architecture, called PRIMA, which focuses on using policy refinement techniques to improve the coverage of the privacy policy. While this approach is not health care specific, it addresses the policy coverage problem in health care, which is due to the over-reliance on the bypassing of security controls to access sensitive medical information. Further approaches include generic security recommendations for privacy in smart homes. For instance, Katzenbeisser and Petkovic (2008) comment on how the use of privacy-enhanced protocols protect patient's privacy among e-health services that are either bound to traditional health-care privacy laws (e.g., HIPAA) or not. Similarly, individual security countermeasures are proposed in other studies (Giannetsos et al. 2011; Fang and Zhu 2010):

- Anonymity: Anonymization techniques, enhanced user control, decision making, and participatory design
- Integrity: Data validation, keyed secure hash function, digital signatures, group signatures, verification protocols, symmetric-key-based message authentication code, and watermarking techniques
- Confidentiality: Link/network layer encryption and access control
- Unlinkability: Produce ciphertexts that appear random

Evaluation of Privacy in Smart Home Health-Care Solutions

In the previous sections, we defined privacy requirements for smart home health-care environments and reviewed existing privacy solutions for this context. Table 3 maps the reviewed solutions/frameworks to privacy requirements. Note that some solutions imply other requirements, but such information was not present or clear in the reviewed literature and it is not depicted on the table. The table serves as a tool for identifying research priorities and challenges.

Data quality and integrity (*R6*) and *security safeguards and controls* (*R7*) are considered as top priority, mainly because they derive by other fields of information security, which do not focus mainly on privacy. Purpose specification (R2) and protecting the patient's location (R10) remain the least addressed requirements. The proposed solutions can be applied to several health-care technological solutions, including smart homes.

Table 3 Framework/solution and privacy requirement map

Requirement privacy framework/ solution	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13
National Framework (HHS 2008)	×			×		×	×	×	×				
Health Privacy Project (HPP 2007)				×	×		×	×	×				
Common Framework (Markle 2008)	×	×	×	×	×	×	×	×					
Certification Criteria (CCHIT 2008)	×			×	×				×				
Mhealth Privacy Framework (Avancha et al. 2012)	×	×	×	×	×	×	×	×	×				
RFID Privacy Protection Framework (Park 2011)						×	×						×
EHR Security Model (Rui and Liu 2010)			×	×		×	×						
Privacy-preserving Scheme (Liang et al. 2011)						×	×			×	×		
Privacy and emergency response solution (Fang and Zhu 2010)						×	×	×			×	×	
Privacy Protector (Gritzalis 2004)				×	×	×	×	×	×		×	×	×
Quality of Privacy (Tentori et al. 2006)						×	×						
Privacy Management Architecture (Bhatti and Grandison 2007)				×									
Generic Privacy Recommendations (Katzenbeisser and Petkovic 2008)						×	×						×
(Giannetsos et al. 2011)						×	×				×		
(Fang and Zhu 2010)						×	×				×	×	
Coverage (%)	26.70	13.40	20,00	53,30	33,30	80,00	86,70	40,00	33,30	6,70	33,30	20,00	20,00

Conclusions

A smart home health-care environment faces several privacy threats and risks that need to be addressed due to the sensitive nature of the transmitted patient information. This chapter presented the privacy requirements that need to be met in such an environment. Existing privacy research for health care has been reviewed, highlighting the challenges in smart home healthcare (e.g., anonymity, integrity, etc.), as well as existing solutions. Indicative types of smart health-care technologies include **simple devices** (such as blood glucometers, blood pressure monitors, oximeters), which provide standardized outputs for specific physiological conditions, **intelligent applications or software** capable of analyzing and processing body signals, **sensor-integrated smart devices** (smartphones and gaming devices), **wearable sensors** (e.g., T-shirts, wrist straps, etc.), and **other devices** exclusively manufactured for the purpose of body signal monitoring/processing (e.g., mainframe computers, tablets) (Athavale 2011). Each of these categories poses different challenges when their designers attempt to comply with privacy requirements. A comprehensive study of the controls needed in order to achieve each requirement for such device types is the direction that smart home developers need to follow in order to ensure privacy for their solutions. One of the main challenges remains the conflict between legal restrictions, individual human rights, and the need for immediate access to a patient's data when his/her health is at stake, which in the case of smart home entails the violation of the sanctuary of his home. Ultimately, smart (home) health care requires a best practice guide, outlining both the technical and procedural countermeasures required in order to maintain privacy, taking into account modern technology environments, such as the cloud, smartphones, and ubiquitous equipment, which are gradually incorporated in smart health-care solutions.

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Human-Centered Design and Smart Homes: How to Study and Design for the Home Experience?

Berry Eggen, Elise van den Hoven, and Jacques Terken

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Abstract

The focus of this chapter is on designing for smart homes. The perspective will be user-driven design research. The chapter starts with a context analysis of the home environment. This analysis shows that, from a user perspective, home is about emotions and not about the physical house with all its smart applications. It is this "home experience" designers have to design for. The core of the chapter consists of the description of three big challenges that modern designers (need to) face when designing or studying smart home environments. These challenges are linked to existing and future design paradigms. The following challenges are addressed: (1) What makes a worthwhile user experience? (2) How to design for user experience? (3) How to design for user experiences that can be seamlessly integrated in everyday life? The chapter concludes with a summary of the main

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insights that emerge from current design research practice facing these challenges.

Keywords
User experience • Human-centered design • Interaction design • Home experience • Design for everyday life

Introduction

"*Homes are not smart, people are smart*."[1] In the end, it will be the inhabitants of houses that give their verdict whether or not their homes behave in an appropriate and meaningful way; they will decide whether or not the predicate "smart" should be attached to the behavior of their home. This insight has led designers of intelligent systems, products, and related services to actively involve end users in all stages of their design process. User-centered design methods have been developed over time, influenced by general theories and ideas within the design discipline on the creation of value both from people's and business perspective. Brand and Rocchi (2011) describe the change from a focus on product ownership (industrial economy) toward the current focus on user experiences enabled by product-service systems (experience economy) and the trends toward self-actualization (knowledge economy) and meaningful living (transformation economy). In this chapter, we focus on designing for the *home experience*.

Over the last decades, "traditional" homelife has been under heavy attack of ever faster developing information and communication technologies (ICT). In particular, the digitization of media and the possibilities to connect people and devices with powerful embedded ICT capabilities through the Internet have changed the home environment. Whereas the digitization of physical media, in first instance, was used to make media like music, pictures, movies, games, newspapers, and books available outside the home on an anytime-anywhere basis, we now see the digitization backfire at home; physical instantiations of media or media collections disappear, and new physical interaction devices like smartphones and tablets enter the home domain to enable experiencing the digital media. The same is happening for "analog" communication. A more recent trend concerns the generation of (personalized) media streams by all kinds of sensors embedded in stationary, portable, and wearable devices in- and outside the home.

It is clear that these recent and ongoing developments are changing and will continue to change homelife for better or for worse. According to Turkle (2011), these developments negatively affect the emotional qualities of life. People's accommodation to changes in perceived sociopsychological constructs like privacy, community, intimacy, and solitude, as explained by Turkle, might impact homelife in particular, as these constructs are core to many home-based user experiences (Eggen

[1] A statement made by participants of a study on the home experience by Eggen et al. (2003a).

et al. 2003a). On the positive side, the advancement of technology has opened up opportunities for designers to create product-service systems that enhance existing and support new home experiences. In this chapter, we take the second perspective and describe three big challenges that modern designers (need to) face when designing or studying smart home environments.

It is important to note that, at the moment of this writing, there is no single definition of what a *user experience* is. Recently, however, a group of more than 30 leading user experience (UX) experts made an inventory of the UX phenomenon and how it is approached in current design practice (Roto et al. 2011). This overview provides valuable insights that can inform the design for home experiences. The experts point out that the true challenge of UX design is to focus on a number of important dimensions that go beyond the "traditional" principles of human-centered design (HCD) for interactive systems (ISO 9241–210 2010). The basic principles of HCD entail the central and participative role the user should take in an iterative design process as well as the identification of user-specific factors to guide and assess the design. Whereas traditionally there has been a strong focus on functionality and usability factors, "new UX factors relate to affect, interpretation, and meaning (Roto et al. 2011)." To identify which factors define a worthwhile user experience is one of the big challenges for the designer of interactive systems. This challenge will be addressed in the next section as "Challenge 1." But also, how to assess designs on the basis of selected UX factors that, for example, relate to social, emotional, and/or aesthetic issues remains a challenge, as, currently, there exists no single overall measure for UX. A related challenge concerns the creation of effective representations of UX concepts and designs to communicate with end users and other stakeholders in the design process. The last two challenges will be combined in "Challenge 2" that addresses the more general question how to design for user experience. Within the special multiuser setting of the home, where highly personal and intimate experiences have to seamlessly fit the daily rhythms, patterns, and routines of family life, we introduce and discuss a third and final challenge: How to design for user experiences that can be seamlessly integrated in everyday life?

Challenge 1: What Makes a Worthwhile User Experience?

For a long time, the functionality of a product or system has been the main focus and starting point for designers. What does the user need, i.e., what should be the intended outcome of the interaction with the product (the end), and what functionality should the product offer to the user to enable him/her to fulfill this need (the means)? But once this "need for functionality" has been fulfilled, the focus of design naturally shifts toward the interaction itself. More specifically, the quality of interaction design, then, is defined and evaluated in terms of the usability of the system. Usability, as defined by the ISO standard, refers to the "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO 9241–11 1998). But what user needs arise when the design meets the set usability goals?

According to Jordan (2000), the next level in the hierarchy of consumer needs is the need for pleasurable products. Jordan defines two different types of pleasures: need pleasures and pleasures of appreciation. Need pleasures move a user from a state of discontentment to a state of contentment, i.e., they help to eliminate negative feelings like discomfort. Pleasures of appreciation are pleasurable in and of themselves and help to facilitate positively joyful feelings and experiences. Jordan distinguishes the following pleasures: *physio*-pleasures that have to do with the body and the senses, *psycho*-pleasure that have to do with the mind and emotions, *socio*-pleasures that have to do with relationships and status, and *ideo*-pleasures that have to do with beliefs and values. Within the pleasure framework of Jordan (2000), the need pleasures relate to usability goals, whereas the pleasures of appreciation are characterized as being cognitively more challenging and emotionally gripping or exciting (Jordan 2000).

In moving up the hierarchy from user needs related to functionality to user needs related to usability and pleasure, respectively, the model of the user as a human being is becoming more complete. A user brings more to the interaction with systems than physical and cognitive abilities and limitations only; a person's values, goals, needs, and pleasures should also be taken into consideration in the design of systems. But still, the overall picture of human-system interaction that emerges up till now remains rather instrumental: the functionality, the look and feel, and the interface offered by the system enable the human user to interact and satisfy his/her needs in a certain context. Experience design, however, takes a more holistic view on the situation, by not only focusing on the what (functionality) and the how (usability, pleasure) but by explicitly putting the why as the leading question to be uncovered, understood, and addressed in interaction design (Hassenzahl 2011). According to Hassenzahl (2011), *form*, i.e., how the system looks and interacts, and *function*, i.e., what the system can do, should follow from *insight*, i.e., why the system can help to satisfy the users' needs. And by doing so, the focus shifts from specific user needs to more general human needs. Within this context, the ten psychological needs that according to Sheldon et al. (2001) make events satisfying, for example, offer a powerful framework to address the basic human needs that make user experiences worthwhile to live, remember, and communicate to others. The needs described by Sheldon et al. (2001) are introduced by Hassenzahl (2010) to guide and inspire experience design. The Sheldon et al. framework includes needs like autonomy ("I can do what I want, the way I want it"), competence ("I am good at what I do"), and relatedness ("I feel close to the people I care about").

A study on the home experience by Eggen et al. (2003a) showed that the use of intelligent systems and products should be seamlessly integrated in everyday activities. At closer inspection, these mundane activities seem to be driven by hidden, but basic, personal and social human needs. Whereas the primary task or activity the product was originally designed for is carried out subconsciously, as a means to an end, the "true" user experience relates to the deeper basic human needs. Family members, for example, indicated that daily household chores like vacuum cleaning or ironing are often considered boring, but, on the other hand, the nature of these activities enables them to create precious moments in time where they can daydream and reflect on or escape from their daily worries (Eggen et al. 2003a). Another example concerns the “Phenom” project in which a system to support the recollection of memories was designed (van den Hoven and Eggen 2008). Initially, the project focused on fast and efficient retrieval of photos that were considered digital representations of memories. Interactions of users with early prototypes, however, showed that the photos only act as a trigger to start the recollection process. The real memories emerge and become tangible in the form of stories told by users. This insight caused the project to shift its focus from “information retrieval” to “storytelling” and the role various artifacts like souvenirs, photo albums, and physical aspects of the environment play in the experience of recollecting. This user experience is closely related to basic human needs like relatedness, self-actualization meaning, and self-esteem.

Challenge 2: How to Design for User Experience?

User experiences are unique and personal and, as we have seen, get their positive meaning from the fulfillment of basic needs. But it is important to also realize that the user experiences people have when using a system might also be influenced by earlier experiences they (or others) had with the system or simply by expectations they have about the system. Besides this psychological state of mind of the user, the social and cultural context of use also determines the UX. For designers it is of crucial importance to be able to communicate with the user and other stakeholders involved in the design process about anticipated, i.e., new user experiences, or about earlier related experiences. This communication process forms the basis for envisioning, representing, evaluating, and creating the design that enables the user experience (Roto et al. 2011). In particular, stories told by users about their experiences with interactive systems are considered informative and a powerful communication medium to get to grips with the intangible nature of the UX phenomenon. The importance of stories is distinguished in the definition of user experience by Hassenzahl (2011) who considers an experience “as story that emerges from the dialogue of a person with his or her world through action.” In this view, a designer cannot design experiences (stories) as such; a designer can only design for experiences, i.e., creates artifacts or environments that enable the emergence of stories. As a consequence, the value of interactive systems lies in their ability to support and mediate user experiences rather than in the underlying technology or the physical artifacts as such.

In this chapter, we put *focus* on the involvement of the user in the design process to understand his/her characteristics, capabilities, and needs. But to design for future experiences, a designer also needs to take the *perspective* of the user to learn about his/her feelings, emotions, thoughts, and dreams. Over the last decades, many methods have been developed that focus on human-centered interaction design; see, for example, Rogers et al. (2011) for an excellent state-of-the-art overview. The shifting focus from usability to experience design has led to the development of many new methods, which have been mapped by Sanders (2008). Sanders (2008) uses two dimensions to differentiate and position the “new” HCD methods. The first dimension captures the contrast between methods that consider users as subjects, or “reactive informers” that inform the “expert” design researcher [expert mindset], and methods that consider users as partners, or “active co-creators” in the design process [participatory mindset]. The interconnecting dimension captures the contrast between [research-led] and [design-led] methods (Sanders 2008). The map nicely shows that the UX methods, more recently developed, are in the [participatiory mindset]-[design-led] quadrant.

As we stated before, for the UX designer, it is not only important to make the context of use of the user-system interaction as concrete as possible but also to empathize with the user. For the first design activity, sound methods are readily available, like, for example, the PACT framework proposed by Benyon et al. (2005) to analyze design situations. This analysis is based on the principle that “*People* use *Technologies* to undertake *Activities* in *Contexts*” (Benyon et al. 2005). Empathy can be defined as the capacity to think and feel oneself into the others’ “emotional state” (de Waal 2008), the others’ “thoughts and feelings” (Baron-Cohen 2003), and the others’ “values and motivations, knowledge, skills, and meanings” (Schwartz 2002). Various methods have been developed to create and involve empathy with users through ethnography (e.g., through contextual interviews and observations), the imagined other (e.g., through role play), and narratives. As stories and storytelling are intricately linked to user experiences, we now briefly describe three methods that center on narratives.

The scenario-based design approach described by Carroll (2000) uses scenarios and stories as narratives to capture and communicate the essence of the interaction design. These informal stories can be used by designers as an “empathic” tool as they represent a holistic view of a situation in which one or more actors with personal motivations, knowledge, and capabilities interact with various tools and objects. Good scenarios present concrete situations, are open-ended, and are action-based. Visser et al. (2005) described the context-mapping method, which aims to identify latent user needs, i.e., needs that people are not yet aware of and that can become realized in the future. As this method intensively involves users in creating an understanding of the context of human-system interaction, it belongs to the [participatory mindset]-[design-led] category of methods that treat users as the real domain experts of the user experience to design for. Design probes, like disposable cameras, workbooks with exercises, postcard prompts, etc., are used to facilitate the creation of content awareness by eliciting (emotional) responses from the participants. Once these probes have done their work in sensitizing the individual participants, generative or projective techniques are used in a group setting to tap participants’ tacit knowledge, i.e., knowledge that people can act upon but cannot readily express in words, to create views that reveal possible future user experiences based on existing and latent user needs (Visser et al. 2005). As a last example, the co-constructing stories method by Ozcelik and Terken (2012) also contains a sensitization and an envisioning phase. This method aims to elicit in-depth user feedback on early design concepts to help designers to investigate if their concept is the right concept and how it should be further developed. A sensitizing story enables the designer to set the stage for dialogue and triggers participants to recollect and tell stories about the past. In the second phase of the method, the new, early design concept is staged in a story about an envisioned future. This visionary story elicits prospective stories from the participant about needs, dreams, and aspirations. These stories inform the designer about the "why" reasons that should be addressed by the design concept; they allow creating empathy with the users, and they contain suggestions to inspire and inform further concept development (Ozcelik and Terken 2012).

The co-constructing stories method of Ozcelik and Terken (2012) exemplifies one of many possible methods that can support designers to design for user experience. A recent study by Offermans et al. (2014) in the area of intelligent lighting systems can serve as an example of how these methods, the context-mapping method in this case, are used in actual design research practice. With the advancement of new lighting technologies, new dimensions capturing functional, emotional, physiological, social, and cultural aspects of the interaction with light are opening up for the design of new interaction paradigms. Offermans et al. (2014) conducted a context-mapping study to better understand people's motivation to interact with light. They uncovered that the needs for lighting are layered and that (1) these layers are highly dependent on the context and (2) the different layers require control at different levels. They found that the context and the lighting needs had a large influence on people's motivation to adjust the lighting in their environment (functional and UX factors). But also, vice versa, it was found that the interaction qualities of the lighting interface itself had a large effect on people's motivation to control the light (functionality and usability needs).

Challenge 3: How to Design for User Experiences that Can be Seamlessly Integrated in Everyday Life?

Designing for user experiences that are part of or actually make up the social fabric of everyday life is a true challenge (Eggen and Kyffin 2006). But designing for the home environment might bring even greater challenges, as user experiences in this context are not only highly personal, they also intimately contribute to and are influenced by the social dynamics of the family life, i.e., the other family members and the family as a unit. Quoting Dutch families (Eggen et al. 2003a, p. 6): "*Home is a feeling*. It is a cozy, trusted, and safe place, a place to return to; where you can be yourself and do what you want; where your own things are; where you meet the people you love and like." And "*Together with your family and friends*. Family members take care of each other and create the opportunity for others to be themselves and to do what they want. However, this freedom is limited by the fact that living together brings responsibilities. This is accepted as a part of home, albeit with mixed feelings."

Interactive systems that are tailored to serve the needs of individual family members do not necessarily work in the multiuser setting that is so characteristic for the home. For example, the personal recommendations a media system offers are bound to fail if there are no accommodations made to cater for social settings where media are shared. Currently, this is often not happening, as designers seem to be ignorant of the delicate balance between basic needs such as pleasure stimulation ("I experience new activities") and relatedness ("I feel close to the people I care about") (Sheldon et al. 2001). If designers do not base their design concepts on a deeper understanding of the complex and dynamic nature of the anticipated user experience, their product-service systems will fail, and, worse, they might even threaten family life as family members get isolated from one another and start to "live alone together" (Turkle 2011). On the positive side, future concepts that are the result of sound user experience design will seemingly fit the rhythms, patterns, and cycles of everyday family life and, as a consequence, will support and enhance the well-being of people.

Future smart homes are supposed to become populated by many smart devices that are sensitive to the presence of people and that can adapt their behavior to serve the members of the household. We should realize, however, that intelligent systems can only behave intelligently, i.e., autonomously, appropriate, and meaningful, if they actively communicate and interact with their environment (just like intelligent people need to do). These basic system needs might easily lead to "nightmare" scenarios once the number of smart devices starts to grow significantly. A smart home scenario in which smart systems will compete for people's attention will automatically lead to situations that are unacceptable to people. To prevent such situations from happening, Weiser and Brown (1997) proposed to develop "Calm Technology" that makes better use of the periphery of the human perceptual and cognitive system. As suggested by Weiser and Brown (1997) and based on human attention theory (Bakker et al. 2012), interaction designers can present information in such a way that people are only subconsciously aware of what happens in the periphery of the perceived situation. However, when desired or necessary, this information can immediately be put in the center of attention. A "peripheral design" approach toward the design of smart home environments could be instrumental in preventing future scenarios in which people are overloaded with information. However, to be able to successfully apply such an approach, designers should not only have to acquire a deeper understanding of the latest psychological theories on human attention management, they should also develop new ways to apply the acquired knowledge into concrete design actions (Bakker et al. 2012).

Within the "Home Radio" project, a peripheral design concept was developed, which addresses the basic human need of "relatedness" expressed by family members as the need to "stay in touch" with each other and their home (Eggen et al. 2003b). Home Radio allows family members to tune in to their home from a distant location, e.g., their office at work, to see, to hear, and to interact with the other household members, home events, activities, and information. Home activities, for example, are coded by the corresponding utility streams they generate (gas, electricity, water, communication, and information). This coded information is streamed on the Internet and family members can tune in to this stream. At the receiver end (e.g., your office), the coded information is rendered and presented in the environment by audiovisual means. The design of the presentation of the auditory and visual information streams in the office space was matched to the perceptual and cognitive requirements for peripheral display. The “Home Radio” project exemplifies a design research effort that tries to serve the everyday needs of individual family members by applying psychological knowledge into concrete design actions.

Conclusions

In this chapter, we have looked at the question of how to study and design for the home experience. We have addressed three challenges the modern designer of smart home environments is confronted with. The first challenge is to fully understand and appreciate the user experience (UX) paradigm. Designing for user experiences calls for a holistic approach in which system components like functionality, interface, and look and feel enable basic human needs. Basic needs such as autonomy, competence, relatedness, and self-actualization are the target to design for once the “lower” needs concerning functionality (means to an end) and usability (effectiveness, efficiency, and satisfaction) are met. The second challenge concerns methods to identify, understand, and come to grips with UX factors that capture the user experience and how to use stories and storytelling to communicate about the user experience during the design process. These design-led and participatory methods focus on user involvement in the various phases of the human-centered design process and facilitate taking the users’ perspective by empathizing with the user through narrative. The third challenge is about designing for user experiences that become a natural part of the complex and dynamic social structures of everyday life. But also, it is about how to design for user-system interactions that take place in the periphery of human attention and only draw attention when wanted or needed. Through a deep understanding of basic human needs in context and through the application of state-of-the-art psychological theories on human processes, UX designers will be able to design for user experiences that enhance everyday life and improve the well-being of people.

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User-Driven Design in Smart Homes: Ethical Aspects

Lesa Huber and L. Jean Camp

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Abstract

Design for values addresses the challenge of making technology accessible, effective, and appropriate for diverse groups of users. Older adult users represent a highly heterogenous, diaphanous, and evolving group of users. The ETHOS project used an extended iterative design process informed by theories of late life. One goal of elder-sensitive design for values is integrated systems that truly support independent living. These designs capitalize on older adults' capabilities and minimize their limitations, are sensitive and responsive to changing functional/cognitive status, and are respectful of the privacy and dignity of elders and their caregivers.

Keywords

Design for values • Older adults • In-home technologies • Privacy

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Introduction

Technologies in the home embed the choices of the designer. Even when the individual living with the technology has a choice, the constraints of those choices are determined by the designer. For example, our most common sensor platform is the cell phone. Modern smartphones have accelerometers, cameras, video cameras, GPS, more detailed location using wireless, and a wide array of client connections to centralized servers (e.g., Facebook, Google, Snapchat). How those are accessed, activated, or on by default is not decided by the person holding the phone, but by the designer. Such sensors are embedded not only in our lives but increasingly in our homes and even our bodies. Unlike phones, which can be updated (depending on the model and thus the designers choice), devices embedded in homes, cars, and humans have a very different update cycle and costs. Thus evaluating the values and choices embedded becomes correspondingly more important.

We begin our article by introducing the concept of value-sensitive design (also known as design for values). We point to the specific design for privacy model from Ann Cauvoukian. We consider these models through the lens of psychosocial motivational theories of late life. We describe the implementation of a design for values approach for home-based technologies as used in the Ethical Technology in the Homes of Seniors (ETHOS) Laboratory. Specifically we discuss both those choices that were made implicitly in design and those choices where we empowered the elder (and potential subject of sensor surveillance) to choose for him or herself.

Design for Values

Design for values (DfV also known as Values In Design or VID and as value-sensitive design or VSD) has focused on a wide range of problems, including accessibility (Shneiderman and Hochheiser 2001), privacy (Golberg 2001), security (Gollmann 2010), inclusion of all stakeholders' viewpoints (Friedman et al. 2002), and digital rights management (Camp 2003; Knobel and Bowker 2011). DfV methods have been used to encourage business ethics by information system design (Stahl 2008) and enable ethical game design as well analysis of the values embedded in traditionally designed games (Belman et al. 2011).

DfV is an iterative design method that begins by identifying the parties that will be directly impinged by a design should a system be successful. The simple act of envisioning the use of the technology and its context of use can make designers more aware of potential impacts. DfV draws from Computer-Supported Cooperative Work, HCI, and participatory design.

Design for Privacy

The DfV approach is related to the Privacy by Design (PbD) framework. The two approaches were developed simultaneously, one in academy with a more generalized approach to various values and one with a tight focus on privacy by the Ontario's Information and Privacy Commissioner, Dr. Ann Cavoukian (Cavoukian 2009).

In the PbD framework the similarity is that there is an initial statement about data from the concept level. Yet rather than adding additional iteration of design, the goal is to evaluate privacy impact at each stage of the design. Cavoukian identifies each stage and the questions to be asked during each stage: development, design, production, and marketing.

Cavoukian provides a set of examples of the end result of the application of the DfV principles. A common theme is the recognition that data compilation has costs but often no value. Data that are compiled create risks as well as the costs of compilation and disclosure. For any data that are compiled, the creation of a plan in the situation that the data are leaked, contaminated, or lost is an important component of PbD. The ability to understand the costs of data decisions as privacy decisions is the core of PbD.

Privacy cannot be isolated from other system design concerns. For example, there are serious privacy concerns if tracking is done on a server. However, consider if there is no server but only a local device. In that case, power is a significant concern and lack of service may be undetectable as there is not a server check-in. In terms of not sharing information, lack of shared data can prevent long-term learning.

Design for Values: The Senior Edition

Designing for smart homes for independent living requires an iterative participatory design process beginning with familiarization. Older adults have little familiarity with functionality of home-based technologies. Potential end users need to first develop a mental model of these technologies, speculate upon their potential usefulness, and then consider what needs these technologies might conceivably meet for themselves or their peers. This process is best accomplished over a series of design meetings to accommodate novice users and the typically slower cognitive processes of later life. Once there is some consistency among participants of potential uses for in-home technologies, the actual design, test, evaluation, and redesign process may begin. For very old potential end user groups, there may need to be several iterations of the process.

Common user-centered design employs processes such as interviews, focus groups, contextual observations, shadowing, participatory design sessions, and in situ evaluations. The processes, and the analyses of the resulting data, are often elder-blind, completely uninformed by biopsychosocial theories of aging. The United States, vis-a-vis western Europe, is a relatively young country. The psychology of old age, particularly late old age, is not present in the collective consciousness of designers in the United States. Concepts including socio-emotional selectivity theory, passive mastery, tolerance, and transcendence, often reflected in western European paradigms, are not adequately represented in most US user studies. The blended nature of decision making, i.e., a carefully negotiated ever changing dance between elders and their caregivers, is often overlooked as well.

Psychosocial Motivation in Late Old Age. We began our user-centered design with an initial privacy values statement from the literature and with an awareness that this statement was unlikely to reflect the actual privacy perceptions of older adults. As we collected and analyzed data through multiple steps described below, we began to build on psychosocial motivational theories and a concept that could serve as a foundation to an elder-sensitive design for values framework and technological prototypes that reflected the principles of the framework. These theories informed our analyses of user study data and resulted in a framework with four essential constructs: control over *data flow*, *type of data*, *role of caregiver recipient*, and *data transparency*.

Socio-emotional Selectivity Theory. First, the constructs of *data flow* and *role of caregiver recipient* were based on socio-emotional selectivity theory. Carstensen and others (Carstensen et al. 2003) posit that older adults place primary importance on important relationships. While the concept of privacy has been shown to hold some interest (Beach et al 2008; Wild et al. 2008; Kwasny et al. 2008), it is the maintenance of key relationships that is the primary motivation for behaviors of cognitively intact people in late life – those we identified as likely early adopters for this study. “If it helps my son to feel better about taking care of me, I don’t care what he wants to install,” stated an octogenarian. *Controlling data flow* to *selected caregiving recipients* helps older adults maintain the primacy of relationships over technology. It can also empower caregivers in blended decision making and data management.

Dignity and Independence. The construct *type of data* is based on theory concerning dignity and independence. Along with a primary focus on important relationships, people in most western civilizations covet a sense of independence, self-worth, and dignity as they age, even into very late life. Sixsmith (1986) suggests that these perceptions are composed of more than one component (p. 341):

1. Being able to look after one’s self; not being dependent on others for domestic, physical, or personal care – physical independence.
2. Capacity for self-direction, free to choose what to do, free from interference, and free from being told what to do – autonomy.
3. Not being under an obligation to anyone and not having to rely on charity.
4. Independence is not threatened if support is based on reciprocity or interdependence.

Independence, self-worth, and dignity are fragile possessions as the old navigate the difficult terrain of very late life. A septuagenarian noted, “How much control do you want to give up? It’s going to be hard enough when you’re older to keep what little sense of self-dignity (you have).” Faced with the threats of institutionalization, the ravages of disease, and well-meaning but overbearing caregivers, older adults may choose in-home technologies as a way to maintain autonomy and dignity or, as a last resort, a way to avoid institutionalization. This choice should not lead to becoming the passive subject of constant monitoring. Thus, in addition to providing control over *data flow* and *caregiving recipients* of data as mentioned above, ethical design for elders provides appropriate levels of control over what *type* and *granularity of data* is collected and transmitted by technologies in the home. It is imperative that the data control mechanism be designed for and adjustable to the changing physical and cognitive needs of the aging adult.

Passive Mastery. The contract *transparency* is based on the concept of passive mastery. Contemporary discourse about privacy, and even technology, has the tone of "us against the machine." Older adults, particularly those in late life, are happy to let others fight this fight. They win through accepting what is, with whatever grace may be mustered (Missinne 2013). There is no place in the very tenets of user studies, at least in the United States, that inculcates the transcendent nature of the psychology and ethos of a good old age. What appears to be naivety, or even ignorance, may well be the tolerant, transcendent nature of someone who has aged long and well.

Although older adults in very late life may be relatively unconcerned or simply transcendent about privacy, they may also lack awareness of the amount of data that is collected through interaction with numerous technologies. Thus, an ethical approach in design for old age is *data transparency*. It is not enough for elders to know monitoring technologies are installed in the home. Because of likely limited awareness of data aggregation in addition to deliberate tolerance, we suggest that data must be visible and comprehensible for an older adult user for true transparency.

Case Study

Ethical Technology in the Homes of Seniors (ETHOS)

To facilitate an elder-sensitive design for values/privacy approach to smart home technologies, we created a highly interdisciplinary research team: a technologist, a privacy and security specialist, an informatics ethicist, a psychologist with expertise in human-centered design, and a social gerontologist. Using a design for values/ design for privacy approach informed by psychosocial theories of late old age, we used an extended iterative user-centered design model. At each step we provided feedback to a focused, yet group of potential end users – likely early adopters and their caregivers.

The user-centered design approach followed by the ETHOS research team was as follows:

1. Initial privacy values statement
2. Delphi method with aging experts to develop focus group protocol
3. Alpha focus groups
4. Data analysis and revision of initial values statement
5. Preliminary prototype design
6. Beta focus groups
7. Prototype redesign
8. Survey
9. Prototype and values statement redesign

10. User studies
11. Final prototype design
12. In situ study
13. Values statement and prototype design review
14. Survey
15. Final values statement and prototype design review

Results from each segment of the study illuminate and clarify the multiple perspectives, interests, and values critical to a design for values and privacy (Caine et al. 2011; Lorenzen-Huber et al. 2011; Shankar et al. 2012). Our initial values statement evolved from an individual perception of privacy to a privacy framework of a densely contextualized, relationship-dependent perception of the multiple meanings of privacy (Lorenzen-Huber et al. 2011). This is design for values, the senior version: multiple stakeholders are affected by smart home technologies, and the key players and contexts change rapidly in very late life.

After the initial values statement, we engaged in a more targeted literature review to identify the specific threats and activities of daily living which would be the focus of the designs as well as theories of late life as a lens through which to better understand older adults' perceptions of threats and values. The early alpha and beta focus groups, averaging about 12 participants, and the survey ($n = 48$) took place over the course of about 6 months and included overlapping groups of participants. During this time, the participants had the opportunity to develop mental models of smart home technologies and were able to identify threats and values statements which enabled quick prototyping.

We initially had four prototypes, each of which had its carefully evaluated data footprint Duncan et al (2009). The ability to pause data compilation was made on a per-device basis. During these early studies, some projects were rejected. The Mirror Motive (Fig. 1) was designed to provide pop-up reminders on a large touch screen that doubled as a mirror, an effort to blend the technology into everyday objects. The

Fig. 1 The Mirror Motive, an early prototype, was rejected by focus group participants

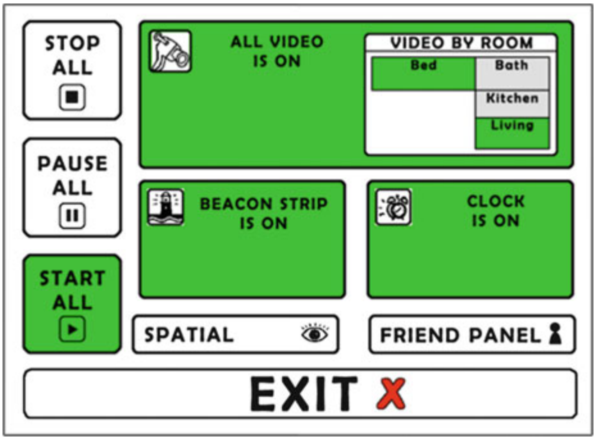

Fig. 2 Main screen of DigiSwitch (all devices on)

Mirror Motive (was rejected by focus group participants for these very design efforts: they did not like the mirror and touch screen, and they were concerned that reminders (such as medication reminders) might pop-up in the living room when there were guests).

Results from these first studies showed that participants were interested in knowing what data was collected, who was accessing it, and being able to control the data flow. The types of control desired were (a) the ability to turn off monitoring, (b) an automatic restart after devices were turned off, and (c) the ability to hide device status from family caregivers. In terms of usability, participants wanted a simple interface for control over personal data. Conscious of the cognitive demand of new technologies, participants suggested several features that would improve usability.

Based on the findings from these early studies, we designed a single device to control the suite of technologies and the resulting data flow. The final prototype design included a single point of control that we named the DigiSwitch (Figs. 2 and 3), reminiscent of a telephone switchboard. The DigiSwitch is a touch screen computer integrated into a digital picture frame. It allows users to turn individual monitoring technologies on and off and allows them to see what data are being collected and transmitted. It thus provides an easy-to-use intuitive interface that allows elders to control their own digital footprints. It provides the ability to mute or pause data (Fig. 4) from leaving the house and a reminder that devices would automatically turn back on after 30 min (Fig. 5). The "Friend's View" can be selected from the main screen (Fig. 6) providing the ability to see the data that did left the house (Fig. 7). We choose the form of a digital touch screen picture frame for the DigiSwitch to eliminate a panoply of cords and peripherals and to blend this technology into the background of everyday objects in a typical older adult's home.

The DigiSwitch provides *data transparency* through "Friend's View," a compilation of data received by a chosen friend/caregiver. Older adults were most interested in the "Friend's View" of the video feed. In our in situ study, we included up to two video cameras, placed in locations chosen by the older adult participants, to

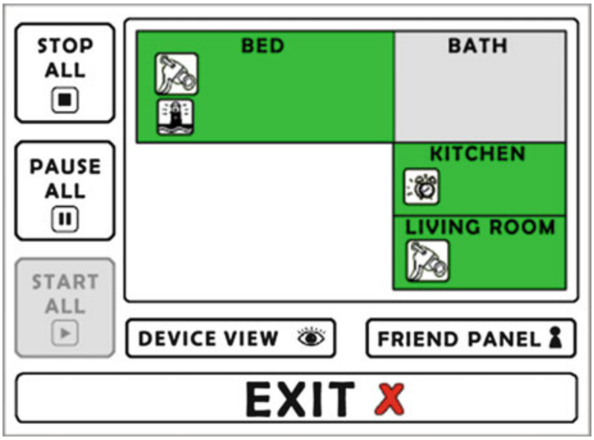

Fig. 3 The DigiSwitch interface showing in spatial view

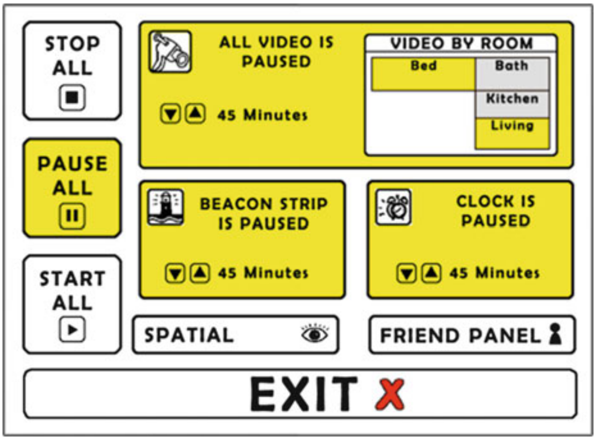

Fig. 4 The DigiSwitch interface with all devices paused. Each device buttons has an adjustable timer

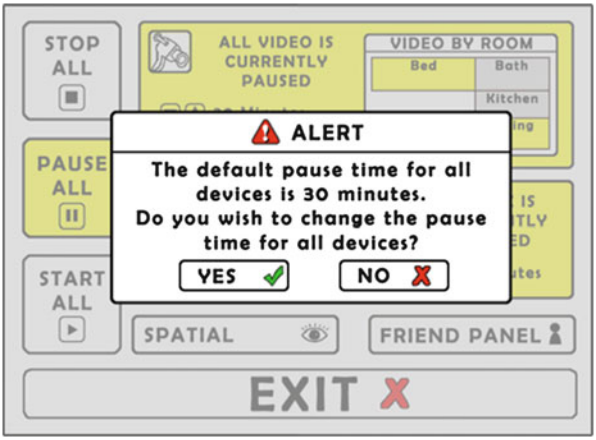

Fig. 5 Pop-up alert window when the user pauses a device or all devices

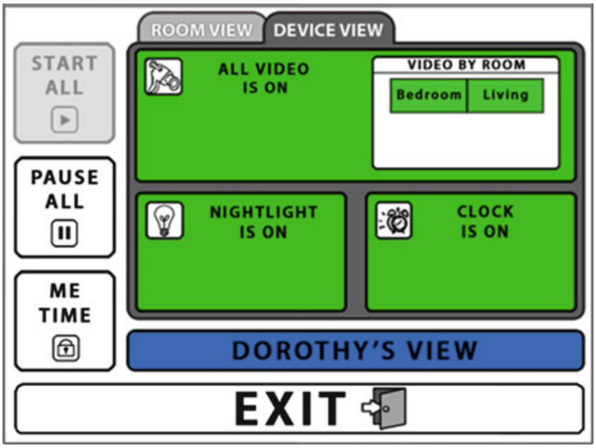

Fig. 6 The main screen of new DigiSwitch with option to select Friend's View

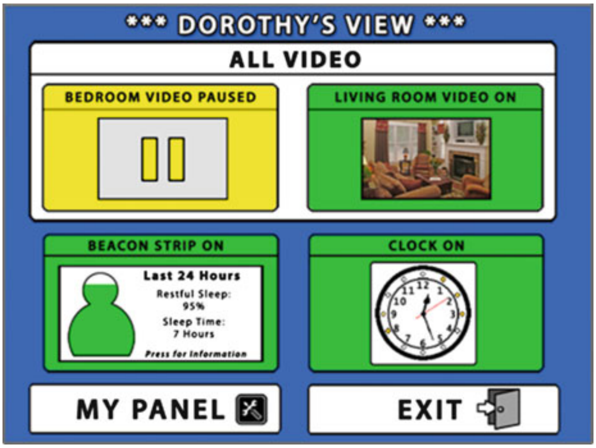

Fig. 7 The Friend's View of DigiSwitch. This is what the caregiver sees on their panel. The user also has access to view this screen

explore perceptions of the collection and transmission of highly granular data. Cameras were typically placed in front hallways or living rooms, and the older adults were fascinated with the views of their lives as transmitted to a friend/caregiver. Their interest in actual data flow corroborated the importance of design for transparency.

The DigiSwitch provides *control* by enabling on/off of all or selected technologies with a simple tap on the touch screen. In response to comments from the focus groups and surveys, we incorporated an innovative feature unique to the DigiSwitch, "Me Time." Me Time was designed for device state privacy, the ability to control information about whether the device was on or off. Thus the DigiSwitch enabled older participants to start or stop devices that transmitted data, but also to control information provided to their caregiver about if and when they choose to turn off the devices.

An elder-sensitive approach to design for values and design for privacy must take into account the constant, sometimes rapid, changes in elders' functional ability, the unique complexities of caregiver networks, the elders' often rudimentary conceptualizations of data and privacy, and the preference for passive rather than active mastery. We propose that the oldest olds' perceptions of the need for privacy are highly contextual, individualized, and dependent upon the recipient of the data, the sensitivity of the activity being monitored, and the granularity of the data. Generic values for design is an important, but inadequate, starting point for design for elders and those who care for them.

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Mindset Changes Among Health-Care Professionals and the Use of Technology

On What Nurses Encounter and Need in Telecare

Annemarie van Hout

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Abstract

Health-care technology is here to stay. We may therefore expect its use to cease to be a novelty and become part of the normal routine. However, telecare (a set of technologies used for care at a distance) is not yet part of the daily routine for nurses. They still have to do a lot of work to accommodate telecare, or they choose not to work with telecare at all. The extra work associated with telecare stems from the fact that telecare is often additional to regular care and involves all kinds of changes to regular work processes. In this chapter, telecare practices are looked at closely in order to find out what happens. By zooming in and looking at nursing telecare practices from different angles, we seek to answer two main questions: what kinds of (small-scale) changes in nursing care are brought about by technology and how can nurses deal with them? The conclusion is that changes brought about by technology can change the work processes, values, and care practices that nurses are used to. Nurses experience how telecare introduces new forms of nursing care, which, being new, require the formation and, when necessary, revision of professional opinions. Research into what the

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new practices involve will help nurses to form professional opinions and deal with the changes taking place within their profession.

Keywords
Nursing profession • Telecare • Technology • Ethnography

Introduction

Health-care technology is here to stay. It will therefore cease to be a novelty and become part of the daily routine. At least that is what one would expect. But numerous small-scale projects, which remain small scale or come to a definite end, show that the reality does not always match the expectation. In this chapter, we consider how health-care professionals, especially nurses, are dealing with technology and whether they make its use part of the daily routine. Various projects which involved nursing care at a distance have been studied in the compilation of this chapter. The main technology used in the projects concerned is the webcam, although some other technologies are considered in this chapter as well. The center of attention for care professionals is of course the patient. However, in order to make a proper analysis of the effects on the (nursing) profession, the focus is on the professional. The patient is considered, but is not the main subject in this chapter.

The title of this chapter could be read as a little tendentious. Is a mind-set change to be forced on nurses in order to achieve the intended outcome? Does the title refer to the desired rise of technology use in care, in order to solve various problems such as the increasing demand for care as a result of an aging population and the associated potential for uncontrollable cost growth? That is one interpretation, but there are others. Such as wanting to support a profession that is increasingly confronted with technology. This chapter is underpinned by the latter motivation. It looks at the difficulties that professionals meet when working with technology. It shows how careful analysis can help them to deal with the changes that technology implies for their profession, by making change a professional response to technological innovation. This chapter builds on insights from nursing theories and science and technology studies, in order to answer the two main questions: what kinds of (small-scale) changes in nursing care are brought about by technology and how can nurses deal with them?

Day-to-Day Routines

When technology is introduced to the work process, it brings about various changes. Normal routines need to be overturned and fixed conditions need to be reconsidered. In this paragraph we consider these changes, describing them and showing what consequences they bring.

Various studies (Milligan et al. 2010; Pols 2012) have shown that technology profoundly changes the daily routines of care professionals. It is important to make the point that a change does not necessarily have to be large in order to be profound. A lot of the changes are small scale, yet significant. Indeed, it is the central message of this chapter that small, easily overlooked changes must be given proper attention if nurses are to use health-care technology in a professional way.

For nurses, the examples are numerous. Care at a distance implies not being present in the same room as the patient. That leads to the obvious changes to the nurse's daily routine, not only because the nurse cannot touch the patient but also because the nurse cannot use other senses while observing the patient and his surroundings. Normally, as in care in presence, whenever a nurse comes to a patient's house to check on his medication, the nurse will observe other changes as well.

> Mister Peter, as he is called by his regular nurses, is 88 years old. He takes three pills a day for various reasons. The morning one is the most important and that is also the one he tends to forget most of the time. A nurse visits him every morning to check his medication. They always chat a bit and sometimes there is even time for coffee. Last year Mr Peter suffered a mild stroke, from which he recovered almost completely. The home care organization started with a project on ICT and care. One of the applications they want to introduce with this project is a medication dispenser. This little machine warns patients to take their pills and warns the nurse if they don't. Mr Peter is asked to participate in the project. He used to work with ICT in his former job and is enthusiastic about giving it a go. Everything works well. In the last two months, Mister Peter has responded appropriately to the dispenser's warnings and has taken all his pills. He hasn't seen a nurse during this period. However, when evaluating the project after three months, the visiting nurse finds both Mister Peter and his home are dirty. When asked, he tells her he hasn't been feeling well for the last two weeks.

When, as in the case described, medication checks are replaced by a dispenser with an alarm, one of the patient's needs is met: he gets his pills on time. This change in available care has been described as dividing care into three parts: monitoring, physical care, and social-emotional care. Once care has been divided in that way, it is easy to separate the individual parts (Roberts and Mort 2009). This implies care in which all three parts are present, but their separation detracts from care as a whole, which means loss of synergy. An interesting feature of Mr Peter's story is that emerging needs are overlooked; needs that have not been expressed are not provided for. The change in need (for one of the three aspects of care) is something to be aware of when caring for frail older people. This situation can be prevented by making alternative house call arrangements, for example, once a week instead of once a day. That may necessitate administrative changes, since funding might be cancelled whenever a medication dispenser is a good alternative to daily visits by a nurse. In that case, it might be necessary to find a new basis for funding the suggested weekly visits, so that emerging needs can be observed.

Another example shows how telecare can lead to large-scale changes. It involves nurses who take care of patients with COPD. In their regular practice, these nurses supplement the care of the doctor by counselling patients during consultation hours at the hospital. Depending on how the patient is doing and on whether the patient can cope with the disease, they meet once or twice a year.

> Mr Allali (52) was diagnosed with COPD two years ago. He finds it very difficult to get used to the idea that he has a chronic disease which forces him to change his lifestyle. Mr Allali used to work full time as an engineer in the metal industry. He used to exercise regularly and although he started smoking at the age of eleven, he completely gave up when he was 35. He takes his medication regularly, but finds it very difficult adjusting his lifestyle to his decreasing energy level. Nurse Tom and Mr Allali discuss this during his yearly visit to the hospital. Tom provides Mr Allali with the necessary information.

In the example, regular care seems sufficient for the patient's needs. COPD is a progressive disease, and when patients enter a more serious stage, their well-being can change quickly.

> Mr Allali has been in hospital for a week. He developed pneumonia, after not recognizing warning signs in time. His yearly appointment wasn't due for another five months. He isn't feeling well. His medication gets adjusted and he visits Tom again. Tom notices that Mr Allali finds it difficult to recognize small changes in his well-being that can predict severe illness such as pneumonia. He suggests that Mr Allali participates in a telecare project.

In this telecare project, the nurses have webcam contact with patients every week. Patients fill in an online questionnaire everyday, and nurses and patients discuss the answers once a week during the online consultation hour. It is notable how profoundly the telecare changes the nurses' normal routine. In this case, both large-scale and small-scale changes are apparent. The large-scale changes include obvious location changes – from hospital to a combination of hospital and home, with use of the webcam. Another large-scale change is in contact frequency: from once a year to every week. It seems almost inevitable that there will also be small-scale changes whenever the large-scale changes are so profound. It turned out that the nurses in this project found it difficult to accommodate the changes, because their routines changed completely. We will return to such changes in care at the end of the chapter.

One further point should be made regarding the large-scale changes referred to above. Telecare projects that are started with the best intentions – providing care at a distance with a view to improving both the quality and the efficiency of the care – frequently do not turn out as expected. In the case of Mr Allali, the telecare project led to an increase in nursing care by a factor of 12. After all, when Mr Allali joins the 3-month project, he "sees" Tom (on screen) 12 times, whereas with regular care he would have seen Tom no more than once in the same period of time. The reason for increasing the frequency of visits by telecare is that the improved monitoring can prevent sudden changes in Mr Allali's well-being. The nurse can advise him on lifestyle issues, changes in medication, or a GP's visit, which is much cheaper than hospital admittance. Such care at a distance raises funding issues, however. The extra costs associated with admitting Mr Allali to hospital only have to be met if admission actually proves necessary. If Mr Allali does not require hospital care, the costs of prevention make the care more expensive. This is an issue within the Dutch healthcare system but will create problems anywhere where the costs of care and prevention are not combined. And of course the situation is complicated by the fact that the party incurring extra costs (in this case the (home) care institution) and the party saving costs (in this case the hospital) are not the same. If such financial issues are not resolved, telecare projects are liable to be discontinued because of the rising costs. Such difficulties could be solved, of course, for example, by more intensive collaboration between health-care organizations, but that would necessitate an enormous change.

Fears and Experiences

Technology is part of who we are, not only as patients and nurses, but also as human beings. Computers and smartphones are part of our lives, both at work and within our social networks. Technical aids, such as coffee machines, cars, and elevators, help us throughout the day. Technical aids are not only around us, but sometimes even inside our bodies, as with ICDs and insulin pumps, for example. When we become patients who are fitted with or dependent on a technical device, it is not just the device that requires attention. Being sick means we also become people in need of care. Nursing is interrelated with technology in the same way. Technology supports nursing but implies the presence of devices that require attention, as part of the patient's body or as a supplier of medication, as with an infusion pump. Sandelowski (1999) states that there is a long-standing relationship between nurses and technology. She gives insight into the different aspects of this "symbiotic relationship," as she calls it. An interesting feature of Sandelowski's analysis is the idea that discomfort between nurses and technology is perpetual but so is the strength of the relationship. Sandelowski shows how, over time, nurses have tried to relate their identities to technology in two different ways. First, they have sought to embrace technology. However, that has not had exclusively desirable effects, since, for example, it also associates nurses with the servile identity of technology. Technology is designed to perform tasks which otherwise had to be performed by human beings, which has a servile aspect to it. The other path – opposing technology – did not work out well either, since it is too readily associated with undesirable gender stereotypes. If nurses state that technology is cold and they give warm care, they associate themselves with skills primarily ascribed to females, which gives the discussion a gender dimension (Sandelowski 2002).

It is worthwhile focusing a little more on one aspect of the relationship between nurses and technology: the idea that nurses fear technology. Their fears seem to relate to the dehumanization brought about by technology (Barnard and Sandelowski 2001). Machines cannot care the way people can. Barnard and Sandelowski argue that creating opposition between the fearful and the fear-free is unnecessary and that it is important to focus on how technology can become a part of care. They state that whether a machine leads to dehumanizing care depends on the user, because the user context defines the use of technology as nonhuman. It is a very elegant and indeed compelling idea, because it offers the space this article seeks to leave the use of technology to both end users. It is also difficult to implement. The debate regarding fear of technology is still active. It is used by managers to explain why a technical innovation is not adopted quickly enough (or not at all). Policymakers, who believe that telecare will solve the problem of an aging population with an increasing demand for care, provide all kinds of funding that reward telecare projects. So it seems that the expectations regarding the success of telecare projects depend on “fear-free” nurses. It is therefore important to highlight the alternative viewpoint that nurses are not fearful but merely – at the very most – careful about handling the changes they meet.

Nurses who object to the use of technology are supported by Roberts and Mort (2009). They regard care as consisting of three distinct parts: monitoring, physical care, and social-emotional care, all three of which can be replaced by a machine or a nonprofessional caretaker. If just one of the parts is provided for in another way, for example, by using technology to monitor patients, you take out the core of care, because care is a whole, which is more than just the sum of its parts. That might be true, but it does not mean that the diminution of the whole is attributable to the use of technology. It has been shown that the opposite can be the case as well, with the introduction of telecare leading to more intense, frequent, and intimate care (Pols 2010). That is consistent with our example of Mr Allali, whose story illustrated implementation problems, but not because of the coldness of care in itself.

So opposing technology does not work. It might help to distinguish what plays a part in the complex changes observed, but it does not explain or remove the barriers to telecare. And even more important, opposition within the nursing profession does not help nurses to deal with the challenges they face. We have seen examples of nurses who were reluctant to embrace technology but also of nurses who were enthusiastic about it. The thing is to find out why nurses are reluctant, whether their reservations are justified and how they think those reservations may be addressed.

Values and Capabilities

Most of the debate regarding the use of technology in care outlined above relates to care values in nursing. Often the argument that counts for nurses is whether the suggested technical innovations will contribute to good care. What counts as good care can differ according to the situation or the patient. If we follow that idea, it could explain why telecare projects stay small scale and are not easily scaled up. Nurses frequently argue that telecare is simply not appropriate for every patient (which may be true in itself, but not helpful to the process of scaling up telecare). It would be helpful, however, if the primary driver were not the scaling up of telecare, but the provision of good care suited to future challenges. Nurses could then make appropriate care available to every patient, in line with their ideas of good care. Eccles (2010) argues for an ethical framework with more layers than the prevailing discourse among policymakers, who tend to be concerned mainly with cost reduction. That argument is consistent with the points we make above regarding the need for an extensive layered analysis of nursing activity in telecare, in order to let nurses make adjustments that reflect the needs of their patients.

Another way of looking at values is to consider how nurses see themselves. What role do they have in care and how do they value that role? Telecare changes roles and responsibilities. Research has been conducted into changing roles in home care, as responsibility shifts between nurses and apparatus and nurses and informal care (Palm 2013). It is easy to imagine that whenever a nurse is less present because the monitoring of a patient is taken over by technology, the informal caretaker is even more present. It thus leads to changing roles in care. The role changes may well influence the way nurses value their own work or the relationship with the patient.

Role changes also give rise to debate regarding capabilities. The overall idea is that education is necessary in order to prepare nurses for the increasing amount of technology in their work (Barakat et al. 2013). This leads to new forms of education, in which technical knowledge and clinical knowledge are combined. There is much to recommend such a trend, as it suggests that new capabilities are necessary. There is also much to be said for another approach, where nurses are educated and trained the regular way, only in a new context. When nurses encounter technology during their training, they acquire skills and develop the ability to form opinions on innovation, using the skills of a critical nurse (van Hout et al. 2013).

Changes in Care

As we approach the end of this chapter, we reach the point that has received least attention. We have seen how technology influences different aspects of nursing practice. Are these aspects of nursing practice equal to care itself? If so, does it follow that, if nursing practice changes whenever technology is used, care will change in the same manner? Instead of starting a narrative discussion on what care is, we want to look at the more subtle, small-scale changes, in order to see whether the use of technology in nursing practice leads to changes in care. The project in which Mr Allali took part serves as a useful example in this context. We saw how, by the use of telecare, Mr Allali received care every week instead of once a year. The same happened to Mrs Borg.

> Mrs Borg has been a participant in the telecare project for a month now. She used to visit the nurse at the hospital twice a year. Mrs Borg has COPD and seems to be deteriorating more quickly than expected. Nurse Tom has been discussing lifestyle and medication according to the protocol. There appears to be no improvement, so he suggests that Mrs Borg joins the telecare project. Because of the webcam, which was set up in Mrs Borg's living room, Tom finds out a lot more about Mrs Borg's situation. During their weekly contacts, he sees numerous things that can influence Mrs Borg's physical situation, such as a parrot that stayed over and a smoking neighbour. Mrs Borg and Tom discussed pets and smoking before. Mrs Borg had never smoked and didn't own a pet, so Tom never paid any attention to it anymore and Mrs Borg didn't see any problem with temporary visits from cigarette-smoking neighbours and feathered friends. Tom now advises her to avoid both, because they do have an influence on her delicate pulmonary balance.

Tom got to understand a lot more about Mrs Borg's circumstances once he could literally see them. All through the project it made him think about the normal care provided during hospital consultation hours. Near the end of the project, he realized what puzzled him:

> Normally I discuss all different kinds of subjects based on a protocol and using a special card. These interventions are based on the idea that a patient benefits by a yearly visit when he is well informed about his disease. In the telecare project I do something completely different. The idea was to monitor patients more closely in order to prevent exacerbations (sudden worsening of the symptoms). These are two separate interventions. I should try to combine these two. The interesting question for us nurses is whether we can find interventions that fit an online consulting hour. It leads to new forms of nursing care, because we don't know if regular care can be changed into an online version just like that.

During the project, Tom gained insight into the (small-scale) changes in his profession and the (small-scale) changes in care brought about by the use of webcam-based technology. It is to be expected that such insights will develop alongside other technologies and other forms of care. It is not just about the obvious changes in work processes, it is about the nurses recognizing that care as they know it, care as enacted, will change.

Conclusion

At the beginning of this chapter, two questions were raised: what kinds of (small-scale) changes in nursing care are brought about by technology and how can nurses deal with them? Changes were seen in day-to-day routines (both large scale and small scale). Routines were turned upside down (for both patients and nurses), and new rhythms in care emerged when weekly consulting hours with the webcam were added to yearly visits to the hospital for patients with COPD. Fears and nurses' experiences changed, and it was shown that, although fears persisted, there were positive experiences as well. As a result, misguided opposition disappeared. Changing values were explored and related to good care and changing roles. Because good care involves patient-specific elements, it is necessary to give nurses space to adjust care and technology at the individual patient level. Finally, we considered the nature of care itself, exploring the changes within it. In one of the observed cases, a nurse concluded that new care originated from the current combination of regular care and telecare.

So technology brings about changes of different kinds: changes in work processes, daily routines, values, and care as we know it. So to our second question: how can nurses deal with such changes? In this chapter, we have argued that nurses should have the opportunity to experience the changes and subsequently tell us how they want to deal with them and the new care brought about by the use of technology. If nurses are sufficiently well equipped to observe changes, they will be sufficiently well equipped to intervene in care as they know it, in order to make that care fit the new situation. So let us, by research and evaluation, zoom in on as many new forms of care and technology as possible, reveal what happens when those new forms of care and technology are used, and let nurses (and patients) make appropriate judgments.

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Political and Regulatory Environment for Smart Home Technology from the Perspective of Singapore

Bert Vrijhoef

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Abstract

Singapore is an affluent urbanized society with an aging population situated in Southeast Asia. Singapore's total population is around 5.40 million (in 2013), with 4.6 % of its GDP spent on healthcare (in 2011) and an average life expectancy of 82.3 years for a newborn Singapore resident (in 2012). As a result of various drivers, a number of likely shifts and changes to Singapore's healthcare system are foreseen. ICTs are regarded as potentially playing a significant role as enablers of the changes required. Singapore is ranked second highest out of 144 countries to leverage ICTs for improved competitiveness and well-being (in 2013). Notwithstanding this achievement, also for Singapore, a spectrum of critical challenges needs to be addressed for making transformative changes in healthcare. Three recent developments indicate Singapore's strategy to strengthen its environment for the use of ICTs for health, including smart home technology.

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Keywords
Singapore • Health care • ICT • Smart home technology • Policy

Introduction

Singapore is an affluent urbanized society with an aging population situated in Southeast Asia. Singapore's total population was 5.40 million at end-June 2013, consisting of 3.31 million Singapore citizens, 0.53 million permanent residents, and 1.55 million nonresidents. The Chinese formed the majority at 74 % of the resident population, followed by the Malays with 13 % and the Indians with 9.1 %. Singapore's population is aging rapidly with the number of senior citizens crossing the 10 % share for the first time in 2013 (Department of Statistics 2013).

Healthcare services in Singapore are provided by different types of providers throughout the entire healthcare value chain, including primary care (17 government-subsidized outpatient polyclinics and around 2,000 private general practitioners), secondary (acute), and tertiary care (a network of 13 public and 16 private hospitals), and step-down care (mostly run by voluntary welfare organizations).

Singapore adopts a mixed health financing system that emphasizes individual responsibility and an attempt to avoid moral hazards that could be faced with pure national insurance schemes when healthcare is provided for free. Healthcare is funded jointly by the government and the individual through insurance, revenue from taxes, as well as savings from each individual's medical savings account (i.e., Medisave). In 2011, Singapore spent 4.6 % of its gross domestic product (GDP) on healthcare (World Bank 2013).

When relating life expectancy data to dollars spent on healthcare, Singapore seems to do well. In 2012, a newborn Singapore resident could expect to live to 82.3 years. A girl born in 2012 could expect to live an average of 84.5 years, while a boy could expect to live 79.9 years. For male residents, the life expectancy at age 65 years was 18.5 years in 2012. For female residents, the life expectancy at age 65 years was 21.9 years (Department of Statistics 2013).

In March 2012, the Ministry of Health in Singapore unveiled the Healthcare 2020 Masterplan, essentially a set of measures to enhance accessibility, affordability, and quality of healthcare, to better meet the needs of Singaporeans. Changing the healthcare system is perceived essential for the well-being of Singapore's citizens.

Key Drivers of Change in Singapore's Healthcare Sector

Four key drivers of change in Singapore's healthcare sector have been identified by a high-level steering committee convened to spearhead the development of Singapore's 10-year masterplan to grow the infocomm sector and to use infocomm technologies to enhance the competitiveness of key economic sectors and build a well-connected society. In short, these key factors are as follows (iN2015 2006):

1. An aging population and the increased burden of chronic conditions such as diabetes, hypertension, high cholesterol levels, and stroke. There is also an increase in the number of patients with chronic degenerative disorders such as dementia and arthritis. Singapore will face a growing need for step-down, nursing, and home care. This will put a significant financial burden on both the patient's family and society. The bill is expected to rise further because the elderly will require more medical care.
2. Rising public expectations of healthcare information and services. Information overload will be a growing challenge in healthcare particularly where there is divergent or even wrong or misleading "health information" being provided to patients by different sources. In addition, much of the information generally available is not readily tailored to the individual's specific set of interests, conditions, or medical problems.
3. The current fragmented and relatively uncoordinated healthcare services. Currently few or no links among doctors from different specialties exist. Neither is there a central database with all the patient's medical records. So, often, no single doctor has a proper overview of a patient's health. Integration of clinical information and coordination of care will become a greater challenge with the increasing number of people with chronic disease.
4. Very rapid advances in information and communication technologies (ICTs), medical science and technologies, and biomedical research. The tremendous speed of advances in medical science and practice makes it increasingly challenging for doctors, other healthcare professionals, and patients to keep abreast of the latest developments. For instance, home diagnostics and remote monitoring applications can make it safe and feasible for many patients with chronic illness and/or physical disabilities to be cared for at home. Many patients and their families are likely to prefer this and it would also ease the pressure on nursing homes and step-down care facilities.

As a result of these drivers, a number of likely shifts and changes to Singapore's healthcare system are foreseen. These include a shift in focus of the healthcare system from treatment of advanced-stage diseases to prevention, health promotion, and wellness care; a shift from provider-centric, fragmented care delivery to a more integrated and patient-centered system of delivery; a shift towards more consistent widespread application of evidence-based medicine; greater role of members of the public in managing their own health; and greater facilitation of data flows between healthcare sector and biomedical sciences research sector to facilitate research that will improve clinical care and outcomes (iN2015 2006).

Like in many other countries, ICTs in Singapore are seen as potentially playing a significant role as enablers of the changes required in its healthcare system. In light of this, a critical question now facing policymakers is how to realize the full potential of ICTs, particularly since the challenges to achieving widespread ICT adoption and use are proving daunting (World Economic Forum 2013).

Preparedness of Singapore to Use ICT to Boost Competitiveness and Well-Being

According to the 12th edition of the Global Information Technology Report (GIRT), Singapore ranks second highest out of 144 countries when looking at the so-called Networked Readiness Index (NRI). Sweden is ranked first and Finland third.

The NRI aims to measure the ability of countries to leverage information and communication technologies (ICTs) for improved competitiveness and well-being. The NRI facilitates the identification of areas where policy intervention could boost the impact of ICTs on development and growth of an economy. It comprises four subindexes that measure (a) the environment for ICTs, (b) the readiness of a society to use ICTs, (c) the actual usage of all main stakeholders, and (d) the impacts that ICTs generate in the economy and in society. The three first subindexes can be regarded as the drivers that establish the conditions for the results of the fourth subindex. These four subindexes are divided into 10 pillars composed of 54 individual indicators in total (Table 1). The final NRI score is a simple average of the four composing subindex scores, while each subindex's score is a simple average of those of the composing pillars (World Economic Forum 2013).

Singapore ranks 1st in four pillars, while Finland leads in two pillars. Singapore shows the way in the environment subindex, earning the top spot in both the political and regulatory environment pillar and the business and innovation environment pillar. The extreme efficiency and business friendliness of its institutional framework, strong intellectual property protection, intense competition, and high university enrollment rate lead to these outstanding outcomes. Singapore's readiness (11th) is also world class, thanks to its excellent digital infrastructure (19th) and skill base

Table 1 Subindexes and pillars together constituting the Networked Readiness Index (NRI)

Subindexes and pillars:
Environment political and regulatory environment
Business and innovation environment
Readiness infrastructure and digital content
Affordability
Skills
Individual usage
Business usage
Government usage
Impact economic impacts
Social impacts

World Economic Forum (2013)

(2nd). The affordability of ICTs (55th) is Singapore's only relative weakness. Within such a conducive environment, it is not surprising to see Singapore in the 3rd position in terms of ICT usage. Among other things, Singapore boasts the world's largest number of mobile broadband subscriptions per capita, above 100 %. Furthermore, it leads the government usage pillar and outperforms the Nordics, including Finland. Within this pillar, Singapore achieves the maximum possible score on the UN's Government Online Services Index. Finally, it ranks 1st on the indicator capturing the importance of ICTs for the government and 4th in assessing the success of latter in promoting ICTs. In this context, it comes as no surprise that Singapore leads the impact subindex, appearing in the top 10 of each of the eight comprising indicators (World Economic Forum 2013).

Political and Regulatory Environment for ICTs Including Smart Home Technology

The policy and regulatory framework in Singapore for the use of ICTs for health consists of a national e-government policy, a national e-health policy, and a national ICT procurement policy for the health sector (WHO 2012).

Notwithstanding this framework, there is a spectrum of critical challenges to be addressed given the scale and complexity of making transformative changes in the healthcare sector. The iN2015 Healthcare and Biomedical Science Sub-Committee (2006) states that "this would include infrastructure development, putting in place the necessary regulatory framework, finding the appropriate funding models, ensuring sufficient infocomm manpower and achieving buy-in by the medical/healthcare community and public. These are by no means trivial challenges. But they are not insurmountable, provided there is leadership from relevant government agencies and healthcare providers to transform the vision into reality."

Three recent developments should strengthen the environment in Singapore for ICTs including smart home technology. First, by means of the National Personal Health Management (PHM) strategy, Singapore is developing an open health technology platform capable of catering to diverse stakeholder needs and one that allows healthcare providers, enterprises, and interest groups to create and build web, mobile applications, and interactive content to support existing and new healthcare programs and services (Gee 2012). Second, the Data Protection Provisions, which is a layer of obligations for healthcare institutions in relation to the protection, collection, use, disclosure, transfers, correction, and care of and access to personal data. Data Protection Provisions is part of the Personal Data Protection Act 2012 and is expected to come into operation in July 2014. As ICTs play an increasingly important role in the healthcare sector, the introduction of the Data Protection Provisions seems timely. Third and final is the development of the National Telemedicine Guidelines which purports to guide best practices in telemedicine interactions. It is expected that these guidelines will be published in 2014.

Conclusions

Changing the healthcare system is perceived essential for the well-being of Singapore's citizens. ICTs in Singapore are seen as potentially playing a significant role as enablers of the changes required. Notwithstanding Singapore's renowned ability to leverage ICTs for improved competitiveness and well-being, its policy and regulatory environment for the use of ICTs for health, including smart home technology, can best be described as "work in progress."

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Assessing Professional Caregiver Needs in Assistive Smart Homes

A. Leah Zulas and Aaron S. Crandall

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Abstract

With the elderly population on the rise, assistive smart technology is positioned to help the elderly living community take on the upcoming age wave. The promise of this technology is focused on providing high-quality data to caregivers. While the research community has published many successes gathering and modeling medical data, there is little work on how to effectively deliver data to caregivers. This study attempts to inform researchers and engineers building smart technologies how to better understand the needs of nurses assisting the elderly. Interviews suggest nutrition, sleep length and quality, cleanliness of the individual,

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safety, and elopement by cognitively impaired individuals are of central concern. It is also important for programmers to make graphs and charts with axis have a real-world relationship. Sensor "events" are not relevant to nursing staff, and should not be presented in their raw form. Time increments are more appropriate for this population than quantity of sensor events. During the design of user-facing tools, a little extra care to the needs of caregivers can ensure assistive smart homes are helpful technologies.

Keywords
Smart homes • Elder care • Nursing needs • User experience • Interviews

Introduction

With the population of those over the age of 65 on the rise around the world, and especially in the developed world, care for these individuals becomes a costly prospect (Fisk et al. 2009). The elder care facilities available simply will not be enough to take care of the projected 17–29% of the population who need them in the coming years. Technology holds promise as part of the solution to this looming issue as a means to assist older adults in remaining independent and at home, while reducing the work load on nursing care practitioners.

Smart Homes are an implementation of the ubiquitous computing concept, where technology is embedded in the environment around us. These technologies are designed to be low profile, second nature to use, and support our conscious and unconscious needs. Inexpensive and low-power modern computers and wireless functionality are rapidly bringing the ubiquitous computing ideals within reach.

The Center for Advanced Studies in Adaptive Systems' (CASAS) smart home implementations use sensors and computers to observe, model, and interact with people living at home (Crandall et al. 2013). These smart homes are designed to monitor the whole living space and preserve privacy, while placing minimal requirements on the residents that could adversely affect their daily behavior. The goals of the system are to build accurate models of how people are living, to measure their physical and cognitive health, and provide tools giving a comprehensive view of the resident to their care providers.

A smart home platform generates data in the form of sensor events, activity models, and quality of activities, such as sleep or medication compliance. However, it is relatively unexplored how to best deliver this information to the caregivers who need it. Nursing staff, physicians, children of the clients, and spouses are all important caregivers who may utilize smart home data to better help those in need. Little formal work has been done with these groups to understand their needs. Currently, the majority of user testing has been to design for the aging adult themselves. Engineering and nursing researchers at University of Missouri's TigerPlace smart elder care facility have performed a series of focus group studies with elderly participants to better understand the needs of those in the home (Demiris et al. 2004, 2008; Arsand and Demiris 2008). This was an important step to understand which activities are key for the individuals residing in the homes, and to establish information about privacy and obtrusiveness concerns. However, it does not tell us what the caregivers need.

Researchers at TigerPlace have collaborated with nursing staff for years, and always stressed the importance of this partnership (Skubic et al. 2009). Their publications often hint at the feedback they have received from such a partnership, but have not formally explored what nurses need from smart home technologies.

Other work has explored the needs of informal caregivers, or those family members who look in on older adults while they are still living in their homes (Hwang et al. 2012). This research included caregivers in a participatory design process using established user-centered design techniques. Researchers brought in future users, showed them various designs, assessed the users' needs, and asked caregivers to run through usability tests in order to effectively design a prompting system interface that would help them do their day-to-day tasks.

To date, the only research assessing professional caregiver needs from smart home technology was a questionnaire with only 18 participants (Chernbumroong et al. 2010). These results are exploratory at best, so further assessments need to be performed.

Historically, visualizations of smart home data are driven by researcher needs. TigerPlace in Missouri published some of their visualization tools, consisting of a simple black and white chart of room occupancy over time (Rantz et al. 2008). The visualization plotted the sensor events occurring over several days. The result was a visible means to see room occupancy density by showing darker or lighter shades of grey.

CASAS has taken this idea a step further (Zulas et al. 2012). The concept of the original occupancy density chart was expanded into a colorized Activities of Daily Living (ADLs) chart (see Fig. 1). The colorized version uses different colors to show the ADLs being performed by the resident, and for how long. In Fig. 1, each row of data (three columns, from left to right) indicates the intensity of activity, the activity taking place, and a layout of the home to help people put the activities and their order in context. However, to better understand what each color means, the user must click the blue link above the graph and then remember the scales from a separate page before returning to the ADLs chart.

This improved ADLs chart was augmented with various plots to include types of activities occurring in the home and a prototype health trend of the resident. The health trend tries to give a global sense of the resident's sleep, activity, and social life in a single plot (see Fig. 2). The six boxes provide information about the home and resident as follows (moving from upper left to upper right, then lower left to lower right): the volume of sensor data gathered at any time, gauges of core daily needs, a socialization over time tool, the total number of events per activity, a pie showing the proportion of time the resident spent in each room, and a "health trend" to try and demonstrate a mechanism capable of showing health behavior over time.

Delivering efficient, clear, and concise information to nursing caregivers is important for the deployment of effective smart home technologies. To move toward this goal of a useful smart home platform, the CASAS researchers interviewed a

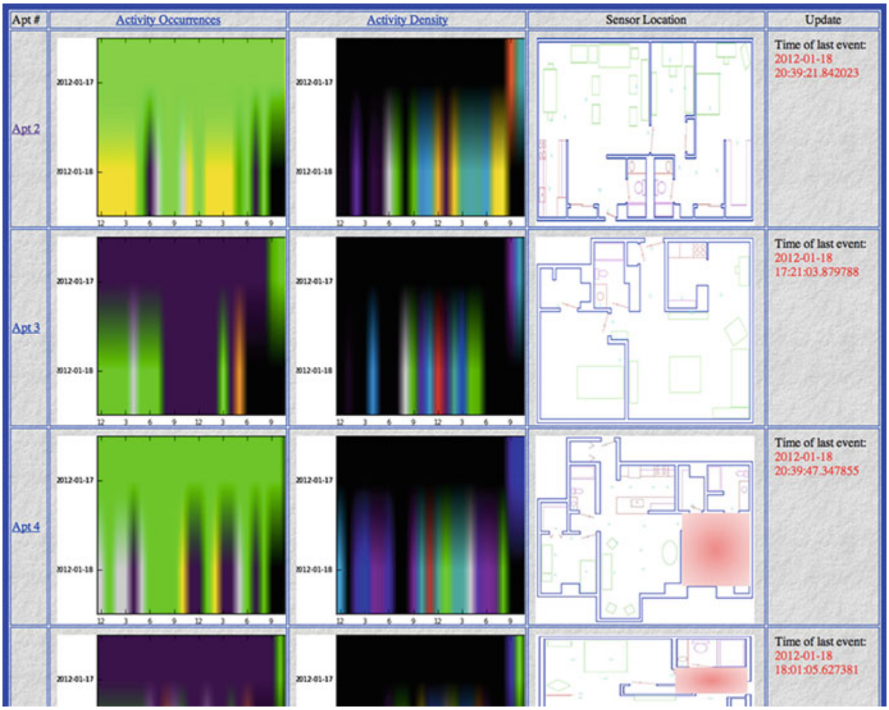

Fig. 1 CASAS dashboard, visualization of smart home data sensor activities. Colors on the *left* indicate number of sensor firings over time with day on the y-axis and time of day on the x-axis. Colors on the *right* indicate activity taking part. Far *right* is a map of the living quarters

series of professional nurses in the gerontology field. While this is not a complete process, the results have already begun to change how the CASAS user interfaces are designed and deployed. This work describes these interviews and summarizes the results.

Methods

Participants

To gather desires, perspective, and feedback on the CASAS tools, a total of nine nurses were interviewed from three different types of nursing care facilities. Three were from a continuing care retirement center with a strong aging in place philosophy, housing high-income residents set in a large metropolitan area, three were from an adult daytime care facility, while the last three were from a nursing care facility, where both of the last facilities reside in a rural city. The university Institutional Review Board approved the study, and informed consent was obtained from each participant. Participants were all female with an average age of 44 years of

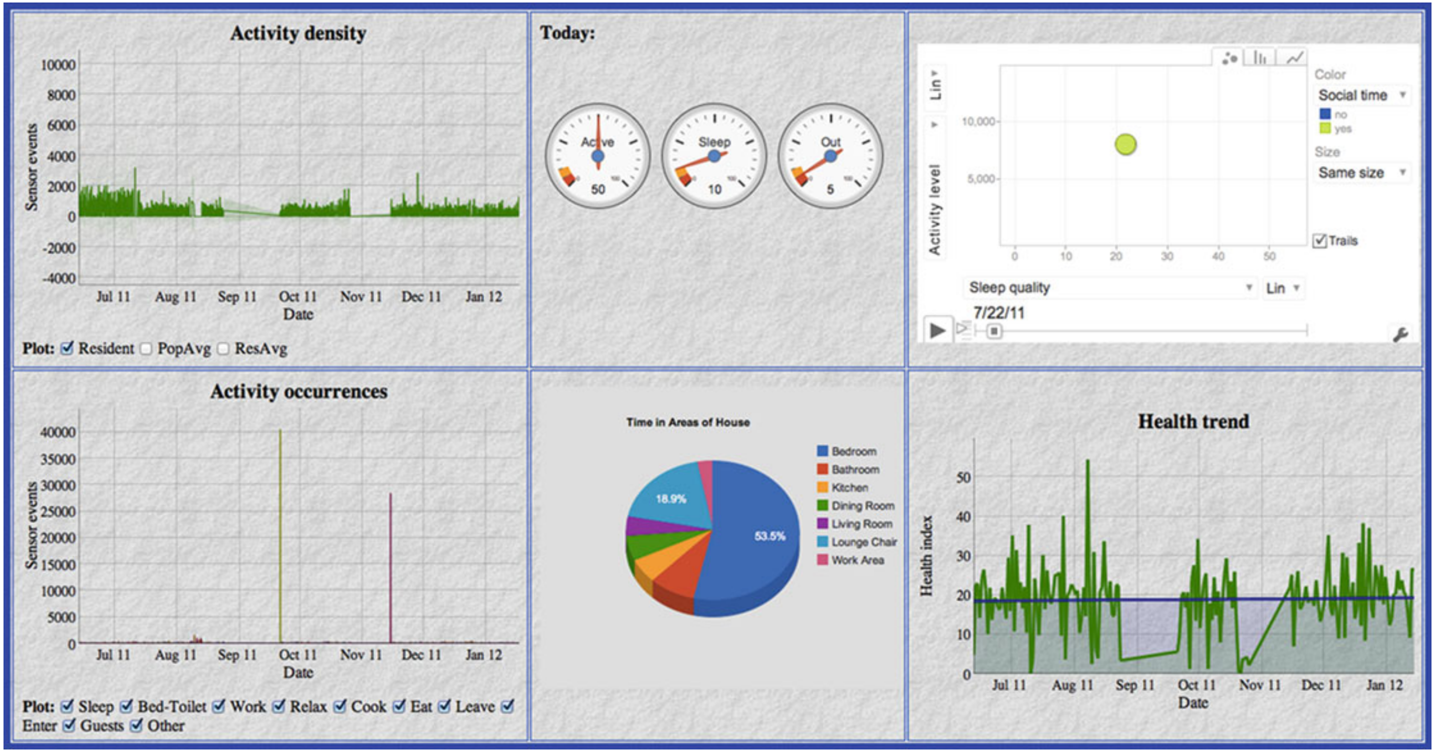

Fig. 2 CASAS profile, visualization of smart home data expanded to include graphs. Graphs include (from *left* to *right*, *top* to *bottom*) overall sensor firings, amount of time spent on specific activities, socialization, sensor firings by activity type, percent time spent in locations around the residence, and a calculated health trend

age and a range from 26 to 68. They had professional nursing experience ranging from two and a half months to 46 years and experience with elderly clients from 1 to 46 years. All participants were at least certified nursing assistants.

Materials

Interviews took place at each nursing facility in an available private office space. Each was recorded using a voice memo application on a smartphone. Viewing of the current smart home visualization tools was made available on a laptop screen with an attached USB mouse.

Apart from the interviews, the System Usability Scale (SUS) was applied. The SUS is a 10-item questionnaire with a five-point Likert-like scale assessing the ease of use and understandability of a system (Brooke 1986). Scores are modified for reversal questions, then totaled and multiplied by 2.5 to give a score out of 100.

Procedures

Participants were led through a directed interview with questions on demographics, computer experience, willingness to learn new technology, and general needs from technology. They were then shown the CASAS smart home visualization of assistive smart home data and allowed to explore this for several minutes. A walk through of the interface by the interviewer was given upon request. Next, the SUS was administered and feedback about the website was obtained. Finally, the participant's needs for the system were obtained, along with any final thoughts.

A secondary observer was present for the proceedings, and 96% inter-rater reliability was achieved on the records kept by both observers.

Results

Interviews proceeded very well, and the system was generally well received. Nurses stated the system was "cool," "savvy," and "fantastic." Some went so far as to want it for all of their clients.

Nurses' computer experience on a 1 to 10 scale was an average of 6.1, with a range from 3 to 10. Their comfort with technology on a 1 to 10 scale was an average of 7.4, with a range from 2 to 10. Lastly, their willingness to learn a simple new technology on a 1 to 10 scale was an average of 8.7, with a range from 3 to 10.

The results of the SUS varied greatly with a score as low as 10/100 and as high as 77.5/100, with an average score of 47.8. Higher scores did not necessarily correlate with greater experience or comfort with technology.

Several themes began to emerge from the interviews to help in describing the overall needs of the nursing staff. These themes centered about important activities of daily living (ADLs), safety of the patient, and delivery of the data.

Activities of Daily Living

Nutrition. Perhaps one of the most talked about ADLs nurses would like to know more about was nutrition. Regardless of location, nurses often wanted to know whether their clients were eating, what kinds of food they were consuming, and how their weight was trending. While current implementations of the CASAS smart home can distinguish when a person is eating or not, it does not determine what was eaten or the quality of their diet.

Sleep. Many aspects of sleep were important to nursing staff. These include how often a person is sleeping during the day time, how long they sleep uninterrupted at night, how many times they got up in the night, overall quality of sleep, and whether the individual has sleep apnea. Much of this is currently modeled in the smart home, but appropriate details about sleep apnea may be difficult to ascertain.

Hygiene. Hygiene of the elderly client was a common theme as well, such as cleanliness of the home, cleanliness of the individual, ability to dress themselves, and cleanliness of cooking or eating areas. Many of these are difficult to detect with general purpose sensors. Showering is easily covered, but cleanliness of the home and ability to dress was out of the scope of the CASAS tools.

Socialization. Socialization may be defined as the individual leaving the house to interact with the community, having visitors in the home, or even accepting help or care to help them with their everyday living. These things are currently being assessed by the assistive smart technologies.

Routine. It was very important to some nurses, and indicated indirectly by others, that a healthy older adult would take part in routines. As stated by one nurse, if an individual often goes to bed at 3am and wakes at noon, this may not be an unhealthy sleep cycle, but simply a person's normal routine. A break from routine is often a solid indicator of a change in the individual's health or well-being. Using the data gathered by the smart home sensors, the CASAS lab has made algorithms to attempt to gauge routines. Further, the question becomes which activities are most important to track.

Activity. Activity can be described by either overall mobility around the home, the amount a person goes out of the home, or amount an individual takes part in facility activities. For differing levels of care, activity was described differently. For independent living, this was activity in the home or leaving the home. For adult day health this was taking part in activities while in their care. For nursing care this was taking part in activities around the ward. All agree that activity is better than sedentary behavior. Activity is central to what the smart home attempts to gather.

Emotional well-being. Perhaps one of the most difficult things to gather information about using technology, is emotional well-being including people's depression, loneliness, and happiness levels. Nursing staff often gathered this data themselves and believed technology maybe should not attempt to gauge this key part of an individual's health.

Quality of ADLs. Nursing staff often indicated if a person's health is declining, the quality of their ADLs might also decline. One nurse described it as a person with a cognitive impairment might go into the kitchen and take twice as long with cooking a meal as usual because they would often forget where they were in the process. There were also worries the system could not detect how well ADLs were being performed. Several researchers from the CASAS lab have been attempting to respond to this need, however, research on the quality of ADL performance is difficult and is still in early stages.

Safety

Medication. Medication may be the second most important thing nursing staff wished to be addressed. It was important to them not only to ensure their clients take their medication on time, and take everything prescribed to them, but also that they do not take too much or take someone else's medication. Doing so might cause serious health concerns. It is often difficult for nursing staff to keep track of when patients are in independent living and adult daycare programs. Several research labs have been attempting to gather medication compliance, however, this is a very involved activity and there is as of yet no perfect solution.

Fall detection. Falls are of major concern for any elderly individual, because they can easily mean hospitalization, rehabilitation, and have serious potential to be fatal, especially if an immobilized individual goes undetected for an extended period of time (Simpson 1993). Effective fall detection with monitoring technology has proven to be difficult. There is no evidence of a real-world deployable solution effectively solving the falls issue at this time.

Fall risk. There are many things nursing staff indicated were risk factors for falls that might be able to be detected more easily than falls themselves. Nursing staff also indicated that often it was better to prevent falls than to deal with a fall once it occurred. Risk factors for falls included clutter in the homes, mobility issues for the individual, transferring problems (i.e., problems getting out of chairs/bed or into chairs/bed), and whether the individual was receiving help with the activities they were no longer able to safely do. Creating technology capable of assessing these risks and warn caregivers could be an important component to better care.

Cognitive health. Another difficult concept to ascertain from a smart home system is an individual's cognitive health. Cognitive problems can lead to wandering or elopement and create a myriad of problems for an individual's ADL performance. Assessing a person's cognitive capabilities is an important part of the smart homes assessment. For this reason, the CASAS lab has several clinical psychologists on staff working closely with cognitive decline in older adults and attempt to learn how to best detect the signs of a change in cognitive health through in-home sensing tools.

Medical information. Many nursing staff participants suggested they would like to know some sort of medical information about their patients including blood pressure, heart rate, and whether they were incontinent or not. These problems would most likely require some sort of wearable device and quality "smart toilet" devices capable of close physiological and chemical analysis of the patients throughout their day. Wearable devices have proven to be problematic, as older participants often forget to wear them. Until a better solution is found, this data may still be left to the nurses and physicians to collect.

Safety equipment. To help prevent falls, increase the quality of mobility, and help patients with transferring, safety equipment is often available. However, nursing staff indicated it is not always used. The capability of a monitoring system to report safety equipment use may help caregivers determine when such devices are not employed. Smart homes currently do not track this information on a large scale. This might be an easy next step to aid in elder safety.

Elopement. For patients with cognitive impairments, elopement, or leaving the home or facility without reason or help, is a problem. This is especially dangerous in winter months in cold locations. It is a major concern for nursing staff, who then need to call local authorities and search the area to find a wandering patient. Detection of elopement for elderly clients with dementia or Alzheimer's would save time, money, and lives. This behavior is difficult to follow outside of the home without a wearable device. The smart home can detect when the door is opened to warn caregivers, however, this may capture times someone is leaving the house for a good reason. Further investigation to address elopement is needed.

Delivery of Data

Overall understanding. Many things that make sense to researchers when displaying data do not work in real-world applications. For instance, the CASAS visualization was often criticized for lacking adequate labeling of graphs and features, using numbers making sense only to the researchers and for having axis labels that did not make sense to the caregivers. This was especially noted when using "sensor events" as a unit of measure. Nursing staff would have much preferred the use of units of time, duration of the activity, number of times an activity occurred, or percent of time in a day spent doing an activity.

Quick visualization. Nurses suggested because they are busy people, a quick visualization of the data they can look at and draw information from was very important. This was reinforced by the pie chart of room utilization on the CASAS visualization being the most liked source of information.

No graphs assuming knowledge. Many graphs created by researchers assume special knowledge. For the CASAS visualization, this was the health trend, a mathematically derived graph utilizing times out of the house, overall activity, and sleep quality. Nursing staff often disliked this graph because they did not know how the trend was derived and wanted more control over any assumptions made in its creation.

Do not trust data. Many times nursing staff did not trust the data to be accurate. They were not sure a computer system could correctly determine what a person was doing through sensor events and computer models. As more than one nurse put it, "What if this person is in the kitchen but they are just wandering and not doing anything in there?"

Too much/not enough information. For some data there was too much information, such as the health trend, where nurses did not know how to use the data.

For others there was not enough information, especially information about what things meant, how to use them, and pure numbers such as, how many times in a single night someone got out of bed or how many times a person left the house in a day. Nursing staff often suggests that they would like an access to the raw numbers without graphs.

Alerts. Perhaps one of the most asked for features of the current system was an alert system. Nurses described a system where they could set a threshold of behavior change and then generate an alert when criteria were met. Nurses would also like alert systems for elopement, falls, and medication changes or compliance.

Communication with other health professionals. A request made outside of the scope of smart home technology was a central clearinghouse for health records for their elderly clients. Some of the biggest problems for most facilities were rooted in not knowing information from all of the many doctors their patients would see, all of the medications their patients would take, and what kind of health records the individual had before they started with the local nurse's program. Effective digital patient records systems are still in development and could eventually be integrated with smart home technologies.

Conclusion

This assessment provided a variety of areas nursing staff care about when attending to older adults. Many of these areas have been addressed by smart home development to date, are being worked on, or could be improved given this feedback. However, some areas, like detecting clutter in the home, were things that have not been addressed yet and might be new opportunities for improving smart homes in the future.

Visualization interfaces for most smart homes need to be clearer for non-researchers. They need to have metrics suited for to the job being by the end user, and aligned with the user's ability to incorporate information into their work. Sensor activities are useful for the researcher and meaningless to the nurse. There are years of research on properly depicting data for quick and accurate retrieval to be taken into account when creating such applications (Tufte 2001; Cleaveland 1985). Participatory design with the nursing staff should be used to include them in the engineering process. Nurses from a variety of locations (i.e., low income vs. high income, assistive care vs. independent care, day care vs. full time care) should be polled to ensure the best generalized design.

Assistive smart homes can be of great use to all who are involved in the care of an elderly individual. It can help to assess decline in abilities and alert caregivers to potential problems. Understanding how to make this data available and understandable for all who need it is an integral step in that process, and the users can truly help researchers to better understand how to make these tools a reality.

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CeHRes Roadmap to Improve Dementia Care

Lisette van Gemert-Pijnen and Marijke Span

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Abstract

Dementia and technology, how do they go together? Technology might be a solution to support health and well-being for patients. Although promising, a lot of technologies are not used due to higher cost than expected, ineffective implementation, and technologies that do not work or help people in a positive way. To improve the adoption and use of technologies for health and well-being, we created a roadmap to guide the process of development, evaluation, and implementation (van Gemert- Pijnen et al. 2011). The roadmap is based on reviews of existing frameworks for eHealth and prior research about development, design,

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and implementation and applied in several research and development projects (van Gemert-Pijnen et al. 2013). In this chapter we elaborate on the use of the CeHRes roadmap for dementia care. First, we will describe the CeHRes roadmap and its principles for development, then we present a case study to demonstrate how the roadmap was used in practice, and finally we will reflect upon the case study by means of lessons learned.

Keywords
Dementia • eHealth • Development

CeHRes Roadmap to Improve Dementia Care

Dementia and technology, how do they go together? Technology might be a solution to support health and well-being for patients. Although promising, a lot of technologies are not used due to higher cost than expected, ineffective implementation, and technologies that do not work or help people in a positive way. To improve the adoption and use of technologies for health and well-being, we created a roadmap, to guide the process of development, evaluation, and implementation (van Gemert-Pijnen et al. 2011). The roadmap is based on reviews of existing frameworks for eHealth and prior research about development, design, and implementation and applied in several research and development projects (van Gemert-Pijnen et al. 2013). In this chapter we elaborate on the use of the CeHRes roadmap for dementia care. First, we will describe the CeHRes roadmap and its principles for development, then we present a case study to demonstrate how the roadmap was used in practice, and finally we will reflect upon the case study by means of lessons learned.

CeHRes Roadmap, Model, and Principles

The CeHRes roadmap is a practical approach to guide professionals (designers, developers, project managers) and researchers in the development and implementation of eHealth technologies. The roadmap entails five different phases to explore and test how an eHealth technology can be perfectly adapted to the target group and successfully implemented in practice (Fig. 1).

The Five Phases of the Roadmap

Contextual inquiry is geared toward identifying and describing the stakeholders' (patients, caregivers/health workers, health insurers) needs and problems. This phase also focuses on selecting those stakeholders who are most likely to benefit from the development of eHealth technology. The objective is to identify the weak and strong points of the current situation (health and well-being), to inquire the needs of stakeholders to improve health and well-being, and to identify regulations and

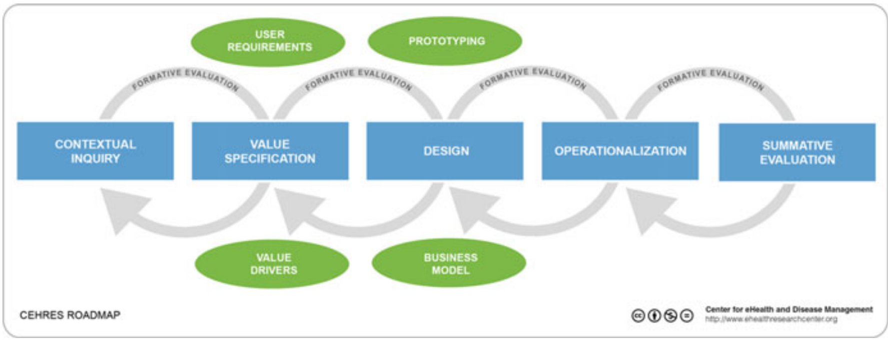

Fig. 1 CeHRes roadmap

conditions that should be taken into account (the context) to implement an eHealth technology. In this phase several activities can be conducted to investigate the context for development (see www.eHealthWiki.org). Important for successful implementation, a project management team should be established to organize meetings between developers and researchers to synchronize the content and system of an eHealth application and to schedule the participation of different stakeholders during the development process.

Value Specification

The value specification phase builds on the results of the contextual inquiry. The stakeholders identify the added values (economical, medical, organizational etc.) that they want to achieve by means of a technical solution for the improvements in health and well-being. These values can be ranked in order to create a feasible technology and to set conditions for implementation (see www.eHealthWiki.org). The values will be translated by the project management team into requirements (user, usage) to design the content and system of the application. These requirements can be formulated as a value map to discuss with stakeholders how a technical solution can contribute to the values to be achieved. For example, to support home care in a safe way for people with dementia, sensor technology can be a solution to alarm family or caregivers in case of a dangerous situation. In a value map stakeholders can discuss the cost and benefits of home care technology for frail people and the conditions for implementation. They can rank the values to set priorities for implementation from the perspectives of patients, caregivers, and those who pay for and maintain the technologies.

Design

A user-centered design can be created with the involvement of end users (patients, families, caregivers etc.). The value map with requirements will be translated into mock-ups, prototypes for the content and system. The prototypes (from paper to technology) will be tested, using scenarios that represent the use in practice of a certain technology. For example, in the case of dementia, several technologies can support health and well-being: technologies that support monitoring sleep/waking rhythms, walking, and eating behaviors; sensor technologies that provide alarms and signals in case of dangerous situations; or coaching technologies to support interaction between users (e.g., patients-caregivers). For example, PAL4 (©Focus Cura) is a touch screen that allows people with dementia to look at their diary and provides video contact with family and caregivers and the "Chatterbox", a game supported by technology to increase social interaction. During the design phase the project management organizes usability testing rounds with several mock-ups representing different kinds of solutions (monitoring and/or coaching technologies). For the design of mock-ups, usability principles and persuasive technology models (e.g., the Persuasive System Model (Oinas-Kukkonen and Harjumaa 2009)) can be used to examine users' preferences for the presentation of the information and the format of technology (mobile, PC, etc.) and to identify factors that can increase the motivation to use the technologies in practice (van Gemert-Pijnen et al. 2013).

Operationalization

This phase focuses on activities to introduce and implement technology in healthcare. The project management team develops a business model with conditions for implementation (timing, activities, actors, budget) and an introduction program to embed technology in practice. For example, to implement sensor systems at home, the caregivers and family should be trained to understand the signals and data provided by these sensor technologies to know whether the patient needs help and to plan the treatment program.

Evaluation

To assess whether a technology fits with the stakeholders' values and end users' needs, formative evaluation rounds are conducted during the development phase and finally, for summative evaluation, to measure the effects on behavior, health condition, and healthcare organization.

For an overview of activities that can be conducted during the five phases, see www.eHealthWiki.org and "improving eHealth" (van Gemert-Pijnen et al. 2013). The roadmap is based on user-centered design principles, persuasive design strategies, and business modeling. The integration of a user-centered design approach, with a stakeholder-driven procedure *during* development, enables a sustainable implementation of technologies in healthcare. In our view development of eHealth technologies is more than creating a tool to support people. eHealth development can be considered as a participatory design process, a process of co-creation between end users and stakeholders to guarantee a fit between technology and the way of living and working. This co-creation process is coupled with continuous and iterative cycles for evaluation (formative evaluation) to know whether technology can contribute to improve health and well-being and what barriers hinder the implementation. Therefore, implementation is not a post design step, but interwoven with development of a technology. As such, eHealth development is not an ad hoc activity, but a structural approach to set the conditions for changing healthcare using technology.

A Case Study: The DecideGuide

The DecideGuide is an interactive Web-based system to support shared decision-making in care networks of people with dementia. Through this system people with dementia, their informal caregivers, and case managers (and/or other professionals involved) can communicate with each other in making shared decisions about care and well-being. The DecideGuide enables participatory design people with dementia, their informal caregivers, and case managers participate in the design to tailor the guide to their needs. The case manager deliberates with the person with dementia and the informal caregivers about the usage of the DecideGuide. All groups have an individual login and use the system on their own or after the case manager alerts them. The aim of the DecideGuide is to give voice to people with dementia as they are often not involved in decision-making about their own health and well-being. Therefore, the DecideGuide has three functions: the first function, *Messages*, is a chat function that enables users (at a distance) to communicate with each other. The second function, *Deciding together*, supports decision-making step by step. The third function, *Individual opinion*, enables users to give their individual opinions about dementia-related topics, e.g., care, living, daily activities, finances, mobility and transport, family and friends, safety, and future. It particularly supports giving voice to the person with dementia. The DecideGuide, a safe and shielded technology, is available for tablets, laptops, and computers (Span et al. 2014a) (Fig. 2, 3, 4, and 5).

Contextual Inquiry

The DecideGuide was developed in an iterative participatory design process. Involvement of all end users in the development process was considered as essential, as this results in better and more user-friendly systems (Span et al. 2013). The CeHRes roadmap was used because of its holistic approach and emphasis on involvement of all stakeholders.

The project started with consulting stakeholders like dementia experts and patient advocates such as the Dutch Alzheimer Association of whom many had a seat in the consortium. The consortium consisted of relevant actors in the field of dementia, like patient and caregivers via the national and regional Dutch Alzheimer's association, the national center of expertise for long-term care, case managers' network, researchers, and representatives of regional dementia care institutions. They were asked about the problems they experienced and expected needs regarding decision-making. Then, we conducted a systematic literature review focusing on how people with dementia are involved in the development of supportive IT applications. Results show that involvement of people with dementia is not self-evident and that involving them in all phases of the development increases the user-friendliness and usability of IT applications (Span et al. 2013).

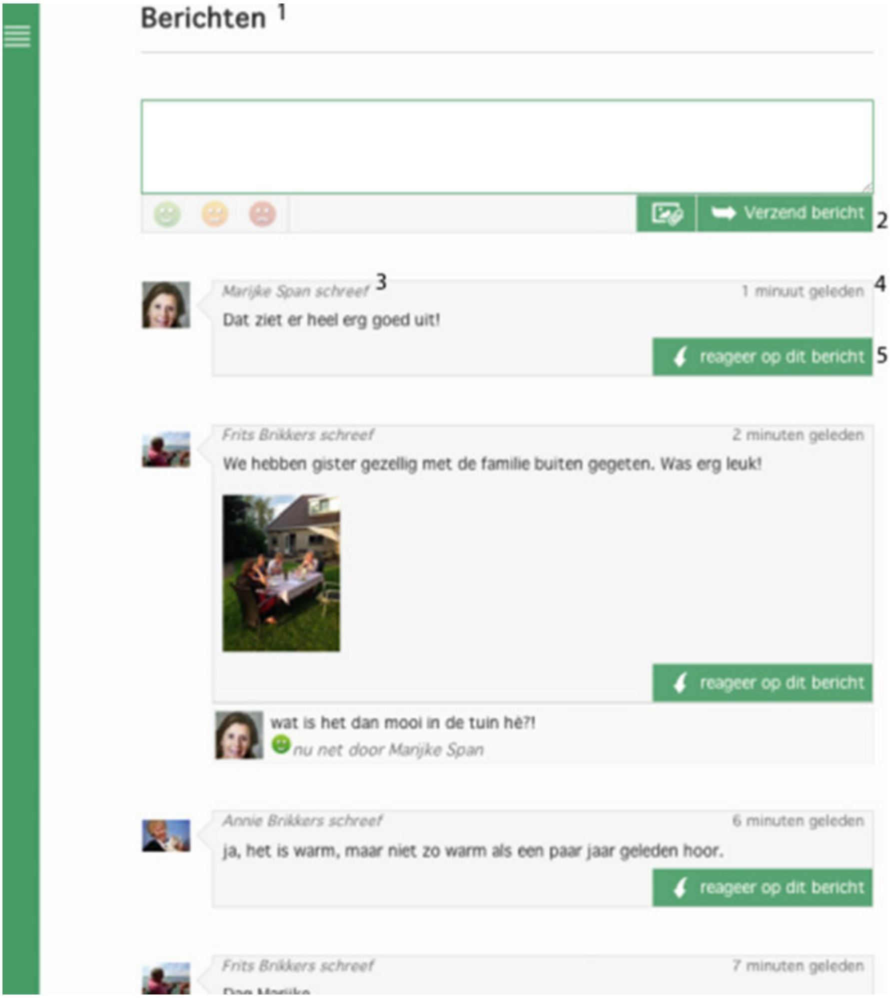

Fig. 2 Chat. (**1**) Messages (**2**) 'Send message' button (**3**) Network member Marijke Span wrote (**4**) Time message was posted (**5**) 'Respond to this message' button

Value Specification

In a stakeholder meeting the goals and values regarding the research and development program were discussed. The overall goal of the research program for the consortium was to improve dementia practice by supporting case managers in facilitating shared decision-making in care networks of people with dementia. Nevertheless, members of the consortium also focused on their goals and values that sometimes differed in content and tempi. For the case managers' organization, it was important the program would result in practical tools. Representatives of the Dutch Alzheimer Association focused on participation of people with dementia and

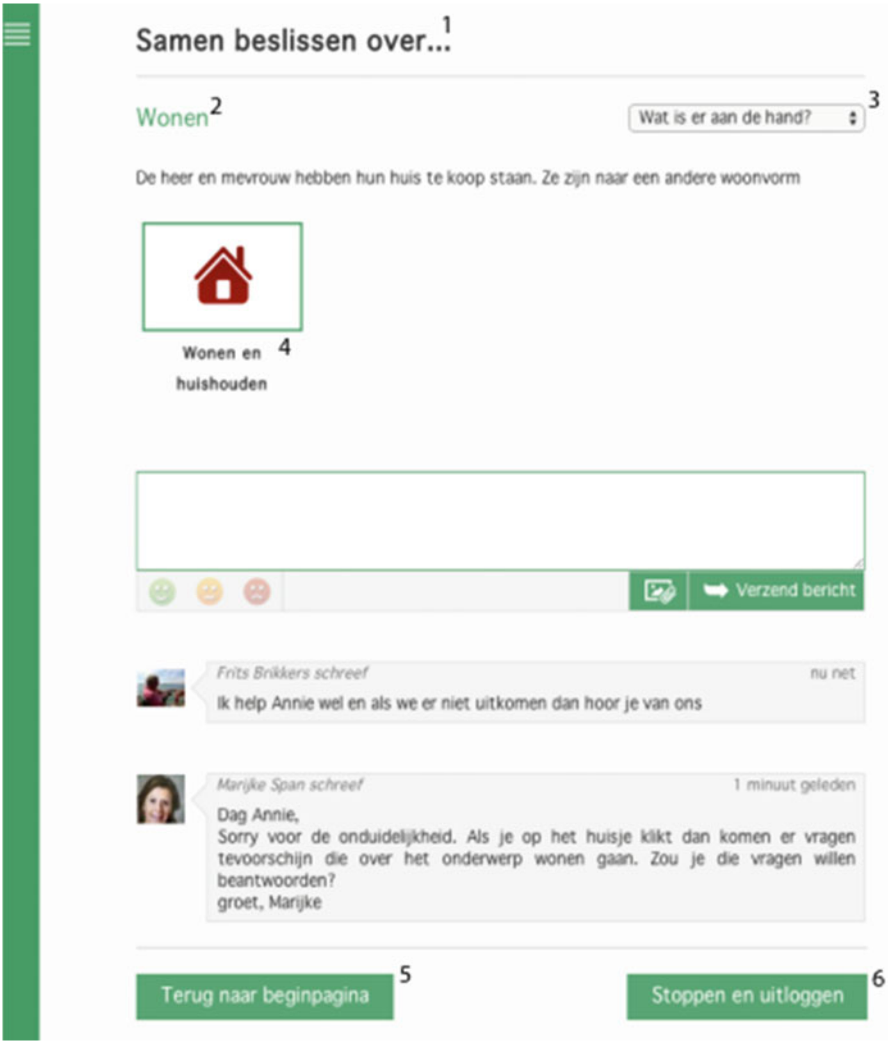

Fig. 3 Deciding together. (**1**) Deciding together about. . . (**2**) Living (**3**) Decision–making phase 'What is going on?' (**4**) Questionnaire 'Living and housekeeping' (**5**) Back to home page button (**6**) Logout button

informal caregivers and attuning to their needs. The national center of expertise for long-term care (Vilans) aimed for the dissemination of the insights on shared decision-making in dementia care networks and implementation of the interactive Web tool. The researchers focused on case management, communication within the networks of people with dementia, self-management, and autonomy of people with dementia and their informal caregivers.

The end users who participated had their own interests. Case managers were in need for practical support regarding decision-making in their daily dementia practice

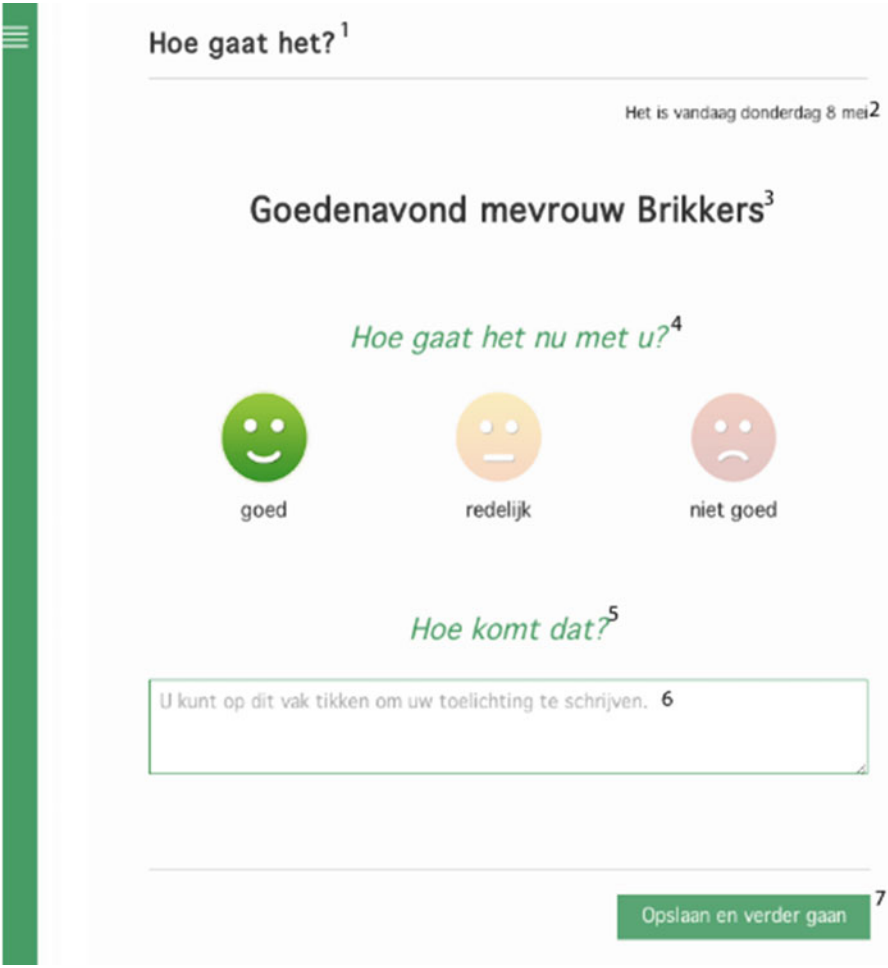

Fig. 4 How are you right now. (**1**) How is it going? (**2**) Date (**3**) Good evening Mrs. Brikkers (**4**) How are you right now? Fine, pretty, not so fine (**5**) Why is that? (**6**) Writing an explanation (**7**) Safe and continue button

that is not time consuming. Informal caregivers were in need for support in the difficult decisions they had to make with or without the persons with dementia. For people with dementia it was important to understand the needs for themselves and future people with dementia.

Design

The next activity was identifying user requirements the system should address. Semi-structured individual interviews ($n = 50$) were undertaken with people with dementia, their informal caregivers, and case managers about decision-making

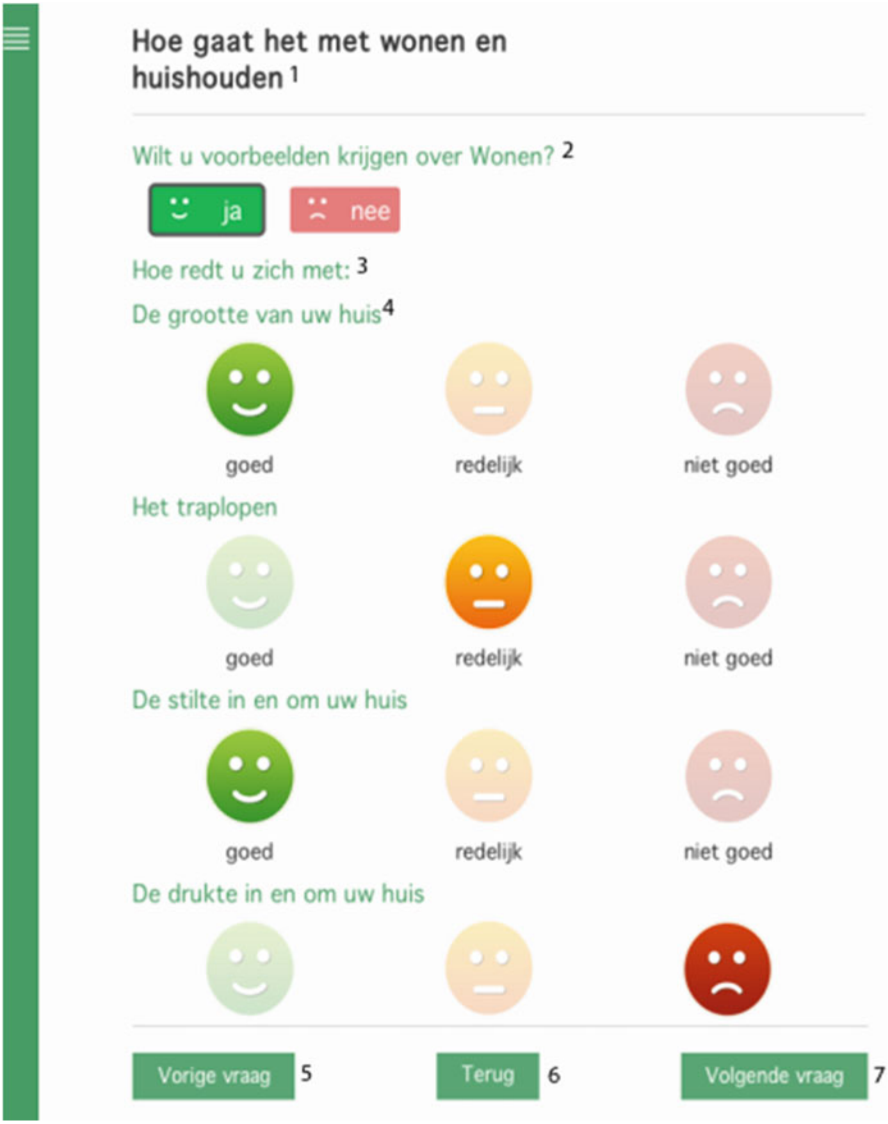

Fig. 5 Individual opinion. (**1**) How are living and housekeeping (**2**) Do you want examples about living and housekeeping'? (**3**) How do you deal with (examples are given) (**4**) The size of the house, stairs, silence inside and outside the house. . . (**5**) 'Previous question' button (**6**) 'Back' button (**7**) Next question button

topics. Consecutively, in separate focus groups ($n = 34$), the three end user groups and a group of dementia experts ($n = 13$) were asked to check the results of the interviews, to add items that were missing in their opinion, and to express requirements a supportive system should address (Span et al. 2014b). In this phase the decision was made for a partnership with an external software developer.

Based on the results of the interviews and focus groups, mock-ups of the system were developed. The mock-ups, a paper-based prototype consisting of 11 screens, was presented in separate focus group sessions to people with dementia, their informal caregivers, and case managers in two consecutive rounds ($n = 27$). A first iteration was made before the second focus group session. Based on the feedback and comments of the end users of both focus group rounds, in a second iteration a first interactive prototype of the system was developed. This interactive prototype, the DecideGuide, was then tested by experts ($n = 3$) in a cognitive walk-through. Based on the experiences of the experts, a third iteration was made before end users tested the system. In individual usability tests with a think aloud protocol case managers, older adults, informal caregivers, and people with dementia tested the DecideGuide ($n = 12$). Their feedback resulted in a fourth iteration of the DecideGuide. Finally, a design checklist of the roadmap was used to assess the quality of the system, content, and service of the design.

Operationalization

The system was used in a 5-month pilot study. Four care networks of people with dementia ($n = 19$) used the DecideGuide on an iPad in their daily lives. Care networks consisted of persons with dementia, their informal caregivers, and case managers. Except for two persons with dementia who participated in the usability tests, the network members were not familiar with the DecideGuide. People with dementia, their informal caregivers, and case managers were interviewed at the start, midway, and at the end. Moreover, observations are made of visits at home and memos and field notes are recorded in a log book. With these activities the impact of the DecideGuide was evaluated. Furthermore, barriers and facilitators for a successful implementation in daily practice of dementia care networks were inventoried.

Two manuals, one for case managers and one for the other participants, were developed that explain the steps of shared decision-making and the possibilities of the DecideGuide. During the development trajectory the project team developed a shared decision-making training that was provided for case managers, nurses, and other professionals working with people with dementia.

Summative Evaluation

Based on the findings of the pilot study, the DecideGuide will be adjusted and an effect study with the DecideGuide will be conducted.

Reflection on the Case Study

We reflect on this case study via lessons learned to provide recommendations for future development projects in the field of dementia.

Lessons Learned

- Involvement of *end users* appeared complicated. Nevertheless, it is essential to involve end users from the beginning of the development and to listen to their opinions and experiences, although older adults and people with dementia need more time to express themselves than other stakeholders. Involvement of people with dementia is complicated because they might have problems with expressing their problems and needs. Standard questionnaires to ask people with dementia about their needs, feelings, and thoughts are hard to use (Nijhof 2013). Criteria for involvement of people with dementia in the development process can be: willingness to learn something, MMSE or other scores related to the phase of dementia, phase of receiving care, eHealth literacy, and expected support from family or caregivers (Nijhof 2013). Caregivers should also be asked about their willingness to use eHealth and their experiences in using eHealth for frail people. From several dementia projects we know that caregivers face problems when using computers or mobile devices in healthcare. They lack adequate education and skills, and in most cases implementation (education, training) is not scheduled as part of their jobs (Nijhof 2013).
- Involvement of *stakeholders* to assess the conditions for implementation was time consuming but valuable. Interviews, observations with caregivers, patients, case managers, management, and work documents (protocol, treatment plans, care pathways) provided the information needed to implement an eHealth system and to set up a realistic implementation plan (time, budget, training, and responsibilities for the maintenance of the eHealth system) (van Gemert-Pijnen et al. 2013; Nijhof 2013). For example, in an ADL project using sensors to measure daily life activities of people with dementia (eating, sleeping, walking etc.), caregivers and family were not able to interpret the sensor data and the data provided by the sensor was not transferable to their treatment goals and plans. This resulted in a non-usage of high cost-effective systems. To avoid such situations, stakeholder meetings, during the early stage of development, are necessary to discuss the values to be achieved and the feasibility of the derived goals to improve health and well-being. In the case study a lot of time (15 weeks for the interviews, focus groups) was invested in identifying goals and requirements with stakeholders and in particular to identify needs of the end users. Although time consuming, these stakeholder meetings resulted in agreement on the goals and requirements to achieve with the DecideGuide. A document with goals and system requirements was developed that was recognized by all stakeholders. This document guides the process of *value creation* among stakeholders and can be used as a first draft for the implementation plan.
- *Prototyping and testing* with end users provide feedback from different perspectives (caregivers, patients, etc.). During the *design phase* several methods were applied to improve the design step by step. The use of mock-ups in the focus group sessions was difficult and confusing for most of the people with dementia. Nevertheless, it resulted in valuable feedback. In the cognitive walk-through, experts (researchers) tested the interactive prototype. Remarkably, the difficulties

experts experienced with regard to the functionalities of the DecideGuide (chat, communication) were not confirmed by people with dementia in the pilot. For example, the expert who played the role of the person with dementia in a chat with two other experts as informal caregiver and case manager experienced the chats as rather confronting. The experts perceived the chat as patronizing patients with dementia, talking about instead of talking with the patients, while "real" patients experienced no problems with the communication at all. This indicates how difficult it is to imagine what patients feel and think and how important it is to include real patients in prototyping.

- To verify the *quality* of the content and system of the DecideGuide, a *guideline* (Nijland 2011, Chap. 5) was used that provides criteria referring to the five phases of the CeHRes roadmap. This guideline should not be used as a checklist to be ticked but as an aid to discuss which research activities and criteria are relevant in each phase of development. The project management team can prioritize what activities and criteria should be taken into account and what activities and criteria are less relevant. For example, items like interoperability of devices, credibility, and completeness of information were considered less relevant for the DecideGuide compared to aspects like learnability and persuasiveness of the content.
- *Project management* is needed to schedule the formative evaluation rounds and research activities (Nijland 2011). The development process of the DecideGuide was delayed because of differences in work dynamics of researchers and designers of the software company. Designers and developers (researchers, caregivers, etc.) work in different tempi and they use a different vocabulary about design. To understand each other, a value map with goals to be achieved and the derived requirements (for system design) can guide the management of a project in health technology development. Important for the operationalization is to discuss the ownership and maintenance of eHealth technologies. The stakeholders of the DecideGuide committed themselves to the implementation of the system in the involved care networks. The consortium was the owner of the content of the DecideGuide and the software company was the owner of the system. An arrangement was made that these two parties could not change the DecideGuide without consulting each other. The same was agreed regarding the maintenance of the DecideGuide. An agreement on ownership and maintenance is needed to be able to update the content and system. The agreement made by the consortium and software company to split the responsibilities might be reasonable, but in practice this can hinder the accuracy and flexibility of the system because of the differences in priorities and the lack of an adequate business model for updating content (who pays for what kinds of updates?).
- To avoid technical discussions, a manual for using technology can be created from the perspective of users (Nijhof 2013). In particular, such a manual can be helpful to clear up differences in priorities (time, interest) between involved stakeholders. For example, in our case the researchers and designers of the system had different priorities in realizing the system, which prolonged the operationalization of the DecideGuide.

- The stakeholders agreed on the *values t*o be achieved, e.g., improving dementia care practice, participation of people with dementia in the development (deciding with rather than deciding for them), and supporting self-management and autonomy of people with dementia and their informal caregivers. However, more attention is needed to business modeling from the beginning of the project. The responsibilities for introduction (training) and responsibilities for technology (maintenance) should be discussed during the value specification to develop a realistic budget case. In the DecideGuide the IT partner for instance, as one of the stakeholders, was not involved at the start of the project to make clear agreements on maintenance tasks. One of the problems with technology is the cost-benefit ratio, for example, it is important to decide how many users are needed in a certain time period to benefit from a home care technology compared to traditional care (Nijhof 2013).
- To be cost effective, a technology can entail different functionalities that can become gradually available. Basic functionalities of the technology can be used at the start for all users and be expanded later on based on *evaluations of the usage* (via logdata). Evaluation is not a fixed end; real-time usage data are important to understand the uptake and impact of a technology on daily life and healthcare practice. Evaluation is an iterative and cyclic activity and starts with the contextual inquiry. To understand the fit between users and technology, logdata can be collected. This requires a log protocol (Van Gemert et al. 2014; Sieverink 2014) to set the conditions for monitoring use and users and to intervene during the period of introduction. This logdata protocol should be incorporated in the system; algorithms should be developed to collect data during usage to measure adherence and dropouts, to predict the impact of usage on outcomes, and to identify user profiles (Nijland 2011; Van Gemert et al. 2014). An informed consent from end users is needed to get agreement to monitor users of technologies.

In the end, to create a fit between technology and people with dementia, a user-centered design is a prerequisite but not sufficient to develop technologies that work, help, and are cost effective. Project management and a stakeholder-driven approach are needed to develop sustainable technologies. Education and training are crucial for caregivers, family, and patients to avoid technologies that overshoot the mark and that make no sense for frail people. The CeHRes roadmap and accompanied tools (eHealth wiki) can be used to create a fit between dementia and technology. To share knowledge and to improve interventions for health and well-being, the eHealth wiki can be expanded with information supplied by project teams involved in developing technologies.

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Professional Values: The Use of Technology and the New Generation of Clinicians

Eveline J. M. Wouters, Thea C. M. Weijers, and Marianne E. Nieboer

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Abstract

For care professionals, the main drive and, related to that, their job satisfaction, is based on being able to satisfy the needs of those who receive their care. Furthermore, most professionals working in contexts in which chronic care is provided, value inter-collegial respect and appreciation of supervisors. Therefore, success and failure factors of implementation of technology in health-care situations are associated with the disruption or support of these values. Mostly, health-care professionals do not themselves think about technological solutions for clinical problems, and therefore, they need support in relating technological solutions to care recipients' needs. In this chapter, a short overview of professional values is given. Next, we outline how technology can be seen as disrupting professional values but also how it can be supportive of professional values, sometimes

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unexpected, as practice examples show. The chapter is concluded by consequences for daily practice and education in health-care professions.

Keywords
Health care • Technology • Education

Introduction

The use of technology in care has a relatively long tradition. At the same time, the extent of the use of technology in chronic health care at a regular and routine basis is not comparable to the current technological developments and possibilities and therefore is still rather disappointing (Westbrook and Braithwaite 2010). One of the possible reasons for this relatively slow uptake is the fact that in chronic health care many different stakeholders are involved. As such, the fact that many different professions need to communicate and collaborate has been found to inhibit spread of innovations (Ferlie et al. 2005). Moreover, not only health-care professionals themselves but also care recipients, engineers, policy makers, and managers in chronic health care have sometimes shared but often also diverse interests by implementing technology (Christensen and Remler 2009). For the actual use and real adoption of technology in routine practice, professionals providing care and care recipients receiving care (within the domain of health care also referred to as patients, clients, or residents) can be considered the most important key figures. In several studies, factors have been distinguished that are attributable to technology acceptance barriers, both in health-care professionals (Christensen and Remler 2009; Ketikidis et al. 2012; Poon et al. 2006) and in care recipients (Peek et al. 2014; Sanders et al. 2012). These factors can, to a certain extent, explain why technology implementation has not always been as successful as intended.

Explanatory factors are based on models that have been developed for technology acceptance in general and that also have been applied to health-care settings. The most often used model is the technology acceptance model (TAM) (Davis 1989) and the unified theory of acceptance and use of technology (UTAUT) (Venkatesh et al. 2003). TAM is a model that is used to understand why persons have the intention to accept technology. This model is globally used as the theoretical basis for many studies of user technology acceptance and was developed for the specific domain of human-computer interactions (Holden and Karsh 2010). The model is used to predict the attitudes and behavior of users of technologies, based on two key variables: perceived usefulness (PU) and perceived ease of use (PEOU). PU is the individual's perception that using the technology (e.g., eHealth, alarm system, social robot) will enhance job performance, and PEOU is the individual's perception that using the technology will be free of effort (Davis 1989). These two variables explain about 40 % of an individual's intention to use a technology in a variety of contexts, including health care.

Although TAM can be useful in predicting and perhaps explaining care professionals' acceptance and use of health technology to a certain extent, there is still much unexplained in the acceptance and actual use of technology in health care (Holden and Karsh 2010). The UTAUT is a technology acceptance model formulated by Venkatesh et al. (Venkatesh et al. 2003). Compared to TAM, the construct of "intention to use" is expanded in UTAUT. The UTAUT gives more insight in users' intentions by adding two extra variables: social influence and facilitating conditions. The theory contains four key constructs for acceptance (i.e., performance expectancy, effort expectancy, social influence, and facilitating conditions), which are direct determinants of usage intention and behavior. Moreover, gender, age, experience, and voluntariness of use are postulated to moderate the impact of the four key constructs on usage intention and behavior (Venkatesh et al. 2003). Validation by Venkatesh et al. of UTAUT in a longitudinal study found it to account for an impressive 70 % of the variance in behavioral intention to use (Venkatesh et al. 2003).

Although intention to use is partly and, in case of UTAUT, even considerably explained, these studies and models of acceptance of technology in health care do not consider the actual use and adoption (resulting in routine use) of technology, nor do they consider the professional values and the relationship of these values to the actual use of technology. In order to understand underlying causes and motives for successful implementation and actual use of technology, we need to understand more about these professional values. By considering these values, we can also understand why technology in health care can be disruptive but also why and when it can be supportive. This insight will help us to enhance and support implementation processes and to be able to make the right choices when doing so. Finally, it will support the education of future health-care professionals in how to choose and use the right technology.

Professional Values

Several values were found to be important in studies addressing patient-centered care (most often studies in nurses) and to be related to job satisfaction and quality of life of professionals working in health care. One of the most important values is the possibility to deliver good care for the patient (Nolan et al. 1995). A *satisfied patient* is considered to be a very important value. Also in other studies on job satisfaction and health care, it was confirmed that satisfaction of care professionals increases when individual care recipients' needs were met in a favorable manner (Brownie and Nancarrow 2013; Nieboer et al. 2014), and one of the determinants most strongly related to professional values and job satisfaction is their patient orientation (Harris et al. 2007). Related to this is the result of another study that found that if a holistic patient-centered approach is applied, caregivers tend to be more satisfied with their job (Nolan et al. 1998).

Another almost equally important value for health-care professionals is being able to work in a *supportive and stable team*. A supportive and cohesive team is associated with higher job satisfaction, less stress, and enhanced perceived autonomy (Larrabee et al. 2003; Nolan et al. 1998; Rafferty et al. 2001), and leaving the job in stable teams is far less common. Also in a more recent study, the importance of a good, stable, and supportive team, together with a good team manager, was confirmed (Nieboer et al. 2014).

The preference for health-care professionals to work in a cohesive team could be both an enabler and a hindrance for health technology. Recent studies from the realm of implementation science show the relevance of teamwork for the success of the implementation of an innovation. Implementation should be seen as the result of a collective, coordinated, and cooperative social action (May 2013). May gives the example of the introduction of a clinical practice guideline. The prospects for implementation and normalization of a guideline will be diminished if nurses do not cooperate with each other and agree on changing norms and roles and work together to accommodate the other changes that it will bring. “It is collective action – nurses working together to put the guideline into practice and continually using it with their patients (or not) that is the central element of the implementation process.” (May 2013, p. 10). In view of the value health-care professionals assign to a stable team, this implies that if the professionals perceive the collective action needed for the implementation as supportive for the stability of the team, they will be more inclined to participate. However, if there is a chance the collective action might break up the team, for instance, because the team does not agree on the new norms and roles, professionals might refrain from the implementation altogether.

Less often ventilated values, and values that health-care professionals are perhaps not explicitly conscious of, are values related to their role as an expert. In former times, doctors, and to a certain extent all health-care professionals, used to be the absolute experts of a patient’s health problem. Nowadays, patients have wide access to health information and, as a result, can better participate in care decisions (Lorig and Holman 2003; McMullan 2006). A related issue is that the responsibility of informal care has become more important (Palm 2013). Technology supports these developments and therefore can be highly disruptive (Willems 2004). In the next paragraph, we will further elaborate on the consequences for the role of health-care professionals.

Technology and Its Effect on Values

Technology in health care can be both perceived as disruptive and as supportive of professional values in care. For instance, studies have suggested that care professionals are afraid that their role as care providers might change substantially or even become redundant because of the use of technology (Lluch 2011). Technology might take over (large) parts of their work, or their expertise is no longer exclusive but easily available on the Internet (McMullan 2006). According to McMullan, health professionals are responding to the more “Internet-informed” patient in one or more of three ways: (1) The health professional feels threatened by the information the patient brings and responds defensively by asserting their “expert opinion” (health professional-centered relationship). (2) The health professional and patient collaborate in obtaining and analyzing the information (patient-centered relationship).

(3) The health professional will guide patients to reliable health information websites (Internet prescription) (McMullan 2006).

The Dutch eHealth monitor 2014 found that, compared to specialists and psychiatrists, general practitioners are more inclined to the second and third response. They feel that well-informed patients will be equal partners in therapy and more capable of taking charge of their own health (Krijgsman et al. 2014). Almost all general practitioners refer their patients to the Internet for information, and a large percentage informs patients on medical apps and self-monitoring devices. This is particularly the case with patients who suffer from chronic diseases.

There is strong, but not undisputed, evidence that these patients might benefit from self-monitoring and tele-support (Steventon et al. 2012). Half of the nurses in the eHealth monitor 2014 expect that self-monitoring might improve the quality of life of patients and their self-reliance, but about 40 % expect there will be no effect at all. A smaller but not insignificant group (20–25 %) expects that self-monitoring by patients might have a negative effect on their workload and the appeal of nursing (Krijgsman et al. 2014, pp. 81–82).

In summary, the impact of technology, especially eHealth, on the daily work of health-care professionals is large, and the opportunities not yet fully explored and applied.

Possibilities and Advantages

There are now several examples that show that eHealth can enable patients and/or their family system to be more in charge and take an active role in therapy, such as in early intervention programs for toddlers with hearing or communication problems (Stredler-Brown 2012). A typical example is the following. In a face to face (F2F) situation, the therapist would start interacting with the child, while the parent would watch. Later on in the session, the parent would do exercises with the child, under the supervision of the therapist. In a telepractice model, such as in the Virtual Home Visit (VHV) project of the Utah State University, this obviously could not happen since the therapist was not in the room with the parent and child (Olsen et al. 2012). Parent coaching became the key component of the service. The early interventionist would now coach the parent, watch the parent interact with the child, and give feedback on ways the parent could interact to promote the child's use of desired skills. In the evaluation, most parents thought F2F and VHV were equally good, but some favored VHV because "[the VHV] makes me work with [child's name] and learn how to help him" (Olsen et al. 2012, p. 275). These findings are supported by other studies. Houston concludes that because they are actively engaged during telepractice sessions, parents are better equipped to integrate communication and language goals into their child's typical routines outside the telepractice sessions (Houston et al. 2014). This means that (future) professionals need specific skills to educate the parents to do the interventions themselves, instead of the therapist doing the intervention.

Royal Kentalis, a Dutch organization that supports people with hearing and communication problems, has conducted several pilot projects with telepractice (also called eCoaching or eCare). One of these pilots used chatting on a special secure website as a tool in the coaching of teenagers (>12 years) (Vetter and van der Vlies 2014). Though the website did not function very well technically, the clients and the professionals were very positive about this new tool that was used in combination with F2F contact. The clients' rating went from a 5 (on a scale of 10) for the F2F contact to an 8 for the blended form. Both clients and professionals mentioned that with chatting it was easier to set up an appointment and have more frequent but shorter communication opportunities. The clients also said that in chatting they felt more comfortable to "talk" about certain feelings and problems. The physical distance and anonymity created by the fact that the coach could not see them led to more intimacy instead of less. Also, in a chat, the client could take the initiative and be more in control.

However, there were also disadvantages. There was always a risk of miscommunication, even with these clients that knew and were known by their coaches as they had already been in therapy when the pilot started. To avert this risk, all professionals participated in a 1-day training to understand the pitfalls of miscommunication and how to avoid them. They also set up a peer intervision group to exchange their experiences and learn from each other. Later on, this was mentioned as one of the advantages of the pilot: that they could meet professionals from another location whom they did not know very well up till then and work together on this pilot. So in this case, the collective action needed to implement the pilot was appreciated.

Both in the case of VHV and eCoaching, professionals had to develop special skills to be able to make good use of these new tools. In the next paragraph, we will discuss what this means for the future generation of health-care professionals.

Future Generation of Health-Care Professionals

As explained, the Internet, as a source of information, can be an important opportunity for patients to become actively engaged in their own care and therefore may have an effect on the patient-health professional relationship by sharing the responsibility for information and communication concerning the health problem of the patient. This could have a direct effect on patient and health professional satisfaction and health outcomes. Health-care professionals and patients become partners in managing patients' care (Forkner-Dunn 2003). Therefore, it is getting more important that health professionals acknowledge patients' search for knowledge and that they discuss the information offered by patients and guide them to reliable and accurate health information. It is recommended that courses, such as "patient informatics", are integrated in health professionals' education (McMullan 2006). A broader perspective on competences of health professionals in the service of patients is given by the CanMEDS framework (Ho et al. 2014). Recently, an expert group looked at each of these roles, through the lens of eHealth. To integrate eHealth as a cross-cutting concept, the CanMeds framework can be used a good starting point for educating new young professionals (Ho et al. 2014). For example, adopting information technologies enhances the professional's expertise and supports decision-making processes. Communication technologies can provide expert consultation in a variety of settings and can provide timely and evidence-based interventions.

In conclusion, technology, especially eHealth, offers great opportunities for improving care. The implementation is not self-evident though, and in education, specific efforts have to be made to prepare future health-care professionals to work and benefit from the possibilities.

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Smart Living in Dementia Care

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Abstract

In order to provide adequate care and housing to the growing number of people with dementia, new technologies are necessary to provide good care and reduce the costs for these care services. Numerous technologies are available, which decrease the need for care and increase the self-reliance of clients and support relatives or professional carers. This chapter discusses the use and implementation of e-health technologies and provides an overview of recommendations on how to start using

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technology for people with dementia in an efficient and effective way. E-health technologies may reduce the number of falls and improve one's quality of life, both for people with dementia and their family carers. For family carers, the technology makes life easier and accounts for a reduction of time spent on caring, improved independence, and a diminished occurrence of depressive feelings. In the field of work satisfaction of professional carers, little research has been done. There are many design and implementation challenges concerning technology for people with dementia, which can lead to the success or failure of technology in dementia care.

Keywords
Dementia • Alzheimer • Ageing-in-place • Nursing home

Introduction

Dementia is an umbrella term for different types of progressive brain disorders, which cause a person to encounter a serious loss of cognitive ability and functional loss in daily life. Dementia affects a person's memory, thinking, behavior, and ability to cope with everyday activities. There are about 45 million people with dementia worldwide, and this number will increase to an estimated 75.6 million in 2030 and 135.5 million in 2050. Much of this increase can be found in the developing countries. Already 62 % of people with dementia live in developing countries, but in 2050 this will have risen to an estimated total of 71 %. The fastest growth in the older population is taking place in China, India, and their South-Asian and Western-Pacific neighbors (Prince et al. 2013).

In order to provide adequate care and housing to this growing number of people with dementia, new technologies and innovations are necessary to provide good care and reduce the costs for these care services. In addition, there is a trend in the developed countries to stimulate people to continue living in their own homes for as long as possible. In the case of dementia, this creates a high burden for family carers, who are the ones who have to step in for additional support that can be considered as very stressful. Over the last decade, different technologies indeed have been developed for the support of care for people with dementia. The aim of these technologies is to decrease the need for care, increase the self-reliance of clients and to support relatives or professional carers. Advanced forms of technology are not used by residential care settings only but also at people's own homes.

This chapter discusses the use and implementation of e-health technologies and provides an overview of recommendations on how to start using technology for people with dementia in an efficient and effective way.

Possibilities of Emerging Technologies

In 2013, Nijhof (2013) published studies on a wide array of technologies that are used for the administration of e-health (Kort and van Hoof 2012) to people with dementia in home-based and residential care:

– Sensor and signaling technology, which generates an alarm when a dangerous situation occurs. Examples are emergency response systems or sensors which register if someone leaves the gas stove on or falls down.
– Social contact technology (related to social behavior). Examples are video contact systems, social robots, and games using technology or a multimedia system.
– Monitoring technology (registering behavior patterns of people). Examples are GPS-based (global positioning system) technologies and sensor technology. Another example is the Actiwatch, a watch which can measure the sleep and wake pattern by the movement of the hands, the body temperature, and heartbeat.

The work encompassed a literature study (Nijhof et al. 2009) which covered 18 international and 8 national studies. Several studies showed effects on behavior (fewer falls) and improved quality of life, both for people with dementia and their family carers. For family carers, the technology makes life easier and accounts for a reduction of time spent on caring, improved independence, and a diminished occurrence of depressive feelings. In the field of work satisfaction of professional carers, little research has been done. To sum up the results of the studies, national studies do not show any effects, and some international studies show some small changes in work satisfaction with the use of technology in a nursing home. Several problems have been identified for the early phases of a project, including high investment costs for the technology, the occurrence of failures and interruptions, and a lack of a successful overall implementation.

An additional four case studies were carried out in which e-health solutions for people with dementia were evaluated (Nijhof et al. 2012, 2013a, b, c) (Text Box 1). The evaluated e-health technologies can be divided into social contact technologies on the one hand and monitoring technologies on the other hand. The monitoring technology used in a situation at one's own home was a preventive sensor technology system. The other monitoring technology in residential care was a smart watch which measured one's sleep-wake pattern. The social contact technology at one's own home was a supportive touch screen, and in residential care an interactive game was used to stimulate social contact between the people with dementia. The first results of the use of e-health for people with dementia in home-based and residential care are positive. Technologies were shown to support the well-being of people with dementia and that of their family carers. In addition, improvements in the care tasks of professional carers were observed. Furthermore, cost savings were achieved by letting people age-in-place for a longer period of time. The overall implementation was, however, not well organized in many of the projects and needs more attention.

Box 1 Four Evaluations of e-Health Technologies from the Netherlands

Preventive Sensor Technology for Dementia Care

A commercially available monitoring system (ADLife by Tunstall, Fig. 1) for older people with dementia living at home was evaluated (Nijhof et al. 2013a).

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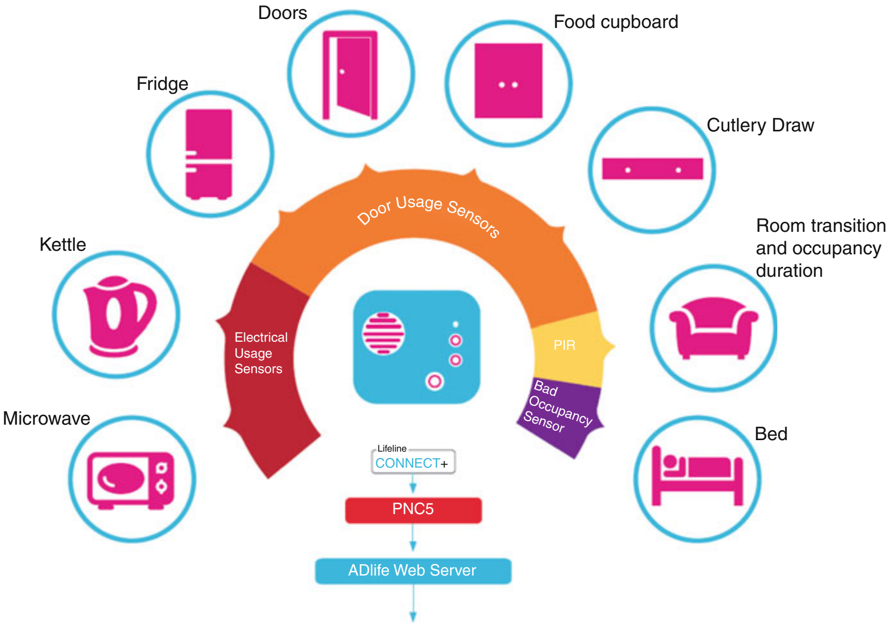

Fig. 1 Schematic overview of the ADLife system

The system was designed to detect problems before they require crisis intervention. Fourteen clients from two healthcare organizations used the system over a 9-month period. The formal and informal carers were interviewed, project group meetings were observed, nurse diaries were analyzed, and a cost analysis was performed. Clients and informal carers reported enhanced feelings of safety and security as a result of having the system installed in the home. The system appeared to reduce the burden of care on the informal carer and had the potential to allow people to live at home for longer. There were financial savings for clients staying at home with the technology compared with the costs of staying in a nursing home: for ten clients living at home for 2 months, the savings were € 23,665. The study showed that the monitoring system represents a potentially useful early warning system to detect a situation before it requires emergency intervention.

The Use of Smart Watches in Nursing Homes to Monitor Sleeping Behavior

The effects of a smart watch measuring the sleep-wake rhythm of residents with dementia were evaluated (Nijhof et al. 2012). The IST Vivago Watch (Fig. 2) was worn on the wrist and measures micro and macro movement, skin

(continued)

Fig. 2 The Vivago Watch being worn by an older user

temperature, and skin conductivity. Measurements for sleep monitoring given include measurements of sleep time and circadian rhythmicity. For the study, seven nursing home residents with severe dementia and a disturbed sleep-wake rhythm wore the Vivago Watch for 6 months. In addition, carers were asked to keep a diary for 3 months to provide insights into the use, usability, interventions, and effects of using the watch. A carer was also studied during a normal weekday, while a researcher kept a descriptive log of events, and interviews were conducted by the researcher with five carers, to gain insights into research questions regarding the introduction of the watch, its usage and usability, interventions taken based on using the watch, and the effects of the device on the sleeping behavior of the residents. Interventions based on the watch showed generally positive results in the sleep time period and circadian rhythm for the residents. Carers found that the watch made it easier to coordinate care during day and nighttime, including the administering of sleep medication and the coordination of care activities.

(continued)

Fig. 3 The PAL-4 system

A Personal Assistant for Dementia to Stay at Home Safe at Reduced Cost

The commercially available PAL4-dementia system (Fig. 3), a supportive touch screen for people with dementia, was evaluated (Nijhof et al. 2013b). The main purpose was to study the advantages and disadvantages of the system from the perspective of the client, family, and professional carer and the potentials to upscale its use. The evaluation was conducted over 9 months with 16 clients of two healthcare organizations. A mixed-method design was used in this pilot, involving log files of system use, interviews with family carers, a focus group made up of professional carers, observations of project group meetings, and a cost analysis. Clients and family carers reported good support of daily life activities. They thought the system could help the client to live at home for a longer period of time. The cost analysis showed monthly savings per client as compared to living in a nursing home ranging from around € 820 (10 clients) to € 860 (50 clients). Despite these positive results, numerous problems were detected: (i) interruptions of technology, (ii) insufficient operation knowledge of professional caregivers, (iii) insufficient active involvement of family carers, and (iv) limited user-friendliness of the layout.

The Chitchatters: A Technology-Supported Leisure Activity

A technology-supported leisure game for people with dementia, called The Chitchatters (Fig. 4), was evaluated in relation to the stimulation of social behavior (Nijhof et al. 2013c). The technology-supported game aimed to stimulate social behavior and interaction among participants via its design features, including a TV, radio, telephone, and treasure box. The additional

(continued)

Fig. 4 The prototype of the game activity in use at the care center for psychogeriatric clients

impact of the game activity on behavioral outcomes of people with dementia in a nursing home and daycare setting was evaluated in comparison to a traditional leisure activity. A mixed-method research design was applied. Ten participants were observed in multiple rounds of observations. In addition, interviews with the activity facilitators were conducted. Social behavior was found to occur more often than nonsocial behavior during the sessions, in particular, due to making comments by the participants. Participants with progressed stages of dementia scored higher for nonsocial and nonverbal behavior. Female participants scored higher for social behavior than males. Activity facilitators stated that the technology-supported leisure activity helps them with their professional tasks. A technology-supported game can stimulate communication and social behavior among players with dementia. Moreover, it helps activity facilitators in making activities more person centered.

Critical Approach Towards the Use of Technology

Although there are reasons to be optimistic given some of the preliminary positive results listed above, there is still room for improvement. In the field of technology for people with dementia, there are numerous initiatives, using technologies that can sometimes yield unwanted side effects, such as confusion and unwanted behaviors, or using technologies that do not work at all in practice (Van Hoof et al. 2011). For instance, we see several examples of automatic curtains opening and shutting seemingly without an operator, or lighting switching on and off automatically, which sometimes creates confusion, restless behavior, or feelings of anxiety among people with dementia. This may, at the same time, also lead to diminished self-care capacities among people with dementia. The wrong use of technology, which can be caused due to a lack of skills among carers, can contribute unfavorably to a project's success. This is particularly the case for the older carers; younger people tend to be more experienced in, and more open and embracing towards, the use of modern technologies. A professional carer may come up with critical feedback, which sometimes leads to changes in the system, but more often to not using the technology at all, as a result of dissatisfaction, stress, or irritation.

Three reasons exist for the problems mentioned above. Only a small number of systematic studies have been conducted worldwide, which dealt with the effects of technology for people with dementia, even though several good arguments exist for the use of technology. Most of the design guidelines that are currently used by developers of new technologies are not more than a collection of practical experiences of pioneers. A second cause is the technology push that can be witnessed in society and which is embraced by a multitude of enterprises selling technologies on the marketplace. This technology push is also caused by the urgency of cost savings and shortages of skilled professional carers on the labor market. Technology is seen as an attractive product which can support care and well-being, even though the evidence base for technological interventions is weak, albeit on the rising. The last cause is the fact that the technology is not implemented in the proper way, even though millions of euros are spent on technological interventions in healthcare. Arguments heard in healthcare are that including the technology creates additional work and tasks, healthcare becomes less personal, the implementation of technology is costly, technology malfunctions most of the time, and so on. These arguments are often rooted in a poorly organized implementation procedure. A well-organized support or backup system is essential for a successful implementation of technology in dementia care. The technology is often implemented in addition to existing care regimens, instead of an implementation within the existing care regimens. In other cases, the situation is even worse, when technology is used, but without any clarity which problem the technology is going to fix in the first place, or what the direct goals of the use of technology are. Examples of such goals are that the five persons working during the night shift should be brought back to three or that the score for quality of life for persons living in residential care should be improved by 20 %. In conclusion, the implementation of technology in healthcare is not just a matter of product innovation but even more a matter of basic service innovation.

How to Use Technology in Practice?

There are many recommendations for the successful use and implementation of smart home technologies in dementia care. First of all, it is necessary to make a distinction between the use in residential care and in the home environment. The use of technology in these two places is quite different, mainly because of the various stages of dementia and the accompanying problems which occur.

When considering the use of technology in residential care, there are many ethical considerations concerning the use of surveillance technologies. These considerations are described by Niemeijer et al. (2011). Apart from the ethical considerations, there are other recommendations that can be followed. For instance, it is of the utmost importance to choose a set of technology which requires no learning by the client on how to use the system. The new technology should look familiar, not take away control from the user and just have a minimum of interaction with the user. The technology should reassure the user, for example, by showing a green light when someone did the right action (Orpwood et al. 2005). Complex technology should not be visible and the effects of technology should not be invasive or unrecognizable. The technology should be integrated into a design which resembles an item from one's past. For instance, a toilet which flushes automatically should still have a pull cord which people can use to flush the toilet. Despite the emergence of tablet computers which increasingly replace touch screens, it is not always evident for people with dementia that they can operate a system by touching a screen when they are not assisted by a relative or a professional carer. For technology used at home, the user-friendliness and ease of use are extremely important. The design of technology should ideally be done together with family carers and people with dementia in so-called co-creation sessions in order to optimize this ease of use.

In addition to the technology itself, the implementation is equally important. In residential care, the care processes should be redesigned, and professional carers should be educated in order to see the benefits of the use of technology and in order to be able to use technology within the required set of tasks. The involvement of professional carers right from the beginning can optimize the implementation process and prevent feelings of irritation or frustration afterwards. At home, a support system is essential in the early phases of the implementation of technology, including a help desk and a service worker. Having access to a professional carer who has experience with people with dementia and is skilled (and regularly trained) in the use of technology is a precondition for a successful implementation.

A natural way of getting people with dementia and their spouses acquainted with new technologies is to start using technologies which aim to improve well-being and comfort. This could, for example, be a wake-up light, which stimulates waking up with the use of light. One step further is monitoring technology, which can monitor the activities of daily living of a user and any deviations of regular patterns. The next step would be technologies that can be used for the support of the person with dementia, for example, a GPS-based track and trace system in case of wandering behavior. The fourth step would be technologies that substitute human activities, including automated curtains, which can be installed when a user is no longer able to move around freely. Ideally, the four types of technology should be integrated with existing household appliances, in order for a person to be able to use these technologies without having to learn how to do so or without the need for buying new technologies. For instance, a regular lamp could be used as a wake-up light. Moreover, the lamp could be used to monitor if someone gets up in the morning and turns on the light, and thereafter, the lamp will create a day and night rhythm for the user if it registers a deterioration in the sleep and wake cycle.

Adlam et al. (2004) identified a number of recommendations for the work of installers. Whenever a professional with a background in technology installs technology, it is important that all questions from the user (even the ones that are repeated) will be answered and that the installer listens carefully and considers the whole client system (wishes from the client, professional, and relatives). Additionally, it is necessary to train the installers in the heterogeneity and health problems of the older population, including the specific needs related to dementia. Furthermore, people with dementia need a quick response if interruptions in the technology occur, because they are not able to understand these interruptions and cannot get around them. In order to create a successful use of technology, it is necessary to train all the involved users. Installers should also realize that the technologies they install for the benefit of the person with dementia may not be enough to meet all needs. Simple and more complex home modifications may be necessary as well, in order for people to move around the house or care facility or receive support of activities of daily living, for instance, bathing (van Hoof et al. 2011).

In conclusion, the right design and a well-organized implementation and installation are essential elements for the right use of e-health technologies in dementia care.

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Technology Acceptance by Patients: Empowerment and Stigma

Martina Ziefle and Anne Kathrin Schaar

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Abstract

Given the increased life expectancy and considering shortcomings in the care sector, it is a fundamental challenge how older and frail people can be empowered to stay in their private home, keeping up mobility and independency for a longer time. The maturity of information and communication technology on the one hand and of medical technology on the other basically allows technology to take over the monitoring and care. However, so far, the inclusion of human factors and technology acceptance into a successful technology design is not adequately met. In the following, we describe relevant facets of technology empowerment and stigmas and the need to rethink traditional concepts. First, the requirements of adequate use and design of information and communication technologies in the medical field are addressed. Second, as the prevailing image of age is no longer adequate to the current demographic change, the need to rethink age and aging is

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described. Finally the need of user-centered design is discussed, followed by the need of a rethinking of the technology design process and the inclusion of potential users. The chapter ends with a discussion focused on requirements of patient empowerment to reflect all the aforementioned aspects from a patient's point of view.

Keywords
Technology acceptance • Demographic change • Patient empowerment • Ageism

Introduction

In the near future, new generations of technical products, services, and interfaces have to meet fundamental societal and technological challenges: first, requirements of the demographic change are to be considered, with increasingly more and older as well as frail technology users. Second, technology is increasingly more complex and needs to be handled by diversely skilled workers. Third, the seamless integrating of technology into our living spaces with the requirements of understanding the impact of invisible technology is the most important issue. As the usage of technology is increasingly less voluntary and often vital (e.g., in case of life-saving medical technology), technology acceptance, the willingness of persons to rely and trust technology, and fear of violating intimacy and privacy are serious issues which have to be handled with care (Mynatt et al. 2004; Lalou 2008). For modern societies, it is a fundamental question how technology and technical interfaces will meet these challenges, especially in times of aging societies. The so-called demographic change challenges European countries like Germany, Italy, Poland, or Bulgaria, but also Asian countries, as Japan, to find adequate answers, solutions, and strategies.

It can be noted that the awareness for this challenge is given, and solutions, strategies, etc. are initiated in many fields. Especially the branch of medical technologies detected the need for progress early on. But although the necessity to react was indeed recognized within this branch as well as an awareness of the specific demands of patients' health and safety, there are several more global aspects that have to be rethought in the traditional development of technology, especially with respect to the complex challenge of meeting technology acceptance.

Central Questions and Challenges

In this chapter, the branch of medical technology was chosen as an example, because it addresses the dilemma between (older) patient empowerment and stigmatization in particular. While older people are obviously in need of extended long-term care, they also wish to maintain their independence as long as possible (Dewsbury and Edge 2001). Studies show that many older people regard their home as a sanctuary and therefore prefer to stay at home, even at an increased risk to their health and safety

(Cook and Das 2007; Ziefle et al. 2011). This wish is connected to a perceived gain in the quality of life in a familiar environment. Generally, quality of life is a quite complex concept referring to the individual perception of one's "physical health, psychological state, level of independence, social relationships, personal beliefs, and relationship to salient features in the environment" (WHO 1994). Additionally, medical technology illustrates clearly what happens if the user is not integrated into the design and development process. Therefore, results from long-lasting research in the field of medical technology acceptance are presented and discussed critically regarding the interplay of patient empowerment and stigmatization.

Technology acceptance by patients has to be thought of as a multifactorial construct. Patients and current technologies are characterized by diversity. User or patient diversity typically consists of age, gender, personality, and level of education and, in the context of technology, of expertise with technology or self-efficacy with technology (Wilkowska and Ziefle 2011). Especially when it comes to an aging society, we have to learn that being old does not always mean the same, even in the same context, and that although the linguistic use makes us believe we have a homogenous user group, it is in fact very diverse (Arning and Ziefle 2009).

For the technological side, we have to remark that technology is, at least since the appearance of web 2.0, no longer limited to single devices or machines (O'Reilly 2007) but represents a combination of devices, data, and information independent from time and space. To face these changes, further deliberations about the following aspects are necessary:

– Novel formats of information and communication technology and technology acceptance as an integral component
– The concepts of age, aging, and images of aging
– The novel requirements of technology design
– Patient empowerment and stigmatization

Rethinking of Information and Communication Technology in the Medical Context

For a long time, the private use of information and communication technologies (ICT) has been specifically tailored to persons, healthy, young, parts of the work force and quite experienced with respect to the use of ICT. Since the early 1980s, ICT has found its way into the working context in which more and more people were confronted with this new form of technology. At least since the beginning of the last decade, this situation has changed completely and ICT became available for the mass. Reasons for that were, on one hand, the expansion of the Internet, a continuously progressing miniaturization of computers, as well as falling prices for ICT that led to a wide distribution of modern ICT among the European population. On the other hand, approaches of modern ICT were also further implemented into various other forms of technologies (e.g., cars, household technology, etc.).

In this chapter, we have chosen to take medical technology as an example as it illustrates special facets of technology acceptance and its sensitive sides depending on user diversity factors particularly well. Additionally, medical technology combined with modern ICT plays an important role for the coping of the demographic change. An increasing number of people that will need more medical care made the branch of medical technology boom in the last decade (Leonhardt 2006). This led to an enormous progress in the field of medical technology for the professional use (e.g., robotic surgery) but also in the development of medical technological devices for the private use. In this context, especially the combination of traditional medical technologies with modern ICT was groundbreaking. The combination of modern ICT and medical technological devices and the medical usage of ICT are creating unprecedented opportunities for both present and future; no longer limited to single devices, interactive, intelligent, and ambient concepts offer ubiquitous support for customers on both sides of the spectrum: patients as well as care givers and relatives.

One huge field is the integration of medical devices within smartphones or other ICT (Leijdekkers and Gay 2006) to help monitor (chronical) diseases like diabetes via smartphone applications (Calero Valdez et al. 2011; Klasnja and Pratt 2012; Scherr et al. 2006; Röcker and Ziefle 2011). Another approach based on the new technological conditions was ambient assistive living (AAL) (Nehmer et al. 2006). AAL is focused on the situational and discreet support of (frail) people within their home environment. One example for that approach is the future care lab (http://www.comm.rwth-aachen.de) which was developed at RWTH Aachen University (Klack et al. 2011; Kasugai et al. 2010). The future care lab is a research space in which older and frail users can experience the character of products developed within a home environment and contribute to understanding of age requirements. Also the sensitive trade-offs between safety and security on the one hand, but also privacy and intimacy requirements on the other hand, are explored (Wilkowska and Ziefle 2012). In addition, the specific information and communication needs of integrated ICT can be examined in context, e.g., when room components (walls, floor) are used as intelligent objects (Beul et al. 2011; Leusmann et al. 2011; Brauner et al. 2013; Fig. 1).

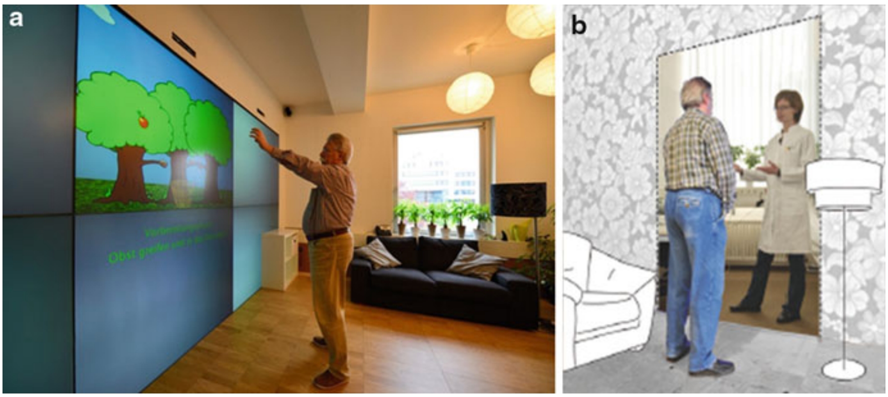

Fig. 1 Examples for applications for the future care lab (**a**) © Brauner; (**b**) © Kasugai)

AAL concepts such as the future care lab are new forms of technology integrated into the living environment that offer a wide variety of possible uses but also different degrees of acceptance based on the respective application.

Beyond the exclusive focus on the potential and feasibility of the technological potential of pervasive health care, the focus on human values, the usage context of a technology, and the requirements of user diversity are key demands of a successful development of medical technologies.

As a summary, a general rethink of ICT and its fundamental innovations is necessary, especially when it comes to fields like medical technology. The rethink is overdue in regard to the following aspects:

– ICT is no longer a niche for small user groups.
– ICT has left the specificity of the job-related context and is a ubiquitous phenomenon today.
– The combination and integration within contexts like medical technology trigger new application scenarios.

Rethinking of Age and Aging in Graying Societies

A central task is to understand the impact of age and aging. It includes a sensible understanding of the societal and individual pictures of age and aging.

The Societal Images of Aging: Although "aging" or "being old" is used in the common parlance as standardized term, aging is a highly complex and individual process that is characterized by a high degree of variability. It should be noted that the process of aging starts at different points in life for each individual and with various effects in regard to decreasing cognitive, sensory, or motor skills. The same holds true for the psychological perception of being old. The functional component of aging is defined via biological and physical developments (Sterns and Doverspike 1989). In contrast, the psychological age is defined by the overall mental or cognitive status, including the ability to react to fast changing situations, make decisions in critical situations, or adapt to multitasking demands. Furthermore, individual perceptions of age and being old are characterized by one's self-concept of being old. Both these concepts undergo a certain progress: whereas the physiological age is particularly influenced by medical treatment, nutrition, life quality, and strain on the human body (through work, pollution, and other environmental stressors), the psychological age is highly correlated to a person's biography, education and upbringing, critical life events, and coping as well as social and societal parameters (e.g., the family support or the social integration in a peer network).

Societal or public parameters also influence the point at which others perceive a person as old. This can be demonstrated when looking into history. Throughout history, the aging picture changed according to the established standards of the respective time period. Before the industrialization, people were perceived as old when they were no longer physically and mentally able to do their work. At that time, the perception of being old was defined by a calendric component as well as the decrease of physical factors. After the industrialization, this perception changed and was influenced by the time of a person's retirement, a more or less fictive point in time, set by public authorities. This led to a more social and political definition of being old. In Germany, but also in other European countries, there was a profound change in the way of the aging concept over time. Starting with the economic miracle, after World War II, the standards of living and wealth increased rapidly, which influenced, on the one hand, the physiological well-being and, on the other one, financial opportunities that allowed new lifestyles, particularly for the time after persons' retirement. Never before had the time after the active working life implied so much space for individual development. Interestingly, although the so-called third age, the baby-boomer age, and health changed so much after World War II, it can be proven that the perception of "being old" did not change to the same degree (Covey 1992). Usually, age is treated in many studies by forming four categories (Shanan and Kedar 1979): the early adulthood (age 20–30), the adulthood (age 30–40), the middle age (age 40–60), and the higher adulthood that is subdivided into a 60+ and an 80+ section. It is a basic question, though, in how far these more or less arbitrary categories hold for future age cohorts, as aging depends also on generation and time.

Another social phenomenon that is highly correlated to aging is *ageism*. The term ageism was introduced in 1969 (Butler 1969) and is defined as social discrimination based on a person's age. Whereas at first ageism included the discrimination of both young and old persons, the focus was quickly set on a negative view of older persons and a stigmatization of aging. In our current situation with an aging society and demographic change, ageism plays an important role regarding the handling of these issues. Even though it is evident that today's societies are factually graying, attitudes towards frail and old people needing technology are still negative. Reflecting this deeply ingrained habit, all ages show this negative attitude towards aging, and it can be seen in many parts of daily life: fashion, social values, advertising, sexuality at older age, earnings, job chances, and, finally, a far-reaching youthism.

A constructive handling of the ageism problem is therefore a serious issue (Palmore 2001; Nelson 2004). Beyond the negative and stigmatizing attitudes towards older persons prevailing in public perceptions by societies, work, and family environments (Iweins et al. 2013), the feeling of older persons being dependent on technology and the loss of autonomy and control are highly negatively connoted for the persons concerned. In contrast, seniors' higher experience in many parts of daily life, their wisdom and life experience, and their ability to play an active part of the workforce are not acknowledged if not ignored.

The situation necessitates a profound *reframing of age and aging* (Allen 1987; John 2013; Sharma and Thomas 2010). We have to deal with outdated but pertinacious mental models of age and aging as well as certain forms of discrimination against older people. These facts make it essential today to rethink aging concepts from a societal and an individual perspective, including the occurrence of ageism, if we want to overcome the challenges of the demographic change in an adequate, respectful, and fair way. Therefore, the following aspects should be considered in research and policy:

– Aging is an individual process.
– Ageism is deeply anchored in society (current vernacular, commercials, films, working context).
– Aging images must be adapted to reality.
– The label “old” is no carrier for specific (negative) characteristics.
– The positive aspects of age should be reflected according to their positive value for an (aging) society.
– Culture, gender, individual background, upbringing, and economic status do have a considerable impact on the self-image as well as on the public image of age and aging.
– Differentiate age and generation.

Rethinking Technology Design: User-Centered Design, Hedonic and Affective Design

The maturity of information and communication technology on the one hand and of medical technology on the other basically allows technology to take over monitoring and care. Today, some solutions are already common practice, e.g., the emergency button, but a future goal would be the combination of different applications that lead to a sophisticated AAL concept (overview in Klack et al. 2011). In order to minimize daily life health risks for old and frail people and to increase the independency and mobility of an aging society, new concepts for unobtrusive health monitoring within home environments are needed. Implementation and integration of medical technology in living spaces requires a new conceptualization of medical device design. Mostly, design aspects of interactive environments have been experimentally tried in controlled conditions, usually as an “artistic” installation. Still too little research efforts address the cognizant effectiveness of interactive environments.

Invisibility and unobtrusiveness of technical components combined with high technical reliability have to be major aspects to be respected within the guidelines for the design of future health monitoring devices. In addition to technical features, technology at home also needs to be architectonically integrated in the personal living space and should not change the character of a comfortable and cozy home, respecting individual requirements for intimacy and privacy.

For a successful scenario in which both patients and health-care institutions profit from home care solutions, the technology has to be unobtrusive, affordable, and reliable. Patients have to be and feel as safe as in a hospital combined with the comfort and the privacy of their normal home environment. A long time ergonomics and human factors have been discussed from a dominantly functional perspective. According to this, mainly pragmatic aspects of technology (usability) are focused upon effectiveness, efficiency, and satisfaction (how satisfied are users when interacting with the interface). However, facing an increasing diversity of users, using contexts, and technology types, the concentration on pragmatic aspects falls short. Traditional approaches usually do not reflect the importance of positive emotions (Wright et al. 2005). In this perspective, the quality of "good interfaces" relies also on affective and hedonic aspects as well as on social values, on attributes emphasizing individuals' well-being, pleasure, and fun when interacting with technology.

To this end, the relationship of users and technological products is of importance, as is a consequent inclusion of potential users, their requirements, acceptance barriers, and wishes. The making sense of user experience is highly needed, facing that information and communication technology moves out of the office and into everyday life.

The requirements for novel and successful technology device development are:

– Development should focus not only on technical aspects but also on design, mental model of age, etc..
– The perspective of users, their wishes, and barriers must be integrated in early technical development.
– Usability is an important component of medical devices. However, the cognitive and emotional passion of elderly with respect to the design should not be underestimated.
– User diversity and diversity of using contexts of medical technology represent critical framing conditions.
– The different faces of technology acceptances and their impact on the design process of assistive technology.

Empowerment and Stigma: Two Sides of One Coin

In conclusion, there are a number of essential requirements, which need to be considered for a user-centered technology development and design in the medical sector. With a focus on an aging society, one of the most striking challenges for (medical) engineers and technical designers is to develop medical support devices for the needs of the elderly, and especially for chronically diseased people in their home environments.

Holistic and Interdisciplinary Technology Development

There is an urgent need to develop novel, integrative models for the design of user-centered health-care systems. This demand includes new concepts of electronic monitoring systems within ambient living environments, which are suited to support persons individually (according to user profiles), adaptively (according to the course of disease), and sensitively (according to living conditions). Thus, the development of medical technology must be a common duty of different disciplines such as medicine, medical technology, engineering, architecture, communication science, ethics, psychology, and sociology. Only if the different perspectives are combined into technology development, humane and human technology designs may result. In those cases, higher acceptance can be achieved by a device design, which includes usability aspects and hedonic components from the very beginning. In that way a medical device can turn into something that patients are proud to wear or to possess, just like a watch or a mobile phone, which are also assistive devices in a person's daily life.

Inclusion of Potential Users

The most important modification in the traditional development approaches in the field of medical engineering is to include those users actively in the design process, for whom the technology is designed. A coherent user-centered design of medical devices will result in a medical technology, which is not only functional in an engineering way of thinking but also addresses fundamental user needs in terms of appearance, ease of use, and privacy. Especially in case of integrating technology in living spaces, this is of great importance. First, there is no other place, which is more intimate and confiding than "the own four walls." Yet, accommodation is extremely important in a human's life for reasons of perceived safety, and it belongs to the basic human needs to feel protected, stable, and secure. Second, health is the greatest wealth and therefore a very sensitive and delicate topic – there is no higher good than this and everyone tries to protect it as long as somehow possible. Thus, putting these two relevant aspects of human life together, it is all the more understandable that the involvement of end users, their perspectives, whishes, and needs into every step of the development process play a great role for a successful rollout.

Age and Frailness as a Dictum to Technology Design

Given the increasing graying of societies and the overall aim to keep older persons as valuable part of modern societies, a profound rethinking is necessary. Technical design must be specifically tailored to the needs of the most frequent user group, the seniors. This includes a reframing of social and societal attitudes and a novel definition of age as a value in and for the whole society. Positive aspects of age and aging – life experience, domain knowledge, skills and expertise, wisdom, lifelong learning, and keeper of values and culture – should be deeply anchored in the public's mind. This seems to be not only a timely duty in nowadays societies; it also secures social and societal traditions, and medical technology development is part of it. If future medical technology adheres to an open-minded age perception, empowerment of the seniors is enabled.

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Successful Implementation of Technological Innovations in Health Care Organizations

Eveline J. M. Wouters, Thea C. M. Weijers, and Tracy L. Finch

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Abstract

In order to accept and implement technology in a successful manner, not only determinants (acceptance barriers or facilitators) related to individual persons, for instance, health care providers as well as health care recipients, are important. Also interpersonal relationships on the work floor as well as the readiness and support of the organization itself are involved in the process of uptake of innovations. The Normalization Process Theory explains how this can be understood. The Technology Adoption Readiness Scale (TARS), developed based on this theory, offers a tool to diagnose the opportunities and challenges in health

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care organizations with respect to the implementation of certain technology- or eHealth applications. In order to guide the process of large scale implementation of technological innovations, also a pre implementation diagnosis is useful. This diagnosis, when provided by a "neutral party" has proved to be helpful for monitoring, guiding and thus supporting the implementation process of technological innovations in health care settings.

Keywords
Acceptance • Implementation • Normalization Process theory • Technology

Introduction

In general, technology offers many opportunities to support processes in health care. At the same time, although promising, technological innovations in chronic health care tend to diffuse at a slow pace (Sanders et al. 2012). Several reasons have been postulated for this slow uptake, such as lack of using a holistic framework for design of technology in health care (van Gemert-Pijnen et al. 2011), the disruptiveness of technology in the interaction with specific groups, e.g., older persons (Peek et al. 2014), but also lack of standards, ethical, clinical and technical aspects (Anderson 2007), resistance to change practice by health care professionals (Li et al. 2013), as well as lack of guidelines for practical implementation in health care organizations (Koch 2006). Even technology that has proved its merits in small scale pilots, has difficulties to be adopted on a large scale in health care (Christensen and Remler 2009; Sanders et al. 2012). This results in disappointing, highly inefficient, and costly investments. In this chapter, we first briefly focus on theory that explains factors that hinder or support implementation of technology within health care organizations. Next, we discuss current possibilities to disclose these factors and an instrument to analyze them, and finally, we describe how monitoring and talking over implementation strategy helps to improve adoption of technological innovations in health care organizations.

Normalization Process Theory

Several theories and models explain acceptance and adoption of technology in individuals, such as patients and health care professionals. Most often cited is the TAM (Technology Acceptance Model) (Davis 1989), and its augmented variants (Ketikidis et al. 2012; Venkatesh et al. 2003). Within organizations, not only personal acceptance is important. Also the context of the organization plays an important part in probability of innovations to succeed (Christensen and Remler 2009). In a large literature review, Lluch gave an overview of implementation barriers associated with management in organizations (Lluch 2011). The main themes described were related to the structure of health care organizational systems (e.g., team coherence or lack of team coherence and changes in work processes), people policies (e.g., training or lack of training, support by the organization in time, money or other ways), accountability and liability issues, incentives (e.g., start-up costs), and information- and decision processes, which can lead to more work load (Li et al. 2013; Mair et al. 2012). These issues have to be properly realized by the organization managers and likewise addressed, in order to achieve successful implementation (Li et al. 2013; Lluch 2011; Mair et al. 2012).

In order to understand the implementation of complex innovations in health care, the Normalization Process Theory (May and Finch 2009) and its predecessor, the Normalization Process Model (NPM) (May 2006; May et al. 2007) is helpful. NPT is a middle-range theory of implementation that is derived from empirical observation and analysis of studies of interventions in clinical practice (May and Finch 2009; May et al. 2009) and includes factors found to be important by several researchers (Holden 2011; Koch 2006; Lluch 2011; Mair et al. 2012; Sanders et al. 2012). The NPT describes those determinants that have been found to influence promotion or inhibition of complex interventions, but it also offers a foundation on which the probability of successful implementation of complex interventions can be judged (May et al. 2011).

Practice

In order to be able to use NPT in health care practice, four main components have been distilled, related to the elements described by May (May et al. 2009). These constructs are dynamic (non-linear) and form the basis for development and evaluation of innovations in health care. The constructs are: *coherence* (does the technology make sense and do staff understand why and how it works?), *cognitive participation* (are people really involved and committed to make the innovation work?), *collective action* (how do people actually use the innovation in their daily work practice?) and *reflexive monitoring* (how do they appraise and evaluate the innovation?) (Murray et al. 2010, see Fig. 1). Of these, collective action will be further described in more detail, as it is the construct of NPT that is most central to understanding how a new technology is *enacted* during an implementation phase.

"Collective Action" is derived from the original Normalization Process Model (NPM) and represents a detailed understanding of what actually happens "in practice" when individuals are required to work in a different way (May et al. 2007). Successful enactment can be considered the goal of any innovation, whether technological or not. In this stage of implementation, working with the new innovation or technology is in some level of operation and is somehow part of the process of every day work practice (May and Finch 2009). If we want to understand what implementers actually have to do in order to achieve this goal (i.e., truly embedding the technological innovation in practice), then the components of Collective Action (reflecting the four original components of the NPM) offer insight. These components are: *interactional workability*, *relational integration*, *skillset workability* and *contextual integration* (May 2006).

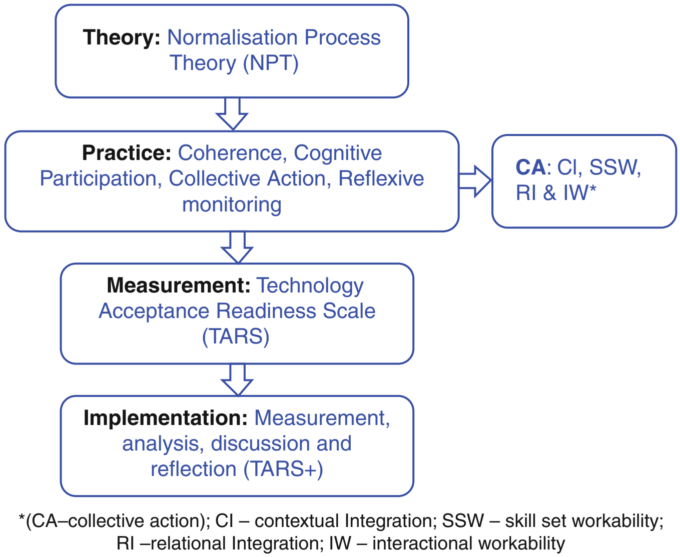

Fig. 1 Implementing technology into health care: from theory to practice

Of these four, *interactional workability* relates to how the technological innovation interferes with interactions between persons, especially between health care professionals and patients or residents, which is considered one of the most important values for professionals working in chronic health care (Murray et al. 2011; Nieboer et al. 2014). One good example (Nieboer et al. 2014) was that of a nurse who perceived the hoist not only to be useful in order to avoid her developing back problems. She experienced that it was also contributing the improvement of her relationship with residents: bed ridden persons who never had been at height level with herself, came at level when sitting in the hoist. For the first time she could "see them in the eyes" properly.

Relational integration refers to the impact that the new technology has on responsibilities between groups of professionals, feelings of trust and confidence, and how these might change as a result of the technology. If, for instance, there is no technical back up whenever technology fails, or if responsibilities in follow up of sensor alarms are not clear, this disrupts relational integration and causes a lot of stress and, consequently, non-adoption of the technology (Nieboer et al. 2014; Niemeijer et al. 2013). Similarly, in a comparative study by Murray et al. (2011), PACS (Picture Archiving and Communication System) was reported as promoting communication and trust between different professional groups because it enabled multiple users to view the same image from different locations. In contrast, a "choose and book" system for appointment making across primary and secondary care impacted negatively on relations between hospital consultants and general practitioners because it replaced personal contact that had previously been made between them in referring patients (Murray et al. 2011).

Skill set workability is about how the technological innovation might require changes in the original skills (and competencies) of work force. If, for instance, health care professionals have to do much more administration when using the technology, or if working with the technology requires high technological skills or lowers clinical autonomy, this is not at all helping implementation. Health care professionals have chosen their profession for certain reasons, related to certain core values (Nieboer et al. 2014), and interventions that interfere with these values are not easily accepted.

Finally, *contextual integration*, refers to how the technology is perceived to be in line with the goals, culture and mission of the organization. When there is trust that the technology supports the organizational goals and, vice versa, that the organization is supportive, for instance financial or otherwise, the implementation is more likely to succeed (Bush et al. 2009).

In summary, for technology to become normalized within a health care organization, it should enhance (or: not interfere with) personal relationships, be transparent as to responsibilities, fit in with skills, competencies and values of staff, and be in alignment with the goals of the organization. Organizations have to be aware of the importance of these factors and have to enact upon them in order to successfully implement new technology. In the next paragraphs, we will first describe the instrument derived from NPT that can help to measure (diagnose and monitor) the organizational "implementation proneness" with respect to technological innovations. Finally we will describe the experiences with the implementation of eHealth systems of several organizations, applying NPT and the four key constructs of collective action: interactional workability, relational integration, skill set workability and contextual integration.

Measurement of Technology Implementation

For organizations to be able to monitor implementation of new technology or eHealth systems on a level of scale, e.g., across sites, it is important to have a tool that offers insight into the dynamics brought about by the innovation, the individuals working with the innovation and the context of the organization in which the innovation is to be used (Proctor et al. 2011). For this purpose, a 30-item instrument was developed. The instrument is based on NPT and is called Technology Acceptance Readiness Scale (TARS) (Finch et al. 2012). With this instrument, the translation from theory to practice can be made measurable (see Fig. 1). In the UK, where it was developed, this resulted in a list of 30 items that included 27 items representing Collective Action, along with individual items to measure the three additional constructs of coherence, cognitive participation and reflexive monitoring that were added when the NPM was extended to Normalization Process Theory (Finch et al. 2012). Of questions on Collective Action, five are about interactional workability, seven about relational integration, six cover skill set workability and nine cover contextual integration. Ultimately, the TARS thus covers the full range of normalization of new technology within health care organizations

(Finch et al. 2012, 2013), but with greater emphasis on Collective Action (see Appendix). The tool is thus ideally suited to examining in detail the processes when a technology is in the stage of "implementation", but with some scope to address issues important to the wider processes of planning, implementing and evaluating as reflected in the extended NPT. The tool was pre-tested in two organizations, using two different eHealth systems (algorithm-based telephone triage, and hand-held digital devices to support community nursing practice). Also, for one organization the technology was relatively new (pilot), while in the other, it was already widely used. TARS was seen to be able to distinguish between levels of experience of the new technologies. It was also found that the overall ratings of level of "normalization" of the technologies that were retrieved from using the TARS were well related to participating health care professionals' reported perceptions of the routine use (or expectations thereabout). For example, in one of the e-Health settings, participants who rated the technology as "completely routine" (compared with "partially" or "not at all"), were significantly more likely to agree with positive statements about implementation factors, for example, about relational integration ("*I have confidence that using the eHealth system does not put patients at risk*"), contextual integration ("*This eHealth system fits in with the priorities and challenges of our organization*"), and interactional workability ("*The e-Health system is easy to use*"). Findings such as these from the TARS tool (Finch et al. 2012) were comparable with qualitative interview data from the same study (Murray et al. 2011) that reported participants' perceptions of barriers and facilitators.

Further Implementation into Practice

Inspired by NPT and its practical possibilities, as well as the strong recognition of acceptance and implementation barriers in the use of technology in chronic health care, the TARS was translated for application in The Netherlands. TARS was translated following the usual procedures (Koller et al. 2007). In two pairs of experts in technology implementation theory the items were translated into Dutch. The resulting two translations were compared and discussed until consensus was reached. One final translation resulted. Some items were also discussed with the author of the original instrument (Finch et al. 2012), who was able to trace back the team decision-making about specific items, and, if necessary, adapted. In the next step, the questionnaire was translated back into English by two linguists (English and Dutch). The final questionnaire was offered to ten health care professionals for comprehensibility. Only minor adaptations were necessary.

Consequently the questionnaire was used in five different organizations, of which the results of two are presented here. We replaced the general word "eHealth system" with the actual name of the technology used and the general word "organization" with the actual name of the organization, as intended for the original TARS instrument (Finch et al. 2012).

The TARS list was discussed with the first organization where it would be applied. This again led to some adaptations. Two questions were each split into two separate questions and some questions that were of interest to this organization were added at the end of the questionnaire. Some of these questions (*do you think the implementation of the eHealth application is successful?; what grade would you give the eHealth application?*) proved useful and were retained to become part of the general questionnaire used later on.

During the translation process and the discussions on the right interpretation of the questions it became apparent that some questions and the answers to them could be interpreted in different ways. For instance, there was disagreement with the statement: "*the eHealth system is a different way of working.*" It was unclear for respondents if this meant "I am so used to the system that I no longer experience it as different" or did it mean "my way of working has not changed much as a result of the eHealth system." And if it means the latter, is that a good or a bad sign for implementation? In-depth interviews might have helped to understand the results better but are time consuming and difficult to plan. Instead we choose to use the presentation of the results to the professionals who had answered the questionnaire as discussion sessions to get a better insight both in their attitude to the eHealth system and their interpretation of the questionnaire.

The first organization where this Dutch version of TARS was applied was a care organization offering outpatient support. The eHealth system in question was video-communication in the interaction between client and professional, as part of a blended form of support. After experimenting with this system for over 2 years the organization had implemented it full scale in the outpatient support division. So there was a small group of professionals that had worked with the system for a longer period and a larger group that had worked with it for a shorter period.

The questionnaire was sent to all the professionals using the video com system ($N = 55$). In total 45 questionnaires were completed. Out of the 45 respondents 13 agreed that the videocom system had completely become part of the routine practice, and 32 thought that it had partly become that. In general the former group tended to be more positive about the eHealth system than the latter group, which can be seen as supporting validity of the questionnaire. We also found that the respondents that had been working with the system for a shorter period of time (<4 months) were overrepresented in the group who only judged the system partly routine. The results of this survey were discussed with the professionals in three regular team meetings. This proved to be a good approach. The professionals very openly discussed how in their opinion certain remarkable results should be interpreted. For example, 30% of the respondents had answered that they did not know whether the benefits of the eHealth system would outweigh the efforts. In the discussion they explained that they were well aware of the benefits but had no idea about the financial costs in particular, and that in fact they were not really interested in them. They relied on management to make such considerations.

In the second organization the TARS was used the set up was different. In this case the TARS questions had been part of a larger questionnaire on the use of a system for virtual projections in a care home, intended to physically activate the residents. The results were discussed within a network of professionals from different care organizations that were using or interested in using the same system. One of the issues that were discussed was that the respondents had answered rather negatively on the questions related to relational integration. It became apparent that this could be related to a lack of coherence: people did not agree on the question whether this was an instrument for physiotherapy or for recreation.

The general results of the TARS were recognized as representative of their opinions on the implementation of the eHealth system in question. During evaluation, both staff and management also mentioned that the presentation of the questionnaire and the discussion of the results with a "neutral party" being the research team, offered a favorable and secure atmosphere to collectively improve aspects indicated as "weak" by TARS. Moreover, the aspects were not only discussed and appreciated, but also practical solutions were suggested in a collaborative manner, thus improving ownership of all parties involved. For example in one case a rather small group of respondents had answered that they did not understand their professional accountability. In the discussion both staff and managers became aware of the fact that indeed both responsibilities and accountability had not been properly regulated and protocols should be adjusted to the eHealth system. Staff and management thought this way of discussing the eHealth system should be repeated from time to time to improve the embedding of the eHealth system in routine practice. Management also suggested this way of working could be very useful when considering the implementation of new technology (i.e., pre-implementation measurement). So the discussion of the results of the survey with staff and management proved to be more than a way to understand the answers better. It was also an instrument to improve the coherence, to share views on the eHealth system and how to use it.

Next, work will be continued on the evaluation of this way of working: using this embedded TARS measurement (referred to as "TARS^{+}") (see Fig. 1). Also, the usability of TARS in pre-implementation stages is of interest and will be further developed and evaluated. Finally, in order to value this "TARS^{+}"-normalization process, it has to be evaluated in the long run, and compared to other implementation strategies.

Appendix TARS Items

1. **CA-CI** The ehealth system is adequately resourced financially
2. **CA-CI** Sufficient organizational effort has gone into supporting the ehealth system
3. **CA-CI** The ehealth system is a different way of working
4. **CA-CI** The rewards of using the ehealth system outweighs the effort
5. **CA-CI** Government policy initiatives are supportive of this ehealth system
6. **CA-CI** This ehealth system is technically and organisationally compatible with other systems and agencies that we are required to work with
7. **CA-CI** This ehealth system fits in with the priorities and challenges of our organisation
8. **CA-CI** This organisation has a culture that is supportive of change

9. **CA-CI** There is a culture in this organisation of involving staff in planning and development
10. **CA-SSW** Using the ehealth system makes me feel autonomous in my work
11. **CA-SSW** Using the ehealth system requires co-operation with other staff
12. **CA-SSW** The workload involved in using the ehealth system is manageable
13. **CA-SSW** In using the ehealth system, the allocation of work between individuals is appropriate
14. **CA-SSW** The skills I have are appropriate for using the ehealth system
15. **CA-SSW** The skills needed to use the ehealth system are easily learned
16. **CA-RI** I have confidence that using the ehealth system does not put patients at risk
17. **CA-RI** Using the ehealth system is an efficient use of time
18. **CA-RI** In using the ehealth system, responsibilities are divided between individuals appropriately
19. **CA-RI** In using the ehealth system, I understand my accountability for my work
20. **CA-RI** In using the ehealth system, I understand my liability for my practice
21. **CA-RI** Technical back-up in using the ehealth system is available if I need **it**
22. **CA-IW** I believe there is good evidence about the clinical effectiveness of using the ehealth system
23. **CA-IW** There is some flexibility in how the ehealth system can be used
24. **CA-IW** Using the ehealth system leads to positive outcomes for patients
25. **CA-IW** Using the ehealth system involves the right amount of time spent
26. **CA-IW** In using the ehealth system, the quality of professional and patient interaction is good
27. **CA-IW** The ehealth system is easy to use
28. **Coherence** The staff who work here have a shared understanding of what the system is for and how it is to be used
29. **Cognitive Participation** The staff here are committed to making the system work
30. **Reflexive Monitoring** There are ongoing mechanisms for monitoring and appraising

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Aging in Digital Places

Hannah R. Marston

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Abstract

This book chapter reviews current research in the area of digital game technology for rehabilitation, socialization, quality of life (QoL), design, and cognition. In recent years, there has been substantial progress in these areas. With technology advancement, there is the potential to facilitate aging in place, resulting in the continuation and maintenance of independent community-based living at varying stages of the life course. As technological developments improve, the concept of integrating digital game technology into the lives of an aging population is becoming more popular than ever before. However, during the implementation into the home, issues of physical space and technology integration may occur. There are many types of dwellings (apartments, houses, or bungalows) where older adults reside which contain a variety of fixtures and furnishings. Implementation of technology into these different dwellings may be difficult due to the added furniture already installed. This chapter initiates discussion within these areas and provides recommendations for future technology integration.

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Introduction

The inevitable issue of the aging population, one which shows no decline in the coming decades, has been highlighted by researchers and governments. Across Europe it is anticipated by 2025 that 22 % of the population will be aged 65 and over, and by 2050, this will have increased to 33 %. This translates as 60 million people in 2004 reaching to 134.5 million by 2050. Further in 2004, 4 % of the population were aged 80+ and this is expected to reach 10 % by 2050. It is suggested that European society will comprise of 32 % of the population living alone by 2050, and the proportion of those who are aged between 65 and 79 years will live with a partner or spouse (63 %) and will decrease to 31 % for those over 80 years (European Commission Information Society and Media 2010). With this in mind, academics in the fields of gerontology, engineering, design, and health have started to explore the utilization of digital technology among the older adult population. Interest is growing on effective use and practicalities for integration of digital technology by older adults within their home to support aging-in-place strategies and to maintain personal independence in the community.

During the aging process, it is possible that one may develop a chronic disease such as diabetes, glaucoma, high blood pressure, osteoporosis, dementia, Alzheimer's disease, or a combination of diseases which will limit one's ability to live an independent life. Blanson et al. (2010) highlight facets associated to self-care and patient empowerment: (1) gaining a good insight into their own health condition, (2) retrieving personal information to support choices of self-care activities, (3) fitting self-care activities in daily life and developing self-care habits, and (4) involving the environment to support self-care (family, community, and friends). Fisk et al. (2009) have provided four age-related characteristics: sensation is the awareness of stimuli such as color or hearing a high-pitched sound. Perception is knowledge of challenging features in an environment or the elucidation of information based on the results from sensation, for example, recognizing the sound of an alarm. Cognition is a human process whereby the brain stores sensory information from the ears and eyes and by transformation; it is stored and recovered when needed, for example, thinking, problem solving, and decision making. Movement control necessitates the coordination of muscles for motion based on perception and cognition, for example, taking an object from a shelf or double-clicking a mouse. These human characteristics can be affected as a person ages and cause activities of daily living to become more difficult. The notion of aging in place is crucial as persons advance across the life trajectory to ensure they are able to live in their community and maintain a sense of independence. This chapter provides an overview of work conducted in the area of digital technology use for older adults with emphasis on reviewing the work of digital games and how assistive technologies can facilitate maintenance of independence within the home.

Digital Technologies

Over the last decade, technology developments, be it software or hardware, have occurred in quick succession. For example, digital game hardware (Sony® PlayStation 3 and 4, Nintendo™ DS, DSi DS/Lite, Wii, Microsoft™ Kinect®), mobile phones (Apple iPhone®, Nokia Lumia, Android, and Blackberry® Q10/Z10), software development (operating systems, mobile “apps”), and tablets (iPad®, Microsoft®, Nexus 7) enable users of all ages to access, engage in, and enjoy a variety of entertainment mediums (watching movies/TV programs, playing games, using social networking sites).

The Nintendo Wii console can detect 3-D movement via light-emitting diodes (LEDs) in the sensor bar which is placed on top of the television enabling user engagement via a wireless remote comprising of accelerometers and infrared detection (Wisniowski 2006; Castaneda 2006). If the user is playing the *Wii Sports* golf game, they would generally hold the remote as a golf club and swing the remote in a motion similar to how a golf player would actually swing a golf club on a golf course. As the user executes these movements, the game responds appropriately to the executed action; therefore, in playing the golf game, the user will hit the ball with their club (shown on screen) – by swinging the remote. In contrast to this the Microsoft Kinect is a motion-sensing device for the Xbox-360 console and enables users to engage without holding a controller via voice and gesture movement (Whitworth 2010). Moreover, interaction with a smart phone or a tablet is executed through the touch of a finger or sliding two fingers on the screen to enlarge or minimize a segment of the picture. This interaction approach has the potential to facilitate user engagement easier than before. With the development of Microsoft’s next-generation Kinect sensor, it is suggested there is the ability to combine one’s health with gaming hardware by monitoring one’s health without discomfort to the wearer (Woollaston 2013). This could be executed via the Kinect recognizing color changes in a person’s face to ascertain how quickly the blood is circulating (Woollaston 2013).

Previous work in the area of digital games and gerontology has explored the attitudes of older adults and their gaming preferences and their needs (Marston 2012, 2013a, b; de Schutter and vanden Abeele 2010; de Schutter 2010; Voida and Greenberg 2009, 2010; IJsselsteijn et al. 2007; Pearce 2008), yet there is still little work within this arena. Prior to twenty-first-century game consoles, game studies focused on the utilization of games to build and enhance the quality of life (QoL) by introducing digital games into one’s recreational pastime, in addition to testing cognitive functioning and physical reactions of older adults (Goldstein et al. 1997; Farris et al. 1994; Whitcomb 1990; Schueren 1986; Weisman 1983). As previously highlighted with age, the potential of chronic illness and dementia can occur as one ages, and researchers have explored the use of games primarily focusing on the cognitive effects and reaction time of digital games on older adults (Basak et al. 2008; Boot et al. 2008; Ball et al. 2002; Clark et al. 1987). The combination of game studies, gerontology, and health is growing. Studies are demonstrating how an entertainment medium initially perceived for young men and boys may (Laurel 2001) be transferred into a variety of settings such as clinical and residential – long-term care (LTC) (Marston et al. 2013) – settings and the home (Voida and Greenberg 2009, 2010). Introducing digital games into the lives of older adults has the potential to have a positive impact on one's life and has the capability to bring families together through intergenerational gaming, socialization/engagement with friends and family, and learning a new skill.

The focus of digital game research has concentrated on three outlets: design, cognitive functioning, and health rehabilitation. This area of health rehabilitation research via digital games initially commenced with the PS2/EyeToy (Flynn et al. 2007). However, there has been increased interest since the release of the Wii and more recently the Kinect console. Marston and Smith (2012) published a narrative review which discussed how commercial and purpose-built software/hardware technologies can be used within a health rehabilitation setting (stroke and fall prevention). A series of recommendations were proposed highlighting the need for digital game technology to coincide with traditional therapy as early as possible. Moreover, technologies should be accessible in both clinical and home environments thus to enable support networks to provide motivation, engagement, and positive reinforcement to the individual while undertaking their exercises. Initiation of longitudinal studies could inform awareness to the potential benefits. A minimum of one year is recommended to gauge the effectiveness of such technology over a long-term basis (Marston and Smith 2012).

In-Home Monitoring

A wristband created by "Jawbone" (cf. Fig. 1) enables the wearer to track a variety of daily activities, including the number of hours slept via the "sleep and nap tracking," which includes a wake up gently function, and a "24/7 activity tracking," which includes what food and drink is consumed and the number of calories taken and level of intensity and distance traveled, and reminds the wearer to move around (Stone 2011; Pierce 2012). These features provided by the UP lifestyle wristband which in conjunction with the UP app can be accessed by the users' smart phone (iPhone and Android) to aid additional motivation, and the wristband has to be recharged every 10 days. Users of the wristband can share their data and challenge one another (Lanks 2012; Pierce 2012) via the social networking app. It is suggested that these technologies have the ability to be integrated into one's home to facilitate both physical and emotional monitoring of one's health via easy modes of tracking either via the next-generation Kinect or the UP wristband. The exploration of physical space within one's home is an area which is lacking of research and knowledge by researchers and designers alike. Technologies such as the Wii and Kinect consoles

Fig. 1 UP wristband by Jawbone (Photograph taken by author, permission given by author and wearer – Dr. K. Delbaere)

implemented into the home environment have the opportunity to transform the home into a "smart" environment enabling monitoring and safety via individually purposely adapted space. Additionally, this space can be improved and modified to address changes in personal needs or health status. Through adaptation of the individual space, the person may engage with the current technology with peers and family members.

An alternative concept which is the utilization of wearable monitoring sensors to assess and measure physical activity or fall risk is becoming a common focus of research (Zijlstra et al. 2011). It is beyond the scope of this chapter to discuss the in-depth area of fall risk and prevention. However, wearable monitoring via body-fixed sensors (BFS) (Zijlstra and Aminian 2007) and general sensor monitoring may facilitate current and future aging populations in particular adults residing within their own homes. Therefore, the integration of sensors could aid researchers to understand more about fall detection but more importantly raise the alarm for the person who had fallen.

The risk of falling can occur through the avoidance of physical activity leading to reduced muscle strength, joint mobility, and cardiorespiratory function in addition to psychological factors resulting in the fear of falling (FOF). Finally, if one has little or decreased experience relating to the performance of certain activities, this can result in deconditioning yet increases in unsafe performance of activity (Zijlstra and Aminian 2007). The respective authors stipulate that to prevent such physical decreases, interventions should be executed to improve motor functioning and facilitate one's safe activity performance (Zijlstra and Aminian 2007).

Integrating fall detection sensors into the home could prove beneficial to enable ease of the individual who is prone to falling based on the ability that the alarm would be automatically activated if the person fell which is more so than the traditional alarm system (Zijlstra et al. 2011). However, as the respective authors have highlighted, there is little published work which concentrates on the assessment of "sensor-based fall detectors" within a "real-life" environment (Zijlstra et al. 2011). Further, Zijlstra et al. (2011) notes that there is an importance to identifying the validity, sensitivity, and specificity of such detection sensors and there is still limited "real validation" of technologies to detect "real-life falls" which would aid in suitable "fall detection method." Additionally, Zijlstra and Aminian (2007) suggest the BFS maybe suitable to address a consistent reporting to researchers and clinicians in addition to being a suitable automatic fall alarm system.

The notion of aging in place can be executed by persons undertaking exercise programs or sports games via digital games/consoles or purpose-built software which facilitates ambient assisted living (AAL) through exercise. Therefore, one should consider the implications of implementing such technologies into one's physical environment such as the living space.

Personal Living Space

The utilization of personal living space to facilitate self-care/health-care requirements has become a focal point of research in the last few years. With the evitable increase in older adults, this concept may prove fruitful for future users and generations to maintain not only personal independence but also to maintain positive QoL and well-being during daily activities. Utilization of this type of technology is generally comprised of sensors, information, and communication to the user which in turn respond to the necessary requirements of the person. In addition to the smart home concept, the notion of digital games and devices such as smart phones and tablets may prove beneficial and support for persons who wish to age in place. Researchers at RWTH Aachen University have identified and implemented a novel approach to facilitating smart home technology to be enjoyed by all persons. The Future Care Lab features a purpose-built living room comprised of everyday objects implemented with technology to explore the sustainability of design, human interaction, and architectural facets against a social science background enabling users to engage with the environment and facilitate prospective user needs and requirements (Kasugai, et al. 2010). In the Future Care Lab, the large multi-touch display can facilitate the notion of space between persons, resulting in the reduction of distance or enhancement of the environment. Additionally, integration of this type of technology into personal living space can provide a sense of social ability especially for persons who are isolated or suffer from chronic illness thus resulting in limited or no social networks. Therefore, enabling persons to communicate face-to-face via this technology may provide a sense of social connectedness (Penninx et al. 1999).

Engaging in digital games may require individuals to address specific characteristics to the physical location during implementation. For example, a person who wishes to engage with the *Wii Fit* may have to move items of furniture (coffee table, chair, or sofa) prior to starting the program. Personal living space can vary depending upon the type of dwelling (apartment, house, or bungalow) and depending upon geographic location of residence. A definition of "place" can combine a series of relationships and social meanings which are surrounded by the physical space and can include the type of behavior which is supported by the environment ascertaining the various actions and interactions (Harrison and Dourish 1996).

For example, a study focusing on console gamers in Australia (Flynn 2003) identified that the purpose of this activity was to be social with friends and family while exercising additional activities such as talking with friends on the phone. This study highlighted that the setup of the living room posed problems to the gamers primarily associated with moving of furniture. Flynn (2003) noted that this domestic space functioned as a multipurpose living space – playing games, watching television, and socializing with friends and family. Similarly, a study comprising of 10 participants across seven households sought to identify the relationships with physical games such as the *Dance Dance Revolution* (DDR) (Konami) within the home. The participants primarily consisted of graduate students and technical professionals, who either lived in college dormitories or rented a bedroom within a house. The respective authors reported how some of the participants suggested placing casters onto tables to allow for easier movement prior to commencing their game playing:

> Usually I have to move the table back a bit 'cause otherwise I'm standing too close to the TV. . . the table is kind of constantly getting moved back and forth 'cause my roommate does exercises over on that end. He'll push it this way and it gets shoved back when I'm gaming. (Sall and Grinter 2007)

Further, one participant reported to prefer to sit in a particular chair which would be moved closer to the television for their gaming session and then moved back to its original place once they were finished (Sall and Grinter 2007). The authors highlighted the necessary locations of digital devices within the space to enable the game(s) to be played. Additionally, the movement of furniture prior to game play was a necessary part of the course and was primarily associated to the game peripherals or was restricted due to the length of the device wires (Sall and Grinter 2007).

It is likely professionals from the fields of engineering, architecture, and computer science will be required to provide additional information regarding the adaptation and/or manipulation of the physical environment. Safety is the primary concern, and the removal of rugs and any other objects which are causing obstruction or are putting one's safety at risk should be considered to ensure a safe gaming environment. Bogost (2005) notes digital games are developed for engagement via consoles which are required to be connected to a television rather than personal computers (PC). Further, it is likely older adults will be required to purchase or update their television sets to receive information or play digital games due to the change over from analogue to digital transmission.

Over the last decade, televisions have grown in size and in some instances can take up the full length of a wall within the family room, and one aspect of aging which should be taken into consideration is the deterioration of eyesight. With this in mind, the effect of physical impairments as one ages should be considered by stakeholders if designing environments to sustain aging in place. Simon (2009) contends the Wii has the ability to bring families together similar to that of the television in the 1950s. The rationale for the Wii is "a family-making machine"

(Simon 2009) providing persons of all ages the opportunity to socialize within one space – this usually being the living or family room. Further, the majority of the games and the marketing tactics of Nintendo do demonstrate how the Wii can be used for this purpose. For example, Marston (2010) discussed the marketing exploits by Nintendo, illustrating how the company demonstrates both the Wii console and the dual screen (DS) handheld can be used in a multiplayer and family format. Additionally, this concept can be transferred to the Kinect, whereby users have the ability to watch one another, but further, when playing games such as *sports* – golf or bowling – they are not necessarily playing within the VE but within their own living space.

Taking this concept a step further with regard to smart home technology and previous work undertaken by Kasugai, et al. (2010), the implementation of such large multi-touch screens into the home could be difficult in the current housing environment because of housing layouts. The layouts may not be big enough for large screens, due to personal and sentimental objects such as photographs and ornaments causing obstruction in addition to large physical objects (sofas, chairs, and tables) being placed in the most suitable positions. The availability of technology such as tablets to control one's television choices is available coupled with the additional gaming technology which may or may not reduce the obstruction of physical space. Many homes are occupied with large sofas and cabinets storing ornaments, and as many homes were built at varying periods of the twentieth century, their interior style could cause difficulties for implementing technologies with a streamlined appearance while providing a monitoring and safety element. However previous works display the usefulness of utilizing digital game technologies for monitoring persons as they age (Demiris and Hensel 2008; Basak et al. 2008; Boot et al. 2008; Flynn et al. 2007; Whitcomb 1990; Clark et al. 1987; Weisman 1983). The conception of future technology requires exploration and studies to gain a full in-depth understanding of how such concepts can be utilized with ease into different living environments.

Recommendations

As presented in the section "In-Home Monitoring", aging populations are at possible risk of falling and may experience FOF within the home. These functional and psychosocial challenges heightening the risk of falls could be alleviated by advancement in technology and integration of sensors into the home. To facilitate further understanding of the roles of these technologies and their effects on aging in place, Zijlstra et al. (2011) propose future research focus on large cohort study undertaken within "real-life" environments with sensor-based fall detection systems.

Furthermore, in the future, stakeholders, academics, technologists, and governments should consider how room design and layouts may need to be altered if the introduction of smart home and gaming technologies is to play greater roles within the lives of older adults. Further, introduction, implementation, and acceptance should be considered especially for persons who are technophobic or who have had limited or no technology experience. It is proposed that a requirement of such technology integration may necessitate the living space to be less cluttered or the ability to integrate said furniture into the virtual environment. Finally, utilization and implementation of the next-generation Kinect and/or UP wristband in conjunction may be more sought after. This could provide users a more suitable approach to accessing their personal information relating to their daily activities, moods, heart rate, health, and well-being. To identify the suitability of these technologies within the home, a pilot study should be conducted, followed by a larger and longer case-control or randomized control trial. By conducting these types of studies, researchers would be able to assess and identify how effective the in-built software is at tracking one's movement and health needs.

In conclusion, this chapter has attempted to provide an overview of research conducted in the areas of game studies with a focus toward aging populations and AAL technology. As technology develops and becomes part of the family home, designers, engineers, and researchers will have to explore, assess, and evaluate the suitability of such technologies within the home. The current work displays a positive mood to such technology, yet further investigation is required on a larger scale, comprising of different dwellings, users (of all ages), and technological experiences to fully gain an in-depth understanding of this area.

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Can Smart Home Technology Deliver on the Promise of Independent Living?

A Critical Reflection Based on the Perspectives of Older Adults

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Abstract

Expectations are high with regards to smart home technology. In particular, smart home technology is expected to support or enable independent living by older adults. This raises the question: can smart home technology contribute to independent living, according to older adults themselves? This chapter aims to answer this question by reviewing and discussing older adults' perspectives on independence and their views on smart home technology. Firstly, older adults' opinions

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on independence and aging in place are discussed. Secondly, this chapter will review to what extent smart home technology can support older adults' independence. Thirdly, it will be explained how community-dwelling older adults' concept of independence entails three distinct types or modes, and how these modes are related to their perceptions and acceptance of technology. In the last section of this chapter, an overview of key points is presented, and recommendations for technology designers, policy makers, and care providers are postulated.

Keywords
Independence • Aging in place • Smart home technology • Technology acceptance • Design • Implementation

Introduction

The increase in longevity, the growing number of older adults, and the decreasing number of newborns denote that the populations of most countries in the world are aging rapidly (United Nations 2013). To date, Europe has the highest proportion of older people in the world. The increase in the proportion of older persons is primarily due to changes in health indicators including improved nutrition and hygiene (Evans et al. 1994). Furthermore, advances in both preventive and curative medicine have resulted in an increasingly large number of (older) patients that survive medical conditions that previously used to be fatal. Unfortunately, this does not imply that older adults are all in good health and well-being. For example, the majority of older adults (i.e., over 75 years of age) report having one, two, or more chronic conditions that they are suffering from (Aarts et al. 2012; Woo and Leung 2014). Since age is positively related to health care utilization and, in turn, to higher health care expenditure, the influence of aging populations on society will be marked (Schulz et al. 2014). Hence, the provision of cost-effective care solutions is asked for.

To anticipate on the growing demand on health care by older adults, governments and policy makers are trying to empower older persons in maintaining independence as long as possible. By enabling them to keep residing in their own homes, i.e., to age in place, costly options such as nursing homes can be avoided. Smart homes have been postulated as a potential solution to support aging in place. A smart home can be defined as "*a residence equipped with a high-tech network, linking sensors and domestic devices, appliances, and features that can be remotely monitored, accessed or controlled, and provide services that respond to the needs of its inhabitants*" (Balta-Ozkan et al. 2013). Several target groups could potentially benefit from smart home technology, one of them being older adults who would like to age in place. For example, smart homes technologies are aimed at supporting aging in place by facilitating tasks such as preparing food and cleaning. Furthermore, smart home technology can assist in monitoring and maintaining health status (Mitzner et al. 2010).

Despite the emphasis on smart homes by government agencies, policy makers, and the industry (Sixsmith and Sixsmith 2008), their existence is not widespread (Schulz et al. 2014; Wilson et al. 2014). Consequently, their suggested potential for older adults in promoting independence and aging in place, and thereby, alleviating pressure on (family) caregivers, and decreasing health care expenditure, has not yet reached its full potential. The question remains why smart home technologies are not yet commonplace in the homes of older people. The current chapter aims to answer this question by reviewing and discussing older adults' perspectives on independence and their views on smart home technology. In other words, can smart home technology deliver on the promise of independent living, according to this target group? This chapter will start by discussing older adults' opinions on aging in place and staying independent. Secondly, this chapter will discuss to what extent smart home technology can support older adults' independence. Subsequently, it will be explained how community-dwelling older adults' concept of independence entails three distinct types or modes, and how these modes are related to their perceptions and acceptance of technology. Lastly, implications and recommendations for technology designers, policy makers, and care providers are postulated.

Older Adults' Opinions on Living Independently

As older age is related to decreases in health, functional abilities, and social relations (Rowe and Kahn 1987, 1997), the home environment is the major living space of older people (Baltes et al. 1999). A study by Gillsjo and colleagues reported the views of older adults, living in a rural community in Sweden, on their experience of "home" (Gillsjö et al. 2011). This study pinpointed that home "*had become integral to living itself*" and was "*an intimate part of the older adult's being*" (Gillsjö et al. 2011). A study by Wiles and colleagues focused on the meaning of aging in place (Wiles et al. 2012). By conducting focus groups, the study illustrated that aging in place was perceived as an advantage in terms of security, familiarity, and people's sense of identity (Wiles et al. 2012). In general, research suggests that the majority of older persons want to keep living independently, in their current dwelling (Barrett 2011; Boldy et al. 2011; Woolhead et al. 2004).

Research also suggests that the desire to remain independent is influenced by a variety of factors including (self-perceived) health status and personal characteristics. For example, the desire to remain in one's current dwelling seems to increase with age (Boldy et al. 2011). Another study showed that, although older adults in general perceive being independent as very important, men were found to value independence as less important than women (Galenkamp et al. 2012). Functional status has also been suggested to influence the desire to remain independent. Being independent seems especially important to those with mild cognitive problems and/or depressive symptoms. However, older adults with severe functional limitations perceive independence as less important than older adults with no or few functional limitations (Galenkamp et al. 2012). Galenkamp and colleagues (2012) suggest that older adults hold on to their independence up to a certain point; once their health deteriorates considerably, they seem to give up (part of) the desire to be independent in order to receive care. Similar findings are reported in a study by Allen and Wiles (2014) in which community-dwelling older adults stated that receiving informal support and using assistive technology was only considered acceptable when help was necessary due to health issues.

In summary, the abovementioned findings indicate that older people wish to remain independent but also highlight the fact that the desire to remain independent may differ per person and that this desire is influenced by factors like health status. As a consequence, older adults' opinions on (technological) solutions aimed at supporting aging in place may also vary. In this respect, it is important to review to what extent smart home technology can support older adults' ability to live independently.

The Influence of Smart Home Technology on the Ability to Live Independently

Many developments are taking place in the field of smart home technology, and expectations are high with regards to the potential benefits. Unfortunately, a recent published systematic review regarding smart home technology identified only three (out of 31) studies that effectively demonstrated that smart home technology can support independence and prevent health events that threaten the independence of older adults (Reeder et al. 2013). These three studies showed that the use of smart home technology was positively related to outcomes such as a reduced length of nursing home admissions (Kelly 2005), preservation of physical and cognitive status (Tomita et al. 2007), and improved social functioning (Brownsell et al. 2008)[1]. All three of studies were similar in that they included a combination of technologies tailored to individual preferences of the user, including activity monitoring technology, and other functionality such as medication reminders (Reeder et al. 2013). The other 28 studies that were included in the review did not demonstrate strong evidence of support for aging in place, mainly due to their study designs and sample size (for more information, see (Reeder et al. 2013)). Other systematic reviews also pinpoint that little methodically sound research is available on the effects and cost-effectiveness of smart home technology (Graybill et al. 2014; Peetoom et al. 2014). This raises the question: how can older adults be convinced to use smart home technology when benefits have not been demonstrated clearly in terms of scientific evidence? In this respect, it is important to consider to what extent older adults themselves perceive smart home technology as something that can help them to age in place.

A recent systematic review conducted by our research group showed that the vast majority of studies on community-dwelling older adults' perceptions on smart home technology are performed in the pre-implementation stage (when a technology has not been used yet). These studies typically include the use of presentations,

[1]Reeder et al. (2013) classified studies as "emerging," "promising," "effective (first tier)," or "effective (second tier)." The three studies mentioned were not considered "effective (second tier)" by Reeder et al. (2013) because they were limited by the use of a historical control group (Kelly 2005), high dropout rates (Tomita et al. 2007), and the use of nonrandomized comparison groups (Brownsell et al. 2008). None of the studies included in the review by Reeder et al. (2013) were classified as the highest type of evidence, which was "effective (second tier)."

vignettes, or scenarios to explain or demonstrate a technology to participants (Peek et al. 2014). Consequently, participants are asked about technology that they have not actually used and experienced for a considerable amount of time. In pre-implementation studies, community-dwelling older adults mention various concerns, when asked about their opinions on technology that is designed to support aging in place (Peek et al. 2014). Frequently mentioned concerns are high cost and privacy implications. Additionally, a number of the mentioned concerns are related to usability; community-dwelling older adults may think that smart home technologies are hard or impractical to use. Furthermore, older adults may be concerned that they have no control over the technology, for instance, its activation and deactivation. Participants in pre-implementation studies also express concerns regarding the burden it may put on their children in their role as caregivers (i.e., causing workload or worrying) and the possible negative effects on their personal health. Moreover, community-dwelling older adults express concerns that smart home technology may be too noticeable or obtrusive within their homes. Older adults can also be worried that they can be considered "frail" or "old" once they are seen using technology that is specifically designed for frail older adults. This fear of stigmatization can be very powerful (Cohen-Mansfield 2005; Lee and Coughlin 2014; Peek et al. 2014; Rush et al. 2013; Steele et al. 2009).

While community-dwelling older adults may have concerns regarding smart home technology, they also see benefits, such as increased independence and increased safety (Peek et al. 2014). However, these perceived benefits do not "automatically" translate in acceptance of smart home technology. This is illustrated in a recent pre-implementation study conducted by Claes and colleagues (2014) that investigated beliefs regarding contactless sensors. These sensors enable tracking of older adults' personal safety, their health status, and their ability to perform activities of daily living. According to the vast majority of the participants in this study, contactless sensors were indeed useful to age in place, both safely and independently. In sharp contrast, only a minority of respondents was willing to accept contactless monitoring at this point in their life (15.5 %). The willingness to accept the technology later in life (82.4 %), or in the case of health decline (91.8 %), was remarkably higher (Claes et al. 2014). These results are prototypical for pre-implementation studies on technology acceptance: older adults think that smart home technology is not necessarily intended from them, but rather for other, less healthy older people (Peek et al. 2014). This is in congruence with older adults' positive perception of their personal health, despite a decline in their objective health status (Cheng et al. 2007; Pinquart 2001).

To date, studies conducted in the post-implementation stage, when community-dwelling older adults have used and experienced a certain technology, are scarce (Peek et al. 2014). One example of a post-implementation study was conducted by van Hoof and colleagues (2011). In this study, interviews were conducted with 18 community-dwelling older adults with a complex demand for care. The participants of this study agreed to have an unobtrusive monitoring system installed in their homes, mostly because they wanted to improve their sense of safety and security and because they wanted to age in place. These participants reported an increased sense of safety and security in the post-implementation stage. Similar findings are reported in a post-implementation study by Pol and colleagues (2014). However, Pol and colleagues (2014) note that, similar to the study by van Hoof and colleagues (2011), "*participants were all old aged and experienced some age- and health-related limitations in their daily functioning*" and that "*they were aware of their vulnerability and expressed a need for strategies to maintain independent living*." Pol and colleagues (2014) argue that these circumstances led to the acceptance of the sensor monitoring system by participants and that research is needed to investigate whether older people who do not express or acknowledge their own vulnerability are also prone to accept smart home technology. The latter seems particularly important considering the fact that smart home technology is frequently postulated to play an important role in preventing functional decline of relatively healthy older individuals (Eriksson and Timpka 2002).

All in all, the abovementioned findings lead to a somewhat puzzling conclusion: many older adults have the desire to age in place, and many older adults also believe that smart home technology can contribute to independent living, yet these conditions often do not translate into a willingness to accept smart home technology. Only older adults who see that they may be at risk of losing their ability to live independently seem to be willing to accept smart home technology. It has been argued that a clear understanding of the motives of (potential) users of smart home technology is lacking in the current literature (Wilson et al. 2014). Therefore, the next paragraph will look more detailed at older adults' concept of independence and its relation to perceptions and acceptance of technology.

Different Types of Independence and Their Relations to Acceptance of Technology

Independence is commonly regarded as the ability to live without relying on external help, being the opposite of dependence (Fine and Glendinning 2005). However, in an important contribution, Sixsmith (1986) showed that the concept of independence, as perceived by community-dwelling older adults, entails three specific modes or types. First, independence can imply being able to look after oneself, not being dependent on others. Second, independence can refer to self-direction, the freedom to do what you want to do. Third, independence can mean not feeling obligated to someone, e.g., family members or caregivers (Sixsmith 1986). The first mode, being able to look after oneself, is the type of independence that policy makers aim for, and suppliers of smart home technology intent to support. Unfortunately, the other two modes of independence, although also important to older adults (Sixsmith 1986), are often ignored in the design and implementation of smart home technology. In a longitudinal qualitative field study, which our research group has been conducting since 2012, several ways in which these different modes of independence can play a role in the acceptance of technology by community-dwelling older adults have been observed (Peek et al. 2012). In this study, 50 community-dwelling participants (with a minimum age of 70) are visited in their own dwelling, every

8 months within a period of 4 years. The aim of this study is to explore and describe factors and mechanisms which influence the level of use of various types of technology (including household appliances, ICT, telephones, means of transport, and assistive technology) that are present in the homes of participants. In addition, the participants are asked to what extent they feel that technology can aid them in looking after themselves (the first mode of independence). Preliminary findings of our study indicate that, according to participants, assistive technology and means of transport (i.e., a car or an electric bike) can be important for maintaining this mode of independence. However, our findings also indicate that there is considerable amount of variation; while some participants state that assistive technology helps them to look after themselves, others indicate that they would rather do things themselves (i.e., without relying on technology): "*we are still stubborn in a sense that we do everything ourselves*".

Regarding the second mode of independence (the freedom to do what you want to do), older adults in our study report that certain types of technology can both support and threaten this type of independence. One example of this is the use of mobile phones. On the one hand, mobile communication technology provides participants with a sense of security, knowing that they can reach someone in case of emergency and thereby facilitating them in leaving their homes and performing activities. On the other hand, carrying a mobile phone also leaves participants open to interference by others (e.g., family members who can call participants whenever they feel they need to). This interference can lead to a feeling of "*not being able to do what you want to do*." A similar ambivalence occurs when older adults are using hearing aids. Hearing aids can have an empowering effect because they enable older adults to hear and respond to stimuli (i.e., sounds) that they would otherwise be unaware of. This enables them to engage in more activities and social interactions. However, at the same time, using a hearing aid can also lead to the avoidance of social activities such as birthday parties, due to overstimulation (i.e., hearing too much sound when many people are present). With both abovementioned types of technology, this ambivalence can lead to older adults using technology selectively: "*I only take it with me when I feel that I might be needing it*".

Looking at the third mode of independence (not feeling obligated to someone), participants in our study frequently mention that they do not want to be a burden to others, particularly family members. For example, participants in our study mention that they want to avoid asking their children to help them in using ICT devices or are afraid to cause false alarms while wearing a personal alarm button. Again, these situations can cause older adults to not fully make use of certain types of technology.

The aforementioned issues are not exclusive to technology such as mobile phones or hearing aids. Studies investigating acceptance of smart home technology also point to problems that seem to be related to perceptions of independence. For instance, Boström and colleagues (2013) have shown how monitoring technology can impact older adults' perceptions of Sixsmiths' (1986) second mode of independence (the freedom to do what you want to do). Their research shows that community-dwelling older adults can fear that monitoring technology could "take over" or "take control" of their lives. Other studies have also shown that community-dwelling older adults prefer to be in control of smart home technology instead of the other way around (Steele et al. 2009; van Hoof et al. 2011). Interference of technology with personal freedom may also occur in the case of lifestyle monitoring technology, which is designed to promote a healthy lifestyle by giving the user visual or auditory reminders and cues that are designed to influence the users' behavior. These reminders and cues may be perceived as meddlesome by users.

Privacy issues are another example of how acceptance of smart home technology can be influenced by perceptions of different modes of independence. Studies have shown that technologies that enable the sharing of personal information to formal and informal caregivers can be seen by community-dwelling older persons as something that enables them to stay in their current dwelling (Boström et al. 2013; Lorenzen-Huber et al. 2010; Wild et al. 2008). In other words, they perceive that technology can have a favorable influence on the ability to look after oneself (Sixsmiths' first mode of independence). In addition, while some studies have shown that older adults feel that the aforementioned technologies can reduce the burden on caregivers (Boström et al. 2013; Lorenzen-Huber et al. 2010), others have shown that older adults are worried that these technologies actually might increase the burden of caregivers (Steggell et al. 2010; Wild et al. 2008). This outlines that to older adults, smart home technology can both positively and negatively influence the feeling of being obligated to someone (Sixsmiths' third mode of independence).

The examples mentioned in this paragraph pinpoint that several of older adults' perceived favorable and unfavorable consequences of using technology in the context of aging in place can be framed in terms of how technology affects three distinct modes of independence. The findings in this paragraph also show that community-dwelling older adults can feel good and bad about a certain technology, rather than just good or bad (Boström et al. 2013).

Implications for the Design and Implementation of Smart Home Technology

In this chapter, we have reviewed and discussed older adults' perspectives on their independence and their views on smart home technology. The following key points were made:

- In general, older adults want to live independently in their current dwelling. However, the desire to live independently differs per person and is influenced by factors such as health status, age, and gender.
- Scientific evidence for the effectiveness of smart home technology in enabling independent living is scarce.
- Older adults who are not using smart home technology feel that it could support independent living, although they also express various concerns. They also perceive that smart home technology is not intended for themselves, but rather for other older persons who are less healthy.

- The concept of independence in the eyes of community-dwelling older adults entails three specific modes or types: (1) being able to look after oneself, not being dependent on others; (2) self-direction, the freedom to do what you want to do; and (3) not feeling obligated to someone. It is important to realize that smart home technology can affect all of these three modes of independence, often simultaneously.

The abovementioned notions have several implications for the design and implementation of smart home technology. Firstly, technology suppliers, caregivers, and policy makers are advised to take a broad view of the concept of independence. While empowering older adults to be able to look after themselves is an important goal of smart home technology, it is also important to realize that smart home technology can, unfavorably, influence older adults' perceived personal freedom and feelings of obligation toward others. These aspects need to be taken into account in order to increase acceptance. This can be achieved by being sensitive to issues related to user control and implications of the technology for social relationships. For instance, one must be careful not to take too much control away from older users, since this may conflict with their concept of independence. In the same way, one should be aware of the fact that social relationships between older users and their social network are influenced by technology. Of particular importance is the relation between family members and older adults, which older adults prefer to keep asymmetrical: they like to "give" more than they "take" (Lindley et al. 2008). Smart home technology that is not designed and implemented in line with this "preference for asymmetry" may threaten older adults' concept of independence. The aforementioned broad view of independence could also benefit (cost-)effectiveness studies on smart home technology. Currently, effectiveness studies have a tendency to focus on measuring outcomes in line with a narrow definition of independence: the ability to look after oneself. Broadening this definition by including all modes of independence as described by Sixsmith (1986) may result in a more comprehensive understanding of the effects of the use of smart home technology on the lives of community-dwelling older adults.

Secondly, the key points made in this chapter implicate that technology suppliers, caregivers, and policy makers need to be sensitive to issues regarding diversification and timing. It is important to realize that older adults' perception of independence and their use of smart home technology may not only vary from person to person but may also vary across time. Moreover, older adults can have different opinions on each of three modes of independence. This complicates both the design and the implementation of smart home technology. Ideally, a smart home technology would be able to adapt itself to different and/or changing independence-related needs of older adults. To our knowledge, such a technology does not currently exist and is very challenging to design, build, and bring to the market. One of the more difficult aspects of such "self-adaptive technology" would be the design of algorithms to identify and monitor the user's independence-related needs. A more feasible alternative might be to let caregivers or care consultants who are in close contact with the older person identify and monitor their needs.

These identified needs should subsequently be matched with suitable smart home technologies that are available on the market. However, this would require that the particular caregiver or care consultant would have a comprehension of (psychological) aspects of aging as well as technical developments. Professionals with this skillset may be scarce and training them might be expensive. Researchers can play a role here, by developing and validating tools (e.g., interview techniques, checklists) that allow individuals to identify and monitor older adults' needs and by developing methods that can facilitate the matching of these needs with technologies.

An underlying cause of the issues raised in this chapter may be that technology designers and older adults have different perspectives regarding the concept of independence. Other authors pinpointed that many designers typically have little understanding of the unique needs of older adults (Doyle et al. 2014; Neven 2010; Wilson et al. 2014). This may be caused by the fact that technology designers are usually considerably younger than older adults, which means that they may be unfamiliar with (psychological) aspects of aging and grew up using other types of technology in comparison to older adults. To overcome this discrepancy, designers need to come into contact with older adults, preferably starting during their education.

Our goal of this chapter was not to provide an extensive overview of all factors involved in the acceptance of smart home technology. Instead, we have looked at the heart of the matter: can smart home technology deliver on the promise of independent living? At this point in time, we are inclined to answering this question unfavorably. This chapter also shows that the number of studies on older adults' perceptions of their independence in relation to smart home technology is limited. Additionally, a recent content analysis of industry-produced smart home marketing materials revealed "*a notable absence of user focused research*" (Hargreaves and Wilson 2013; Wilson et al. 2014). In our opinion, the way forward is to deepen our understanding of the (potential) needs and preferences of older people. In this way, the promising industry of smart home technology can make an important contribution to the independence of older adults.

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User Driven Design in Smart Homes: Design Techniques

Yvonne Schikhof and Marleen Goumans

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Abstract

User driven design in smart care homes means designing for different end users with different values. In an extended user-centered design and research model, the Value Sensitive Design methodology as well as elements of Technology Acceptance Models are incorporated. The stages of the design model are explained and illustrated with experience from two cases in health care, in which determinants of success can be identified in retrospective view. These determinants and elements of the design model are summarized in an advice for future designers, combined with appropriate methods.

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User driven design • Value sensitive design • Technology acceptance model • Determinants for success

Introduction

Designing for smart care homes and applying user driven design, means addressing two main groups: future residents as well as care professionals. Both groups will use the interfaces within the smart care homes, or smart apartment building with assisted living facilities. This explains the first difficulty of designing in the health care domain: the user groups are not only internally heterogeneous but also very different from each other. Therefore, they have different needs, wishes and values as well.

In this chapter, the five phases of the extended user-centered design/research model (Fig. 1) will be explained and illustrated using the experience from two projects. These two cases will demonstrate how health care technology can be successfully designed and implemented. The most important factor for successful use of the technology in care apartments is acceptance by the users, thus in both user groups. Based on our practice-based case study research we feel that the extended user-centered design model has still some shortcomings. Therefore we will also incorporate elements of other models or methodologies. In retrospective view determinants of success can be identified, and we will describe these determinants in the phase where they should be attended to.

Two Cases

In the project Monitoring at Night (Schikhof et al. 2010), a night watch monitoring system for new small-scale nursing home care for people with dementia was designed. The monitoring system was to be used by a nursing assistant, who is responsible for

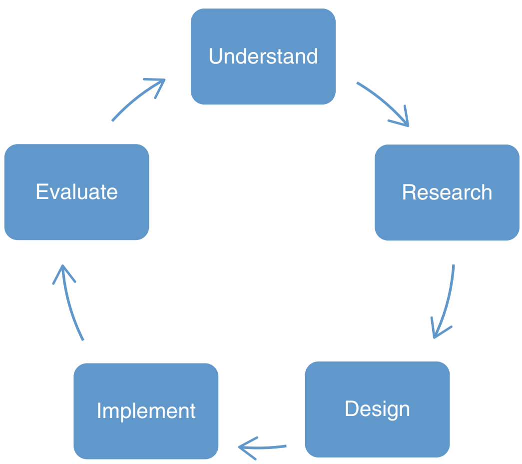

Fig. 1 User-centered design/research model (Adapted from Harper et al. 2008)

residents with dementia in four homes at night. The system is used to alert staff in case a resident needs assistance, for example because of a high risk of falling, agitation, panicking or wandering. IP (Internet Protocol) cameras, connected to a variety of sensors, are activated in case of an event by sensors. When activated, live video and sound is sent to a mobile device of the nursing assistant on duty. Staff can also steer the camera at distance and decide if and how urgent the resident needs assistance. The residents with dementia themselves do not actively use the system, but their representatives play an active part in the decision process if and how the system should be used. They have to give informed consent. For that reason the system was designed keeping the care professionals as well as the representatives of the residents in mind.

The innovation project Vital Link (Goumans et al. 2012) included designing and implementing an integrated system for smart care technology and communication within a new apartment building (54 care apartments), where older adults can live independently with some assistance. All residents are in need of care and support because of chronic conditions, up to 24-h nursing home care. The integrated system includes a videophone, which is used by the residents, nursing staff and a specialized nursing home physician for both planned and unplanned care. The residents also use the videophone for social calls. Here the users are a heterogeneous group of residents, and diverse care professionals (nursing assistants, nurses and physician).

In both cases, there are many lessons learnt concerning designing and successfully executing and implementing the design in practice. In retrospect, determinants of success can be identified (Schikhof and Goumans 2013) as well as in which phase these determinants should be attended to. At the end of this chapter, we will also give advice which activities can be undertaken to work on these determinants.

Although the two cases presented above differ in the applied technology, they are equal in the way the researchers worked together with the SME's (small and medium enterprises) involved, to design and implement new smart home technologies for use in daily care practice. In both cases, a user-centered design model was used to gain insight in the designing and implementation process, see Fig. 1.

Next, the design- and research cycle will be explained.

Understanding the Context

In the first phase of the extended user-centered design and research model, it is important to understand the context and to focus on the human values of the users we want to design for. Who are the users and the important stakeholders, and in what kind of domains of activity, environment or culture do they live or work?

Value Sensitive Design (VSD) emphasizes the values of direct (users) and indirect stakeholders (such as family), using a Tripartite methodology (Friedman et al. 2008). In this phase, conceptual investigation is needed to understand which values should be considered to be part of the design process.

Most of the time the context and design task will require working together with different disciplines and using different methods, for example observing in practice; interviewing stakeholders; desk research. This phase also provides a framework to guide design and further research.

When the domain is well defined, like dementia care in small-scale nursing homes in the case of Monitoring at Night, it is easier to identify the users and stakeholders and learn to understand the context. There are publications in the Netherlands in which the concept small-scale nursing home care for people with dementia is defined. Desk research was used to understand the meaning of this care concept as used by the care organization involved in the project. We compared this with the definition in national literature. The specification of the meaning of the small-scale care concept in the specific context of this new location provided better understanding, not only of the care concept but also of the context. Interviews with management and care professionals, and observations in practice were used to understand the situation at night in nursing homes of the care organization. This included the acceptance and use of technology. In the Monitoring at Night project, the use of infrared sensors (PIR, Passive Infrared) and coping with false positive alarms, revealed to be the main issue.

In the innovation project Vital Link it was, compared to the small-scale nursing home care situation, more difficult to understand the meaning of the care concept of an apartment building with assisted living facilities, which provides up to 24-h nursing home care, and its (future) residents. The reason for that is the lack of comparable examples within this domain and the fact that the care concept was not in depth explored and specified by management. The new residents would probably generate a heterogeneous group. Residents would live alone, or with a partner; residents would require different levels of care because they all had different limitations and possibilities to cope with everyday life. Besides desk research into the new perception of assisted living facilities up to nursing home care, as seen by the local health care organization, Image-based research (Prosser 1998) was used to understand the neighborhood of the new care apartment building and its older inhabitants.

As illustrated above, this phase can require the first practical research in the cycle. In these two cases desk research, interviews and Image-based research were carried out by researchers and students from different disciplines. In both cases the context was explained. Also the (potential) end users were identified and, as much as possible, their value systems. Furthermore, subjects for further research were identified. The findings were shared with the SME's involved.

Research

In this phase, a deeper understanding of values of the end users and practices concerning technologies is developed. Empirical investigation of the values of end users and stakeholders is needed. User studies are an important part of this phase, including their interaction with technology and how to influence their acceptance of technology. The conceptual analysis of the first phase helps to pinpoint relevant existing literature or work on relevant subjects still needed. Also, ideally, the technology intended for use in design, can be tested on quality and usability in a laboratory setting by representatives of end users. This will result in a mix of

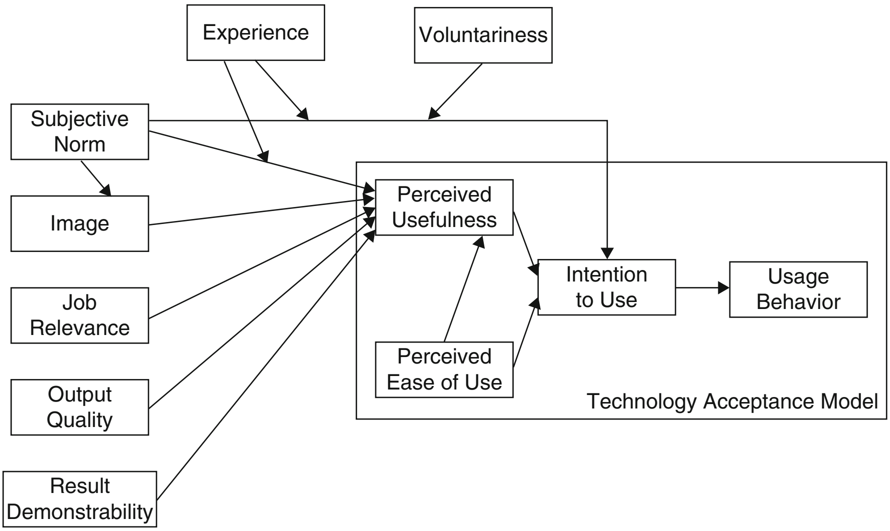

Fig. 2 TAM2 (Venkatesh and Davis 2000)

perspectives and insights within which the design can take place, using different technical possibilities, suited to the end users and stakeholders.

The research can require mixed methods and complex analysis. The complexity shows in the need for different disciplines to interpret the results, which will provide a base for designers to continue in the user-centered design process. Also, it can require more cycles of research. A theoretical model can help to order and weigh the research outcomes, in order to understand deeper how values can influence the acceptance and actual use of technology. We suggest to use the Technology Acceptance Model. Although literature concerning the Technology Acceptance Model (TAM) in health care is available, additional practical research is necessary (Holden and Karsh 2010). Perceived usefulness is influenced by Subjective Norm (including values), Image, Job Relevance, Output Quality, and Result Demonstrability, according to TAM2 (Fig. 2).

For example, in Monitoring at Night the work processes of the nursing assistants were observed, questioned, and charted in flow charts, including actions on false positive alarms. These flow charts were the input for interviews with the care professionals involved in setting up the new group living homes for people with dementia. The outcomes can be positioned under Job Relevance in TAM2. This resulted in insights which led to the design of a feasible monitoring system, both concerning costs and job relevance.

In Monitoring at Night the next design phase started at the same time as the research, using sketches of the possible monitoring system to investigate whether a similar system could be acceptable for both care professionals as for family of people with dementia. A survey was carried out before and after information was provided about the possible design of a monitoring system, including cameras in the bedrooms of residents with dementia. Also, the conditions for acceptance were investigated both in focus group and in individual interviews, following the introduction of the first design. These interviews disclosed the important values to be incorporated in the design.

In the case of the Vital Link, focus groups were used to choose a video phone that was acceptable for older residents in this neighborhood. Both usability, such as clear image, sound, and easy-to-use touch screen as well as press buttons, and minimal intrusiveness in the living room (size, resemblance to an ordinary phone) were important outcomes of the focus groups.

In a laboratory setting, different sensors and cameras were tested on quality and a new interface was tested on usability in the research phase of Monitoring at Night, providing valuable input concerning user requirements. Both technical and health care background was required to analyze results, leading to realistic user requirements.

Without a first design and prototype, it is almost impossible to study the effect of values and perceived usefulness. This means that the design- and research model is an iterative model, where research and design will alternate.

Design

As demonstrated, in the actual design phase more research can be necessary. By integrating the Value Sensitive Design (VSD) tripartite methodology, conceptual and empirical investigation is situated in the first two phases. Technological investigation is needed in the design phase (Friedman et al. 2008). In designing smart (care) home systems, usually different technologies have to be integrated in the system. Thus, a system integrator is necessary. The system integrator also needs to be aware of the need to incorporate values and can play a part in the technological investigation. While designing, prototype testing can take place.

After designing and testing, it is advised to go back to all stakeholders to investigate the feasibility and acceptance of the designed system. A positive evaluation of testing in practice will be an important factor in the decision-making process whether or not to build and implement the design. Checking if all important values are identified and incorporated in the final design may be necessary when working in a new domain. Obviously, cost effective studies can also be necessary, before moving to the next phase.

For example, in Monitoring at Night, a SME was introduced in the new context and played an important part in the research, design, and implementation phase. The SME combined the infrared (PIR) with other sensors, cameras, and Wi-Fi in a computer system, completed with a mobile interface (Personal Digital Assistant and later smartphone) to be used by nursing assistants. In the Vital Link the SME involved, combined the technology used in business communication systems with a personal alarm system, fire alarm system, video door opener system and different interfaces for residents and care professionals within an integrated Internet Protocol system.

In Monitoring at Night a working prototype system was used during one month in a nursing home. Nursing assistants used it alongside the already existing technology (PIR and pager) for four residents with dementia, as not to endanger the residents when the prototype would not function properly. Informed consent was asked from proxy. After every night duty, the nursing assistant completed a short questionnaire concerning perceived usefulness and usability of the system, as described as the factors in the TAM2. After 1 month, staff was interviewed about their intention to use the system. In this particular case, the nursing assistants said they did not want the system to be removed after the testing had finished. Consequently, result demonstrability proved to be an important factor.

In Vital Link prototype testing was only possible with students in a laboratory setting for testing the new communication interface within the system for this domain, i.e., the video phone. As there were no residents in the apartments yet, further testing of the system was incorporated in the implementation phase, when they moved into their new apartments. This could be one of the reasons for later encountered difficulties in acceptance by the end users.

In Monitoring at Night, a focus group of indirect stakeholders was used to check values and job relevance on a broader scale. This resulted in an addition to the design. This made it possible to use the system also during the day for monitoring unassisted residents in the living room, when requested in special circumstances. In Monitoring at Night, the positive evaluation of testing in the nursing home and the cost estimate by the SME was sufficient for management of the care organization to decide to implement the newly designed system in the new small-scale nursing homes for people with dementia. The investment in the new system could be paid for by extending the night shift one hour. Thus saving some salary costs, because at night there is only one nursing assistant on duty and before the night shift there are two professionals on duty in the evening. The return on investment took approximately 4 years.

Building and Implementing in Practice

Executing the final design, as in building the system to be used in practice, is usually the work of engineers. Implementing the system requires engineers and other disciplines.

Support, training, usability, and quality are identified determinants, which influence the implementation of technology in health care (Broens et al. 2007). Hence, testing in place, writing instruction manuals, training, and supporting end users are important tasks in implementing new technology. During implementation, usability and ease of use are important determinants for success, which can be influenced by providing adequate instruction, support and training. Also, having a role model among the care professionals, who can adapt to the new technology quickly, and who can demonstrate the ease of use, makes a difference.

In both cases, testing the system before bringing it fully into use with residents, was performed using staff and students, for obvious reasons of quality control.

In Monitoring at Night, more time was invested in training and supporting staff than in the case of Vital Link. In Monitoring at Night team leaders were trained first and they could also function as role models for the other team members. In Vital Link the technology was believed to be more customary to the end users. But in this case there was less intention to use the technology. Spending less time, combined with the lack of a role model, explains this lower intention to use the technology than was the case by Monitoring at Night. Nursing assistants in Vital Link more often physically checked if assistance was needed by residents rather than using the video phone. It was also a task of nursing assistants to help new residents in the care apartment building getting used to the video phone. Unfortunately, because of less use of the video phone by nursing assistants, there was less opportunity and necessity for residents to get used to the video phone and less support than expected.

In Monitoring at Night, a manager and the team leaders naturally performed as role models, because of their involvement in testing in practice and training. Diffusion is also a determinant for acceptance (Broens et al. 2007). Peer and management support are also important factors.

In the case of Vital Link, instruction for staff and residents was rewritten to better adjust it to the level of experience of both staff and residents, and extra support was given by students. It was only during this implementation phase that the level of experience became clear. Also, moving to a new apartment was an inconvenient moment to investigate the new residents' ability to adapt to the technology, since they were overwhelmed by their new living environment and all the changes in their lives. The staff was also new and needed time to consider the new work processes within the new care concept.

Evaluation

Evaluation is needed to describe the perceived ease of use and the effectiveness of the implemented technology. Venkatesh and Bala (2008) adjusted TAM with added variables on perceived ease of use to TAM3 (Fig. 3), accompanied by a new research agenda focused on pre- and postimplementation interventions that could enhance adoption and use of IT.

Therefore, the influence of management support and incentive alignment, when relevant, besides successful design characteristics and user participation, should be part of the (preimplementation intervention) evaluation. Important postimplementation interventions are training, organizational support, and peer support, as presented by Venkatesh and Bala in TAM3 (see Fig. 3). The similarity with the identified determinants for successful implementation of telemedicine by Broens and others (2007), underlines the importance of evaluative research.

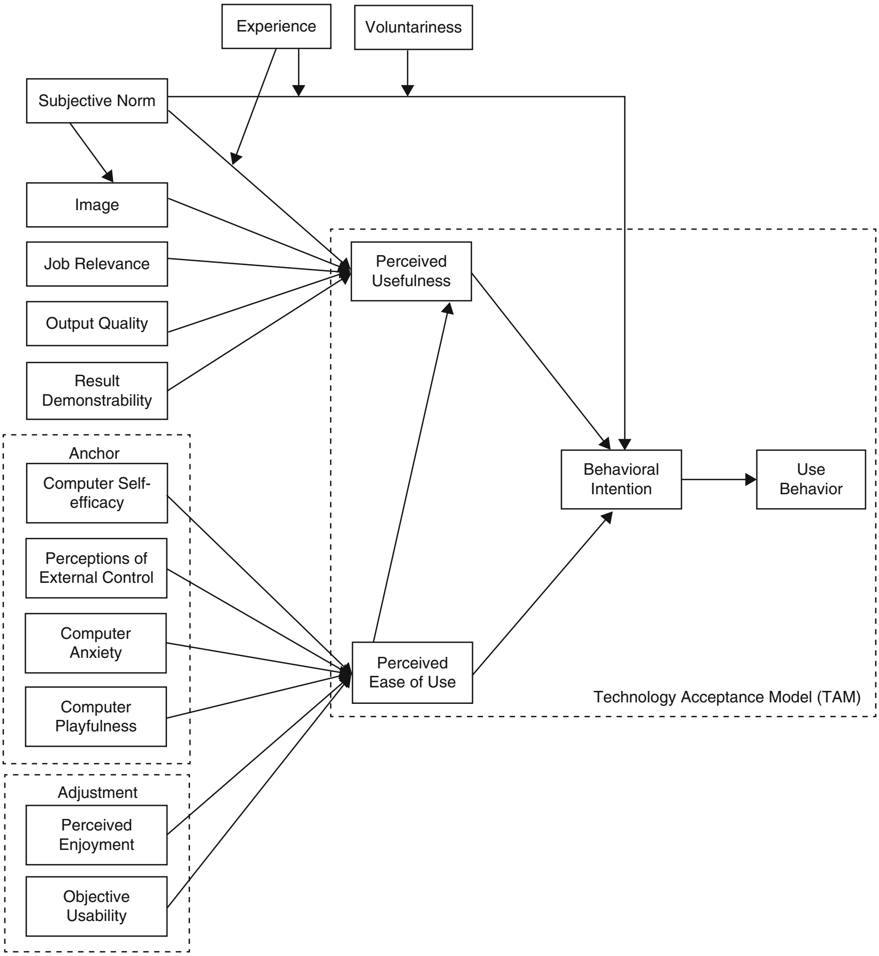

Fig. 3 TAM3 (Venkatesh and Bala 2008)

According to Venkatesh and Bala (2008) perceived ease of use (of IT) is directly influenced by

1. Computer self-efficacy
2. Perceptions of external control
3. Computer anxiety
4. Computer playfulness and adjusted by
5. Perceived enjoyment
6. Objective usability

Qualitative research methods are best suited to learn to understand the acceptance of technology in smart (care) homes to the end users, leading to good use in practice and hopefully to positive effects.

An early evaluation can serve to detect some new problems in practice, which can to be solved by adjusting the system.

Evaluating effectiveness is not easy. Reeder and others (2013) published a systematic review of evidence for health smart homes and identified three effective studies that demonstrated support for independence and prevention of adverse health events in older adults, over the years 1998–2011.

In the case Monitoring at Night, a focus group of staff using the monitoring system and interviews with family of residents indicated good use of the system and possibly better quality of care/quality of life for the residents concerned. No comparison with a similar situation could be made. When using a standardized method to measure job satisfaction of staff, no evident effects could be found.

In the case of Vital Link, unfortunately, research ended as soon as the implementation was accomplished. Interviews with staff still indicated less use of the technology than expected, but no new difficulties emerged. The interviews also pointed out the perceived usefulness of the system, once staff members started to reorganize their work processes. Another indication of positive effects, resulted from an interview with the physician involved. She mentioned she could do her job better using the video phone, compared to giving information by telephone. Interviews with residents showed an increased acceptance. They needed time to learn how and when to use the videophone and started also to contact each other and caregivers to ask questions. After at least one year new research to evaluate the perceived ease of use, acceptance and effectiveness is expected to start.

Conclusion

We recommend using the extended user design and research model in an iterative way. First, learning to understand the context and subsequently going back and forward from research to design, or even to redesign during implementation, takes up a lot of time. Successful determinants are mainly identified for implementation, but successful implementation needs a successful design, preceded by thorough preliminary work, as described in phase 1–3. Therefore a conscientious execution of the extended design and research model is time consuming.

All parties concerned, researchers, managers and SME's, should ideally take their time to deliver and implement the best possible design, but in reality this has proven to be very difficult. When the technical people involved (engineers, SME) are willing and able to adjust the design after evaluation, the learning process can be fully utilized.

Over time, we have incorporated successful design characteristics (as in Value Sensitive Design) and user participation to enhance acceptance in the extended user-centered design/research model (Harper et al. 2008). TAM3 and studies of

Table 1 Overview of design phases, activities and appropriate methods

Phase	Elements	Activities	Methods
Understanding the context	Values of end users and stakeholders	Identifying end users and stakeholders Conceptual investigation Value Sensitive Design (VSD)	Desk and practice based field research
	Domain Culture Environment	Identifying issues for further investigation	Desk and practice based field research Image-based research
Research	Perceived usefulness Subjective norm Image Job relevance Output quality Result demonstrability	Leading towards realistic user requirements	Focus group Interviews Observations Work flow
	Feasibility	Insight in costs and achievable goals	Desk research Interviews Calculations
	Usabilty Output quality	Selecting possible technology/ interfaces combined with user requirements	Focus group Laboratory setting
	Acceptance: Important values/ possible conditions	Empirical investigation VSD	Survey Focus group Individual interviews
Design	Acceptance and chosen technology	Technical investigation VSD	Laboratory setting
	Result demonstrability	Prototype testing	Testing in practice or laboratory setting
	Feasibility and acceptance	Testing feasibility and acceptance after design and re-design	Interviews
	(Future) end users and technology: (Computer) technology self-efficacy Perception of external control (Computer) technology anxiety (Computer) technology playfulness	Specific design requirements user group	Survey

(*continued*)

Table 1 (continued)

Phase	Elements	Activities	Methods
Building and implementing in practice	Usability	Testing final design Training Instruction manual Diffusion/role models Peer support Management support External Support	Testing in place Training end users Writing and testing instruction Support system
	Intention to use: Perceived usefulness	Testing in first period of use	Observation in practice Survey Interview User journals Re-design when necessary
	Intention to use: Perceived ease of use (Computer) technology self-efficacy Perception of external control (Computer) technology anxiety (Computer) technology playfulness	Testing in first period of use Re-design when necessary	Survey User journals
	Intention to use: Perceived enjoyment Objective usability	Testing in first period of use Re-design when necessary	Focus group Interview User journals
Evaluation	Usage behavior	Evaluation of regular use	Observations Focus group User journals Chart work process and daily routine
	Effectiveness	Effect study	Survey File research Cost-benefit analysis

determinants of successful implementation of technology in health care can help to emphasize important factors in designing, researching, and implementing technology systems in smart (care) homes. We, therefore, advise to take all factors into account, as arranged in Table 1.

Elements of both the Technology Acceptance Model (Holden and Karsh 2010) and Value Sensitive Design (Friedman et al. 2008) can ameliorate a user-centered design model.

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“Sleeping Like a Log. . .”? Technology Supporting the Implementation of Person-Centered Care at Night

Ingrid Eyers, Roger Orpwood, Bruce Carey-Smith, and Nina Evans

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Abstract

Sleep is widely acknowledged to be vital to our well-being, yet its importance is often overlooked or taken for granted. However, it has been identified that older people living in long-term care facilities in the United Kingdom, Germany, and the United States experience poor sleep. However, the evidence-based development of technology has the potential to support the provision of person-centered care enabling residents to "sleep like a log" and experience restorative sleep, thus improving their ability to actively participate in everyday life. This chapter provides an insight into research that underpins the need for technology to support the provision of person-centered nighttime care. The issue of acceptance is related to research findings and four technological devices developed enabling older people to "sleep like a log" and supporting care staff are presented and discussed.

Keywords

Person centred care • Sleep disturbance • Technology

Introduction

How we experience sleep is vital to our individual sense of well-being. For older people sleep has been identified to be further of relevance as a good night of restorative sleep enhances, for example, cognitive and physical abilities and reduces the risk of falls (Livingston et al. 1993; Leger 1994; Ersser et al. 1999; Busto et al. 2001; Martin 2002; Stepanski et al. 2003). It is also seen to improve rehabilitation following major vascular events and cancer (Krishnan and Hawranik 2008). However, research findings from the United States of America (Alessi and Schnelle 2000; Martin and Ancoli-Israel 2008), the United Kingdom (Kerr et al. 2008; Luff et al. 2011; Meadows et al. 2010), and Germany (Garms-Homolová et al. 2010; Flick et al. 2010) have identified that older people living in care homes do not sleep well.

In order to improve sleep, the first step taken needs to identify the determinants of poor sleep in care homes. Based on the resulting findings, the second step is to develop best practice that will ameliorate the situation. After considering the physiology of sleep, this chapter addresses the determinants of poor sleep in care homes and how they can be ameliorated through the use of technology.

The Importance of Sleep in Later Life

Sleep is a very individual and private experience that for an older person living in a care home tends to become institutionalized and issues of privacy and dignity become questionable. We each have individual circadian rhythm (Gronfier et al. 2004; Rimmer et al. 2000) and our brain reacts to "zeitgeber" that signals our bodies when to go to sleep and wake up. A further important factor is that studies involving electroencephalograms (EEG) indicate that we all go through five "stages of sleep" (Rechtschaffen and Kales 1968). In stages 1and 2, we are "falling asleep" but not yet in the "deep sleep" of stages 3 and 4, and in stage 5 our brain is active again and we dream. In stages 2 and 4, it has been found older people are more easily awakened by a given level of noise (Busby et al. 1994; Zepelin et al. 1984) and also light has been indicated to disturb sleep (Gronfier et al. 2004; Rimmer et al. 2000; Schnelle et al. 1999).

The role of light as an endogenous circadian pacemaker in humans is studied in detail by chronobiologists, and the indication is that intermittent exposure to bright light induces phase changes in the circadian rhythm of an individual (Gronfier et al. 2004; Rimmer et al. 2000). This means that a disturbance in an individual's sleep pattern can be due to ordinary room light exposure during the night (Boivin and James 2002). The dislocation of diurnal rhythms, which light has been identified to cause, is especially prevalent in those with dementia (Volicer et al. 2001). A considerable proportion of care home residents have dementia (Lievesley et al. 2011; Netten et al. 2010), and clear day-night lighting cycles are likely to have an even greater impact on the well-being of this group (Volicer et al. 2001).

Identifying the Determinants of Poor Sleep in Care Homes

To establish an evidence base that identifies key determinants of poor sleep in care homes, an in-depth study was conducted in ten care homes in South East England. Prior to conducting the research, information about the study was provided to the home management, all care home staff, residents, and their relatives. On the day that the data collection commenced, a presentation was made to residents and staff in each home. Residents who had volunteered and were judged by the care home staff to be cognitively able to participate in the study each had a detailed conversation with the researchers before signing the consent form to participate in the study. Participation involved wearing an Actiwatch (small activity and light exposure monitors widely used in sleep research) to record levels of movement for 14 days and keeping a daily diary over the same period noting their daily activities.

As the majority of participants were not able to personally maintain the diaries, researchers visited daily and chatted with the residents to elicit information about activities during the previous 24 h. The diaries were maintained in a standardized questionnaire format which facilitated analysis using SPSS (Statistical Package for Social Sciences). The questions asked included how well the participant had slept, how often they had got up during the night, and if they were disturbed during the night. Further information was collected to establish what time the resident went to bed and got up and what activities they had undertaken during the day. Collecting data in this way also facilitated keeping detailed field notes during the 2-week period of data collection. Over 250 h of observational data was collected, including observing at dawn, dusk, and during the nighttime in the participating care homes. This in-depth observational data on care home life also allowed the researchers to evaluate the validity of the daily information provided in the diaries and informed the interpretation of the actigraph data.

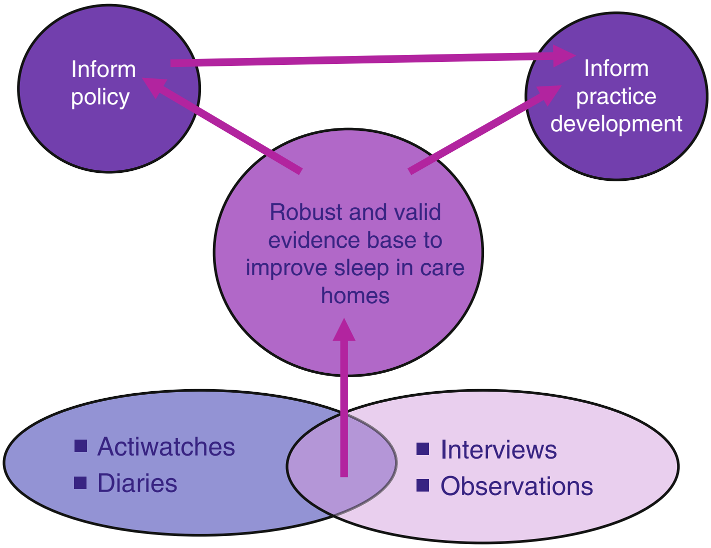

Fig. 1 Conceptual framework: identifying the determinants of poor sleep

Each diary also recorded demographic information and the participants' dependency level based on the amount of time needed to provide care each day (Eyers 2007). It was anticipated that not all informants would be qualified nurses and could therefore not be expected to relate to standard nursing assessment tools; this was the more reliable, tested form of data collection. Information about individual participants' continence care plans was also recorded. Audiotape-recorded semi-structured interviews were conducted with all ten care home managers and a further 50 members of day and night care staff.

This multi-method approach facilitated "rigor without rigidity" (Fielding 2009, p. 428) for this study with vulnerable older people living in a complex community. Bringing together the qualitative and quantitative data facilitated data analysis that provided a deeper understanding of care home life and the interaction between older people and the staff employed to support them (Fig. 1). The findings aim to inform policy and practice development as well as to inform the further development of technology. To integrate a practitioners' perspective into the analysis, two well-attended "day workshops" in South East and South West England were held, which enabled discussion about the findings with care home managers and night staff.

Quantitative Data Findings

Actiwatch and diary data was collected from 145 participants who completed all or part of the 2-week diary data. There were 105 women and 40 men, covering an age range of 60–100 with the strongest representation of both genders in the age group 85–89.

Information about the participants’ health-care needs was provided by care staff and their perception of time spent meeting care needs. The indication was that 27 needed under 90 min physical assistance per day, while 79 received 90–180 min of physical care and support per day. Three to five hours of “hands-on” care was perceived to be provided to 30 residents, while six participants received over five hours of assistance to meet their health-care needs. Data relating to dependency was missing from three participants.

The actigraphy (data from Actiwatches) analysis established that many participating residents experienced fragmented sleep (Meadows et al. 2010); in correlation to this, the findings from the diary data indicate that 65 % of sleep disturbances were reported by the participating residents to be related to toilet/continence care. The data strongly indicated that such a sensitive, very personal bodily function that a healthy independent person undertakes in privacy is a core element in the everyday (and night) life of vulnerable old people living in long-term care facilities.

A key finding from the diary data was that the mean length of time care home residents spent in bed at night was 10 h 50 min. However, it would be erroneous to equate the hours in bed with long hours of sleep, as a high proportion of the participating residents reported spending a number of hours awake in bed each night (Luff et al. 2011; Venn et al. 2010). The qualitative data in the following section provide an insight into the nightlife in long-term care facilities and further extends the evidence base that informs the development of best practice in nighttime care.

Qualitative Data Findings

In all ten homes, the qualitative data provided an understanding of 24 h life in a care home for older people and the care staff. An emerging theme from the qualitative data set was the frequency of nighttime monitoring by staff, which was driven by two care issues:

- *Dead or alive?* Reliably monitored by entering the bedroom to visually assess residents’ well-being (are they safe and still breathing?)
- *Wet or dry?* Reliably monitored through the physical evaluation of the continence pad or sheet

These actions invariably also involve the use of light and unavoidable sounds, both factors which as stated earlier can disrupt sleep. Undertaking these surveillance tasks was seen to be important to both management and care staff. Not heeding these aspects of caregiving could be interpreted to mean care staff are failing to do the work they are employed to do and not fulfilling their duty of care (Eyers et al. 2012). Regular hourly checks were expected by managers and routinely performed by care staff, which was evident from the interview, observational, and actigraphy data. During the nighttime observations conducted in the study, it was noted that to ease the surveillance visits, bedroom were often left open letting in light and noise.

The open door also enabled residents to call out when they noticed staff going by. Leaving open was done in consultation with the residents and was perceived to be reassuring for all concerned. At the workshops, managers were pleased and reassured to hear that the research findings confirmed the regular surveillance expected of night staff.

Based on the interview data collected and discussions during the workshops, it was clear that night staff generally do not intentionally wake residents at night. Interviewed care staff also tended to believe that "their residents" sleep well. They made this evaluation on the basis of the following three key points:

- "Their residents" did not need to take "sleeping tablets"
- "Their residents" did not use the "buzzer" during the night
- The sound of "their residents" snoring

The managers' expectancy of nighttime care is reflected in the following interview extract:

> they [residents] are checked hourly [during the night]. . . unless residents specifically request that we do not go into the room. . . they are checked hourly. . .

This is further underpinned by care assistance description of nighttime care exemplified by Madge who said:

> . . .checking on them. . . that's our work, we have to look after them

However, to counterbalance the above two interview extracts, a thought needs to be given to the following statement made, among others, by Stanley a resident taking part in the study:

> . . .when the staff come into my room I wake up

Depending on his stage of sleep, Stanley will have noticed staff coming in but not been awake enough for it to be noticed by care staff that he was in fact being disturbed by the intrusion involving light and noise. From the interview and observational data, the indication is that care staff try hard not to disturb residents. However, considering that the Actiwatch data indicated that a high proportion of the participants experienced fragmented sleep, it becomes clear that there is a potential area of conflict between care staff facilitating a good night's sleep and undertaking the tasks expected of them.

Regular surveillance of nighttime sleep by care staff restricts residents' experience of restorative sleep, which could enhance their cognitive and physical abilities during the day. Improving sleep in care homes has the potential to improve the caregiving and the quality of life experienced by older people receiving care. Which stage of sleep someone is in cannot be easily recognized by night staff entering a bedroom to check if all is well. The intrusive process unavoidably also involves light and sound.

Care at Night

Facilitating empowered, personalized care tailored to an individual's person-centered needs (Innes et al. 2006) with the support of state-of-the-art technology could enhance the experience of sleep in care homes. Having information about someone's sleep hygiene habits, what time they habitually used to go bed and get up, accompanied by information about nighttime visits to the toilet, provides a basis from which person-centered care at night can be provided. Sensors that are, for example, connected to the mattress can transmit vital signs and have the potential to enable staff to only enter someone's bedroom when a care need has been identified. The evidence that a resident is dead or alive and wet or dry throughout the night is recorded, privacy and dignity are maintained, and most importantly restorative sleep is facilitated. Thus, care is provided when it is needed, not when it is determined by the routine of the facility. However, to reassure the staff are fulfilling their duty of care, the use of technology needs to be supported by policy makers and management (Eyers et al. 2013). Having identified the determinants of poor sleep in care homes, a key recommendation is the implementation of technology to support nighttime caregiving and eliminate the need for regular physical surveillance, reduce the use of light, and contain the level of noise. As was pointed out by the engineers accessing this data analysis, the use of sensors to monitor vital signs indicates sleep cycles and dampness is technologically feasible but to date has been difficult to introduce into the care sector.

Technology and Care at Night

In the following section of this chapter, consideration is given to the use of technology involving sensors, to detect whether a resident was wet or dry and dead or alive (Eyers et al. 2012). These aspects were selected as they provide discreetly measurable indicators of well-being while someone is asleep in bed. A further technological aspect of importance at night is the nurse call system and the introduction of "intelligent lighting." The engineers were fully aware of suitable technology in the form of sensors that, for example, transmit vital signs and indicate when bed linen was damp. Their knowledge of interpersonal communication systems informed their approach toward the use of nurse call systems that are integral to care home life. They investigated how the technology could be made acceptable to care home staff and the people they are employed to care for.

To help develop technological devices that could be successfully introduced to support person-centered care, research was undertaken to gain further understanding of the people who would potentially use new devices to provide nighttime care. The focus was on staff and resident attitudes to the use of remote monitoring sensors that could reduce the need for regular nighttime checks. The "wet or dry" element relates to continence care where the literature indicates that continence care practices, involving physically moving the resident, result in wakening and were seen to cause 87 % of sleep disturbance (Schnelle et al. 1993). In the same study the combination of noise and light that form part of the context in which care is provided was identified as the likely cause of 75 % of the awakenings (Schnelle et al. 1993). These findings by Schnelle (1993) were reflected in the identification of the determinants of poor sleep and will now be presented and discussed.

By reducing the number of nighttime checks through the use of acceptable technology, sleep disturbance could be reduced by the use of technology. However, any sensor-based system would have to allow monitoring of all critical indices. In scoping the requirements of such a system, a good understanding is needed of how staff and residents view the role of nighttime checks. To achieve a basic understanding of the requirements needed to develop user-friendly technology, a study involving both residents and care staff was undertaken.

The aim was to both gain an understanding of the problems of sleep quality in care homes and to develop potential technological solutions to help improve it. A user-centered approach was taken, involving over 40 care staff and residents. Four distinct phases were followed: an initial needs analysis, prioritization of needs, development of potential technological solutions, and refinement of the solutions through longer-term evaluation on care homes (Carey-Smith et al. 2013).

Needs Analysis

The needs analysis aimed to gain an understanding of the attitudes of care home residents and care staff, as well as the care home environment in which the technology would be used. Semi-structured interviews were conducted with residents and staff and questionnaires were completed by care home staff. The topics on the interview guide for residents and staff centered on sleep experiences within the care home. The aim was to explore perceptions of sleep, the nighttime environment, bedtime and morning routines, and nighttime experiences. The findings were combined with data from project partners and previously published observational studies to provide a summary of the key psychosocial, environmental, and behavioral factors contributing to poor sleep. This summary is shown in Fig. 2 (Carey-Smith et al. 2013) which also indicates the technological solutions proposed to address these needs.

Prioritization of Needs

In the second phase the potential technologies were presented to 27 care staff in the form of conceptual sketches and they were asked to comment on these and to judge them using an analogue scale. Based on this feedback and comments from the multidisciplinary, experienced team, the ideas were ranked in order of preference.

As with any work of this kind, resources are limited and so just four of the concepts were selected to be taken onto full development in phase three of the study. Initially physical models of the ideas were constructed to enable staff and residents to have a better idea of what was being proposed, and these were discussed in detail with them, both individually and in group settings. This interaction with the potential

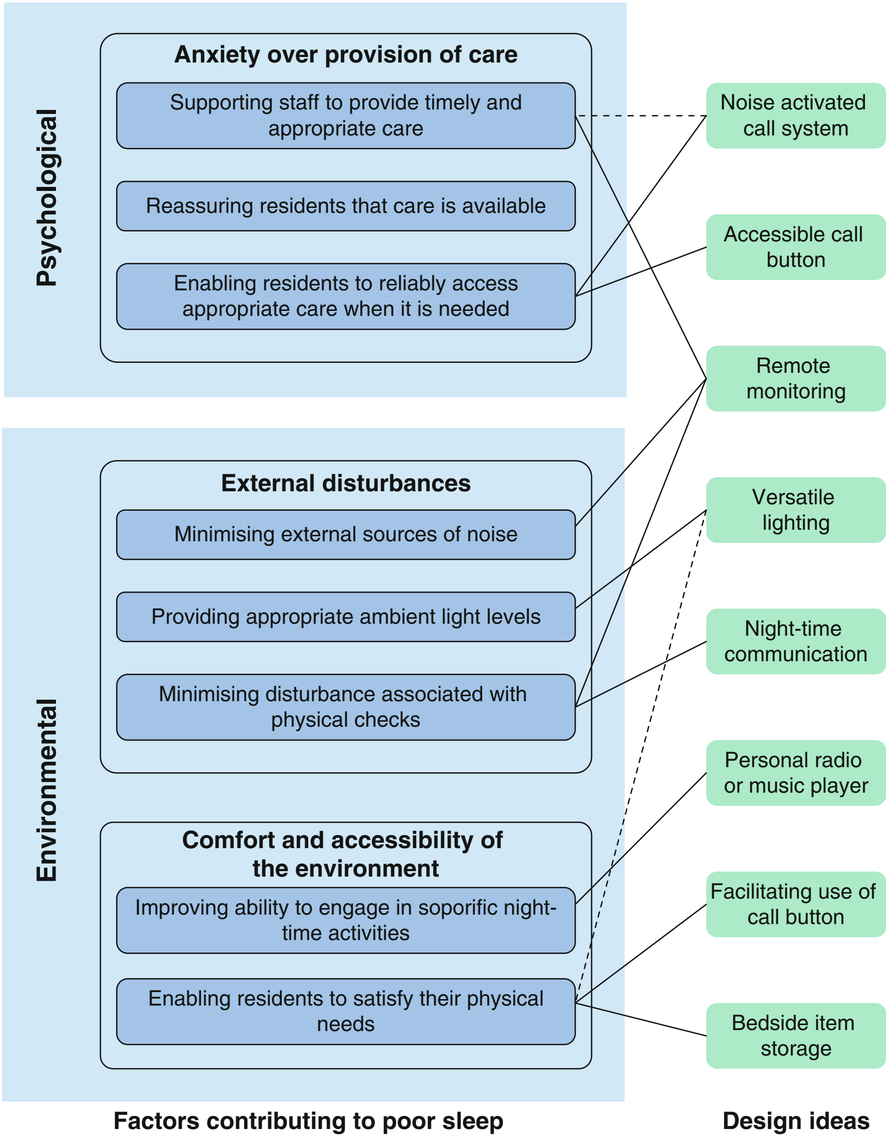

Fig. 2 Linking factors contributing to poor sleep to design concepts

users of the technology was very helpful in guiding the designers and was repeated at intervals as the prototype devices evolved.

The four devices developed were as follows:

1. A bedside organizer for reassurance during the night (a tray to hold items needed during the night, such as glasses, drink, etc., and which automatically illuminated as soon as the resident reached out to it)

2. An in-pillow audio to reduce nighttime disturbance (for playing music, the radio, or audio from the TV and which automatically faded off when the resident fell asleep)
3. Automatic lighting (low-level lighting under the bed which came on when the resident put their legs over the bed or if care staff came in the room)
4. Portable hearing aid (a handheld ear cuff that care staff could gently place over the residents' ear at night so they could communicate without shouting)

In the last phase, these devices were further developed, again in conjunction with comment from users, and left with residents for longer periods of evaluation. All were found to provide a significant improvement of sleep. So far one (the bedside organizer) has since gone on to become available commercially.

Development of Potential Solutions

In addition to the prototype development work, a study was carried out to explore remote nighttime monitoring. All the necessary technologies are already available but are not integrated into a single monitoring package. The discussions with care staff indicated that three key elements were all that was needed: an in-pad enuresis monitor, a basic respiratory monitor, and a movement monitor. If this information could be displayed simply outside the residents' room or on a system such as a mobile phone, it was felt it would give staff confidence to reduce their more intrusive nighttime monitoring of residents.

Within this context participants were asked about their experience of nighttime checks. A total of 27 interviews were conducted with 13 members of care staff and 14 residents in three different nursing homes. The interviews were transcribed verbatim and analyzed thematically. A questionnaire was designed to investigate what care home staff were looking for when they performed nighttime checks and to explore the perceived usefulness of a remote monitoring system. The questionnaire was circulated to care home staff by mailing copies to a number of care homes and by handing out questionnaires to delegates attending a care home workshop relating to sleep. A total of 87 completed questionnaires were returned from a mix of care assistants (42 %), qualified nurses (38 %), and managers (17 %), while the remaining 3 % did not specify their role. The majority, 70 % of the questionnaires, were from staff based in nursing homes, 23 % from residential homes, and the remaining 7 % from a home offering a mix of services.

Resident's Views of Nighttime Checks

A considerable majority (88 %) of the participating residents were aware of staff checks, even if there was no direct contact. Only one resident, who was fully aware of the checking process, preferred not to be checked, and the majority of comments about nighttime checks were neutral or positive. A common comment in staff interviews was that they were under the impression that older people now living in care homes felt reassured by the noise and activity of staff during the night. This was further supported by staff making the observation that the majority of residents moved into nursing homes after an incident at home and, as a consequence, were more concerned that there was someone there for them if they needed support or assistance. However, as has been stated in this chapter, the findings from the study identifying the determinants of poor sleep suggest that residents were disturbed at night by regular checks made by staff at night.

Staff Views and Practice

Care home staff in this study confirmed the nighttime practice of regularly checking residents which took place hourly to two hourly. Attempts were made to use low-level lighting and to keep noise levels to a minimum; however, the use of overhead light did occur and the sound of the nurse call systems could not be eradicated. Checking to see that someone is still breathing, to assess whether someone is alive or not, does require a certain level of light as does checking the bed to assess whether it is wet or dry. Ideally absorbent continence products are used; however, these are expensive and can be seen to stretch care home budgets. The products used in the United Kingdom are often provided and selected by the Local Authority Social Services and may be rationed per resident. Irrespective of which product is used, regular checking to ensure the residents' comfort is part of caregiving procedures at night. The observations made by care staff and resulting actions taken were acknowledged to be an important part of providing care at night confirming the findings of Eyers et al. (2012) where staff physically checked whether bedclothes were wet or dry and assessed visually whether residents were dead or alive.

Staff Attitudes Toward Nighttime Checks

The disturbing nature of checking procedures were acknowledged by care staff participating in the study. The majority of observations that care staff record are related to vital signs that could be monitored remotely with the use of appropriate sensors. However, care staff were overwhelmingly in support of continuing the practice of regular checking (96 %) even if information was available to them remotely. Of care staff who responded to the question, 15 % would probably and 81 % would definitely still want to physically check their residents even in the presence of a reliable monitoring system, thus indicating that care staff consider their own senses would be more reliable than any sensor and exemplifying a lack of understanding of how important nighttime sleep is to the well-being of an individual's ability to function during the day.

The checking procedures undertaken by the interviewed care staff clearly encompassed making sure the older people living in the care home are safe and sound. This involved observing the resident and the immediate environment and taking relevant action where needed. These observations are mainly related to vital signs that could be monitored remotely. The other important aspect of nighttime care is the saturation of the continence product used, and the majority of staff respondents (83 %) felt that a remote monitoring system would be useful to provide the relevant information.

Technology in Use: Nurse Call Systems

The one item of technology used in care homes is the ever-evident sound of the nurse call system. The findings indicate the key role of communication systems by both residents and care staff to establish contact with one another throughout the building. Of considerable importance to staff respondents was the ability to differentiate between levels of urgency on the alarm call system. The majority of staff felt two levels of alert were needed: "emergency" (90 %) and "assistance needed" (93 %). Over half (55 %) felt a third low-priority tier (social call needed) would be beneficial. The intention is to enable residents to indicate that they request the presence of care staff. However, interviewed residents said that they did not use the alarm call system because they did not want to disturb other residents or "trouble" already busy staff with their requests. They indicated an awareness that care staff needed to prioritize and other things might be more important. Instead many residents attempted to catch the attention of staff when they were passing in the corridor. Confirming that bedroom doors are left open letting light and sound into the room. This is likely to have been negotiated between resident and staff and will be perceived to be a convenient solution for both. These residents indicated that they might use a call system in which they could let staff know that they had a low-priority request in a non-alarming way. A subsequent survey exploring multi-tiered call systems indicated that care home staff disliked this idea (Carey-Smith et al. 2010). This may be due to the perception that this would generate extra requests for staff to deal with. However, the results from this survey also indicate that a significant proportion of staff see value in developing a communication system that will help them in the constant time juggling aspect of caregiving (Eyers 2007) where judgments need to be made about which task to undertake next. Our findings suggest that communication systems within care homes need to be reconsidered to also incorporate communication between colleagues and possibly facilitate a method of allowing residents to indicate the urgency behind the reason for using the call system.

A final issue inherent in alarm call systems relates to noise that forms the consistent ambient noise in any care facility, the buzzing or ringing sound of the nurse call system, possibly accompanied by vocalized calls for assistance. In addition there is often the need for care staff to raise their voices when communicating with residents who are hard of hearing and do not wear their hearing aids at night. At this point it would be erroneous to think that all residents could be expected to be hard of hearing and that consequently it would be irrelevant to consider noise-related issues. This is an aspect of care home life that calls for further more detailed research.

Technologies for Monitoring Nighttime Well-Being

Systems using noncontact sensors to monitor vital signs (pulse and respiration), body movement, bed occupancy, and sleep state are already in existence (Spillman et al. 2004; Tenhunen et al. 2011). As has already been stated in this chapter, sleep quality has a major influence on general health. An advantage of being able to measure an older person’s well-being during the night is that more accurate records of nighttime care could be gained, allowing staff to prescribe and assess interventions that are aimed at improving the sleep experienced by residents. Interviews revealed that both residents and care staff value personal contact during nighttime awake periods. An awareness of residents’ stage of sleep could maximize this important personal contact.

Wetness detection in incontinence products is also an area that has attracted considerable research attention (Zaffaroni et al. 2009; Wai et al. 2008). The sensors that perform this wetness detection must be built into the pad and be capable of transmitting information wirelessly to the monitoring system. For these sensors to be successful, it is likely that they will need to be fully integrated within the pad and add minimal increase to the cost of the pad. Integration is necessary to avoid the additional time and complexities associated with fitting an external transmitter to the pad. Overall cost of the pad is critical as it directly impacts on the cost of care.

Discussion and Conclusion

As the quotes from both the home manager and Madge, the nighttime care assistant, imply, “checking” residents at night is what is expected of care staff on duty. This was further substantiated by the work undertaken by the engineers highlighting the importance of the duty of care imposed upon night staff in care homes. Yet as both the exemplifying quote from Stanley and the actigraphy data indicate, care home residents’ sleep is disrupted by the “checking” processes that form part of caregiving at night. The disruptive nature of checking procedures is further underpinned by sleep research that indicates that light and noise impact on sleep. The provision of information to monitor dead or alive and wet or dry using technology could lead to a significant reduction of in-room nighttime checks. In conjunction with accommodating individual habitual daily routines, remote monitoring systems and advanced communication systems have the potential to improve sleep quality.

As the research undertaken by Bouwen et al. (2008), Ersser et al. (1999), Leger (1994), Livingston et al. (1993), and Stepanski et al. (2003) exemplifies, sleep is important to the well-being of older people. Depriving an older person living in a care home of sleep can be seen to reduce their quality of life. The evidence base identifying the determinants of poor sleep in care homes provides a starting point from which best practice can be developed. A fusion of person-centered care and the supportive use of technology has the potential to improve the sleep of older people living in care homes.

The provision of information to monitor dead or alive and wet or dry and indicate the stage of sleep using sensors could lead to a significant reduction of in-room nighttime checks. Addressing noise- and light-related issues with advanced lighting and communication systems would also reduce sleep disturbances that where observed. The intelligent implementation of technology in care homes has the potential to improve the sleep quality experienced by older people living in care homes.

A further advantage of remote monitoring systems using sensors is to immediately alert staff to concerning circumstances and thus draw attention to an older persons' needs in a timely fashion, rather than relying on short periodic checks to highlight emergencies or relying on the reluctant use of the nurse call system in an acute time of need. Remote monitoring also has the potential to enable staff to see when residents are restless, asleep, or awake, consequently facilitating the provision of care or company when a resident needs it, without disrupting deep sleep or the nurse call system being activated. Bedroom doors could be closed thus eliminating unnecessary light and sound that disturbs sleep. Intelligent lighting systems within the bedroom would reassure the older person when light is needed, for example, to find the way to the bathroom. In addition a monitoring system has the potential to provide automated record keeping, reducing the paperwork associated with care activities and reassuring relatives, management, and regulatory bodies that the residents were safe and sound throughout the night.

The perception is that within the context of a "duty of care," care staff are responsible for their actions and therefore appear to trust their own senses above those of a sensor. The strong sense of responsibility that involves personal physical involvement overrides any knowledge or understanding of sleep care staff or managers may have. Despite recent developments in information technology in many peoples' everyday life, when it comes to care provision, it is the personal relationship between caregiver and care recipient that is seen as of importance. Technology has the potential to be perceived as a threat rather than an element that could enhance caregiving. It could put jobs at risk, as after all "checking up" is seen to be the work night staff undertake. However, used appropriately, technology has the potential to support nighttime care and be advantageous for both residents and staff.

Facilitating good sleep has the potential to improve the cognitive and physical abilities of a resident so that the older person can participate more effectively in the undertaking of activities of daily living that care staff are supporting them with during the day, ultimately resulting in the provision of efficient and effective caregiving that extends social interaction between staff and residents that are not only initiated by the use of the nurse call system. For older people living in care homes, state-of-the-art technology could be used to support the care received at night and result in improved physical and cognitive abilities during the day. To be able to sleep like a log and wake up with a sense of well-being would surely add quality to life. It was not without reason that in the recruitment process, one of the participants spontaneously sang the old Beatles favorite with the words "It's been a hard day's night, I should be sleeping like a log. . ."

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Integration of Health Care and Social Care by Technology

Ilse Bierhoff and Wil Rijnen

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Abstract

The potential of ICT-enabled forms of support for health care, social care, informal care, and self-care can be exploited in a radically more effective way if these were more systematically embedded within a *continuum of care approach*. Integrated care should be regarded as a complex ecosystem of organizations, caregivers, technologies, and care recipients who are all interdependent. But the most important aspect is that the focus is on the individual care recipient. In order to make integrated care a reality, several research initiatives address this complex task by using different starting points. Initiatives focus on acceptance by users, the use of service platforms, electronic health records, cooperation between health and social care, supporting the role of the informal caregiver, and public

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procurement of innovations. Projects have in common that they are all focusing on the organizational changes needed to overcome barriers that currently prevent large-scale rollout and to build the critical mass needed to live up to the expectations raised by the results of small-scale pilots. This chapter presents the result of a literature review and several years of experience in carrying out the beforementioned research projects.

Keywords
Integrated care • ICT-enabled services • eHealth • Care continuum • Innovation

Introduction

As the population ages, the way we support older adults has to change. It is socially and economically unsustainable to have the same proportion of older adults being looked after in institutional care as we have today and to continue to offer care as we have done to date (Raad voor de Volksgezondheid en Zorg 2010; Rigby 2014; EIP AHA 2011). Both healthcare (chronic and acute) and social care (daily activities) are important aspects in supporting older adults to live safely and well at home. There is evidence that care service provision is enabled and can be improved through the use of ICT solutions (Rijnen et al. 2014a; Zorgverzekeraars Nederland 2011).

On an organizational level, however, up until quite recently, national welfare and health systems along with regional/local support practices were developing an increasing number of specializations, and clear boundaries prevented them to cooperate (Rigby 2014). Therefore, it may not come as a surprise that today's reality is characterized by more or less fragmentation and bureaucracy in current care provision systems resulting in disjointed and patchy support services. Such a silo-based care system has negative effects on the different people involved. For older adults, who often are confronted with multi-morbidity, this can cause practical difficulties like having to switch from one provider to another or being unsure about who is responsible for what. Also for (health and social) care professionals, this can lead to difficulties, for instance, if important care recipient information is available only at one provider but not at another or if double or adverse diagnostics and/or treatments occur. For service providers this separation between health and social care causes inefficiencies, duplication of resources, and potentially low levels of care and life quality.

Only recently the dangers of "closed silo service provision" have been recognized at the policy level, and steps have been taken to spread responsibility more widely and introduce cooperative structures, including third sector and citizens' groups. Some governments are now beginning to seek to improve collaborative support of older adults living in the community. Evidence points into the direction that models of integrated health and social care for older adults, supported by ICT, can result in improved outcomes, user satisfaction, and/or cost savings (European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry 2011). ICT suppliers are beginning to respond to this trend and make interoperable components available to care providers.

Despite positive experiences, there are problems with the integration, scalability, and interoperability of ICT systems. And, even worse, there seem to be barriers to move from a successful pilot to mainstream ICT-supported services. To overcome these barriers, several EU-funded projects focus on different aspects of the problem and have in common that there is a focus on organizational aspects, on ICT-enabled services, and on large-scale rollout to build the critical mass needed to live up to the expectations raised by the results of small-scale pilots. This chapter focuses on some of the key preconditions covered by and experiences acquired from the EU-funded projects INDEPENDENT,[1] SmartCare,[2] HEREiAM,[3] VictoryaHome,[4] and STOPandGO.[5] The main difference between the projects is the starting point they have in relation to the continuum of care; this ranges from welfare and participation services up to aftercare.

The HEREiAM project starts in one end of the continuum and aims to promote older adults' independence and active participation, by developing an innovative and user-friendly ICT platform for offering third-party services that can support them in managing daily activities.

VictoryaHome is a support system that monitors health and safety and facilitates social contact. The main goal of VictoryaHome is to improve people's well-being, independence, health, and safety – not only for older adults but also for their family, friends, and professional caregivers. It is therefore more or less in the middle of the care continuum focusing on a mix of services and on integration between informal and formal care.

Within the completed INDEPENDENT project, the focus was on enabling, with the help of technology, a better joining up of health and social care services as they existed at six trial locations across Europe when the project started. There was also emphasis on strengthening the participation of the so-called third sector, family caregivers, and voluntary community workers who would otherwise not be in the usual information sharing loop. This project therefore focused more toward the end of the care continuum with a focus on linking health and social care services.

SmartCare aims at delivering services that will provide full support to cooperative delivery of care, integrated with self-care and across organizational silos, including essential coordination tools such as shared data access, care pathway design and execution, as well as real-time communication support to care teams and multi-organization access to home platforms. The common services will allow efficient cooperative care delivery and empower all older adults, according to their mental capabilities to take part in effective management of their health, wellness, and chronic conditions and maintain their independence despite increasing frailty. This

[1]www.independent-project.eu

[2]www.pilotsmartcare.eu

[3]www.hereiamproject.org

[4]www.victoryahome.eu

[5]www.stopandgoproject.eu

project is also focused more toward the end of the care continuum with a focus on supporting technologies instead of “only” services.

The overarching strategy of STOPandGO is to pilot an innovative procurement process to improve the lives of older adults with long-term conditions, according to the instrument named “Public Procurement of Innovative Solutions.” STOPandGO services use innovative methodologies to enable greater mobility and independence of people living with long-term conditions. The services include both the health and social care activities provided by formal and informal caregivers, including the promotion of self-care and healthy lifestyles. As procurement can cover all sorts of services along the continuum of care, this project has the broadest approach.

These projects each provide complementary information and insight into ICT-enabled integrated care. The projects are complementary due to the fact that the care continuum does not refer to social versus medical care. Rather, it looks at care as a journey, from referral, and assessment, to delivery, outcomes and follow-up. The care continuum involves a range of stakeholders who play a role at various points along the care pathway. Key stakeholders can include the older adult, the family and informal caregivers, the community, governmental bodies, social care professionals such as social workers, and formal care assistants, as well as care coordinators and service managers and healthcare professionals such as general practitioners, nursing staff, and geriatricians. Within the mentioned projects this variety of stakeholders is represented and increased cooperation between the different stakeholders is one of the expected key outcomes of the projects. The activities carried out in the projects mentioned above are described in this chapter based upon three main topics: (1) the care network, (2) technology-related aspects, and (3) financial aspects.

The Care Network

With respect to the care network, two important aspects are highlighted in this chapter. The first aspect is the integration of a new approach into care processes to be sure that expected outcomes can be reached. The second aspect is the increased role of the informal caregiver, third sector organizations, and volunteers.

Real Integration into Care Processes

In many projects pilots are executed in parallel with regular care. Despite positive results, the step to mainstreaming appears to be difficult. Within the INDEPENDENT project, experiences have been gained resulting in guidelines for the deployment of integrated care service delivery (INDEPENDENT Project 2014). The following requirements are extracted with regard to organizational, staff, and business issues.

In relation to organizational aspects, it is vital to adapt current systems and processes to the new way of working. When the ICT solutions are offered alongside the regular care, it is not possible to optimize processes, and the use of ICT solutions will be treated as an experiment on the side and, therefore, will not deliver the expected outcomes. Achieving expected outcomes requires a clear vision from a care organization on how the use of ICT is intended to be of added value to care delivery and how ICT can act as an enabler for integrated care.

Care professionals are often the stakeholders that have the most direct contact with the care recipient and on a daily basis experience the problems related to fragmented care provision. They are therefore the ideal ambassadors for integrated care. For that it is important that they are convinced about the benefits of sharing information and increased cooperation among care professionals. As the integrated care approach requires a major change in the current work practice, involving care professionals as experts in their field increases their motivation and willingness to participate. In terms of benefits from a new way of working, care professionals are interested in ways to increase care quality, care recipient satisfaction, and workload reduction. One aspect of workload reduction is to make sure that ICT solutions are seamlessly integrated into existing infrastructures and procedures. This requires a clear vision on how technology can enable service delivery before starting to use technology.

One specific aspect of real integration into care processes is the continuity of service delivery after a successful pilot. In order to accomplish sustainable service delivery, all stakeholders intended to have a role in the service delivery should be involved in the pilot. For example, when the involvement of certain organizations is needed from a business point of view, they should be involved when setting up the pilot, so that they can also indicate what is important for them to test during the pilot and to have their initial commitment. It is very difficult to include other organizations to play a role in financing the services after the pilot has ended. The focus should be on flexible partnerships and alliances to reduce risk and uncertainty, provide ready access to particular resources and activities when needed, and make it more likely to achieve economies of scale at any given point in time. Although stable long-term relationships are often important, this needs to be balanced with the market agility enabled by such a mix. Partnering with (other) commercial SMEs and large companies is often a hallmark of successful cases, especially where these provide strong brand recognition and large regional or national scale, for example, through dealership networks (European Union 2013).

For example, within the SmartCare project, Máxima Medical Centre in Eindhoven/Veldhoven in cooperation with Smart Homes, a case study is planned with a focus on cardiac tele-rehabilitation for care recipients with coronary artery disease. This offers an example of how ICT solutions can be integrated in care processes. The focus of this case study is on deployment and mainstreaming, rather than on pilot testing.

To optimize multidisciplinary care after hospital discharge, it is of great importance that all care providers communicate and collaborate well. Therefore, care services will be coordinated by a care coordinator. He/she will take care of ongoing treatments by healthcare providers (such as physical therapists, dieticians, and psychologists), and social work is continued and well organized outside the hospital

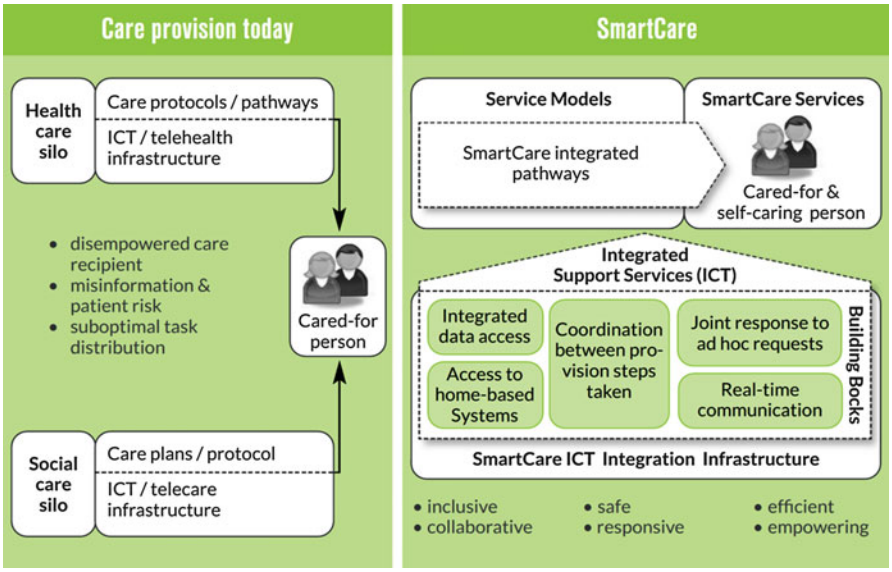

Fig. 1 Vision of SmartCare project

if necessary. Ideally, it would be one single person in charge irrespectively whether the care recipient is in the hospital or at home. In practice, due to current financing mechanisms, the role of the care coordinator will be played by a hospital case manager (in the 3 months after hospital discharge) and by a GP assistant (after 3 months). Besides, care professionals will share data from their individual systems and use the SmartCare ICT platform to support their workflow across sectors and to view data from the different caregivers. Information shared from the hospitals and general practitioners could be lab results, measurements, notes, symptoms, and diagnosis as well as goals set with the care recipient, activities, questionnaires, reports, and self-care indicators. They will also be able to see the information provided by the different actors such as care recipients, informal caregivers, home care organizations, and social workers.

This case study is part of the SmartCare project and adopts this vision of the SmartCare project toward integrated care as shown in Fig. 1. *In this example the care coordinator plays a key role in ensuring that multidisciplinary care is offered. The SmartCare ICT platform supports this multidisciplinary approach.*

Support and Peace of Mind for Informal Caregivers

As human resources will be limited in the near future, more tasks and responsibilities are allocated to informal caregivers (Eurocarers 2014; Hoffmann and Rodrigues 2010), priceless and inexpensive at the same time. In addition, the informal caregiver lives in close contact with the care recipient, which is an extra added value in monitoring and supporting beloved ones. Close involvement of the informal caregiver, however, requires a well-thought approach. In line with more tasks and responsibility for informal caregivers, the support of informal caregivers is an increasingly important aspect of delivering services.

Support can be given in several ways. Within the INDEPENDENT project, positive experiences have been gained with giving informal caregivers access to data about the care recipient. This can lead to a sense of reassurance. The informal caregiver can also be supported in dealing with the disease of a care recipient by learning about a disease but also by sharing frustration and feelings. Informal caregivers like to receive clear information about the care recipient's condition, how to deal with it, and the existing equipment and services. Therefore, it is important for them to stay in contact with care professionals, preferably accessible through one central contact point.

In terms of the burden of informal care, it is important to find a balance between work capacity and work load. Building a network of informal caregivers and professionals can help to divide all the tasks, including care, welfare services, personal hygiene, domestic help, mobility support, small chores, and administration. Jointly this network can provide the needed assistance. The burden of informal care is not only related to time but also emotional burden plays a role. Dealing with people who need more and more care and support can be rather difficult. Besides all the practicalities and tasks, it can also be painful to see that the health situation of a beloved one is deteriorating. Professional mental and emotional support or peer-to-peer contact can be helpful. Besides, it is important that informal caregivers take also time for themselves. Respite services (e.g., care in daytime) can lower the continuous burden on the informal caregiver. In some situations, a safety net (backup) would be welcomed to temporarily and immediately take over care when necessary.

Care organizations admit the importance of informal care and see the added value of an integrated care approach. Nevertheless, they mainly focus on the care recipient. Informal caregivers would like to stay in direct contact with the care professionals and to actively take part in the care processes. An example of how formal and informal care can cooperate is given by the VictoryaHome project. Within this project the focus is on supporting the informal caregiver by offering peace of mind and by offering follow-up by care professionals when needed.

The VictoryaHome system is a tool for caregivers, professionals, as well as family and friends to create possibilities for older adults to live their life as they always have, in their own home. It includes smart devices like an activity monitor, fall detector and an automatic medication dispenser, a smartphone app called serenity app for family and friends (Fig. 2)*, an online dashboard for response centers, and the Giraff mobile telepresence device that stays with the older person* (Fig. 2).

The smartphone app shows family, friends, and other caregivers at a glimpse whether everything is OK with the older adult by presenting an overview of the older adult's well-being, by showing, for example, missed medication, falls, and "visit me" requests sent by the older adult via the Giraff. In response these caregivers can use the Giraff to make a virtual visit. In case of emergency, professional care can be included using the dashboard and the Giraff for instant presence.

Fig. 2 VictoryaHome smartphone app (*left*) and Giraff (*right*)

The app's widget will have different states, depending on what is happening with the older adult:

- *Green: Everything is OK (no alarms)*
- *Yellow: Warning (for instance, missed medication)*
- *Red: Serious event (for instance, a fall)*
- *Gray: The mobile app user has not logged in*

By having this information at their fingertips, informal caregivers can take control and handle the events, rather than leaving it to the call center and professional caregivers. Informal caregivers will have much more peace of mind, knowing that they can get in touch very quickly, that they will be notified if something happens, and that if they are unable to assist, the call center and professional caregivers will take over.

In February 2015, long-term trials have started in four countries (The Netherlands, Sweden, Norway, and Portugal). These evaluation studies will include 50 VictoryaHome systems with over 100 users (older adults and family). The older *adults will have the VictoryaHome system installed in their homes for a minimum period of 8 months. Family and friends, professional caregivers, and response centers will all be involved following newly defined care procedures.*

Technology

In terms of technology for integrated care, three relevant topics will be described in this section. The first one is interoperability to ensure sustainability of systems. The second one is the use of electronic health records as the communication bridge between different stakeholders. The third topic is the use of modular service platforms to adapt and align service delivery with changing needs of individual users.

Interoperability

The European Commission recognizes that the interoperability of European public services is a necessity, identified in the Digital Agenda for Europe, which is essential to maximize the social and economic potential of information and communication technologies. In the case of healthcare services, the necessity becomes urgent in order to cope with the new challenges to be faced regarding continuity of care and sustainability of the public systems, as is established in the eHealth Action Plan 2012–2020 (European Commission 2012). The implementation of interoperability is a challenge that is necessary to prepare, knowing the prerequisites and the different types of standards as well as the various levels of interoperability. Only then it is possible to take the appropriate decisions. The growing importance of interoperability comes largely from new requirements that healthcare systems are facing in organizations and the functionality to continue providing an effective and efficient service in a sustainable manner, including demographic changes, mobility of citizens, and equity of access.

Different types of interoperability can be distinguished: technical, legal, semantic, and organizational (European Union 2011). Technical interoperability targets the planning of technical issues involved in linking computer systems and services. Agreements should address interface, security and messaging specifications, communication protocols, data formats, dynamic registration, and service discovery specifications. Legal interoperability focuses on aligned legislation so that exchanged data is accorded proper legal weight. Semantic interoperability focuses on the precise meaning of exchanged information which is preserved and understood by all parties. It can take the form of reference taxonomies, schemes, code lists, data dictionaries, sector-based libraries, etc. Organizational interoperability focuses on coordinated processes in which different organizations achieve a previously agreed and mutually beneficial goal. It therefore targets integrating business processes and meeting user requirements by making services available, easily identifiable, accessible, and user focused.

Within the STOPandGO project an interoperability framework is being developed with the goal to be implemented as part of the tender specification. The goal is to make sure that interoperability aspects are taken into account when bids for services are submitted, ensuring that all offered solutions provide full interoperability to guarantee seamless service provision and avoid the risk of purchasing "black box" technology. The STOPandGO interoperability framework will establish a common minimum, based on previously developed European standards (mainly those proposed by the concurrent initiatives – EN ISO 13606, EN ISO 13940), to guarantee that the services, at least, will be able to communicate normalized information while at the same time retaining the data's full intended meaning and context (STOPandGO Project 2015).

The Electronic Health Record as a Bridge for Communication

When collaborating in the continuum of care, it is crucial that every caregiver involved in the treatment of a care recipient is able to easily and securely access the most recent health-related data (Krijgsman et al. 2014). Therefore, in recent years, a huge step is made with respect to digitalization. Thanks to a shared electronic health record (EHR), care professionals will eventually be able to exchange care recipient data digitally. In this way, double or adverse diagnostic tests and treatments can be avoided, and the chance for medical mistakes can be decreased. The care recipient does not have to tell all details when visiting another general practitioner (GP), and the specialist and pharmacist can look into the EHR for the medical history, medication usage, and possible allergies. New data as treatment reports are added to the EHR.

Up till now, most social care providers and home care organizations do not record data electronically and have no access to shared files. They often only have electronic administrative and financial systems and make use of paper files and paper care plans. Care coordination is most often done by direct, personal contact between professionals, also across organizational borders. Transfer nurses of the hospital and home care/nursing home nurses will inform each other through some kind of handover documentation. In case of questions or specific treatment and care options, there will be a phone call with the specialist.

The integration between healthcare and social care, however, could have a huge added value. Social workers could detect changes in health or check for evolution when visiting the care recipient at home. It is also interesting for the social worker to know when the condition of a care recipient is deteriorating and he/she might need extra support. Slowly, social care providers and home care organizations start to make use of electronic files and experiment with e-transfers. In this way the organizations are moving toward care recipient-oriented EHR systems.

In terms of the role of the client, different approaches can be taken. Care recipients could have access to the EHR used by care professionals but most of the time they use an online portal to gain access to their data. An important aspect to take into consideration is who is allowed access to the data. Within the SmartCare project the following approach is taken in relation to data management:

The care recipient accesses the SmartCare ICT platform for consulting care-related data in their personal record. Information accessible to the care recipient also includes diagnosis, measurements taken by themselves or by professional caregivers, data on lifestyle and social issues, and treatment plans and notes. Besides medical data consultation, the SmartCare ICT care recipient portal will serve as a services platform for a wide variety of interactive apps to increase quality of life, social connectedness, self-management, a healthy lifestyle, e-inclusion, etc.

The care recipient plays an active and prominent role and stays in control of the private data in the SmartCare ICT platform. He/she decides whom to give access to which piece of information. He can include informal caregivers, social workers, and care professionals in the treatment and permits access to the electronic data in the SmartCare platform. The care recipient defines the access rights for each relevant stakeholder.

Upon consent by the care recipient, relatives and/or friends can have access to the electronic data through the SmartCare ICT platform. In principle, they perform all tasks for the care recipients on permission with the person they care for. A delegation policy – including the use of YubiKeys – controls the access and data management.

Social workers involved in service delivery to the older care recipient deliver different types of on-site support such as education in lifestyle, including diet, exercise, alcohol, and smoking behavior. A number of SmartCare users receive home care services such as cleaning, food delivery, bathing, shopping, and support for other daily activities. These social workers have access to selected pieces of information (stored by other care providers such as hospital staff and GPs) about the care recipient's disease and self-care capabilities. They might also leave notes in the care recipients' personal record, set up goals together with the care recipient, and help with filling out self-assessment questionnaires.

Modular Service Platforms

A service platform is a well-integrated set of hardware and software components to support the execution of tele-health and tele-care services (Krijgsman et al. 2012). More often, service platforms are seen as the main entry point for end users to make use of services that can assist them in living independently. The advantage of a modular service platform is that it can be fine-tuned to the needs of an end user at any point in time and by doing so can provide exactly the services that end users perceive as beneficial to them.

After an evaluation of existing service platforms carried out as part of the HEREiAM project (Rijnen et al. 2014b), guidelines related to service platforms were developed. The guidelines focus on the added value of the services offered, interoperability, and interface design.

To offer added value for the older adult, it is important to involve both the care and social network around the older adult. A service platform is often used as a tool to interconnect all relevant parties in the care network of the older adult, living either in institutional care facilities or at home. Depending on the kind of target user, the network can vary as well. In the last few years, more and more parties are motivated to hook up to the platform, ranging from formal and informal caregivers to municipalities and communities. Also players not related to care provision like schools, banking companies, and local entrepreneurs start to become interested in being part of the network.

Offering flexibility and the ability to adapt to changing needs of individual users also provides added value. In the beginning service platforms were simple and offered limited functionality; most of today's platforms offer a combination of comfort services, well-being, safety, and care. To provide all these functionalities, platforms are linked with external websites and systems from third parties. The user can choose which services to install and use.

A service platform can only offer added value on a continuous basis when it remains interesting for a user to visit the platform. In order to create activity on the platform, tasks can be allocated to formal caregivers, informal caregivers, and volunteers. Professionals (home care or care institutions) can put services and information online for specific user groups. The informal caregivers – friends and family – can add extra enjoyable and personal content like messages, pictures, music, and so on. Also new kinds of voluntary work emerge, where people provide content for others and help each other out.

The interoperability aspects is related to the fact that as a service platform provider, you cannot know everything and do everything yourself. By making use of standards and open software architecture, it is easier to collaborate with third parties. For users this will prevent them from vendor lock-in. Furthermore, users already have ICT equipment at home, and/or they prefer to choose their own brand and type of device. Therefore, service platform providers make their systems accessible on each device; this is also what users expect to be possible.

The user interface is the main entry point for the user to acquire the services, and this is why the accessibility is a vital property of the interface. Besides large screens, large font sizes, and large buttons, increasing attention is paid to overcome age-related restrictions. Certain touch screen interactions like right mouse click, double click, and swiping are enabled on some platforms, and even solutions like eye tracking and speech input are applied to make systems usable for users with a paralysis.

Financial Aspects

Economic outlook for Europe remains extremely challenging. Resources will be under unprecedented pressure to meet the rising demands of the graying population. Therefore, it is needed to further improve efficiency and to transform the way services are delivered. Reshaping the provision and organization of health and social care services requires collaboration among all stakeholders. Changes in care ask for trust, commitment, and continuity in policy and financing (Wind 2012).

The goal of the integrated care approach is high quality for all, now and for future generations. The commitment to put quality at the heart of everything must be in the context of care cost cuttings. Money needs to be spent wisely and fairly to secure the best outcomes for both care recipients and the tax payer. Innovative approaches to service delivery are ever more important in the current economic climate to deliver better at lower cost (NHS England 2012). Since healthcare systems switch their reimbursement model from paying for products and services to rewarding clinical and health-economics outcomes, interventions must be targeted to the right care recipients, and adapted to each individual situation, so to get the best possible results (Kearney 2013).

Cost-Benefit Shifts and Shared Budgets

By definition, integrated services are delivered in a multi-stakeholder environment encompassing older adults, informal caregivers, health and social care professionals, provider organizations, insurance companies, and governance bodies. Applying an integrated approach, tasks and responsibilities are shared. Organizations take new responsibilities and operate in new ways to shape better service delivery. As a consequence, cost and revenue streams are mixed up. Sometimes benefits will take place at another point than the investment is made, resulting in unbalance for the different parties involved. It can be imagined, for example, that one stakeholder has to bear all or most of the costs of the service (investment and/or running costs), while one or more other stakeholders reap most or all of the benefits. This kind of cost-benefit shift can result in the disadvantaged stakeholder refusing to become part of the service. Therefore, a thorough cost-benefit analysis of the complete care provision picture is crucial to build a viable business model. To overcome the abovementioned cost-benefit shifts, money can be transferred among different stakeholders accordingly, or it can be decided to set up a common budget. Joined-up care budgets will lead to a shared responsibility and more cost-efficiency. After all, a split in budgets equals a split in tasks.

Hospitals, doctors, and care organizations across Europe are paid by different methods: salary, capitation payment (fixed yearly payment per care recipient), and fee-for-service. Each of these principal payment methods has advantages and disadvantages that result from the degree to which the payment method is related to actual care output, since financial profit can be influenced by over-registering, under-servicing or over-servicing, and over-referral to high-cost specialists (Esmail and Walker 2008). A shared responsibility for results in combination with shared budgets puts the focus on collaboration and cost-efficiency (Wind 2012). Together, treatment should be reformulated with regard to task allocation. The goal is to keep older adults in primary care as long as possible and only refer them to (more expensive) secondary care when necessary. In addition, it should be considered how care recipients can be supported by social services, informal caregivers, and volunteers, avoiding unnecessary care expenditures (Wind 2012). In this way, collaboration can lead to positive healthcare results in a cost-efficient way. A good example of such a quasi-market-oriented approach is the Lombardy healthcare system (Italy), in which a separation between the purchaser and provider of healthcare can be found and competition between public and private providers is stimulated. This Lombardy model has driven to a good quality of services, together with a sharper presence of the private sector (Esmail and Walker 2008).

Public Procurement of Innovations

Within care and cure services augmented by technology can increasingly meet the current needs of older persons and their caregivers. They have often been developed through publicly funded research and development. Several local programs, usually focusing on specific health issues in a limited area, have demonstrated that these innovative services can significantly improve health and care outcomes, reduce morbidity, improve economy, and extend service reach. Most of the initiatives are driven by the introduction of the technology, adapting the organizational models in consequence.

Time is ready to reverse the process of technology adoption: several effective solutions are available, and the process should start now from a clear engagement of public decision makers to introduce more effective and sustainable service models for care and cure provision, perhaps with different professional profiles and innovative forms of contracts, based on performance. Then the technology could assist (or enable) the desired change.

Within the STOPandGO project, a new procurement process is developed and tested by seven procurers across Europe. The novelty of the procurement process is not in the focus on a particular technological component, but in the integration and in the simultaneous improvement of the models of care and cure, to provide care and cure services, i.e., managed services augmented by a coherent set of interoperable technological components.

The unique aspect of the approach of the STOPandGO project is it focuses on procuring cost-effectiveness/outcomes via the development of outcome-based service specifications with clear built-in key performance indicators (KPIs). KPIs will be developed to assess the clinical and social outcomes in the target population; to assess the satisfaction of care recipients, informal caregivers, and professionals; to monitor the progress of the deployment; to evaluate the performance of the services; and to evaluate the innovative technological solutions.

In order to build critical mass, the transnational procurement will take place in the Netherlands, United Kingdom, Italy, and Spain, which will make up more than 5,000 users. During the project a standard “European Specification Template” (EST) for the tendering process will be produced and validated (STOPandGO Project 2015). The EST will consist of criteria to assess the bids for each component of the tender, a detailed list of potential indicators that could be later used to evaluate the deployment of the contracts, core components that create a single pan-European tender specification with agreed "national" provisions to reflect localized service and delivery requirements, and guidelines on applying the EST at the level of a locality.

Conclusion

The care continuum does not refer to social versus medical care; rather it looks at care as a journey. The projects mentioned in this chapter each focus on a subset or specific aspect of this journey, at a piece of the puzzle. It can be argued that the only way to really achieve integrated care is to include all aspects, but on the other hand in order to achieve results, the intended change in care processes should also be manageable. An approach that works in practice is to focus on a specific disease/ end user needs and involve all stakeholders in that care/service chain.

Current projects show that even with barriers that prevent from having the ideal situation, still agreements can be made among partners to achieve a higher level of integrated care. Interoperability, the willingness to reorganize care processes, and new financing models remain to be the key aspects to focus on to achieve integrated care.

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Part II

The Technical Aspects of Ambient Assisted Living: Functionalities, Systems, Engineering, and Design

Smart Homes, RFID, and Wandering

William D. Kearns and James L. Fozard

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Abstract

Radio frequency identification devices (RFID) provide information about the identity and location of people and objects in a monitored space. Passive RFID such as those found on many grocery items have no power supply of their own and are powered entirely by energy from the radio signal transmitted at them, and their range is approximately 1–3 m. Passive tags indicate presence but not vector information. Active RFID tags typically contain a battery which allows the devices to respond to signals transmitted potentially over one hundred meters. Active tags can vary significantly in complexity and the kind of response they emit when struck by radio signals from a reader. In the simplest case, the active RFID tag responds just like the passive one but at a much greater range. In the ultra-wideband version, the RFID tag is the functional equivalent of an aircraft

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transponder that reveals vector, and identity of the wearer at all locations throughout the monitored area with a practical accuracy of 20 cm in x, y, and z (altitude). The applications of RFID in smart houses and the management of dementia – particularly wandering – are reviewed, and the uses of RFID in clinical research and fall-risk prediction are briefly discussed.

Keywords
Active and passive RFID • Smart homes • Dementia wandering • Fall risk prediction • Ambient assisted living

Introduction

The increasing numbers of individuals retiring from the work force have placed enormous financial and logistical strains on nations seeking to provide services for older citizens. An inverted pyramid with fewer available caregivers limits older persons' options to independent or semi-independent living or transfer to community-based care (assisted living or a nursing facility). In some European nations (e.g., the Netherlands), the government has moved to phase out funding for assisted living facilities in favor of facilitating programs promoting aging in place until final transfer to a nursing home. Aging in place promises a number of potential benefits to elders preferring to remain in their own homes and to governments seeking to control costs while encouraging elders to maintain their independence. Implicit in "aging in place" is service delivery via telecommunications or mobile caregivers who provide care on site or transport the elder to a care facility. The assumption is these methods will ultimately be less costly than providing community-based (residential facility) care.

Smart Homes and Location-Aware Technologies

Smart homes promoting aging in place are domiciles equipped with technologies that sense the environmental conditions and occupant behavior and physiological measures (Tamura 2012) and accumulate data with the intent of maintaining or improving the quality of life of the resident and/or caregiver (Demiris and Hensel 2008). The information gathered may be stored and acted upon locally or distally and can serve various purposes, including passive *surveillance* or remote monitoring of elder health and behavior that can include telesurveillance, telecare, or telemedicine. A more interactive use of surveillance data is *ambient assisted living*, a form of pervasive computing that involves an artificially intelligent agent detecting changes in resident or building data and interacting to alter resident behavior or the local environment. The agent may present memory cues to a person struggling to remember the next behavior in a routine action such as hand washing (Frank Lopresti et al. 2004), or it may electronically lock an exit to prevent a person with dementia from wandering away and becoming lost. The malevolent “Hal 9000” from Stanley Kubrick’s “2001 A Space Odyssey” provided us with a notorious example of an ambient AI environment gone awry. Today’s smart homes are considerably more benign, but their complexity and expense have continued to limit widespread adoption Demiris and Hensel (2008), but technology development continues in engineering environments. An early smart home oriented specifically to rehabilitation was the University of Florida’s “Gator-Tech Smart House” (Helal et al. 2005). The Gator-Tech Smart House served largely as a technology development platform, and little behavioral or health data was collected on residents during its operation (it is currently inactive). Demiris and Hensel (2008) listed a total of 21 smart home projects active worldwide in 2008. The University of Missouri’s Tiger Place (Rantz et al. 2013; Galambos et al. 2013) has applied a variety of sophisticated passive and active sensing systems, including optical recognition and radar-based gait estimation to monitor the movements of older adults in a “smart” independent living facility. Tiger Place researchers seek to reduce fall probability by developing online metrics which can assess fall likelihood from changes in normal mobility over time that are detectable by a mix of optical and radio frequency monitoring.

Smart home retrofit technologies have progressed significantly, and home automation products (i.e., X-10) allow novices to create home networks capable of managing lighting, simple appliances, and even door locks. For the more skilled, ZigBee networks and Arduino microprocessors invite creative hobbyist to devise home automation products customized to meet their specific needs. For example, a person suffering cognitive impairment related to dementia might benefit by receiving simple memory prompts to remember to take their medications whenever they approach a wall-mounted iPad located near their bathroom that is triggered by a passive infrared sensor.

Most older persons remain in good health throughout the latter portion of their life; yet with advanced age comes an increasing likelihood that an older person will suffer with dementia. The likelihood of getting dementia rises to 50 % at age 85 with potentially significant yet slow deterioration dragging over several years, making early transfer to a nursing home a potentially bankrupting event for the elder and their caregivers; US nursing home costs can exceed $50,000 per year. Technologies capable of reducing the burden of caring for a person with dementia are particularly attractive because they may offset the psychological and physical exhaustion resulting from the extended vigilance task, that is, caregiving, especially if the care recipient wanders.

RFID Technologies

A number of technologies are available for the management of wandering behavior and dementia. Many of these have been presented in a recent engineering analysis by Applegarth et al. 2013 and they include door and chair alarms, mattress pads with sensing capabilities, and advanced systems employing radio frequency technologies and RFID tags. Briefly, radio frequency ID tags respond to radio signals at specific frequencies by echoing back a response code that incorporates a specific identification number that informs the transmitter as to who heard the signal. RFID tags come in two types, the familiar passive tag found on many grocery items and the more expensive active tag. Passive tags have no power supply of their own and are powered entirely by energy from the radio signal transmitted at them, and their range is approximately 1–3 m. Passive tags indicate presence but not vector information. A somewhat controversial use of passive tag technology in dementia wandering was presented by Digital Angel, Inc., which received US Food and Drug Administration approval for a glass-encapsulated RFID device for implantation in the upper arm. The glass cylinder containing the RFID was approximately the size of a grain of rice and was designed to function for over a decade and have minimal physiological reactivity. In practice the tag was to be read by an electronic reader in the form of a "wand" to be passed over the elder's arm by authorities involved in the retrieval of the lost person who wandered away from their domicile. Many persons with dementia who wander away are found with no identification materials, making their recognition by authorities difficult and delaying their return home to their caregivers. The subcutaneous implantation of the device had the advantage of reducing stigma since it was invisible to anyone without a reader, and the implanted device only responded with an index number in response to the reader's transmission (Brent Ballard, Vice President, Digital Angel, Inc., personal communication). The number was indexed in a secure database accessible to authorities and medical personnel which would reveal the identity of the individual and any information critical to their care. Unfortunately significant marketing hurdles prevented this scheme from reaching commercial viability at the time, although Kearns et al. (2007) found that older veterans expressed few qualms about being implanted with an identifying microchip, likening the process to having a pacemaker or other medical devices installed. Interestingly, VeriTeQ recently acquired rights to Digital Angel's tag, and it is now marketed as the "Unique Device Identification" (UDI) incorporated into implanted medical devices such as artificial knee and hip joints, breast implants, etc., to improve quality control of these devices. Passive RFID continues to make inroads into ID and credit cards and into inventory control systems where recordkeeping of large numbers of items imposes significant time and labor burdens. Doubtless passive RFID will continue to find new uses in the management of wandering in persons with dementia as practitioners and researchers discover its untapped potential.

In contrast to passive tags, active RFID tags typically contain a battery which allows the devices to respond to signals transmitted potentially over 100 m. Active tags can vary significantly in complexity and the kind of response they emit when struck by radio signals from a reader. In the simplest case, the active RFID tag responds just like the passive one but at a much greater range; these tags are currently employed in wander management applications such as WanderGuard which electronically locks an exit door when a person with dementia in danger of eloping approaches. The WanderGuard tag gives no information on its direction of approach, speed, or its activity prior to activating the lock (and/or possibly notifying an attendant or triggering an alarm). Some active tag RFID have recently been hybridized with optical devices to provide directionality and some ranging functions. CenTrak, a provider of services for the US Department of Veterans Affairs real-time location system (RTLS) project recently awarded to Hewlett Packard (see http://www8.hp.com/us/en/hp-news/press-release.html?id=1358799#.Upztcye0b1M), makes use of optical interference patterns to slice the monitored area into approximately 3 × 2 m zones, allowing the system to get approximate tag location at all times, not just when approaching the exit door. The tag's identity is also broadcast on the optical channel allowing differentiation of multiple tags and persons.

One of the more elaborate and expensive variants of active tag RFID is the ultra-wideband implementation. Here the RFID tag is the functional equivalent of an aircraft transponder that reveals vector, speed, and identity of the wearer at all locations throughout the monitored area with a practical accuracy at the time of this writing of 20 cm in x, y, and z (altitude). Because the system also generates altitude data, it is uniquely suited for detecting when an individual has fallen (Bowen et al. 2010). An individual who fell will appear to have zero altitude above the floor. Approaches toward an exit door can be readily determined from the x-, y-, and z-coordinate data generated as often as 10 times per second while the tag is in motion.

RFID Technology and Dementia-Related Wandering

Wandering is among the most difficult behaviors caregivers of persons with dementia must deal with, yet defining what exactly wandering is has proven elusive (Algase et al. 2007). Algase and colleagues reviewed the literature and found more than 20 definitions of wandering, some of which were contradictory, but a common theme running through all was the presence of aimless or random ambulation. Paradoxically, it is patterned walking (lapping and pacing) and not aimlessness that has garnered the most attention by Algase. This may be due in part to the innate ability of humans to perceive patterns in the actions of others but our relatively poor ability to detect its opposite, randomness. Randomness in movement paths, the common characteristic of wandering definitions, must be independently quantified to gain a better understanding of wandering's etiology and learn how to control it. Without good measures of randomness, the common element of all definitions of wandering, progress in understanding wandering, and its management is slowed.

To study random ambulation, Kearns et al. (2008) discarded the fallible human observer in favor of precise indoor tracking technology. Observers can maintain attention on perhaps one or two individuals at a time and may miss important events if they glance away briefly or leave the site. The insertion of a stranger with a clipboard attempting to catalog movements of an elder in an assisted living facility or private home can be highly reactive, changing observed behavior. A ubiquitous tracking system that remains on station for weeks at a time and monitors many individuals simultaneously can gather necessary longitudinal data and aggregate group statistics required for a more complete understanding of the genesis of wandering in a large number of individuals. The second, more crucial factor involves the extraction and quantification of random movement from the tracking data, something humans cannot do by simple observation (e.g., what does "random" look like and how does one train a person to estimate if one is walking twice as randomly as they did yesterday?). Counting laps or pacing episodes is considerably less challenging because they are periodic and their topology can be defined; however, their periodicity means they are not truly random. The quantification of randomness in paths gathered from coordinate data has to be accomplished mathematically using analytical techniques such as Fractal Dimension, which quantifies each movement path as a continuous number ranging from 1.0 (a perfectly straight walking path) to 2.0 (a completely random walking path approximating Brownian motion or a "drunkard's walk"). By averaging the Fractal Dimension for all paths of each ALF resident over 1 month, Kearns et al. (2010) found they could empirically determine the amount of random wandering present in each person's walking, and this metric was negatively correlated ($r = -.45$) with mini-mental state exam (MMSE) scores (Crum et al. 1993) and specifically to the MMSE geographic orientation items (Kearns et al. 2011). The geographic orientation items measure the ability of an individual to discern their position in space. These items include the following "What state are we in?" "What city are we in?" "What is the street address of this place?" Persons who could answer all the items knew where they were and had less lower Fractal Dimension scores and made less "tortuous" paths (the paths had fewer random turns) than those who were more geographically disoriented according to the MMSE items. In short, our subjects were indeed informing us that they were lost in the most well-known places and that the randomness contained in their paths reflected this fact.

RFID and Fall-Risk Assessment

In a more recent study (Kearns et al. 2012), 53 ALF residents had their Fractal Dimension values calculated continuously over 1 year as they traversed a monitored space between their bedrooms and the dining area. Fall and medication history in the prior year and standardized gait and balance measures, MMSE, and medication history at the outset of monitoring were gathered. Over 43M movement measures were recorded over the 1-year monitoring interval, and the analysis of the movement variability in the week prior to a fall found significantly higher Fractal Dimension values for fallers than for elders who never fell. Furthermore, a logistic regression found that Fractal Dimension and fall history together resulted in over 80 % correct classification (faller vs. non-faller) compared to a rate of only 50 % correct when fall history alone was used. It is noteworthy that travel speed was removed as a predictor when Fractal D was added to the equation.

RFID have significant potential for informing a person with dementia about the world surrounding them. The unique number borne by each tag can be associated with any object, allowing a smart phone or other wireless device to serve as a prompting device capable of showing a short video on what to do with the object.

This could be helpful in the case where recognition and procedural memory had become impaired.

In earlier examples, the location and identity of the person wearing the RFID tag was the main goal of the location-aware technology. In the present example, the location of unique objects in the environment is the primary goal of the technology. Accordingly, the functions of the tag reader go with the person. Once located, the use of the object can be communicated to the user as described in the example with the smart phone.

Kim et al. (2007) describe a "smart" glove consisting of an RFID reader plus glove-embedded technology that allows the wearer to remotely sense and control devices. One application was remotely controlling devices in a vehicle driven by the person wearing the glove using a code of tapping and pinching the fingers. Another very sophisticated application was the use of the smart glove and supporting computer capabilities in a classroom to inform students and a teacher what RFID-tagged educational tools such as a chalkboard located in the classroom were in use when, by whom, and for what purpose.

In these applications "...hands do not have to hold and manipulate interfacing devices, but hands can be the interfacing devices themselves for ubiquitous environments to interpret" (Kim et al. 2007, p. 546). Depending on the application, the tagged object or space may provide only information of its existence and location to guidance concerning its functions and directions for its use.

Applying RFID Technology in Clinical Research in Dementia

Up until this point in the discussion, we've considered the role of RFID technology to direct clinical intervention (e.g., implantable RFID), using it as a tool for studying wandering behavior itself (Fractal Dimension) or helping to identify objects for persons experiencing early-stage dementia (i.e., smart glove). In this section, we describe a potential application of RFID to clinical research studies which has a direct impact on the development of new therapies. Recently Moore and colleagues (Moore et al. 2013) presented evidence supporting the use of RFID as a method for assessing the effectiveness of behavioral interventions for wandering. These investigators sought to test the effectiveness of different visual barriers on exiting behavior in 19 veterans with mild dementia living at home. Two visual barriers (an opaque cloth door covering and a black doormat with diagonal white stripes that created the appearance of depth) were tested in a counterbalanced order for 2 weeks separated by 2-week baselines, while approaches to and exits via the test door were measured during the 8-week study by an ultra-wideband RFID system accurate to 20 cm (Kearns et al. 2010). Moore and colleagues found that the door covering markedly reduced exiting behavior compared to the illusory doormat. Moreover, reductions in exiting were the result of a corresponding decrease in *approaches* to the door, suggesting that the veterans' inability to see the door removed it as a potent stimulus eliciting exiting behavior.

The results of this investigation clearly show that RFID technology can be used to gather long-term information on clinically significant behavior change in natural settings as a result of behavioral interventions to manage wandering. The role of the tracking device in this investigation is purely confirmatory and is not required for the intervention to be effective, rather it can be employed to establish efficacy and then removed without significantly affecting the clinical outcome. Such applications of location-aware smart technologies in home settings where persons with dementia reside offer great potential for gathering information critical to the generation of effective home-based interventions. A potential added benefit is that whereas caregivers have in the past been required to maintain logs of wandering behavior and elopements to inform therapists of the effectiveness of their interventions, automatic behavioral logging using RFID may lessen caregiver burden while leading to more effective treatments.

Conclusion

In this chapter we have attempted to present a brief overview of how radio frequency identification devices (RFID) can be used to help create smart environments which lead to better care for persons with dementia. RFID technology varies dramatically from very inexpensive unpowered passive devices with 3 m ranges up to highly accurate powered transponders capable of performing centimeter "GPS-like" functions over ranges of 100 m allowing "geofencing" and access control to specific regions of a building contingent on the wearer's identity, location, and the time of day or any combination of these. Unlike GPS, however, the more expensive RFID variants don't suffer from signal degradation due to "multipath," a phenomenon that limits GPS use inside buildings due to reflected signals; ultra-wideband RFID was specifically developed and hardened to operate continuously in electrically noisy industrial environments and is used to control vehicular assembly lines in the automotive, industrial, and aviation industries.

Dementia wandering by its very definition involves spatial disorientation (Algase et al. 2007); thus, a complete understanding of its origins and progression must of necessity involve an understanding of how the person with dementia uses space as the disorder progresses. To date, researchers have relied heavily upon psychological tests and observational data to understand wandering behavior, but with the evolution of smart technologies, we at last have the opportunity to observe its progression under natural conditions and design evidence-based approaches to managing wandering behavior that are both effective and humane and which can potentially reduce caregiver burden.

In comparison to most optical and passive PIR devices used as location-aware technologies, RFID provides superior information about the identity and location of people or objects in a monitored space. It may do so at a relatively higher cost both in location-signaling tags and sensors; the ultra-wideband version of active RFID has proved particularly useful for describing dementia-related wandering and the increased movement path variability that often occurs shortly before a movement-related fall. Because location-aware technology is an essential component of smart houses, both passive and active RFID will continue to be important in the development and dispersal of smart living arrangements.

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Types of Sensor Technologies: Functionalities and Measurements

Marc Mertens and Lieven De Maesschalck

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Abstract

One of the major changes in the last decade in e-health has been the development of monitoring technologies for smart homes. An important part of such a monitoring system are the sensors. Sensors measure physical variables and transform this information to numerical values as input to smart algorithms. This chapter gives an overview of different types of sensors and their applications as well as new types of sensors and trends. It aims to give a nontechnical introduction in the emerging technologies of sensor design and applications. It also discusses topics which are relevant with respect to architectural choices, communication aspects, installation, and acceptance by the end user. Finally, some projects are mentioned which use sensor information in an e-health environment as illustration of the information covered in this chapter.

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Introduction

One of the major changes in the last decade in e-health has been the development of monitoring technologies for smart homes.

Sensors are the eyes and ears for these systems. Sensors translate physical environment variables, such as blood pressure, temperature, weight, and presence and position in a room, to measurable electrical signals. These signals can be conditioned before being used: noise can be removed through filtering, and the level can be adjusted by scaling and amplification. If the conditioning of electrical signals is performed at the sensor itself, we call them intelligent sensors. Otherwise, conditioning can be done at a higher level of the system. If signals from a large variety of sensors can be combined in the system to give an amalgam of information about the environment, we call this sensor fusion.

All this information is fed into smart systems, which can deduct in what state the environment is in, what the condition of the patient is in, etc. Finally, the conclusive information is visualized and communicated to an actor who can intervene if needed, that is, care givers, nurses, family, etc.

A typical block diagram of a sensor-based system is shown in Fig. 1.

This chapter gives an overview of different types of sensors and their applications as well as new types of sensors and trends. It aims to give a nontechnical introduction in the emerging technologies of sensor design and applications. It also discusses topics which are relevant with respect to architectural choices, communication aspects, installation, and acceptance by the end user. Finally, some projects are mentioned which use sensor information in an e-health environment as illustration of the information covered in this chapter.

Types of Sensors

To give an overview of existing sensors, different divisions can be made. In this context of smart homes, we chose to differentiate between sensors collecting physiological data such as blood pressure, weight on one hand and behavioral data such as presence and position in a room on the other hand. A further subdivision is made

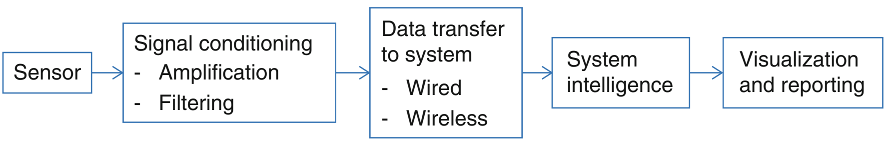

Fig. 1 Block diagram of a sensor-based system

between wearable sensors, sensors which have to be on the body to collect data and nonwearable sensors, which are integrated in the patient's environment in a least obtrusive way.

Sensors for Physiological Parameters

Measuring physiological parameters of the human body is an important aspect of evaluating the health state of an individual. An historical overview of measuring these parameters is described by McAdams et al. (2011) in detail. As the population age increases, so does the number of chronic diseases. To assist elderly in living as long as possible in their own environment, insight in these parameters is essential. Several of these parameters such as blood pressure, heart rate, electrocardiograph (ECG), electromyography (EMG, electrical measure of muscle activity), and body temperature can easily be monitored with sensors. The most common and well-known wearable measuring device for ECG is the Holter monitor, which logs for instance the ECG for several days. The device's sensors are attached to the person's body, measuring the electrical heart system signals. Using these data, a cardiologist can analyze the data for, for example, heart rhythm disorders.

Complementary to these sensors are nonwearable sensors. As an example, recently, intelligent toilets have been developed, which can monitor health conditions by measuring temperature, body weight, body fat, and blood pressure and can perform urinalysis to measure sugar levels in the blood by using built-in sensors. Also devices such as intelligent weight scales which measure and log weight, body fat, and BMI are finding their ways in the homes to assist in maintaining a healthier lifestyle. The recent development of smartphones and smart tablets has contributed in a plethora of easy to use health monitoring sensors and application. One example is the Philips vital signs camera, which measures heart and breathing rate (www.vitalsignscamera.com).

Sensors for Behavioral Monitoring

With the aging population, it is important to assist people to live in their own environment as long as possible. However, to facilitate this and to evaluate the level of support these people need, we have to assess their ability to live independently in an easy, objective way. Currently, questionnaires are used to assess the ability of performing activities of daily living (ADL). One such tool is the Katz scale of independence in ADL (Sidney Katz et al. 1963). The scale ranks the ability of performing ADL in six functions: bathing, dressing, toileting, transferring, continence, and feeding. The disadvantages of questionnaires like these are that they are intermittently taken, prone to subjectivity in the interpretation by the caregiver and subject to socially desirable answers from the interviewed person. Modern technology using sensors can however automatically monitor performance of ADL, can detect changes of the person's regular living pattern, and can alarm the caregiver for unexpected changes in a living pattern. These changes in living patterns can indicate a health issue or a cognitive decline of some sort, such as oncoming dementia. Examples of patterns which can trigger an alarm are gradually increasing times needed to perform an ADL, wandering behavior, forgetting to turn off the gas after cooking. Also the detection of fall incidents is a very important reason to use assistive technology in the living quarters of an elderly.

Again, as for the physiological parameters, we can divide the sensors for behavioral monitoring into two categories: wearable and nonwearable. Commonly available wearable sensors are acceleration sensors. These sensors measure the acceleration of the body part they are attached to, over three axes. They can provide information of changes of force in any of these axes. This information can be used to detect and classify motion, activity levels, fall incidents, and transition between postures (Sim et al. 2011).

Another monitoring method using body wearable technology is the use of radio frequency identification (RFID) to detect the performance of ADL. RFID is a technology using radio frequency communication to transfer data contactless between two components. One component is the so-called tag, a small label which can be discretely applied to a device. The tag can be passive or active, using a battery. The other component is an RFID reader, which can interrogate the tag's unique identification and if needed additional information. The principle of monitoring with RFID technology is to attach passive RFID tags to devices, such as household appliances, cupboard doors, drawers, refrigeration doors, and the reader to the elderly, integrated in a bracelet for instance. Every time the person comes near a tagged device, the event is logged together with a time stamp. Using smart algorithms, the performing of relevant activities can be extracted, logged, and evaluated. An example of this is described by Stikic et al. (2008).

The evolution of smartphones facilitates enormously in behavior monitoring. Smartphones are typically equipped with a range of sensors such as acceleration sensors, GPS, camera. The combination of information of these sensors can be combined, to develop monitoring systems to detect wandering or fall incidents and measure activity levels.

We should also mention in this section the personal alarm system (PAS), which typically contains a panic button for the owner to press in case of an emergency, therefore alarming the caregiver. Recently, these systems are being enriched with smart features such as fall detection system and medicine intake reminder.

The major drawback of wearable sensors however is the fact that people tend to forget to wear them or remove them before performing activities such as showering or cooking. To tackle this problem, wearable sensors are designed in such a way that can be, thanks to their small size and modern technologies, easily integrated in clothing, shoes, jewelry such as bracelets, necklaces, and watches. Technology nowadays also permit to weave sensors in textile, which allows, for instance, for diapers for elderly with urinary incontinence. An alarm is triggered when the diaper becomes wet, even if the person is unable to communicate his or her discomfort.

There are a lot of nonwearable sensors available for behavior monitoring. One of the most commonly available sensors is the passive infrared motion detector or pyro

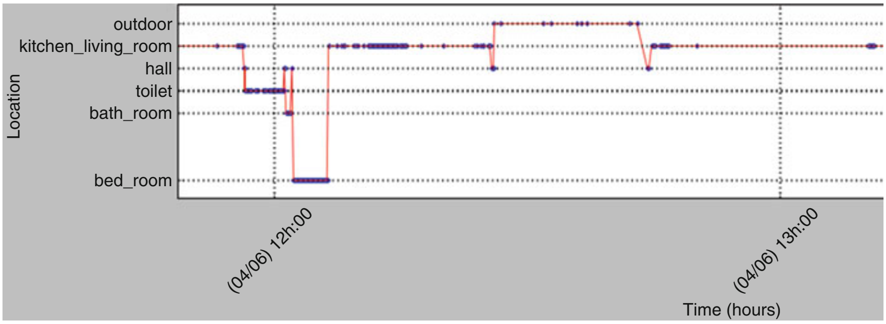

Fig. 2 Visualization of movement during a part of a day, each blue dot is a trigger from a motion sensor

electric infrared detector (PIR). This sensor detects the change in temperature of its environment. Since every object transmits energy in the form of heath, which is infrared radiation, the object is detected by the sensor when it moves in front of the sensor's lenses. Typical use of this sensor is in alarm systems to detect intruders or in home and office automation systems to turn on or off lighting. However, installing one PIR sensor in each room, and combining the motion detection events with time stamps, gives valuable information of the person's behavior such as how long does he or she stay in which rooms, how frequently is the bathroom visited and for how long, is there unexpected (i.e., nightly) wandering, and which are the most frequently used walking routes. An example of the visualization of the part of a day is given in Fig. 2.

Another contactless sensor is the camera. Now that high-quality cameras with direct network connections become readily available is worth considering to implement this sensor in a monitoring system. Information from the camera can be used in the same way as with the PIR sensor, but on top of that, fall detection systems can be developed such as in the Fallcam project (Debard et al. 2009), position of the person in a room can be defined, postures can be detected, facial recognition can be implemented, etc. One issue of concern with cameras is however the privacy issue and the user perception of being watched. Another factor to consider is the complexity of the camera. Several types are available with different optical options, which effect field of view, light sensitivity characteristics, and image distortion. Single-camera systems are different from multi-camera systems, and cameras with fish eye lenses have other characteristics, which can be beneficial in some scenarios. Also the installation of a camera system requires attention with respect to lighting, occlusion of desired viewing field, and so on.

Many studies have been done recently on the Kinect sensor from Microsoft (TM). It allows to detect and analyze human gestures. However, initially intended to serve as a contactless interface for gaming, a lot of successful research studies are done towards therapeutic use, such as applications in physical and cognitive revalidation but also in fall incident detection.

Another class of sensors, which can be used as behavioral monitoring, is utility signals monitoring: the sensing of electricity, water, and gas usage. Initially mainly used in an energy management context, these sensors can provide valuable information towards regular behavior of the person monitored, especially in combination with position sensors. Example applications are detecting when and how long the microwave is being used, if the toilet is flushed, when a bath or shower is taken.

An example of research where the fusion of information of all these sensors is used is the Amacs project (www.amacs-project.eu).

Additional behavior information can be obtained with low-cost contact sensors. Contact switches can be applied to doors or drawers, giving a simple open or close indication. Pressure sensors installed in beds, couches, floor tiles, etc., can provide valuable information of the position of the person.

A special class of sensors is acoustic sensors. Recognizing sounds to classify activities or alarming situations is possible with advanced digital processing algorithms. But as for cameras, privacy concerns are an issue with these sensors as well.

A lot of sensors are typically oriented towards distinct alarm situations. They detect situations such as flooding, fire, smoke, the presence of gas, and carbon monoxide.

All of the above-mentioned sensors are currently being used in applications and research with respect to health monitoring. There are many more we did not cover given the limited space, and on top of that, the technical evolution is rapidly evolving. In the next paragraph, we try to touch on some emerging trends in sensor design.

New Trends in Sensor Technology

As discussed earlier, many e-health applications are becoming available as a result of emerging smartphone technology. Some examples are activity trackers using the GPS and acceleration sensors, classification of skin disorders using the onboard camera, and a classification algorithm to detect skin cancer, diagnosis of eye diseases using the camera by analyzing photos of retina.

Concern has risen however to this development from the medical world. The need for a framework for medical validation for this type of technology is emerging.

Miniaturization of sensors also gives great opportunities; a tri-axial accelerometer sensor integrated in a tooth can collect data from the activity the mount performs such as chewing, drinking, and speaking.

Data are sent wireless to the smartphone to be logged and analyzed. Sensors can also be integrated in shoes with a sensor interweaved in the shoe material to monitor foot health.

One last technical evolution we would like to mention is microelectromechanical systems (MEMS).

MEMS are the creation of three-dimensional electromechanical structures using integrated circuits fabrication technologies and special micromachining processes.

Fig. 3 MEMS, www.memx.com

It allows to implement moving parts within the electronic integrated circuit housing. The structures can be electromechanical devices such as valves, switches, pumps, and sensors. The main advantages for using MEMS are the small size, light weight, high reliability, and low cost. A typical example for MEMS application is an all-silicon micro-G accelerometer. Another example is shown in Fig. 3.

Sensor Networks

When implementing sensors in an application, it is important to consider the connection between the components, that is, between the sensors and the system. While it is not in the scope of this chapter, we would like to point out some technologies. Communication can be either wired or wireless. Each choice has pros and cons. Wired systems are typically simpler to develop, but put higher strain on infrastructure since the wires have to be installed unobtrusively. Depending on bandwidth being used, care has also to be taken towards installation with respect to signal buffering, cross talk, and signal loss. Wireless systems are often more flexible, are easier to expand, and are easier to integrate in the environment. Several options are available such as Zigbee, Wi-Fi, and Bluetooth. Each protocol has its own merits, and careful design considerations must be evaluated and taken into account such as required bandwidth, power requirements, flexibility, and security. Self-harvesting technologies are nowadays being developed to provide power from the environment for the sensors.

Architectural Choices

When developing a health monitoring system, it should be clear that the architecture being used is very important. We have to be aware that there is no "one size fits all" solution. Whether the system is to be used as a remote revalidation monitoring system or for detecting early stage dementia, demands are completely different. Even within one typical application area, every user most likely has different monitoring needs. These needs will also evolve in time. Therefore, it is very important to think ahead and find an architecture which is flexible from the start. Adding additional sensors and modules should be possible within reason. Another factor to be considered is the level of intrusiveness; is the integration of the system in the living quarters feasible? Can sensors for instance be integrated in luminaries, furniture, walls, etc.? This adds highly to the acceptance by the user.

The number of sensors is often a tradeoff between having a large amount of highly detailed data and system simplicity, cost, and maintainability.

Also to consider is the issue of re-usability. To leverage the cost of an installation, it would be beneficial if a monitoring function can be used for more than one dedicated purpose. For instance, cameras and motion sensors can be used for both health monitoring and alarm system. A Kinect-based cognitive revalidation system can double up as an exercise platform for physical fitness.

Last but not least, serious consideration should be given to reliability and data integrity. System redundancy can ensure that sensors that no longer are active are covered by other (types of) sensors or at least by an alarm message to inform the user.

Visualization and Interpretation of Data and Trends

In order to use the data in an efficient way, a careful examination has to be done to whom is going to use these data. If, for instance, trends in data are to be interpreted by caregivers, the necessary visualization tools have to be provided for this purpose. Figure 4 gives an example of a heat map of activities of a person over a period of time. The data are collected from PIR sensors, one in each room. In this image, the days are plotted vertically, while the time of day is plotted horizontally. The resolution in which time slots the days are divided into is selectable by the user. A heat map such as this gives an overview of a person's behavior over a given period of time.

Another example is the ECG. Modern sensor devices can monitor the ECG signals with high accuracy and consistency. Data can be logged over a period of days or weeks. However, smart visualization techniques should enable the cardiologist to focus quickly on problematic symptoms hidden in the large amounts of data as measured by the device.

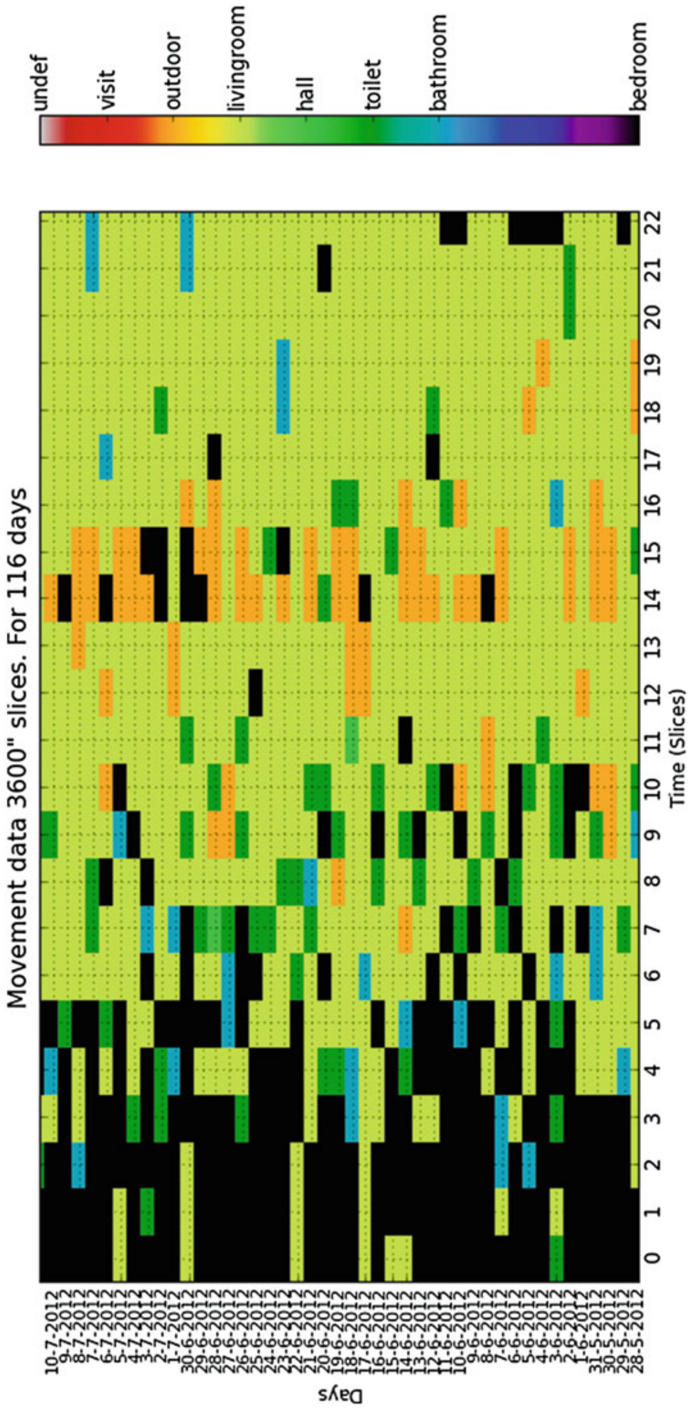

Fig. 4 Example of visualization of movement data over a period with a resolution of 1 h

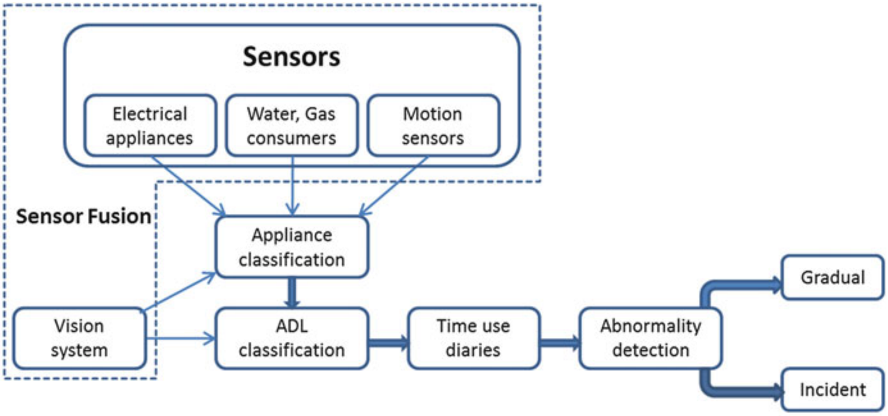

Fig. 5 Amacs, an example of combining data from several contactless sensors to detect ADL

Example Applications

As an example application, we can consider the Amacs project (Automatic Monitoring of Activities using Contactless Sensors) (www.amacs-project.eu). The Amacs project is partly financed by EU EraSME (FP7).

Within the project, several sensors are used to detect the performance of ADL. Gradual changes in the regular behavior are detected and trigger an alarm to the caregivers. Also incidents such as fall incidents and appliances which are left on for a longer period than expected are reported.

The sensors used are motion sensors, cameras, electricity, water, and gas sensors (Fig. 5). Data transfer from motion sensors to the system is done wirelessly, using the Zigbee protocol. The main reason for this choice is the combination of the technology's low power consumption and low bandwidth requirement for this type of data. The information of all the available sensors is fused and is the input of machine learning algorithms to detect the performance of ADL.

Another example of combining sensors in an e-health application is the detection of nocturnal epileptic seizures with children (Cuppens et al. 2012). Sensors used in this example are acceleration sensors and cameras.

Conclusion

There are a lot of sensor types to monitor the health status, both on a physiological and on a behavioral level. Which type suits most for a monitor system depends on a lot of factors. Emerging technologies and trends make it possible to use sensors in a way which was impossible some years ago.

Sensors are only a part of the system, and this system should be designed with several design factors in mind: cost, privacy, flexibility, reliability, and maintainability.

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The Wired Infrastructure in Smart Homes

Guy Kasier

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Abstract

The wiring in a house or apartment is part of its basic structure in the same manner as plumbing, ventilation, and other integral aspects. To enable smart technology to be used in a home, the basic structure has to be both appropriate and allow flexibility. This chapter will discuss several cabling concepts and good engineering practices for the various electrical subsystems and networks in the home.

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Introduction

Smart Homes. Everyone is talking about them. However, it requires the integration of new technologies and techniques available for homes. Every aspect of the structure has to communicate with every other. In short, everything must be integrated. When it is, comfort, flexibility, communication, safety, and care components are improved and energy consumption reduced.

The basis for achieving all of this is the home's electrical system. However, smart home wiring differs from traditional electrical installations. If the goal is optimum integration and implementation of the available new techniques, the concept must be examined thoroughly and a number of good engineering practices followed.

It is sometimes argued that integration should be solved wirelessly. However, this is not an optimal choice for several reasons. A wired network is faster and more reliable than a wireless network. If possible (e.g., in newbuilds and extensive renovations), always opt for optimum wiring in the home.

General Principles and Good Engineering Practices

Multiple Subsystems in the Home

Smart homes contain a wide variety of subsystems in addition to the wiring for sockets, lighting, shutters, blinds, and other power consumers that need to be steered. These include various types of controls (push buttons, keypads, touch screens, smartphones, tablets, and more), sensors for temperature, humidity and light, the LAN network, and the wiring for access control, door communication, telephony, burglar alarms, video, audio, heating, air conditioning, and much more.

All of these subsystems partly have their own intelligence. Consider the heating system that makes allowances for indoor and outdoor temperatures and the boiler temperature. There is no communication between these so-called stand-alone systems. However, using an Integrated Home System (IHS) makes integration and communication between multiple subsystems possible. For example, upon arriving home by car in the dark, we press the button on the garage door remote control. Result: The garage door opens and lighting in the garage comes on as well, and if desired, a light path can be created to the kitchen or living room and the heating is told that it should switch to a more comfortable temperature.

Each subsystem has its own wiring requirement and regulations. Moreover, the type of cable and the topology can vary significantly within IHS systems, depending upon the brand used and the system or the application (newbuild versus renovation).

Topologies

Typically, three topologies are used: the star, the bus, and the tree.

- Star topology:
  - A separate cable runs from each node to a central point.
  - Operational reliability is high.
  - A large number of connections are required.
- Bus topology:
  - The bus cable runs from the first to the second node and so on until the last node is reached. No other taps may be made to the bus.
  - In many cases, a terminal resistor must be installed at the beginning and end of the bus to prevent reflections.
  - Relatively few connections required.
  - Lower operational reliability if the cable is broken at some point. TIP: Install a cable back from the last node to the first, but without connecting it at this stage. After all, you do not want to create a ring topology. If the cable is severed for any reason, a bus topology can be restored using this spare cable. The terminators must then be connected to other nodes (immediately in front of and behind the break).
- Tree topology:
  - Is a combination of the previous topologies.
  - Taps may be made at any point.
  - Relatively few connections required.

Central and Decentralized Intelligence

Certain IHS systems use central intelligence. Such systems always have a central control unit or master. There are also many IHS systems with a decentralized intelligence. These do not have a central control unit. The intelligence for transmitting, receiving, and processing is contained in each component.

Central or Decentralized Positioning in the Home

IHS systems usually offer the option of positioning their components centrally or noncentrally. This is certainly the case for controls such as push buttons and keypads located throughout the home. There is often a choice between central or decentralized positioning for the output modules (relays, dimmers, et cetera). Since most homes do not have a floating floor or a modular suspended ceiling (often the case in offices), centralizing the output modules in the distribution board or in several distribution boards is recommended. There is normally far too little space in a home to position the output modules noncentrally. One exception is an existing installation in which no new wiring can be installed. In this case, it is possible to position the output modules noncentrally. However, a bus cable will be required unless installers are willing to resort to wireless modules.

Use the Recommended Cables

Each manufacturer will recommend a specific type of cable for connecting the IHS modules (output modules, controls, sensors, et cetera). Sometimes this is a twisted pair (TP) cable, other times not. Sometimes a shielded cable must be used, sometimes not. In certain cases, manufacturers prescribe their own brand-dependent cable. Others specify a standard cable available from wholesalers.

It is strongly recommended that the optimal cable be used. Few if any manufacturers will guarantee the effective and interference-free operation of its systems unless the prescribed cables are used. This also guarantees Electromagnetic Compatibility (EMC).

Respect the Prescribed Distances

In regard to immunity from interference, virtually all manufacturers specify a maximum length for the bus cable and maximum spacing between components on the bus. If these maximum lengths are exceeded, the manufacturer will no longer guarantee the effective operation of the system. For homes, the maximum distances are fairly large (around 300–1,000 m), so in practice this is usually not a problem.

Take Voltage Loss into Consideration

In addition to sending information packets, the bus is usually also responsible for supplying certain bus participants. For most systems, this is a VLSV (very low safety voltage) of between 9 V DC and 30 V DC. Voltage losses may occur, depending upon the distance from a bus participant to the supply and the section of the bus wire. This can lead to the bus voltage being too low for the farthest components on the bus.

In addition, the maximum power of a supply must be respected. The sum of the individual powers of the bus participants may not exceed this maximum supply power. The installer must take this into account and in certain cases will have to provide an additional supply.

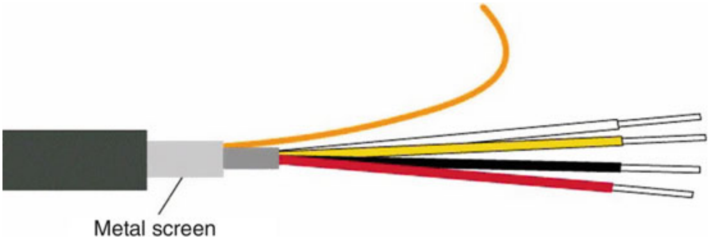

Fig. 1 KNX bus cable with shield (Source of illustration: KNX)

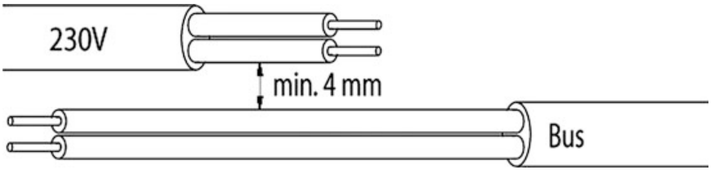

Fig. 2 KNX prescribes a minimum distance of 4 mm between the insulation of a bus wire and that of a 230 V wire (Source of illustration: E&D Systems)

Shielding the Bus Cable

A shielded cable is used for the bus in many cases. The manufacturer usually specifies that this shield must be connected as far as the last bus participant and must only be connected to the earth at a single point. In the case of KNX, a shielded cable is also prescribed, although the shield need not be connected to the earth (KNX Handbook for Home and Building Control, Basis Principles 2006) (Fig. 1).

Keep VLSV and 230 V Cabling Apart

The breakdown voltage of the insulation of a bus cable is generally lower than that of a 230 V cable.

It is therefore common practice to keep such different wiring apart and not to install them in close proximity (Fig. 2).

Specific Principles and Good Engineering Practices

Socket Circuits

Some European countries (Belgium, France, Germany, et cetera) use the loop-through topology for the cabling of socket circuits. In this topology, a feeder cable passes from an automatic switch in the distribution board to a first single or multiple

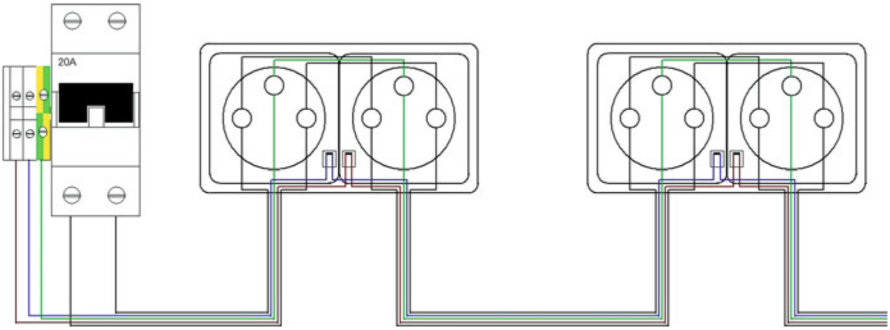

Fig. 3 The loop-through topology is initially created with the two black wires and the yellow/green wire. The blue and brown wires provisionally act as spares. A wall socket can be connected at any time using the blue or brown wire. A relay or dimmer output module in the distribution board can ensure that the socket in question can be switched/dimmed (Source of illustration: E&D Systems)

sockets. From there, a cable is installed to a second socket, and so on to the next one. The sockets are looped through from one to the other. A 3G2.5 cable or wire is standard for this. Because of the flexibility in a smart home, however, it is more interesting to install 4G2.5 or even 5G2.5 cabling. In this way, specific sockets in the circuit can be controlled individually (switched or dimmed) by the IHS system, now or at a later time (Fig. 3) (Kasier 2012).

Many southern European countries (Spain, Portugal, Italy, et cetera) use a star topology in each room instead of the loop-through topology. In that case, a feeder cable is installed from an automaton in the distribution board to a junction box in a room. From there, each socket is wired separately in a star topology. The disadvantage of this installation method is that there is a high probability that each socket in a room will be connected to the same automaton. If this circuit subsequently fails, all the sockets in the room are immediately without power. There is also the aesthetic aspect to consider since at least one junction box is installed visibly on a wall in each room. Such topology also means there are many more connections spread throughout the home. This can have a negative impact on safety.

To increase flexibility in such installations, the feeder cable must be produced with a 5G2.5 cable. If it is then decided to send a separate socket through the IHS, the spare wires can be used (Fig. 4) (Kasier 2009a; 2010).

Cabling for Lighting and Other Consumers

Place the output modules of the IHS system in the distribution board or boards in newbuilds and major renovations since there is little room in a home to install decentralized modules. The topology for the consumers is then a star topology.

Lighting

This means that a cable is installed from each light point or group of light points to be controlled separately, to the distribution board where the output module in question

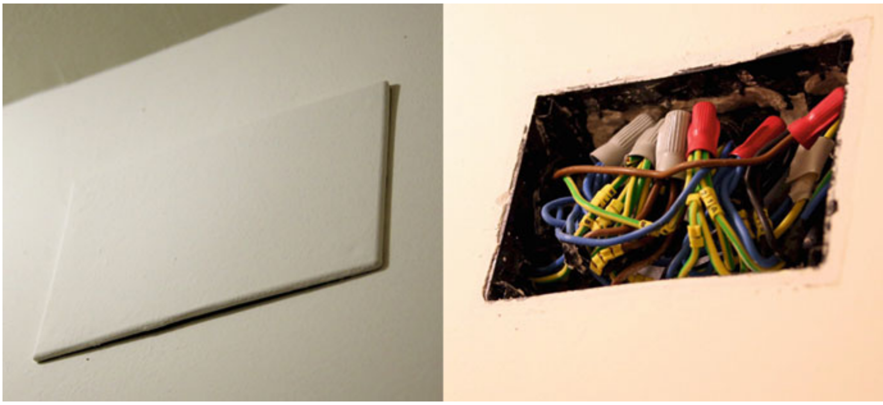

Fig. 4 Apart from the aesthetic aspect of a finished branch box in each room, the inside also looks confusing and cluttered (Source of illustration: E&D Systems)

(relay/dimmer) has a place. The cabling is usually 3G1.5. However, this section can increase for low-voltage lighting when the transformers or converters are installed in or near the distribution board. At lower voltages, the currents increase and – depending upon the length of the cable – the section of the cables has to be increased.

Example If the cable of a low-voltage lamp or group (12 V) with a power of 40 W has a length of 8 m to the transformer, the section of the conductors is 2.5 mm^2, assuming a maximum voltage drop of 3.5 %. For a distance of 10–12 m, the section is 4 mm^2. In practice, the latter situation will probably not be feasible since small light fittings are not designed for connection to 4 mm^2 cabling. In such cases, the transformer must be installed closer to the light source (Bogaert 2000).

In a classically designed installation, situations arise where no new cabling can be installed. The output modules will then have to be positioned noncentrally. If a bus cable cannot be installed, powerline communication or RF control will have to be used. In both cases, there must be a 230 V supply at those points where the output module is built in (recessed box behind the control).

Shutters and Other Motors

Motors that can operate in two directions (shutters, blinds, curtains, et cetera) have four connections: a common wire, one for running left, one for running right, and an earth. Here too, the star topology is used. The 4G1.5 cabling runs from each motor to the distribution board.

In contrast to lamps and light fittings, shutter motors must never be connected in parallel with each other since this would create a yo-yo effect. If the first shutter reaches the bottom a fraction of a second sooner than the second shutter, an unwanted current path means the first shutter is raised again (Kasier 2009b).

Example Two motors in parallel are lowered. Shutter 1 reaches the bottom fractionally sooner, causing limit switch ES1 to open. Because motor 2 is still running,

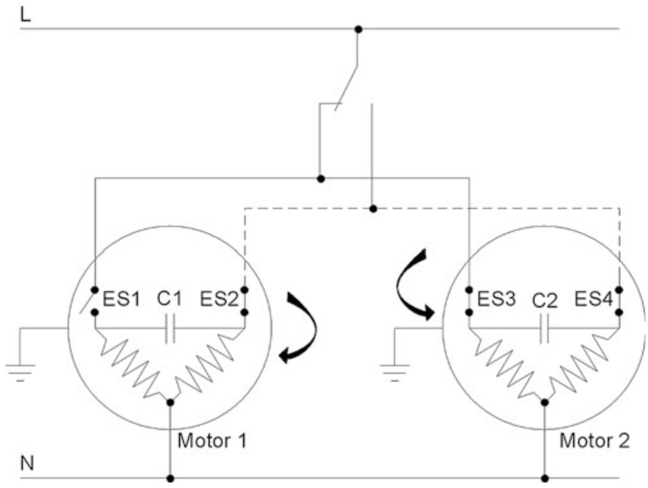

Fig. 5 If one of two motors in parallel stops before the other, the first motor is sent in the opposite direction through the other motor (Source of illustration: E&D Systems)

an unwanted current path is created at that point (dotted line). Motor 1 receives voltage via ES3, capacitor C2, ES4, and ES2 on the opposite winding (other direction). This causes motor 1 to run in the opposite direction (shutter is raised again). This persists until shutter 2 has reached the bottom and limit switch ES3 has opened. Each motor must have its own cabling to the distribution board and each must be connected to a different output of a shutter output module of the IHS. If desired, an isolating relay may offer a solution. In that case, a single shutter module output is sufficient (Fig. 5).

Heating

Cables also have to be provided to control the heating. A solenoid valve or circulation pump has to be controlled for each heating zone. Each solenoid valve gets a separate 3G1.5 cable to the distribution board. In addition, the heating boiler has to know when heat is requested somewhere in the home. An output of the IHS system then controls the heating's boiler contact. Here too, a 3G1.5 cable is sufficient.

Cabling for Sensors

The most commonly used sensors in a home are standard push buttons. In most cases, these are connected to the bus by a small input interface behind the push button. Sometimes the push buttons can also be installed with star cabling and connected to input modules in the distribution board. However, the latter installation method adversely affects the flexibility and scalability of the installation.

A bus connection is standard for keypads with one or more keys, as well as those fitted with an infrared receiver (IR). Certain makes and systems also offer other sensors (motion, light, smoke, temperature, and more) that are connected directly to the bus. However, some makes and systems do not include bus-controlled sensors. In these cases, an adapted cable (normally with shielding – follow manufacturer's instructions) must be installed between the sensor and the digital or analogue input module of the IHS system.

Cabled types are recommended for installing smoke detectors. These are supplied at 230 V and have a backup battery. In contrast to ordinary smoke detectors (powered by battery only), the user no longer has to replace batteries. Also of interest in a smart home is the use of smoke detectors with an output. If the alarm sounds, this output closes. A two-wire cable to an input module of the IHS system then ensures that the IHS system can react appropriately if something is amiss (lights on, shutters up, et cetera).

Multimedia (TV, Video, Audio)

TV and Video

TVs are often desired in several places around the home (living room, home theater, bedrooms, kitchen, et cetera). This means that coaxial connections for TV will also have to be available in various rooms. In order to give the occupants the choice of where to position a TV in a room, each room must have several connections. Opposite-facing walls are usually best (Kasier 2009c). Use an approved coaxial cable for the coaxial connections (these may vary by country or region) and install in a star topology at the central point where the TV amplifier is positioned.

The arrival of digital TV has complicated the situation somewhat. Apart from the coaxial connection, a LAN connection generally also has to be provided to allow two-way communication via the Internet. For each TV connection, therefore, there is also an RJ45 connection connected in a star topology to the router of the LAN network via a UTP or FTP cable. In existing homes where such connections are not positioned behind the television, Powerline or RF products may be used. However, the speed is significantly lower than with a wired network.

If a media player is used, an RJ45 LAN connection also has to be provided for this device. It is therefore advisable to provide a double LAN connection behind the TV in the most important locations in the home, one for the setup box for digital TV and one for the media player.

Audio

Active and passive speakers are available for the sound system. In the first type, the amplifier is built into the speaker, as well as the volume control. Such speakers are more difficult to control from an IHS system due to the distribution of the amplifiers and controls. Things are easier with classic passive speakers. These just need two wires per speaker connected to the amplifier. A twin speaker cable $2 \times 0.75\ mm^2$ is

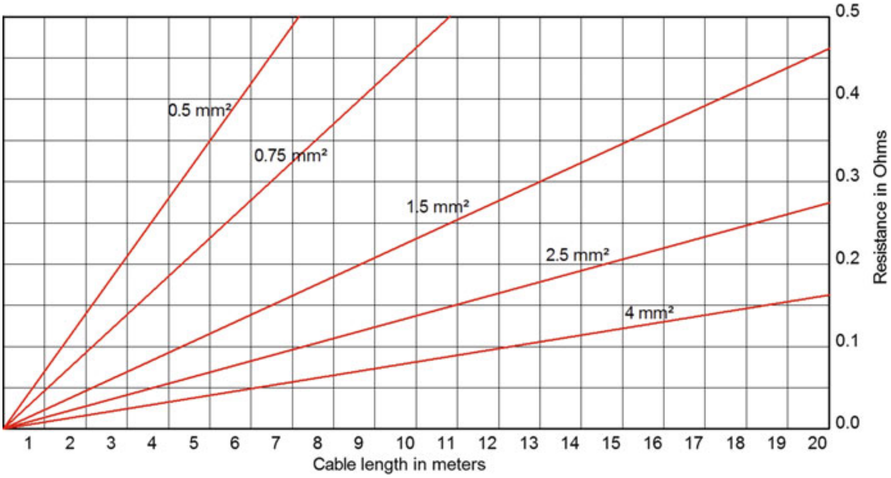

Fig. 6 Table in which the section of the speaker wires for 8 Ω speakers can be determined according to cable length and wire resistance (Source of illustration: E&D Systems)

normally used, with one conductor being insulated in black and the other in red, to allow the polarity to be respected.

Please note, however, the resistance of the cable used is very important for the proper operation of the system. For an amplifier with 8 Ω outputs, it is best to keep the cable resistance below 0.4 Ω. Use a section of 1.5 mm^2 for a 10 m cable length. For 20 m, that becomes 2.5 mm^2. The cable section must be doubled for 4 Ω speakers (Fig. 6).

If multiroom/multisource systems are not linked to the IHS system via an interface, separate control panels for the audio system must be installed in each room. Depending on the make and type, these may be cabled in a star or a bus topology. Follow the manufacturer’s instructions closely, including the type of cable.

Door Communication, Access Control, and Security

Door Communication and Access Control

Since 2000, a great many door communication innovations have appeared on the market. Previously, classic multi-wire cabling in a star topology was used. For videophony, a coaxial cable also came into use. Such systems are still available and are generally classed under the heading of analogue systems. The number of wires and their color code often differ depending on the manufacturer and the system. However, manufacturers generally make wiring and connection diagrams available over the Internet.

Certain manufacturers have developed a digital technology for blocks of apartments. This uses a multicore cable. In the case of Bticino, this is a cable with two cores of 1.5 mm^2 for the feed plus two twisted pairs of 0.35 mm^2 for audio and video communication, and a further twisted pair for the bus. The cabling runs in a star topology from the external post and from the internal posts to various modules.

For homes, it is more interesting and much easier to use two-wire systems since only two wires are required for the connection between all modules. Here too, the manufacturer generally offers its own cable.

Finally, there is the rise of IP systems, currently still mainly used in large buildings. It is expected that this technology will make inroads into separate houses. Obviously, the usual CAT5e or CAT6 LAN cables are used here.

Standard electrical locks have often been used in the past for the remote opening (via the internal post) of the door. However, these offer little protection against break-in. It is therefore better to opt for a system that is built into the door and automatically activates the double lock when the door closes. The door can always be opened from inside the house using the door handle, even in the event of a power cut. Such systems are connected to a module in the distribution board. The door can be unlocked by means of short pulses (by a push button or an output of the IHS system). Here too, the cabling is manufacturer dependent.

Several systems are available for external access control: code locks, proximity readers, iris scanners, and fingerprint readers. The last two are mainly used in businesses, and the first two are more common in houses and apartments. The external component (code lock, proximity reader) is normally connected via a bus to a module in the distribution board or directly to the bus of the IHS system. The cabling is manufacturer dependent.

Security

Generally, the detectors of an intruder alarm system are connected in a star topology to the security switchboard. The cable used can vary depending on the system and the country. Such a cable generally has two thicker cores (0.5 mm^2) for the feed to the detectors, two thinner cores (0.22 mm^2) for communication with the switchboard, and a further thin pair of cores as an anti-sabotage loop. One detector can also be looped through to the next by using multicable, in which case, a separate pair of cores is provided for each detector in addition to the feed cores and the anti-sabotage loop. Shielding is sometimes present.

Data Communication, Telephony, and Multifunctional Networks

Data Communication

The most standardized network in the home is the LAN network. A UTP or FTP twisted pair cable runs straight to the router or a switch or a patch panel from each RJ45 data socket. To anticipate faster data speeds in the future, it is better to install a CAT 6 cable instead of the hitherto customary CAT5e cable. To guarantee flexibility, use a double cable to each connection point. This gives two RJ45 access points per recessed box (Fig. 7).

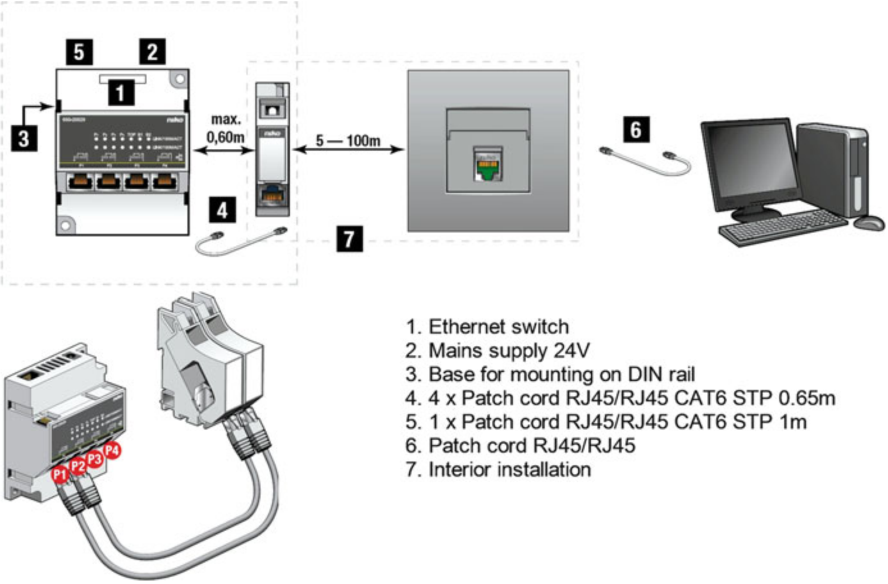

Fig. 7 Each connection point is connected to an access point in the patch box. There, the access points to be used are patched to an Ethernet Switch (Source of illustration: Niko)

Telephony

In recent years, home telephone systems have been virtually ignored due to the spread of mobile phones. Yet they remain quite interesting, among other things for internal communication. There is then no need to stand at the bottom of the stairs shouting at the children that dinner is ready. It is also perfectly possible to integrate telephone systems with door communication. This changes the internal devices for door communication into telephones, possibly with a monitor to see who rings the doorbell.

The twisted pair telephony cables that were formerly used (VVT 4×2) are being replaced by a UTP or FTP cable. The connection then passes through an RJ45 socket. The star topology is used for telephony. The installation method is therefore exactly the same as for a LAN network. This has advantages when working with a patch box. Each RJ45 socket can then be used for either telephony or LAN.

Multifunctional Networks

Multifunctional networks are increasingly emerging. A special shielded TP cable makes the connection between a patch box and an RJ45 socket in a star topology. The patch box contains several modules for LAN, TV, telephony, and audio. It is possible to instantly change the function of each RJ45 socket by patching, i.e., computer connection, TV, or telephone. Such installations offer the greatest flexibility (Fig. 8).

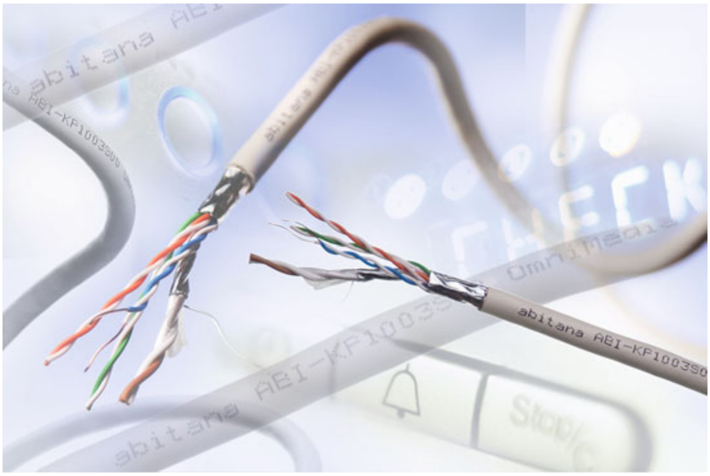

Fig. 8 This multifunctional shielded cable contains four twisted pairs. One pair (white/brown) has additional internal shielding. This pair is used for the TV or video signals (Source of illustration: Abitana)

Fig. 9 Some installation tips (Source of illustration: Niko)

Some Installation Rules for UTP and FTP

The correct handling of UTP and FTP cables is extremely important during installation to ensure the cables work properly. Installation tips include:

- The cables must not be bent into right angles but must describe an arc, the radius of which is at least equal to eight times the diameter of the cable's outer sheath.
- During installation, no tensile force must be applied to the cable.
- The cable must not be squashed or pinched by the use of cable ties or other material.
- It is best not to install cables for data, TV, or telephony in parallel with live (230 V) cables. Making crossings is not a problem. However, if a parallel path has to be followed, maintain a distance of at least 30 cm from live cables (Fig. 9).

Cabling for PV Installations

A standard photovoltaic (PV) installation can be divided into two separate cabling sections. First, there is the DC (direct current) cabling. Each PV panel delivers direct current. Several PV panels are connected in series into a PV string. One or more PV strings must be connected to the central inverter or convertor. This converts the DC voltage into 230 V AC voltage (alternating current). The second cabling section then consists of the connection of this 230 V AC voltage from the inverter to the general distribution board.

The AC cabling is the simplest. Standard domestic cables are used. The section is determined according to the maximum current. In practice, that is a 3G2.5, 3G4, 3G6, or even a 3G10 cable depending upon the size of the PV installation.

The DC cabling is a little more complex. The PV panels are connected by solar cables. These are double insulated and each cable has a single core. The reason for this is that the chance of dangerous arcs forming in the event of a short circuit in a DC circuit is many times greater than in an AC circuit. Two single-core cables run to the inverter from each PV string. Since the solar cables are also used outside, they are protected against harmful UV radiation and harsh weather conditions.

The question that now arises is where to put the inverter? It can be positioned either near the general distribution board or close to the PV panels. In the first case, the result is long DC cabling (from the roof to the inverter on the ground floor). That means two separate single-core cables for each PV string. These cables must be installed either in a vertical shaft or in a mechanically protected PVC pipe. Determining the path to be taken by this cabling is very important, especially in the first case. This is because there is always a voltage in these DC cables during hours of daylight and sunshine. Accidentally piercing these cables (e.g., drill, screw, or nail) can have disastrous consequences, both for the people and the building. In the event of a house fire, this cabling makes extinguishing work more difficult because there is voltage in the wires.

Another possibility is to position the inverter as close as possible to the PV panels (attic). The DC cabling then remains short, but there is likely to be long AC cabling from the attic to the distribution board.

More recent technology no longer works with a single central converter but with so-called micro-inverters. Here a micro-inverter is installed behind each PV panel. The output of these inverters is 230 V. This keeps the DC cabling very short (only from the PV panel to its own inverter behind the panel). There are also other advantages to micro-inverters, such as reducing the influence of partial or full shadows and being able to monitor each PV panel via a Web page.

Finally, let us return to the DC and AC cabling section. Losses must also be taken into account when determining these sections. In practice, it is wise to keep these losses below 1 % since each kW lost means less energy and lower yield. When determining the cable section, it is therefore advisable to install a larger section than is strictly necessary. The installation cost will be slightly higher but is offset by a higher return (i.e., the energy that is not lost). This will be more beneficial in the longer term (Kasier 2011).

The PV panels have metal parts. The mountings are also made of metal. Each PV panel or group of panels must therefore be properly earthed. The section depends on the installed power.

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Analysis of Home Health Sensor Data

Ben Kröse

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Abstract
This chapter focuses on the analysis of data that is collected from sensors in the home environment. First we discuss the need for a good model that relates sensor data (or features derived from the data) to indicators of health and well-being. Then we present several methods for model building. We distinguish between supervised methods that need data annotated with the desired health indicators, unsupervised methods that find characteristic patterns by just analyzing large amounts of data, and knowledge-driven methods that use expert knowledge. We discuss the advantages and disadvantages of the different methods.

Keywords
Health monitoring • Sensor data analysis • Smart homes • Machine learning

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Introduction

With the increasing number of older adults that live independently in their own homes, sensing systems that monitor someone's health are becoming popular. For quite some time now, sensors are used in home automation tasks; just think of the thermostat in the heating system, the proximity sensor for the lamp at the front door, or the burglar alarm. However, in order to determine the health condition of an inhabitant in a house, many other sensors are needed. A number of survey papers have been published that give a good overview on the state of the art. Alemdar and Ersoy (2010) focus on the wireless sensor networks and describe design considerations like scalability and security. Acampora et al. (2013) give a survey on the different kinds of sensor systems for health-monitoring applications, and Chen et al. (2012) present an overview of activity recognition methods from a broader perspective. In this chapter we focus on the automatic analysis of data from the sensors: what are the different approaches for sensor data analysis and how do they compare?

Sensor Systems and Sensor Data

A sensor is a device that transforms physical properties into digital signals. For health monitoring an important distinction can be made between *wearable* sensors and *ambient* sensors. The choice which sort of sensors to use depends largely on what sort of health functions have to be monitored. For this, it is good to look at the various models for health assessment and the use of sensors. According to the International Classification of Functioning, Disability, and Health (ICF) of the World Health Organization (World Health Organization 2001), there are three levels of functioning related to health: (1) bodily functions and structures, (2) ability to perform activities, and (3) ability to participate in society. Body-worn sensors that are able to measure vital signs such as heart rate or blood pressure will have an important role in measuring the first level of health function. Ambient sensors that are mounted in the living environment and that measure physical and social activities are very well suited to measure the second and third levels of health functions. In this paper we will describe the data analysis for ambient sensors, but in fact there is not such a very strict distinction between the analysis techniques for ambient and wearable sensors. More information about the body-worn sensors can be found in Alemdar and Ersoy (2010) and Acampora et al. (2013).

A basic ambient monitoring system consists of passive infrared (PIR) sensors for presence detection placed in all major areas of the apartment such as the bathroom, toilet, living room, kitchen, bedroom, and other areas such as the study room or hallway if applicable. In addition, contact switches can be placed for detecting whether doors and cabinets are used, floating sensors for detecting a toilet flush, and pressure mats for detecting whether the resident is lying in bed or sitting on a

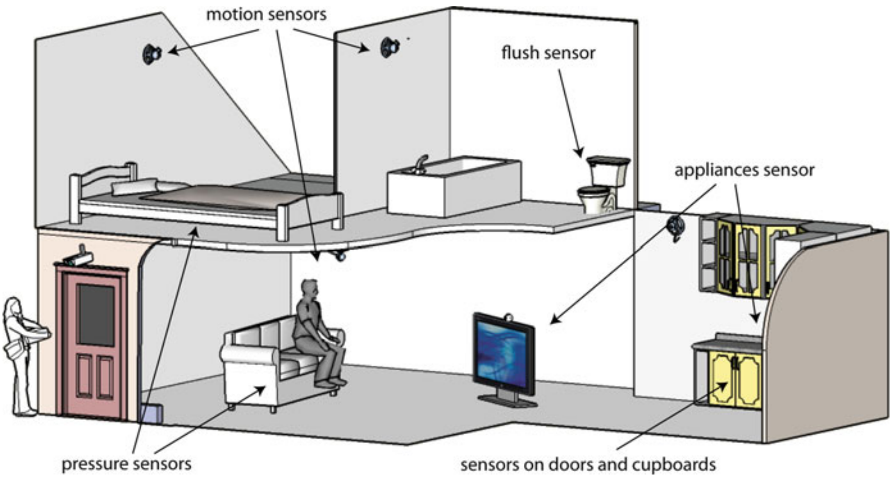

Fig. 1 Overview of a smart home equipped with motion sensors, pressure sensors, and switches on doors and cupboards

couch. Camera (or other imaging systems) mounted in the environment are also ambient sensors, but have more problems of acceptance in domestic environments because of privacy issues. In this chapter we focus on simple ambient sensor systems as sketched in Fig. 1.

Even in a setting where simple binary sensors are used, the amount of data that is collected is high, and little prior knowledge is available on the best features to select. Since we have to infer activities of the resident, it is needed to look at the temporal information of all sensors. Processing temporal information generally requires that the continuous sensor signal is *segmented*, which involves determining boundaries that divide the stream into distinct intervals that are then input for further analysis. In a *clock-based* segmentation, the boundaries are spaced equally in time, resulting in fixed-duration intervals (see Fig. 2a). In an *event-based* segmentation, the boundaries depend on the state changes of the sensors, and the segments have variable duration (see Fig. 2a). Most of the work in data analysis for sensor monitoring rely on clock-based segmentation (van Kasteren et al. 2010a; Wilson and Atkeson 2005), but also event-based segmentation has been presented (Rashidi et al. 2011).

For clock-based segmentation, a choice has to be made about the duration of the segments. This choice, in its turn, depends how the raw sensor data within the segment is transformed in a *feature* vector that describes the observations best. In (van Kasteren et al. 2010) the feature vector derived from the signal consists of a binary vector x_t with elements representing whether the sensor was active within the segment. Segment duration in this case was typically 60 s. Sometimes more involved features are derived within a segment, such as the count of events in a segment or the number of transitions between different locations (sensors). In those cases the segment length is usually longer (up till 30 min).

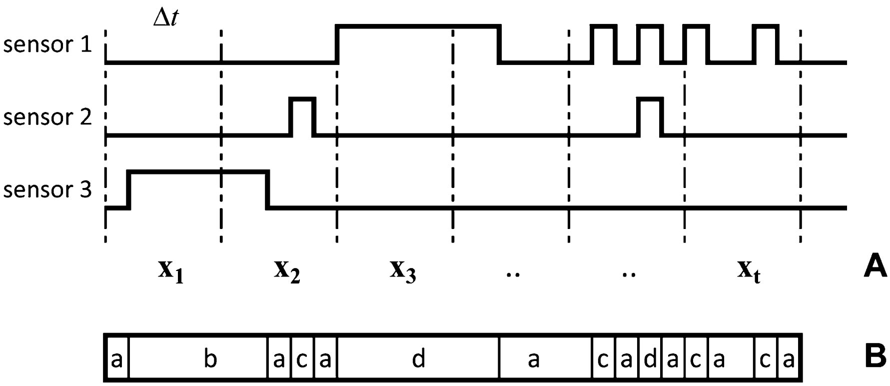

Fig. 2 The signals of three binary sensors, a clock-based representation (**a**) and an event-based representation (**b**)

Modeling

In many applications of sensor monitoring, we want to model the relationship between sensor data and some health-related variable. The purpose of a model is the prediction: if a correct model is available, the health-related *hidden* variable can be derived from the sensor data. The question is how to build such a model and how to set the parameters of such a model. For this there are typically two approaches: models are learned from example data using machine learning techniques (data-driven approaches), or models are hand crafted using rule-based or ontology approaches (knowledge-driven methods) or, of course, a combination of both.

In this section we first discuss the type of health-related variables that we want to model. Then we focus on *supervised* learning methods, in which labeled sensor data are available. Labeled data are sensor data of which a human annotator has provided the corresponding health-related variable. Then we describe *unsupervised* (no labels) learning methods. Finally we will briefly focus on methods that use expert knowledge.

What to Model?

First it is good to focus on the output of the model: which health-related variables are being modeled? As mentioned before, the ability to perform activities is one of the indicators of independence and functional health. The so-called activities of daily living (ADL) (Katz 1983) is a collection of activities that is used by medical professionals. This motivated a large body of research focusing on the *recognition* of activities (van Kasteren et al. 2010; Tapia et al. 2004) which is a *classification* problem.

Table 1 Three tasks of health data models, example papers and reported methods

Task	Examples	Method
Activity recognition	Tapia et al. (2004), van Kasteren et al. (2010a)	BN, HMM, CRF
Functional health modeling	Robben et al. (2014)	Gaussian processes
Anomaly detection	Jakkula et al. (2009), Nait Aicha et al. (2014)	Temporal reasoning, MMPP

Although performing activities is indicative for health status, an activity recognition model is not yet a health model. It may help professionals to gain insight in the behavior of a patient, but will not automatically provide a health measure. Attributes of the activities are needed to describe how activities are performed, how they relate to each other, and how they related to functional health. In a meta-review on health-monitoring systems, Brownsell et al. (2011) questions whether it is sufficiently understood which attributes of activities are relevant for health assessment. These attributes can be learned from data, but also expert knowledge can be used to determine this. Currently our group tries to develop a model for this.

If such a model is available, we actually can relate health values to the observations and do predictions. This is a *regression* problem. The model can be used by medical professionals to register a trend of the user, or by the user himself/herself for coaching.

Finally, in health modeling one is often interested in *anomaly detection*, which is basically a classification problem, where the sensor signals have to be classified as being normal or being abnormal. This type of modeling is useful in case of alarm systems, for example, fall detection or wandering. In Table 1 we list the three types of models, activity recognition, health modeling, and anomaly detection, and some relevant papers on building these models.

Supervised Learning Methods

Methods that use a large amount of data are usually based on statistical grounds. Models that are learned are probabilistic and give distributions on their output variables. In *supervised learning* method the model is learned from annotated data: sensor data and examples of corresponding output data. This means that large amounts of annotated sensor data have to be available. This holds for both regression and classification problems. In the following examples we will use a classification problem as a modeling task, but the methods can be used for regression as well.

The probabilistic approaches can be divided in so-called *generative* models and *discriminative* models. The generative approach models the joint probability density function between the output of the model and the input, while the discriminative model directly models the probability of a given output given the input variables.

Naive Bayes One of the simplest generative models for classification is the naive Bayes classifier. The task of the classifier is to model the probability $p(y|\mathbf{x})$ of a class label y (e.g., "cooking" or "sleeping") from the sensor feature vector x $= x_1, x_2, \ldots, x_N$ (e.g., the sensor values of kitchen, living room, and hallway). In the naive Bayes approach this is done by estimating the joint probability $p(y, \mathbf{x})$ from data and using Bayes' rule to derive the posterior probability $p(y|\mathbf{x})$. Furthermore, naive Bayes assumes that the sensor values are independent, simplifying the modeling of the joint distribution:

$$p(y|\mathbf{x}) = \frac{p(y, \mathbf{x})}{p(\mathbf{x})} \tag{1}$$

$$= \frac{1}{Z} p(y)(p(x_1|y)p(x_2|y)\ldots p(x_N|y)) \tag{2}$$

where the evidence $Z = p(\boldsymbol{x})$ is a scaling factor dependent only on x that is constant if the values of the feature variables are known. The likelihoods $p(x_i|y)$ (e.g., the likelihood that the kitchen sensor $i$is active given the activity "sleeping") and the prior $p(y)$ can be learned from training data. The sensor feature x_i can be the value of a certain sensor but can also indicate the order of events. For example, Tapia et al. (2004) derive features that are "1" if two sensors fire in specific order.

It is of course also possible to feed a *sequence* of observations to the classifier; in that case it has to model (e.g., for three observations) $p(y_t|\mathbf{x}_{t-1}, \mathbf{x}_t, \mathbf{x}_{t+1})$. With the independence assumptions the joint distribution can again be factorized in sensor likelihoods.

Hidden Markov Models It is also possible to learn the probabilities of transitions between activities. Naive Bayes models do not explicitly model any relations between subsequent class labels. The hidden Markov model (HMM) is probably the most popular generative approach that includes this temporal information. Given a sequence $y_{1:T} = y_1, y_2, \ldots, y_T$ of hidden states and a sequence of observations $\mathbf{x}_{1:T} = \mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_T$, the joint probability is given by $p(y_{1:T}, \mathbf{x}_{1:T})$. Most HMMs have independence assumptions that make this joint probability density function much simpler (see Fig. 3). First of all the assumption is that the current observation $\mathbf{x}_t$ depends only on the state y_t at that moment. Secondly, the current state y_t depends only on the previous state y_{t-1}. This leads to the following model:

$$p(y_{1:T}|\mathbf{x}_{1:T}) = \frac{1}{Z(\mathbf{x}_{1:T})} p(y_1)p(\mathbf{x}_1|y_1)\prod_t^T p(y_t|y_{t-1})p(\mathbf{x}_t|y_t) \tag{3}$$

The probabilities $p(\mathbf{x}_t|y_t)$ (observation model) and $p(y_t|y_{t-1})$ can be learned from training data.

Several inference problems are associated with hidden Markov models. One possibility is to predict the distribution over hidden states of the last latent variable at the end of the sequence, i.e., to compute $p(y_T|\mathbf{x}_{1:T}, y_{1:T-1})$. The forward algorithm is the most efficient algorithm for this. Another inference problem that

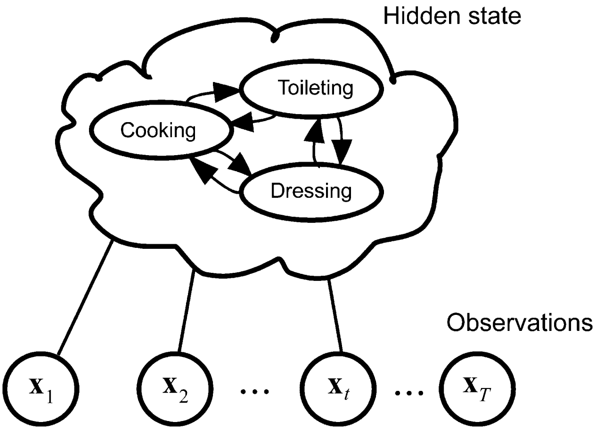

Fig. 3 The time series of observations can be used to infer the most likely sequence of activities

we encounter most often in health monitoring is to compute the joint probability of the entire sequence of hidden states that generated a particular sequence of observations. For example, we can make an overview of the activities of a resident given all the observations during a day. This task requires finding a maximum over all possible state sequences and can be solved efficiently by the Viterbi algorithm. For descriptions of the inference algorithms, I refer to textbooks (Russell et al. 1995; Bishop and Nasrabadi 2006).

Discriminative Models Discriminative models are a class of models used in machine learning for modeling the dependence of y on the observation $\mathbf{x}$. This can be represented in a deterministic or a probabilistic way. The simplest discriminative approach is nearest neighbor (NN), a nonparametric model in which novel observations (or sequence of observations) are compared with a set of examples in a training set, and the most closely matching item in the training set votes for their activity labels. To avoid storing all examples, *support vector machines* (SVM) can be applied that classifies an unknown observation sequence on the basis of a comparison with only a subset of the training samples. Good performance was reported on activity recognition problems by Brdiczka et al. (2009). Parametric methods estimate the parameters of a discriminant function from the training data. Neural networks have been presented for a smart home that has to optimize the energy control (Mozer 1998).

Within a probabilistic framework, the conditional probability distribution $p(y|\mathbf{x})$ is modeled directly from data. Again neural networks have been presented as probabilistic modeling tools, for example, restricted Boltzmann machines (RBM) Smolensky (1986). Conditional restricted Boltzmann machines (CRBM) have been used to model such time sequence Taylor et al. (2011). However, most of these approaches do not explicitly model any temporal relations between the hidden states because of impossibility of learning. For this, the conditional random fields as described in the next subsection are interesting alternatives.

Conditional Random Fields Using independence assumptions, conditional random fields are discriminative models, in which we learn the model parameters by optimizing the conditional likelihood $p(y_{1:T}|\mathbf{x}_{1:T})$ rather than the joint likelihood $p(y_{1:T},\mathbf{x}_{1:T})$. Conditional random fields represent a general class of discriminative models. A CRF using the first-order Markov assumption is called a linear-chain CRF and most closely resembles the HMM in terms of structure. Here the following dependence assumptions hold:

- The hidden variable at time t, namely, y_t, depends only on the previous hidden variable y_{t-1}.
- The observable variable at time t, $\mathbf{x}_t$, depends only on the hidden variable y_t at that time slice.

These assumptions are represented in the model using feature functions, so that the conditional distribution is defined as

$$p(y_{1:T}|\mathbf{x}_{1:T}) = \frac{1}{Z(\mathbf{x}_{1:T})}\prod_{t=1}^{T}\exp\sum_{k=1}^{K}\lambda_k f_k(y_t, y_{t-1}, \mathbf{x}_t) \tag{4}$$

where K is the number of feature functions used to parameterize the distribution, is a weight parameter, and $f_k(y_t, y_{t-1}, \mathbf{x}_t)$ is a feature function. The product of the parameters and the feature function $\lambda_k f_k(y_t, y_{t-1}, \mathbf{x}_t)$ is called an energy function, and the exponential representation of that term is called a potential function Bishop and Nasrabadi (2006). Unlike the factors in the joint distribution of HMMs, the potential functions do not have a specific probabilistic interpretation and can take any positive real value. $Z(\mathbf{x}_{1:T})$ is a normalization term.

Unsupervised Methods and Data Mining

All methods described so far use a training set that contains the observations $\mathbf{x}_{1:T}$ and the corresponding outputs $y_{1:T}$. In many cases we have to rely on only observations and do not have corresponding outputs. In that case we have to find structure in the observations and model this structure as clusters of similar sensor patterns or as normal vs. abnormal patterns. Figure 4 shows the difference with supervised learning: no predefined classes are modeled but clusters are formed. The following two methods are examples of the so-called "unsupervised" training methods.

Markov-Modulated Poisson Processes for Anomaly Detection Without any annotation we can use the sensor data to model regular daily or weekly patterns and find deviations from those patterns. In the section "Sensor Systems and Sensor Data," we explained that the observations may be defined as sensor counts during a time slice. The best way to model sensor counts is a *Poisson* distribution, with a probability mass function defined in Eq. 5.

$$P(N = n; \lambda) = \frac{\lambda^n}{n!}e^{-\lambda} \tag{5}$$

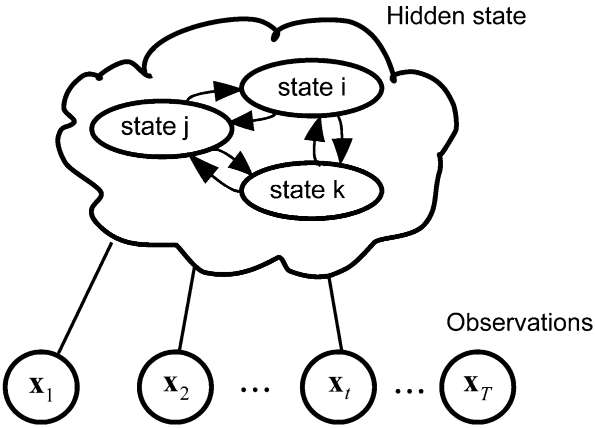

Fig. 4 In unsupervised method no output labels are given during training. The time series of observations is used to detect similar patterns

A Poisson process is a stochastic process widely used for modeling counts $N(t)$ that occur during a sequence of time intervals. This standard Poisson process is not sufficient for modeling many real-world applications where the rate λ varies over time. In such cases the daily and weekly cycles should be taken into account. The periodic portion of the count data (daily and weekly cycles) is done by decomposing the rate $\lambda(t)$ as given in Eq. 6.

$$\lambda(t) = \lambda_0 \cdot \delta_{d(t)} \cdot \eta_{d(t),h(t)} \tag{6}$$

where λ_0 represents the average rate over a full week, δ_j represents the effect of the day j of the week, and $\eta_{j,i}$ represents the effect of the time i of day j of the week. The day of week effect $\delta_{d(t)}$ and the time of day effect $\eta_{d(t),h(t)}$ are normalized such that the average effects are equal to 1. This means that it is required to have $\sum_{j=1}^{7} \delta_j = 7$ and $\sum_{i=1}^{D} \eta_{j,i} = D, \forall j$, where D is the number of time intervals in a day. Figure 5 gives an illustration of the overall average λ_0, the day of week effect δ_j, and the time of day effect $\eta_{j,i}$ applied to a 4-week sensor data, using room transition counts as a feature, in a resident's apartment.

In order to model anomalies as multiple states in a Poisson process, a Markov-modulated Poisson process (MMPP) was introduced as a doubly stochastic Poisson process, of which the intensity $\lambda(t)$ is controlled by a finite, non-observable, continuous-time Markov chain with hidden variable $z(t)$ (Ihler et al. 2006). The counts caused by an anomaly are denoted by $N_A(t)$. In their model the two processes assume that $N_0(t)$ and $N_A(t)|z(t)$ are Poisson distributed and that the two processes are additive. The anomalies are identified using the Markov chain Monte Carlo (MCMC) sampling method. However, MMPPs are univariate and as such cannot deal with the richer datasets that are common to ambient sensor networks such as sensor activities at different locations. In Nait Aicha et al. (2014) we presented the Markov-modulated multidimensional nonhomogeneous Poisson process (M3P2) for the detection of visits to the older resident.

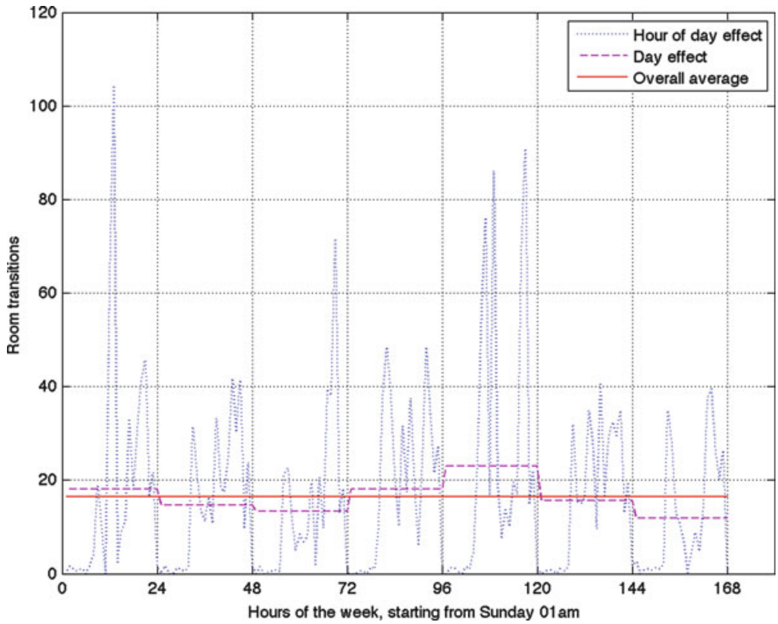

Fig. 5 From the 4 weeks of data from a specific home, the weekly, daily, and hourly effects are learned (From Nait Aicha et al.)

Topic Models Another unsupervised model that is used for categorization of sensor data is the so-called topic model. This model based on "latent Dirichlet allocation" is initially developed to analyze text documents, and the data is usually represented as a "bag-of-word" (BOW) (Blei et al. 2003). The idea is that a document consists of several topics and that a specific topic is characterized by a distribution of words. The model is a generative model, in which the topics z are generated according to a multinomial distribution with parameter θ. Because the words w are symbolic items, they are also generated from a multinomial distribution with parameter β and conditioned on the topic z.

Such a topic model may very well be used for the categorization of sensor data into different "topics." As sensor data we use again the data described in the previous section, for example, a vector with the counts of the different sensors. Analogous to a document containing different topics, we may define a day as containing several activities, in which an activity generates the sensoric patterns. The challenge in using these topic models for activity mining is to transform the continuous sensor vector $\mathbf{x}$ into a discrete representation. One way is to just have uniform segmentation on the different dimensions of $\mathbf{x}$. Another way is to perform a vector quantization step, where the quantization depends on the distribution of $\mathbf{x}$. In Rieping et al. (2014) a method was introduced that models the distribution as normal distributions of which the mean and covariance were estimated simultaneously with the LDA parameters. This method proved to cluster the days in meaningful patterns.

Knowledge-Driven Methods

In knowledge-driven methods the models are built using expert knowledge. This avoids a number of problems of data-driven models in which the parameters are learned from large-scale data sets. In particular it solves the problem of the requirement for large amounts of observation data, and the inflexibility that arises when each activity model needs to be computationally learned. Knowledge-driven methods generally are decision support systems that consist of a knowledge database and an inference machine. Knowledge in general comes from experts by knowledge elicitation. Kaptein et al. (2010) give an example on knowledge from social sciences and how it can be used in persuasion, attitude change, and behavior change in ambient intelligent environments. Knowledge engineering is used in building a model on the relation between functional health and sensor features in Robben et al. (2014). A more elaborate overview on knowledge-driven methods is given by Chen et al. (2012), where a categorization is made in mining-based, logic-based, and ontology-based methods.

Discussion

The decreasing costs of sensor systems in combination with the increasing computational power of low-cost processors makes it possible to build domestic observation systems that can monitor activities of people in their home environment. However, we do not see a large-scale rollout of such systems yet. Experiences in our living labs in the Amsterdam region indicate that various problems are not solved yet. First of all the low level, hardware side of the systems may cause problems. Although many commercial systems are available for networked sensors, they still have shortcomings. We encountered problems with battery usage, communication between sensors, and (Internet) communication with the central server.

The second problem deals with the data analytics, described in this chapter. Learning from data is promising, but not always possible in real situations. For example, annotated data sets that are usually available in lab settings are hard to obtain in real situations. A possibility is to use transfer learning, as described in van Kasteren et al. (2010), where annotated data sets from one user/home are used to model another user/home. Usually this requires domain knowledge to map the different sensor systems to each other. The other issue with supervised learning is that it does not cope well with changing environments. We found that residents sometimes change locations of furniture and electrical appliances which make prelearned models invalid. Unsupervised methods are more suited for dynamic environments because they can adaptively update the models without any annotated data. In particular for anomaly detection these models may be very useful.

The last problem – and that goes beyond the scope of this chapter – is that advanced health-monitoring systems are not incorporated in the care process at a large scale. Partly that has to do with the perceived usefulness and ease of use. Because of the earlier mentioned problems with hardware and the data analysis, the systems may not be robust and are sometimes hard to control. Because of this, the acceptance among care professionals is often low since the systems do not answer their expectancy.

What we learned in our living lab projects is that making systems robust and easy to use is essential, even if such systems do not have the most advanced sensors or data processing methods. It is also very important to introduce the technology together with a change in the care process. And of course in the education of the care professionals, a more important role has to be given to new technological developments. Only in that way there will be an added value of the technology.

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Behavior Recognition in Smart Homes

Linda Chua

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Abstract

One application of Ambient Intelligence (AmI) that supports people in their daily activities is the smart home, which has become a popular topic for research over the past 10 years. The smart home can support the occupant in a variety of ways: watching for potential risks, detecting any abnormality, adapting home for environmental conditions, inducing behavioral change, and many more. For a smart home to support its occupant, it must recognize their behaviors, which is the first part of the smart home problem. In this chapter, we introduce a method that can accurately recognize the occupant's behaviors. We demonstrate our algorithm on sensor data from a real smart home.

Keywords

Behavior recognition • Hidden Markov model • Activity segmentation • Variable window length

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Introduction

Ambient Intelligence (AmI) has a wide range of applications including smart home (e.g., detecting anomalies in a home), transportation (e.g., alert driver about possible dangers and provide route planners), health monitoring and assistance (e.g., reminding of tasks to be performed), industrial applications (e.g., analyzing social patterns in organizations), and education (e.g., observe students' learning progress through their interactions).

One prominent example of AmI is the smart home, which aims to support the occupant, typically the older adults or cognitively impaired who are living alone. In a smart home, the behaviors are likely to be the standard human behaviors of living, and the observations will depend upon the sensors that the house is equipped with. Since sensor observations from the home in some way represent the occupant's behaviors, we view the behavior recognition problem as a task of finding a mapping from a stream of sensor information to a sequence of activities performed by the occupant. We assume that activity in the house is presented to the learning system as a set of "tokens," which arrive in a sequence over time. Depending on the particular sensor, a token could be the direct representation of the current sensor states being triggered (i.e., kitchen light is turned off, heater is switched on, bathroom door is closed, etc.).

However, data from a sensor stream consists of an unending sequence of sensor readings, where the start and end of a behavior are unknown. This poses a challenge to segment the sensory stream into appropriate pieces that represent individual behaviors before any behavior classification can be performed on the sensor sequence. Very few methods described in the literature perform segmentation and behavior recognition simultaneously on the sensor stream. This chapter presents a method that can accurately perform segmentation and behavior recognition simultaneously on the labeled sensor stream using a variable window length and a set of hidden Markov models (HMMs). To evaluate the effectiveness of our proposed method, we use a real smart home dataset and compare the labels produced by our method with the labels assigned by a human to the activities in the sensor stream.

Relevant Literature

Since behaviors themselves are not directly observed, only the observations from the sensors, it is no surprise that probabilistic models, such as the naive Bayes classifier and hidden Markov models, have been the most popular method of recognizing behaviors. Among the works that use the naive Bayes classifier in behavior recognition are those of Tapia et al. (2004) and Sarkar et al. (2010). The work of Tapia et al. (2004) incorporates temporal information into the classifier in order to capture the sequential ordering of sensor readings. Sarkar et al. (2010) address the zero frequency problem, i.e., sensors that are presented to the learning algorithm during testing but not during training. Although the strong independence assumption in the naive Bayes classifier makes it a tractable approach for learning, in order to use it on sequence of sensor readings, temporal information needs to be considered.

The hidden Markov model and variants, which all model the temporal information directly into the model, are also popular methods for behavior recognition. These models estimate the probabilities of the unobserved events (i.e., occupant's behaviors) given a sequence of observable sensor readings. Wu et al. (2007) use HMMs to recognize human physical activities (e.g., walking, sitting, ascending stairs, etc.). They trained a bank of HMMs, each representing one physical activity. Behavior is classified based on the HMM that achieves the highest probabilities. Crandall and Cook (2010) use HMMs to identify and distinguish the behaviors between the different occupants in a home. Al-ani et al. (2007) use HMM to detect fall and physical activities of the occupant from accelerometers. Although HMMs can be used to recognize behaviors from the observed sequences, it becomes difficult to model when a number of states grow.

Given that a behavior is decomposed into a series of individual activity events, many methods represent behaviors hierarchically and use a more complicated variant of the HMM such as the hierarchical HMM to recognize behaviors at varying levels of abstraction (Duong et al. 2005; Youngblood and Cook 2007). In this model, the top level represents the individual behaviors to be recognized (e.g., cooking or making coffee), and the low level represents a set of individual activity events that arise from the sensor values. As this model attempts to recognize a complete model of behaviors, it requires more data for training and has a higher computational complexity, which often becomes intractable for learning.

There are also works (Hu and Yang 2008; Liao et al. 2007) that use the conditional random field (CRF), which relaxes on the independence assumption between sensor observations, for behavior recognition. However, CRF in general is computationally intractable and often relies on approximation techniques such as Monte Carlo Markov Chain (MCMC) for inference.

Many of the works discussed in the literature either assume that the activities have been segmented or address the segmentation problem by using a window that slides across the sensor stream. The work of Govindaraju and Veloso (2005) recognized activities using a set of HMMs but maintained a single fixed window size, which was determined by averaging the length of the training segments used. However, determining the window this way may result in inaccurate segmentation especially when two similar activities occur close to one another in time.

Kellokumpu et al. (2005) use a set of HMMs, one for each activity, and apply the forward algorithm to monitor likelihood values. However, they do not use a sliding time window, preferring multiple window sizes and thresholding in order to separate out the activities. Kim et al. (2007) turn the problem around and perform segmentation before classification, in this case for gesture recognition. The starting point of gestures is detected, and then a window is slid across the observation sequence until an end point is reached. The extracted gestures are then fed to HMMs for gesture recognition, with the final gesture type being determined by majority vote.

Our Proposed Method

We approach the behavior recognition problem by using a set of hidden Markov models that each recognizes a behavior and they compete to explain the current observations. Figure 1 shows an example of two HMMs, one HMM represents the “grooming” behavior and another represents the “showering” behavior.

In our work, the observations are the tokens from the sensors, and the hidden states are the events that arise from the observations. The HMMs were each trained on the relevant training data using the standard Expectation-Maximization (EM) algorithm (Dempster et al. 1977).

Once we have trained a set of HMMs $\lambda_1, \lambda_2, \ldots, \lambda_m$, our next task is to recognize the behaviors from the sensor stream. The data that is presented to the HMMs is chosen from the sensor stream using a variable window that moves over the sequence. A winning HMM λ_{winner} is chosen based on the HMM that maximizes the likelihood of the sensor observations $O_1, O_2, \ldots, O_T$, i.e., $\lambda_{\text{winner}} = \text{argmax}_i P(O_1, O_2, \ldots, O_T|\lambda_i)$.

Many methods reported in literature used a fixed window length to partition the sensor stream. However, the choice of the size of this window is important, because it is unlikely that all of the activities in the sequence belong to one behavior, and so the HMM chosen to represent it will, at best, represent only some of the activities in the sequence.

We use a variable window length that moves over the sequence of observations, where it has the ability to automatically configure the window size based on the sensor observations. We first slide a window of length 10 across the sensor stream,

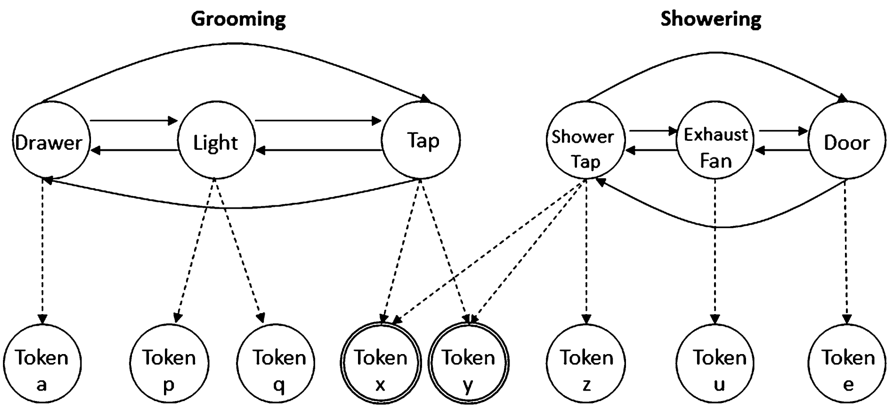

Fig. 1 An example of two HMMs, one represents the grooming/dressing behavior, and the other HMM represents the toileting/showering behavior. The nodes with double lines refer to tokens that are shared between two behaviors

presenting the 10 observations in the window to the sets of trained HMMs for competition (this window size of 10 is determined experimentally). A winning HMM is chosen based on the HMM that maximizes the likelihood of the 10 observations in the window. Since we want to ensure all behaviors in the window are recognized, we perform a re-segmentation using the forward algorithm (Rabiner 1989). This is achieved by calculating the likelihood of each sensor observation $P(O_1, O_2, \ldots, O_T)$ in the window according to the model of the winning HMM λ, i.e., $P(O_1, O_2, \ldots, O_T|\lambda)$.

The computation of the conditional probability in the forward algorithm involves three steps: (1) initialization, (2) induction, and (3) termination. The initialization step computes the joint probability of state S_i and the initial observation O_1:

$$\alpha_1(i) = \pi_i b_i(O_1) \tag{1}$$

where b_i is the probability of observing observation O_1 given that current state is S_i, $i = 1, 2, \ldots, N$. The induction step involves the computation of the forward variable $\alpha_{t+1}(j)$, which is the probability of reaching state S_j at time $t + 1$ from any of the N states S_i at time t, where

$$\alpha_{t+1}(j) = \sum_{i=1}^{N} \alpha_t(i) a_{ij} b_j(O_{t+1}), \tag{2}$$

$t = 1, 2, \ldots, T - 1, \quad j = 1, 2, \ldots, N$. The computation iterates for all the observations $t = 1, 2, \ldots, T - 1$ following Eq. 2.

The termination step is to calculate the probability of the observations given the model $P(O|\lambda)$:

$$P(O|\lambda) = \sum_{i=1}^{N} \alpha_T(i). \tag{3}$$

By monitoring the forward variable (α) for each sensor observation, we can determine how well the "winning" HMM matches a given observation sequence. When $\alpha > 0$, it means the model of the "winning" HMM recognizes the sensor observations, while $\alpha = 0$ means that the winning HMM does not "recognize" the sensor observation, i.e., none of the states in the HMM recognize the sensor observation. The changes in α value signify a "change" of activity from the observation stream.

Figure 2 shows how the α values computed by the forward algorithm applied to one particular HMM, the one selected as the "winner" for this window. To simplify the illustration, the α value in the figure is quantized into the set $\{0, 1\}$. When $\alpha = 1$, it means that the winning HMM recognizes the sensor observations and 0 otherwise.

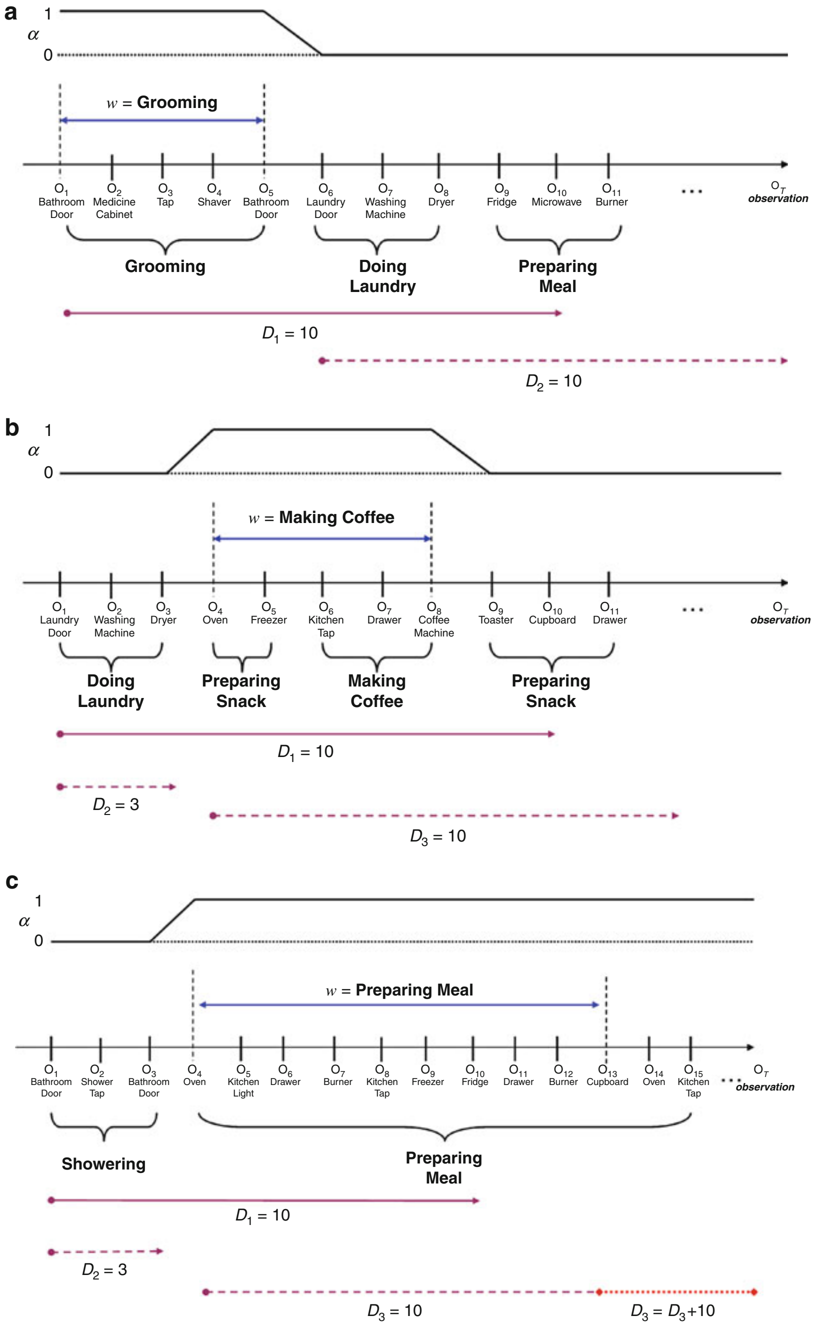

Fig. 2 The solid line above the observation sequence shows the possible representations of a winning sequence using the α values. For simplicity, the value is quantized into the set $\{0,1\}$. D is the default window size and $O_1;O_2;\ldots;O_T$ is the observation sequence. The original observation sequence is shown as the down curly brace

If the $\alpha > 0$ at the beginning of the observation sequence, then it is likely that the case in Fig. 2a is occurring. Following Fig. 2a we see that there is a drop in α value between observations O_5 and O_6, which suggests that the behavior has changed. We can therefore classify O_1, O_2,. . ., O_5 as belonging to the winning behavior w (i.e., grooming) and then initialize a new window of default size (D) at O_6. When D is initialized, all the observations within D will then be fed to HMMs for competition and the process iterates.

The second case occurs when the winning behavior best describes observations that fall in the middle of the window, e.g., O_4, O_5,. . .,O_8 in Fig. 2b. Since the winning behavior (w) does not describe observations O_1, O_2, and O_3, the probability for these three observations is low (i.e., $\alpha = 0$), and we observe a jump in the α value at O_4. When this is observed, a new window (D_2) is initialized that contains only the three observations (i.e., O_1, O_2, O_3) that are not explained by behavior w. The HMM competition is then rerun on this window, where the winning behavior for this window is "doing laundry." With regard to the remaining sequence (O_4 and onwards), a new window of default size is started at O_4, and the HMM competition is rerun on this sequence.

Since the two cases have been considered when the winning behavior is at the beginning and middle of the window, the only possibilities remaining are that the behavior is at the end and either stops during the window (Fig. 2a) or does not (Fig. 2c). The first case is already dealt with, and in the second case, we extend the size of the window (shown as a dashed arrow in Fig. 2c) and continue to calculate the α value for each observation until α drops.

Experimental Results

To demonstrate our system, we used a real smart home dataset from the MIT PlaceLab (Tapia et al. 2004). They collected data using a set of 77 state-change sensors that were installed in an apartment and collected data while a person lived in the apartment for a period of 16 days. The sensors were attached to household objects within the home such as the washing machine, toaster, etc. The dataset was annotated by the subject herself, meaning that there was a ground truth annotation of the dataset.

We used a leave-two-out cross-validation method for each evaluation in order to calculate the confusion matrix and measure the recognition accuracy. From the total of 16 days, we used 14 days for training and the remaining 2 days for testing. We repeated the process eight times, with the final recognition accuracy being calculated by averaging the accuracies in each run. The main metric that we are interested in is *recognition accuracy*, which is the ratio of the total number of behaviors correctly identified by the algorithm over the total number of activities used for testing.

To test our system, we conducted two separate experiments. In the first, we looked at the accuracy of the algorithm to recognize behavior based on the HMM competition and variable window length, while in the second we compared the algorithm with fixed window length.

Table 1 Results on supervised learning based on competition between HMMs and variable window length on different training/testing splits

Test sets	No. of behavior examples for testing	No. of behaviors correctly identified	Recognition accuracy
1st set	31	28	90 %
2nd set	54	49	91 %
3rd set	20	19	95 %
4th set	33	30	91 %
5th set	49	45	92 %
6th set	34	31	91 %
7th set	37	35	95 %
8th set	52	44	85 %
Average			91 %
Standard deviation			3.2

Experiment 1: Competition Among HMMs and Variable Window Length

The aim of this experiment is to test the efficacy of our method based on competition among HMMs and a variable window length. In this experiment, we used a default window size of 10 and ran the entire algorithm over the sensor observations on different test sets. The recognition accuracy results across different test sets are shown in Table 1. Our method achieved an overall accuracy of 91 %, which shows that our method based on competition between HMMs and variable window length can be used to recognize and segment the sensor stream into behaviors.

Experiment 2: Comparison Between Variable Window Length and Fixed Window Length

This experiment is designed to compare the algorithm with the fixed window length. In this experiment, we used a fixed window length of sizes 5 and 10 and ran the algorithm over the sensory stream on different test sets for each evaluation. Each window is shifted over the sensor stream with increments according to the size of the fixed window. For example, for fixed window length of size 5, the window is shifted over the sensor stream with increments of five sensor observations. The results are shown in Table 2.

The results showed that using a variable window length outperformed a fixed window length (on both window size = 5 and 10) and that our approach of re-segmentation improves the recognition results, achieving an average accuracy of 91 %. The problem with fixed window length is that it can only identify one winning behavior and resulting in other behaviors not being able to recognize in the window.

Table 2 Comparison results between the variable window length and fixed window length based on window size = 5 and window size = 10

Test sets	Recognition accuracy			
	Window size = 5		Window size = 10	
	Variable window	Fixed window	Variable window	Fixed window
1st set	90 %	55 %	90 %	48 %
2nd set	91 %	69 %	91 %	54 %
3rd set	95 %	75 %	95 %	75 %
4th set	91 %	76 %	91 %	58 %
5th set	92 %	49 %	92 %	51 %
6th set	91 %	68 %	91 %	62 %
7th set	95 %	70 %	95 %	59 %
8th set	85 %	60 %	85 %	46 %
Average	91 %	65 %	91 %	57 %
Std. deviation	3.2	9.6	3.2	9.3

Discussion

Our algorithms worked very well, producing over 90 % recognition. However, it is still instructive to see if there are consistent reasons for the misclassifications that did occur.

We identified one main reason for misclassification, which is that individual sensor observations can be in several behaviors. There are two places where this can be a problem. The first is when the end of one behavior contains observations that could be in the start of the next. This will not pose a problem if the second behavior happens immediately after the first. However, if the second behavior happened two hours after the first, that would be a totally different unrelated behavior. The second place that this can be seen is where the winning behavior is not at the start of the window, but those activities at the start could be interpreted as being part of that behavior.

It was experimentally observed that this was more likely to happen where the size of the window was large, because more behaviors were observed. One way to reduce the misclassification is by adding extra information in order to improve the classification accuracy. This can be achieved by augmenting the current algorithm with spatiotemporal information. If spatiotemporal information is included, then places where two behaviors abut one another can be reduced.

Conclusion

For a smart home to support its occupant, it must first recognize their behaviors. This chapter has presented a system that performs behavior recognition and segmentation simultaneously on the sensor stream based on competition between a set of trained hidden Markov models (HMMs) and a variable window length. Our experimental results show that our method works effectively, achieving an average accuracy of 91 %. We have also shown a comparison between variable window length and fixed window length and that the variable window length works best.

In the future, we plan to apply our method on other datasets that consist of both object and motion sensors and investigate on how far this can improve the recognition performance.

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Interoperability and Intuitive Controls for Smart Homes

Rob van Mil

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Introduction

Too often, smart home technologies are seen as an innovative type of technology for expensive and upscale real estate and housing or for application in the domain of healthcare. There are three main goals for the application of smart home technologies. The first goal is to improve the level of comfort and ease of use of dwellings. The second goal is to improve the sense of safety and security inside and around a building. The third main goal is to use energy more efficiently. Despite the good intentions, the use of smart technologies at home does not automatically lead to achieving the three goals mentioned above. In addition, there are a number of requirements that need to be fulfilled in order to maximize the acceptance of such technologies by consumers. To date, the market of smart home technologies has, despite the growing number of companies and organization involved in this domain, not reached its stage of adulthood. Since the 1990s, many scenarios were laid out in which smart home technologies were portrayed as a promise for the future. Despite these positive scenarios, smart home technologies are still not daily business for many building services companies, advisers, and installers. Only when we can reach more uniformity in the domain of smart homes, we can expect a general growth of the market of smart homes. With the aging of society, there is an increasing need for more comfort and safety. But at present, there are simply too many standards, as well as producer-bound systems, which cannot, or hardly can, be combined or require the use of complicated and costly gateways. At this moment this is the most important obstacle.

Too Many Standards

The producers in the domain of electrical engineering have tried to turn the situation around in the past decade. They have collectively developed systems and products that improve the ease of installation. Even more important is the trend to base new products and systems on international standards. In daily practice, many customers and principals are hindered by the large array of systems and standards that they encounter when opting for home automation systems. In addition, the multitude of systems and products are a cause of lack of compatibility. The pioneers in the field of home automation, the frontrunners who equipped their dwellings or buildings with smart home technologies, often notice that, when retrofitting or expanding their existing systems, the investments are annulled. New systems and services are in many cases not compatible: the systems cannot exchange information and work together. This problem is acknowledged internationally. This is why in a European context, the project SmartHouse Roadmap (SHR) was set out. In 2011, CENELEC, the European standardization committee, finished the first phase and sent an official advisory report to the European Commission. In their report, CENELEC pleaded for an improved coordination

Table 1 A short list of ecosystems of standards which have been deemed relevant by the SmartHouse Roadmap

TCP/IP	Zigbee	TR-069	Microsoft protocols	HomePlug
Ethernet	G.hn	Open IPTV	EN 50523 series	EN 14908 series
Wi-Fi	EN 50173 series	SIP	UPnP	U-SNAP
DECT	OSGi	Continua	EN 50090 series	EN 61850 series
Bluetooth	DLNA	DLMS/COSEM	HGI	EN 50065 series

and steering concerning the large number of ICT standards for smart home technologies. CENELEC further called for the reduction of the number of ICT standards and to get more tuning and synergy between the existing standards. Only through these actions, it will be possible to couple and exchange advanced technologies and systems in the dwelling.

The Need for More Interoperability

One important objective for the call for more uniformity in the domain of smart homes is the expected growth of the market of care-related applications at home. With the aging of society, there is an increasing need for care and care services, and the current nursing home capacity will be limited to those who cannot be accommodated in their own home environment. Home automation systems, telecare, and telemedicine are, thus, needed to turn dwellings into lifetime homes. This desire, which is based on societal changes and trends, can only be achieved if as many systems as possible can be combined in practice and, thus, are interoperable. At present, there are simply too many standards, as well as producer-bound systems, which cannot, or hardly can, be combined or require the use of complicated and costly gateways. The SMR showed that there are over 6,000 standards, which is a truly staggering number. A part of these standards lead a dormant existence or are no longer in use. Many of the standards which are in active use are so different that they cannot be combined and work together. The technical experts who stood at the basis of the SMR concluded that about 300 standards are relevant for today's practice. These standards have been subdivided into 59 so-called ecosystems. This means that the standards of a given ecosystem are to a certain extent operating within a specific domain. Some of these domains are, for instance, building services technologies, ICT devices, audio and video telemedicine, and so on. In the SMR, an overview of the most relevant standards had been included (Table 1), in which the technical advisers explicitly do not state that all standards need to be interoperable at all times. By demanding so, they would take away all competition and thus incentives for innovation. Having a large degree of interoperability is essential. It is in fact the most important precondition for changing dwellings into lifetime homes.

New Infrastructures

Apart from standards, the infrastructure of smart homes has seen a lot of ever faster developments during the last decades. Twenty to fifteen years ago, it was common to use a special BUS cable for smart home technologies. Even today, special twisted pair cables are being used. With the arrival of new technologies, other modes of transporting data find their way into the home environment. The strong growth of IP had led to the use of IP cables for smart home technologies. Even infrared is a feasible medium of transportation for certain systems. There are also ways of sending data through 230 V power lines, the so-called “powerline” communication. Two recent technologies that are emerging or are in the phase of research and development are the use of radio waves (wireless protocols) and optical fibers. In the public space, we refer to optical fibers as glass fibers used for television and the Internet. Inside the dwelling, fiber glass can already be used, although a swift is expected towards plastic optical fibers as well.

Optical Fibers and Wireless Technologies

Plastic optical fiber (POF) seems a promising mode of transportation in the future of home networks. One important advantage is that this type of wiring is fully made of plastic and can be inserted into existing electricity ducts without any negative side effect as interference. Standards and building codes will not form an obstacle to the implementation of POF, and it will therefore be possible to have an access for home automation at any plug socket in the home. The general consensus is that home automation technologies will never be fully wireless. A wired “backbone”, which can be based on POF, will always be important for obtaining the highest degree of security and robustness, for covering large distances in buildings, and for the transmission of data through heavy concrete walls and floors. Within a given space or for short-distance data transport, wireless systems can function unchallenged. From the perspective of radiotechnology, there are numerous developments which support stepping over to “smart radios”, as many existing radio frequencies remain largely unused in terms of their bandwidth. About 15–25 % of the time, the whole bandwidth is used. It should, therefore, be possible to use the empty periods within the existing frequencies for transmitting signals for smart home applications using intelligent technologies. These signals are often transmitted in an instant of a second.

Opportunities for Existing Housing

There are a number of producers in the field of smart homes who bring wireless products, based on radio frequencies, to the market. Some of them use transmitters that can control lighting or solar blinds. There are also companies who use transmitters and receivers which send out bidirectional signals, which is important for the robustness of the system. By only using transmitters, the smart home system does not know how and if any given command has been executed correctly. Only a bidirectional system guarantees such a feedback. The emergence of such bidirectional, wireless systems is important for offering robust home automation systems to customers. And wireless systems are indispensable if the sectors want to install home automation systems in existing dwellings on a large scale.

Not Just One Kind of Wi-Fi

One of the most important wireless standards that can be found in the majority of dwellings is Wi-Fi. Because the Internet Protocol, one of the most frequently used network technologies, is available via Wi-Fi, the importance and use of this protocol will increase even further in the coming years. There is not just one type of Wi-Fi. The development of this protocol has not reached its end point, as the interoperability of the technology remains an important selling advantage. The introduction of the so-called ac-variety of Wi-Fi is currently being undertaken, which is more secure and robust than the current standard. Behind the scenes, researchers work hard on the successor of the ac-variety, namely, the ad-variety with a 60 GHz frequency that offers an even faster and more robust wireless network. The disadvantage of this ad-variety is that it is not able to penetrate walls. One way to overcome this problem is to install a separate access point in every room, which creates a Wi-Fi network in every individual room. This, however, goes together with an advantage to the security because a wireless network no longer reaches beyond the limits of a given space. Everyone can get his or her own personal area network (PAN). In order to achieve this scenario, wired solutions are needed, for instance, via POF. Via POF and Wi-Fi access points, every room will be equipped with an advanced Wi-Fi network, a so-called fiber to the PAN system. POF offers, at a rate of 1 gigabyte per second, sufficient capacity in dwellings, in terms of bandwidth, to cover the net for Internet services for the next 20 years. In buildings of the future, one will walk from one room to another and at the same time from one PAN to another, in which scenario mobile devices will switch from one network to another.

Preparations

Researchers and experts are convinced that POF is easy to install in existing dwellings and buildings. The introduction of all these networks, technologies, and combinations of services goes together with a need for maintenance services. Think for example about the maintenance of crucial backbones, which at present can be found largely in the outdoor world but which will be installed inside buildings in the future. In newly designed buildings, home automation services can be easily implemented. In new buildings, the building services sector should install a standard BUS wire to any room so that users can apply or expand smart home technologies in any room of the house. The additional costs of these BUS wires are marginal, given the total costs of a new construction, whereas the practical value of a house increases substantially. In existing dwelling, inserting BUS wires in existing electricity ducts is not possible, in contrast to POF, as they need to be inserted in their own empty ducts. For existing dwellings, POF and wireless systems are the most promising solutions. Such technologies allow users to get control systems in their home without the need for thorough retrofitting.

The bidirectional, wireless systems are sufficiently developed and are being launched on the marketplace. Large-scale and fully functional POF concepts are not yet available on the marketplace.

Invest in Sales Techniques

Apart from all the standardization and technological requirements, which is mainly a domain of interest for professionals with a technological background, there is a need for making potential customers interested in smart home technologies. Raising the awareness among, and triggering of, potential customers was not a top priority in recent years. This was partly due to the price levels of smart home systems, which are still relatively high, and because of the lack of transparency which advantages a smart home system can provide to its users. The cost-benefit analysis could not be made without having a lot of insight and knowledge. The lack of transparency concerning the number of systems and standards was a further hindrance to potential clients. In short, retailers of smart homes have an important task in providing clear and straight information. The fact that smart home technologies are expensive is not necessarily a hindrance for being attractive. Smart phones, LED televisions, and tablet computers are pricy devices too, and yet, they sell by the thousands. Apparently, the advantages and attractiveness of such technologies are clearer and more obvious. These benefits seem to be poorly understood for smart homes by the society at large. In addition, the attractive technologies mentioned before have intuitive controls and have actually become "must have" items for many of us. How can this entrepreneurial trick be repeated for installers of smart home technologies and system integrators? As soon as the requirements for smart home systems are clear (a future-proof system based on a sustainable standard and allowing interoperability), it should be possible to convey the message of the many advantages smart homes may bring to the population. Every target group will have its specific set of needs. These needs may be related to the want for comfort or care-related services; sometimes it is the need for energy reduction. In practice, customers will be truly convinced if a system integrator comes to offer a combination of advantageous solutions.

Intuitive Controls

The moment a costumer chooses to have a home automation system installed at home, he or she is mainly occupied with the control system that is part of his/her future smart home. The control system should operate flawlessly, and it is detrimental to the acceptance of smart home technologies if the system cannot be easily operated.

Producers of switches and controls offer solutions combined with up to ten functionalities into a single switch, which leads to an unwanted degree of complexity. Even esthetically pleasing touch panels with even more pleasing interfaces can quickly become too complicated for users, especially when the system is operated through a number of multilayer menus. Occupants of large houses will not only get physically lost in their dwelling but also in the virtual home displayed on the touch panel. In Europe, steps are taken to start standardization in the field of universal control. The Figaro project is a collaboration between knowledge and research institutes with producers in order to come up with new standards for the control of audio and video systems, telecare, and energy management. The protocol that is to be developed is UPnP; this is the engine behind the DLNA standard and which is integrated in consumer electronics which is already commonly used. Eventually, a visually pleasing and intuitive control of smart home systems will be a key element in winning the hearts and minds of future users. With the emergence of smartphones and tablet computers and their connection to smart home technologies, skilled system integrators can make the control systems even easier to master for future users. A control app on a private tablet is accessible to all groups of users and can be manipulated through intuitive hand movements. In combination with the increasing level of standardization of the underlying technology of smart home systems and the growing chances for wireless technologies, the future of smart home technologies suddenly looks much brighter.

Action Needed to Streamline a Myriad of Standards

In order to increase the marker potential of home automation systems and smart home technologies, the technologies used need to become more universal in terms of their use and application. Customers and principals will have to demand from their building services engineers and consultants to supply them with a system which is future-proof, in particular from the perspective of interoperability. The European Union has already embraced this view, and within a broad consortium of stakeholders, a search was commenced for a selection of universal standard which can offer these guarantees. Within the project SmartHouse Roadmap, a selection has been made of relevant standards out of over 6,000 existing standards related to the use of smart home technologies (Table 1). A description of some of the most important standards is provided below.

IP

In today's world, information and communication technologies are omnipresent. An important exponent of these technological possibilities is the Internet Protocol (IP). Through IP, ICT has produced numerous communication standards. The best known are the Ethernet, as well as FireWire (wired), USB (wired), Bluetooth (wireless), DECT (wireless), and Wi-Fi (wireless).

BACnet

BACnet (building automation and control network) is a standard, which was developed in the United States as a protocol to allow intelligent devices to exchange information, irrespective of their functionality and producer. BACnet allows the use of multiple devices from various producers in a single project. BACnet can be used for the automation of systems and for the automation on a management level. The system controls a wide array of functions of a building, including heating, ventilation and air conditioning systems, lighting, fire control systems, as well as entrance controls, elevators, and the supply of energy. BACnet is standardized in compliance with ANSI and CEN standards, as well as ISO 16484-5. BACnet claims to be the broadest protocol for the control and automation of buildings. It is independent of producers and is being tested and developed by independent laboratories.

KNX (EN 50090)

KNX is an open protocol for the automation of homes and other buildings. Via KNX, the exchange of data is facilitated to and from all components within a certain home automation system. KNX works on the basis of decentralized intelligence, which does not require a central computer. Each separate component has its own degree of intelligence, which leads to a robust system. KNX has been around for over 20 years, or at least the systems that form the foundation of KNX (EIB, EHS and BatiBUS, which were developed by European electronics companies). In 2005, these standards merged into the KNX protocol. KNX manages the communication via various media (twisted pair, radio frequency, power line of IP/Ethernet). KNX was recognized as an international standard (ISO/IEC 14543-3), as a European standard (CENELEC EN 50090 and CEN EN 13321-1), and as a Chinese standard (GB/Z 20965). Worldwide, over 350 producers use this protocol for their products. Hence, KNX is a standard with over 10,000 certified products and with the largest degree of support among all building services technologies.

LON

LON (Local Operating Network) technology was developed by the American enterprise Echelon in the 1980s by the order of the American aviation industry. The goal was to control all electrical components, independent of the producer, through a reliable network. LON technology has since developed as an independent, open standard for decentralized intelligence. A LON network does not require the use of a central computer, server, or PLC (programmable logic controller). LON is a worldwide standardized protocol that has been certified by a number of international bodies. About 4,000 products are certified for the use of LON worldwide.

CAN and CANopen

CAN (controller area network) is the dominant data protocol that enables communication between the intelligent systems of cars. CAN is internationally certified according to ISO 11898-2. A derivative of CAN is CANopen, which is also an internationally standardized protocol according to EN 50325-4. This standard is being used in the domain of mechanical engineering, medical installations, rail vehicles, and maritime applications, as well as home automation and energy installations on an occasional basis. CiA is the international organization of users and producers which further develops the CANopen standard. Worldwide, about 500 enterprises are participating in CiA.

Profibus

Profibus was developed in 1989 by a number of European companies and bodies. The goal was again to realize a single communication standard for automation of components of various producers. Shortly after the introduction, Profibus was standardized through the DIN-standard 19245. Profibus was developed for the automation of production lines and buildings, en in 1995, it was also adapted for use in the process industry.

IO-Homecontrol

IO-homecontrol (IO: InterOperability) is a wireless communication technology to control building services technologies. It was developed by a group of producers of technologies that supply comfort, safety and security, and energy management for new and existing buildings. The wireless communication controls doors, skylights, blinds, lighting, heating, air conditioning, garage doors, and automated fence gates. Only seven producers support this protocol. IO-homecontrol does offer bidirectional communication.

DLNA

DLNA, the Digital Living Network Alliance, is an organization that developed a protocol in order to exchange digital media files between devices and which offers this protocol as a worldwide standard. The standard encompasses the reliable exchange and storage of files, as well as the possibility to play or process digital files from one device onto another. About 25 top brands in the domain of consumer electronics joined the organization. In addition, there are over 100 “contributor members”, organizations who support of use the standard in an indirect manner.

Including Smart Architecture in Environments for People with Dementia

Cathy Dalton

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Abstract

Environments which aim to promote human well-being must address both functional and psychosocial needs. This paper comprises a description of a framework for a smart home environment, which aims to comprehensively address issues of environmental fit, in particular for a person with cognitive impairment associated with dementia, by means of introducing sensing of user affect as a factor in system management of a smart personal life space, and in generation of environmental response, adapting to changing user need. The introduction of affective computing into an intelligent system managing environmental response and adaptation is seen as a critical component in successfully realizing an interactive personal life-space, where a continuous feedback loop operates between user and environment, in real time. The overall intention is to maximize environmental congruence for the user, both functionally and psychosocially, by factoring in adjustment to changing user status. Design thinking, at all scales, is perceived as

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being essential to achieving a coherent smart environment, where architecture is reframed as interaction design.

Keywords
Smart homes • Dementia • Responsive architecture • Affective computing • User–centred design

Introduction

"Residential healthcare" broadly describes a category of architecture for people who need considerable assistance in daily living. These needs can stem from either congenital or acquired disability, which can be physical, mental, or psychological. The increase in the population of elderly people in developed societies across the globe, and with that, a commensurate increase in the numbers of elderly people with dementia (Alzheimer's Association 2013), has created demand in recent years for suitable living accommodation for these users, sometimes in the form of residential healthcare, or sheltered housing. Elderly people with dementia, in particular, require considerable support. As dementia is both progressive and systemic, the condition eventually comprehensively impairs functioning: it is far more than a matter of mere memory loss, but rather the related loss of ability to access a lifetime's worth of knowledge about "how to," including in relation to carrying out the many tasks of daily living, and the knowledge of how to interact successfully with environment. Total environment includes built environment and architecture, as well as social environment; however, it should be borne in mind that physical environment also impacts on the social possibilities available, as much as it does on the functional. In the latter stages of the disease, independent living is no longer possible, but quality of life remains an issue. Research and applied design solutions in recent years have demonstrated the capacity of good design to assist people with dementia in navigating and understanding the built environment, most importantly their own living environment (Day et al. 2000; Judd et al. 1998), whether that is their lifetime home, or purpose-built supported accommodation.

It is immediately apparent that smart technologies might prove of considerable benefit in the home environment of a person with either cognitive or physical impairment, or both, by providing compensation for loss of ability to interact successfully with the environment, effectively creating a prosthetic environment. So far, however, there seems to have been little by way of consideration of comprehensive and integrated approaches to the design of such environments. Much smart home research takes the approach of dealing on an individual basis with a plethora of computationally enabled applications or devices, rather than by taking a joined-up and more design-based approach to the whole concept. Ideally, the design of a smart home environment should be first approached from a broader perspective, and then broken down into its constituent parts, remembering always how they link to one another from a user perspective, interacting to form a total user experience (UX), which forms a constituent part of the user's experience of the complete architectural space.

User Experience in Interaction Design and the Architecture of Care

The concept of UX is common in web and application design, but how might it operate in a total architectural environment? To consider this, it is useful to conceive of a smart home as a total interface at the architectural scale, whether that is a single room, an apartment, or an entire building, so that the design of the built environment is effectively treated as an exercise in interaction design. The significance of the user, and of user experience, is acknowledged as critical to successful interaction and interface design, which is built around the trinity of person, context, and activity. Who exactly is the user, what are her defining characteristics, and how will they impact on the design of a successful interface? Where does the interaction take place? What does the user want to achieve, and what needs must be met? The architecture of residential care should similarly place the user, and detailed consideration of user characteristics, at the center of design decision making. However, it must be acknowledged that this particular concern with user-centered design has only emerged in recent years and that for many years preceding that, people who were extremely vulnerable by virtue of age, disability, illness, or even temporary impairment, including in the context of acute hospital care, were, and still are, routinely placed in environments inherently hostile to them and, which present, for them, considerably greater difficulties in use than they would for any fit and healthy person. Historically, the "architecture of care" has often poorly served those who had no choice but to inhabit it. For an example, one need look no further than the design of workhouses in Britain and its colonies, originally deliberately designed to contain and control those unfortunate to have no choice but to live in them. Many such buildings were subsequently adapted for healthcare use, often to house elderly people incapacitated by age-related conditions, including dementia. Their built form has continued, in some cases, to influence perceptions of what is still deemed appropriate as an architectural setting for users who are, by their very nature, more vulnerable than the general population and whose needs are ill met by the limited possibilities such environments afford. The tide has turned, but in many countries, it still carries with it the detritus of outdated thinking in design terms, founded on notions of the end-user as "other," rather than on contemporary ideas of a continuum of ability, and Universal Design. Though all human users share many needs and characteristics, when designing a compensatory interface or interaction, the designer must always be mindful of the particular characteristics of the end-user. In the case of the person with dementia, the designer, whether it is the architect or interaction designer (and in this scenario both, or some new hybrid), must grapple with the idea of a user with whom it can be especially difficult to identify, as this user has particular problems with both interpreting and interacting with the built environment. As the disease progresses, the individual's ability changes, and so, in a fashion, the design brief continually evolves. In a sense, the designer must design for many notional users, not one; in UX, this translates into designing for many "personas." So, in the particular case of a person with dementia, the idea of an adaptive environment that can alter to meet a range of user conditions makes particular sense. A responsive environment can also begin to address the transactive nature of the person's relationship with her environment and its effect on task performance, which is recognized in occupational therapy (Law et al. 1996).

Context

In the case of architecture, and with reference to smart homes, the term "context," as used in interaction design, acquires the same meaning as that of "context" in architectural theory generally; that is, it implies a specific physical locale. In this discussion, that locale is taken to be the personal living space of an elderly person with dementia, though some of the conclusions that emerge may well have applications for other users in other contexts. Malcolm McCullough, in "Digital Ground" (McCullough 2004), proposes that pervasive computing in architecture should be used to reinforce placemaking and context, making a case for a "quiet architecture," where focus returns once more to the user. McCullough further maintains that appropriate use of computational technologies in architecture should always be determined by context. For the elderly person with dementia, especially in the light of the associated loss of ability to perform previously learned tasks, or to easily learn new tasks, familiarity is an essential aspect of the personal environment. An appropriate approach might therefore be one which embodies a "quiet architecture," where ICT is subsumed, as "calm technology" (Weiser and Seely Brown 1996), into the built fabric, remaining at the periphery until such time as it is called on by the user. In an appropriate intelligent home environment, technology does not need to be overt unless it is specifically required by the user to assist in a given task or interaction. Here, design for the sake of aesthetic novelty loses its power in the face of the inherent possibilities of an alternative embrace of technological potential.

McCullough goes as far as to suggest that interventions made using pervasive computing technologies might be compensatory in the case of existing architectural design that has failed to address concerns of usability and human-centeredness, so that "interactivity becomes a remedy for architecture, which as a discipline has ignored usability, performance and inhabitation in its quest for attention-seeking novelties in form" (McCullough 2004). With the emergence of sophisticated computational systems to manage environment and interaction, there exists also the new possibility of designing remedial technological interventions, in order to improve the quality of user experience in architectural settings which fail to satisfy user needs by virtue of their existing physical characteristics.

Person-Environment Fit

"Congruence," or person/environment fit, is a useful perspective from which to examine the relationship between person and built environment in smart home design. Congruence breaks down into functional and psychosocial congruence. There are many and overlapping theories in environmental psychology, those of

Kaplan (1983), Boyden (1971) and Kahana (1980) being of particular interest. Boyden theorizes that humans have well-being needs, in addition to basic survival needs, and that these higher needs must be met in order to maintain and promote both physical and psychological health, which are now generally seen to be inextricably linked. Boyden also refers to a need for meaningful change and sensory variability in environments which address well-being needs. While much effort in smart home design has been put into addressing functional needs, far less progress has been made in the direction of designing for psychosocial fit.

Lack of congruence can be a source of stress, in particular where the user is either physically or cognitively impaired, and all the more so where that lack of fit is continuous and persistent over time, leading to what Boyden terms the "Gray Life": a life of psychosocial maladjustment, of depression, of aggression, and furthermore of stress-related physical illness. The significance of psychological stress in the onset of acute illness, as well as lifestyle illnesses, including dementia, is beginning to be understood, through growing knowledge of neurochemical and biochemical mechanisms (Johannson and Guo 2010; Khansari et al. 1990; Sotiropoulos et al. 2011). A healthful, or salutogenic environment, can contribute to optimizing human functioning (Heerwagen et al. 1995; Day et al. 2000). As the capacity of the person with dementia to cope with environmental stressors is progressively lowered over the course of the disease, design of long-term care accommodation must take a dual approach to addressing stressors of environmental origin, in order to promote well-being. Firstly, it should be designed to minimize unnecessary stress in interpreting and interacting with the built environment (Hall and Buckwalter 1987) but, beyond that, should provide opportunities, through considered design intervention, for recovery from stress and for attentional restoration. The latter is particularly valid if it can contribute to recovery from cognitive overload, arising from progressive loss of function. Small tasks become large tasks; frustration at being unable to do "ordinary" things increases, while at the same time the person continues to be aware of and often embarrassed and frightened by a growing inability to manage ordinary day-to-day tasks and environmental interactions. In order to be truly "smart," smart home design needs to take consideration of both aspects of environmental fit. In "smart" architecture, the designer may begin to find integrated solutions that can potentially create an environment that delivers best user "fit" by continually adapting to the user, in a manner that is not possible without the integration of smart technologies. Computational technologies can thus serve to extend the remit of inclusive design, pushing the envelope outwards towards universality.

Environmental features which contribute to well-being have been usefully summarized by Heerwagen (Table 1). Very often, the same design feature in the built environment caters for both functional and psychosocial fit, and so it should be in Smart Home design. An example from built environment is that of the level threshold, which, functionally, allows a person with limited mobility to move from one space to another. In so doing, it can allow access to outdoors, facilitating visual change and spatial variability, but also gives the person ease of access, or independent access, to other behavioral settings, supporting personal control

Table 1 Features and attributes of buildings linked to well being needs and experiences (Heerwagen)

Experience/need	Environmental features and attributes
Connection to nature and natural processes	Daylight; views of outdoor natural spaces; views of the sky and weather; water features; gardens; interior plantings; outdoor plazas or interior atria with daylight and vegetation; natural materials and décor
Opportunity for regular exercise	Open interior stairways; attractive outdoor walking paths; in-house exercise facilities; skip-floor elevators to encourage stair climbing
Sensory change and variability	Daylight; window views to the outdoors; materials selected with sensory experience in mind (touch, visual change, color, pleasant sounds, and odors); spatial variability; change in lighting levels and use of highlights; moderate levels of visual complexity
Behavioral choice and control	Personal control of ambient conditions (light, ventilation, temperature, noise); ability to modify and adapt environments to suit personal needs and preferences; multiple behavior settings to support different activities; technology to support mobility; ability to move easily between solitude and social engagement and spaces to support both
Social support and sense of community	Multiplicity of meeting spaces, use of artifacts and symbols of culture and group identity; gathering "magnets" such as food; centrally located meeting and greeting spaces; signals of caring for the environment (maintenance, gardens, personalization, craftsmanship)
Privacy when desired	Enclosure; screening materials; ability to maintain desired distances from others; public spaces for anonymity

over socialization. This is not to say that architecture is deterministic, but that it can nonetheless contribute to shaping patterns of human behavior. How, then, does the designer of smart homes for elderly people, including people with dementia, go about integrating concerns of congruence into design approaches? A first step is to derive principles for interaction design in the built environment. Corcoran and Gitlin have previously derived principles for environmental interventions for people with dementia (Corcoran and Gitlin 1991). These may be extrapolated into principles and recommendations for design interventions in an intelligent personal living space for an elderly person with dementia (Dalton 2014), where environmental affordances are consciously manipulated to match user ability. While the original principles refer to total environment, including social environment, they can be usefully applied to built environment and interaction design embedded in the architectural environment. The latter, in its turn, can limit or enhance possibilities for social and psychosocial functioning. A simpler way of expressing this is with the maxim that "good design enables, bad design disables" (EIDD 2004). For the architect and the interaction designer, or the new hybrid designer of Smart Homes, to think of dementia in terms of ability/disability can bring much clarity to design decision making.

Affective Computing in a Smart "Life Space"

The central proposal made here is that in order to be user-centered, which is singularly appropriate as a design approach in the architectural context of care, any system which manages a personal living environment must of necessity include affective computing (Picard 1997) as a consideration in the management of system response and thus of environmental response. MIT MediaLab's Affective Computing Group describes affective computing as "computing that relates to, arises from, or deliberately influences emotion or other affective phenomena." The term implies that systems or devices, or in this case, an entire environment, are designed so as to become empathetic to human affect, or emotion. The goal can be to increase usability of systems, but also to inform decision making, by rendering it more efficient. Critically, affective computing is regarded as being, of its nature, multidisciplinary, cutting across such seemingly diverse areas of research and application as computer science, psychology, psychophysiology, engineering, and interaction design. User-centered design and architecture might now be included in that list.

To begin with, user data is required. In addition to data on user position, velocity, and so on, which can now readily be acquired from mobile healthcare applications, data from which the user's affective state can be inferred must be acquired though sensing of bio-signals which are indicative of affect. These can include heart rate (HR), galvanic skin response (GSR), and data acquired from processing of video of facial expression, which has proven extremely accurate in inference of affective state. The last is not usable in the latter stages of dementia, when facial expression is lost, no more so than with users who have autism spectrum disorders (ASD), and who, as a result, do not successfully express emotion facially. In order to usefully interpret user data, it must then be contextualized in data acquired from the ambient physical environment, and thus principles which apply generally to interaction design (those of user, context and activity), applied. Information which is indicative of user affect, specifically in relation to stress of environmental origin, is a useful indicator of when a user is interacting successfully or otherwise with a given application or with the room environment as a whole. In the context of care of an elderly person with dementia, it might conceivably provide carers with an invaluable source of information about the user's well-being, especially from the point in the progress of dementia at which that individual loses the ability to communicate needs successfully. The inability to communicate need, coupled with a growing inability to personally manipulate environmental affordances – even, for example, through the previously simple mechanism of switching on a light or altering the temperature of bathwater, can become source of much frustration and distress for the person with dementia and can limit maintenance of independent functioning.

Contextualization of user data gives meaning to that data. Is an increase in HR, which is an accepted indicator of stressed states, simply due to the person standing up or moving about? Is data indicating that a person has not moved for a period of some minutes a source of concern? Is the person sitting quietly or standing still in confusion? Are there patterns of behavior, such as agitated movement, which can predict whether the user is likely to have a “catastrophic event”? An intelligent system which includes a measure of affect can begin to address such considerations.

Intelligent System Design for an Affective Responsive Environment

In computational terms, the various applications and many user interactions which go to make up a smart living environment require an intelligent and embedded ICT system to manage them. The nature of the design problem suggests using a distributed system, which implies that intelligence is spread and shared between the various devices, applications, platforms, and interfaces which got to make up the complete system. Furthermore, in order to be successful, such a system requires a cognitive sensor network based on a dynamical paradigm, that is, a system which can “perceive, learn, reason, and act” (Henderson 2007). If user-centeredness is regarded as an essential characteristic of a smart home in the context of residential healthcare, the system, by inference, must be equipped to observe and learn from the user as much as from the context. To date, much design which can be categorized as “adaptive architecture” has been predicated on the use of systems which learn from environmental context only, ultimately with the goal of reducing energy consumption. Responsive facades provide an example, where they are designed to respond to environmental cues such as light intensity and direction. Internal Building Management Systems (BMS) similarly respond primarily to contextual information, such as ambient temperature, humidity, or lighting levels, regulating the internal environment in order to maximize user comfort, and latterly, to minimize energy consumption. However, notions of user comfort are still predicated on average values, which may have little relevance in the domain of the personal living space and still less so in that of the person with dementia, where perception of environmental conditions, such as thermal, visual, or aural comfort, may be affected by the disease. Current adaptive applications in general use in building services include switching of environmental controls (e.g., lighting) which are actuated by RFID, while more sophisticated applications at the research stage also include factors such as room occupancy. A truly intelligent environment requires a more joined-up approach (Fig. 1).

Computational technologies in this context should quite literally become an intrinsic part of architecture of the building fabric, so that they are unobtrusive, and have minimal impact on the user, unless there is specific benefit to their being made overt. This approach is also in perfect keeping with Weiser and Seely-Browns’ seminal paper “The Coming Age of Calm Technology” (Weiser and Seely Brown 1996), which predicts the advent of pervasive or ubiquitous computing, referring to the benefits to the user of technologies which recede into the periphery of the user’s awareness until such time as required and called into use. In the MyRoom model (Dalton and Harrison 2012), notions of minimalism in architecture and product design coincide with the same principles in computing and interface design. However, Albert Einstein’s maxim that things should be “as simple as can be but no simpler” should be applied. An intelligent environment created by an intelligent

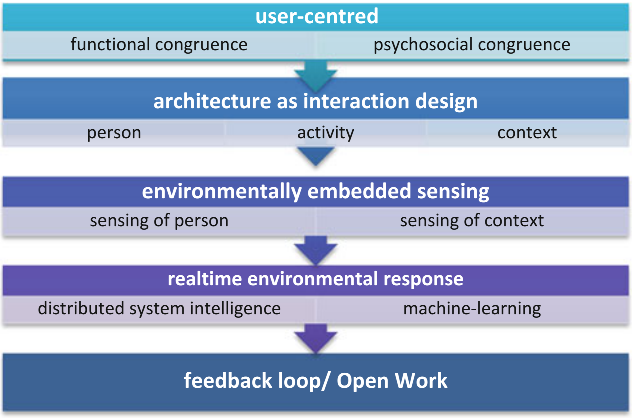

Fig. 1 System characteristics of an affective responsive personal life-space (Dalton 2014)

designer (or rather, an interdisciplinary team of intelligent designers) need not be "all-singing, all-dancing." The meshing of undoubtedly sophisticated technologies required to match individual needs and environmental affordances on a continuous and adaptive basis does not need to loudly announce its presence. If there was ever a scenario where technology should recede into the familiar and recognizable, where the technologically strange should consciously be made familiar through the efforts of the designer, it is in the physical context of design for a person with dementia. It is assumed as a general principle in this discussion that, while wearable sensors might provide short-term or interim solutions, the preferred situation for this user is likely to be one where all sensing becomes environmentally embedded and is literally subsumed into the built fabric. This excludes the possibility of a wearable sensor in itself becoming a source of additional stress, particularly as an unfamiliar object. The development of new sensors and sensing methods facilitates such an approach. McCullough's "quiet architecture" represents, in many ways, the antithesis of the "hyperfunctional" designed devices which Sarah Kettley queries in, "Interrogating Hyperfunctionality" (Kettley 2012). However, when hyperfunctionality is moved outward into the domain of the built environment in a carefully managed fashion, space is readily found, both literally and metaphorically, for the personal, the crafted and the intimate. The inclusion of such items, which are often imbued with personal meaning, in environments for people with dementia, is now regarded as significant in supporting and maintaining a sense of self. Reminiscence is not limited to the verbal but also facilitated by places and objects.

Affective Environmental Feedback Loops

When response to affect is introduced as a consideration in an intelligent environmental management system, the system, and thus the environment, is equipped to learn how to respond to the user in new ways which are conscious of affect.

Data acquired an intelligent system, from which the user's affective state is inferred, might firstly be used as a measure of the usability of a given interface or application, in that negative affect may indicate difficulty with using a specific interface or environmental feature. Similar applications are being piloted for online marketing and advertising applications, where webcams are used to gather video data of facial expression from which user reaction to online content is inferred. Continuous feedback on user interaction with the environment may prove invaluable in the case of a user with cognitive impairment, or where there are issues with communication of user need to a carer, coupled with an inability to independently carry out tasks or activities. Where it is feasible to acquire and process the necessary data regarding affect on a continuous basis, this allows the possibility of setting up a real-time feedback loop between user and environment. Such feedback loops are characteristic of responsive architecture, though design explorations to date have tended to be for aesthetic purposes, or playful in nature. In this scenario, which arguably takes a more inherently architectural approach, feedback might be used not solely for monitoring of usability, but to initiate changes which improve system performance through machine learning, thus enhancing person-environment fit. In addition, affective feedback could be utilized to actuate and manage real-time visual and multisensory changes in the room environment which in turn act on the user so that system and environment learn to respond to critical changes in the occupant's affective state. Research on the efficacy of natural imagery and the fractal patterns found in nature suggests design approaches to the production of therapeutic visual content (Taylor 2006). This might be best delivered in tandem with an intelligent cycled lighting system and so also used to further reinforce circadian and seasonal rhythms. These rhythms are often disrupted as dementia progresses, not solely as a result of the neurological effects of the disease but also by the person frequently spending prolonged periods indoors, with little exposure to natural environments where daylight can reset the body's internal clock.

Machine learning in this particular smart environment might be refined through coaching from carers, described as "interactive reinforcement training" (Thomaz et al. 2005) of the system, or "supervised learning" (Fiebrink 2010). System training by carer intervention should aim at high level rather than micro-management of system operation.

Conclusion

The addition of affective computing to the factors which manage response in a smart environment produces many possibilities for articulating the continuous dialogue between the user and her personal space, beyond the realm of the functional, in a fashion which was hitherto simply not feasible. Real-time response to user affect closes the feedback loop between user and environment. Feedback based on sensing

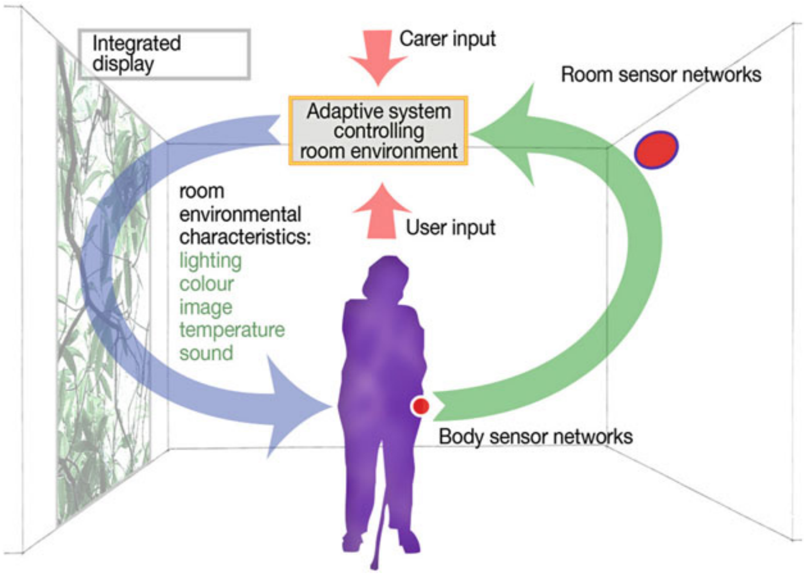

Fig. 2 MyRoom: diagrammatic representation of an affective responsive personal space (Dalton 2014)

of the affective state can be used to reinforce system learning of user preferences, in order to maximize both functional and psychosocial congruence. This may in turn enable a degree of environmental management appropriate to the user's physical and cognitive status at any given time in the progression of dementia, or on a day-to-day basis, by tracking and responding to variation in user needs. The constant interaction between user and personal space might also be expressed through visual and other sensory changes in the ambient environment, reflective of, and even designed to impact on, the user's affective state. A responsive environment might also be "trained" to intervene, by initiating changes in the ambient environment prior to an anticipated negative user event, predicted through applying machine learning to sensed user data. While ideally, such interventions will be multisensory, ambient visual interventions, involving changes of color and imagery in the environment, may well be the least obtrusive. At the same time, more functional assistive technologies, operated by an intelligent system, and informed by considerations of user affect, also have the capacity to contribute to psychosocial congruence. Where interaction between user and environment is generated on a continuous basis, and creatively articulated within the space, impacting on the user's experience of that space, architecture finally acquires the capacity to operate as an "Open Work" (Eco 1989), where the user/observer becomes implicitly involved in the generation of aesthetic output. In the context of the personal life-space of an elderly user with dementia, the expression of that interaction has potential to be therapeutic (Fig. 2).

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Apps and M-Health Within the Context of Smart Homes for Healthcare

Anthony A. Sterns

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Abstract

While the oldest old (85+) are the fastest expanding demographic group, the number of health-care professionals trained to support their care is predicted to shrink from even today's inadequate levels. Institutions are under pressure from changes in health-care policy as the percentage of older adults continue to increase, while the number of working age adults decreases. With personnel and financial resources constrained, efficiency and better approaches to care are required. Empowering older adults to better self-manage and automate monitoring of their own care means that the one increasing resource, the older adult, is

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playing the key role in maintaining health. Telemedicine, specifically mobile health or M-health, can be integrated to bridge this need.

In the near future, it is likely that we will finally have affordable, commercially available services for the home that provide comprehensive and flexible monitoring, safety, self-management support, and comprehensive communication with health-care professionals overseeing recovery and ongoing care. It is our purpose here to review the state of the art in app development within the context of smart home-care technologies and how to best create apps to serve in this bridging role. We describe here an organizing model to better understand the ability of these technologies to deliver care in the home and importantly provide a bridge to care and for the use in self-management of chronic conditions. Our proposed organizing model focuses on the degree of support and the degree of integration with the health-care professional to assess the technology ability to ensure successful outcomes for the patients, the organizations, and health-care professionals that care for them.

We discuss the use of user stories to best leverage building apps and discuss key design elements for smart home apps and share several examples of two difficult home health challenges, medication reminding and wander control.

Keywords

App design guidelines • App user interface design principles • Connectedness • Continuity • Home-based wander control • Intervention development team • iRxReminder platform • Organizing model • Smart technology organizing model • Supportiveness • User stories • Wagner’s Chronic Care Model • Wander control • Home based

Introduction

As the oldest old (85+) continue to be the fastest-growing demographic group, and the large number of baby boomers aging into older adults (65+) in the coming decade, there is a significant growth in global demand for improving the care and safety of persons with both acute and chronic conditions including dementia (Sterns and Sterns 2014). As this demand increases, the available resources for caring for these individuals are not keeping pace. There are predicted to be fewer gerontological specialist such as geriatricians, geropharmacologists, and gerontologists per capita in the coming years (Beck and Butler 2004; Kane 2002). Institutions that specialize in caring for these individuals are also not keeping pace as the economic climate in the new millennium has slowed their growth and adversely impacted their business models.

With fewer institutional resources likely to be available in the long term, there are additional forces that have been shaping health-care policy (Godwin Welsh 2004). There are a number of technologies that have produced systems that provide aspects of support for self-management and the support of caregivers, including monitoring. In the near future, it is likely that we will finally have commercially available services for the home that provide comprehensive and flexible monitoring, safety, self-management support, and comprehensive communication with health-care professionals overseeing recovery and ongoing care.

It is our purpose here to build a set of criteria and recommendations for mobile app development for the use by older adults in a smart home setting. We begin reviewing the state of the art in telecare, defined here as passive monitoring, and telehealth technologies, defined as interactive monitoring technologies. We propose here an organizing model to better understand the ability of these technologies to deliver care for patients in the home setting. Our model focuses on the degree of support and the degree of integration with the health-care professional to assess the technology ability to ensure successful outcomes for patients living in the community, by the health-care organizations and professionals that care for them.

Individuals with cognitive impairment due to acute conditions such as recovering from stroke or fractures due to falls are the kind of patients that would benefit from such technologies. Other adults, particularly those with comorbid conditions that include dementia and a second chronic disease such as diabetes or heart failure, would also be a case to consider with respect to how apps in combination with these smart telecare and telehealth technologies can be utilized to improve self-management and monitoring and the quality of care.

Theoretical Considerations

Chronic Care Model. We conceptualize any smart home system within Wagner's Chronic Care Model (Fig. 1) (Wagner et al. 1996) and the Medical Traumatic Stress Processing Model (Kazak et al. 2006). Wagner et al. theorize that optimal care for patients with chronic illness is not possible in traditional health-care systems that emphasize disease treatment over illness prevention because providers typically do not have the time, expertise, or data to provide the components required for effective chronic illness care. Medication adherence is a critical component of patient recovery and has proven particularly challenging to support and follow in real time in the community. As there are many reminder apps, it seems a good target for discussion.

Medication Adherence Model. Staying adherent is challenging for patients. Most research on adherence shows that only about half of adults take their medications correctly. To understand how an app might be designed to support medication adherence, we need to understand the factors that influence medication adherence. A conceptual framework for the development of a platform for supporting medication management based on the work of Farris and others is shown in Fig. 2 (Farris and Phillips 2008). Establishing that individuals have the functional capacity to take their medications is the basis for self-medication and ultimately medication adherence (Baroletti and Dell'Orfano 2010; Arlt et al. 2008). Functional capacity to manage medications is an instrumental activity of daily living that involves capacity to (1) order/obtain medications, (2) organize medications, (3) remember/cue to take medications, (4) self-administer medications, and (5) assess the impact of medications (Medication Adherence Telehealth Platform; Farris et al. 2003; Farris and

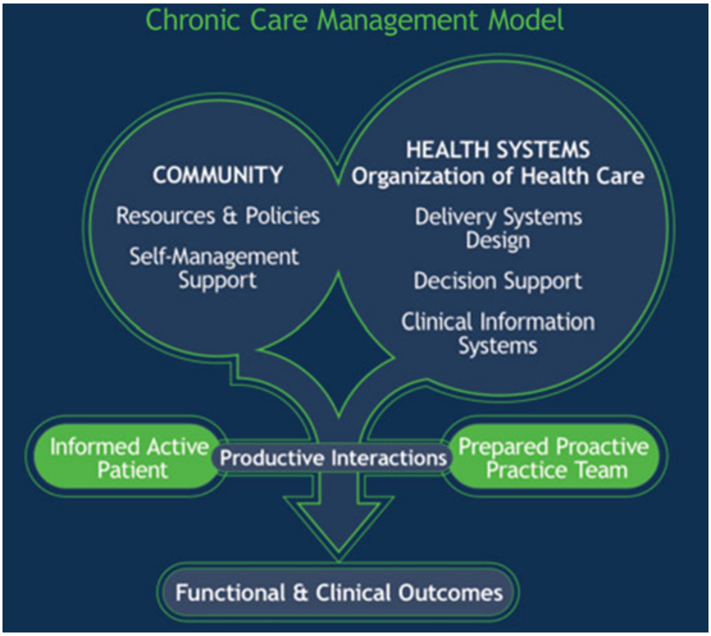

Fig. 1 Wagner's model shows current technology is effective in hospital settings where patients are seen every few hours. When patients return home, they do not have the same support. In clinical studies, or in recovery at home, patients are seen only episodically. With iRxReminder's technologies, patients are monitored. Because recovery can be stressful, iRxReminder's technologies allow patients to have control and support, reporting their status and following medication taking effortlessly. Patients experiencing high stress can be identified and helped, improving care

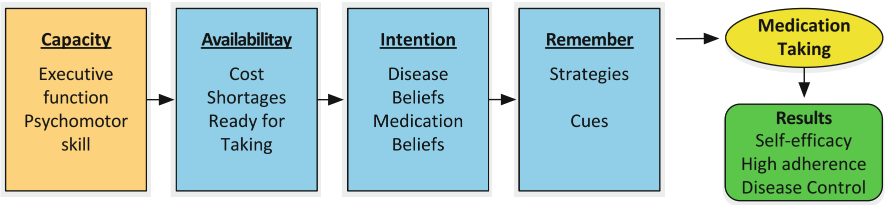

Fig. 2 Model system to affect reasons for medication taking among patients with chronic disease. One way to enhance availability, intention, and remembering are the use of technologies integrated into the smart home

Phillips 2008). For some medications such as injections, inhalers, or external preparations, the skill to self-administer is an important aspect of capacity (Franks and Briggs 2004; Allen et al. 2009).

Factors that impact medication taking include availability, intention, and remembering. Medications must be available to be taken, and having medications ready to be taken from a pill center or dispensing system well meets the criteria. The intention to take medications is related to patients' beliefs about their disease(s) (e.g., they can improve their health by treating the condition) and beliefs about their medications (e.g., side effects will decrease over time) (Baroletti and Dell'Orfano 2010; Arlt et al. 2008; Medication Adherence Telehealth Platform). Patients must also remember to take medications on a regular basis, and it is useful to have specific strategies (e.g., link medication taking to a part of your daily routine) and environmental cues (e.g., utilizing soft cues like an LED flashing on the pill-dispensing system or a vibration and sound cue from a smartphone application with reminding).

If the pill-dispensing system is networked within the smart home, the options for reminding are greatly expanded. If the person does not take the medications on time on their own, they can be alerted on the TV screen if it's on, given a verbal cue by the voice communication system (e.g., Amazon Echo), or alerted by their smartphone if they break the geo-fence when leaving the house without taking his or her midday medications with them. So any app integrated into the smart home needs to be ready to do much more than simply remind.

Once patients are taking their medications regularly, this should improve patient outcomes. This conceptual model provides the basis for setting the criteria for defining well-implemented technology. Such comprehensive and well-implemented technology is required to achieve improving medication self-management above other less comprehensive methods.

A Smart Technology Organizing Model

To gauge how comprehensive an app should be, we propose an organizing model. There are several key dimensions that make up our organizing model. The key aspects are the degree of connectedness of the technology, the degree of supportiveness of the technology, and the continuity of the technology. Our model is illustrated in Fig. 3 on the following page.

Connectedness. Connectedness crosses a continuum from stands alone to integrate within an isolated system to integrate into the health-care professional network. An example of each would include a standard 7-day pillbox with alarm, a reminding system that can send an alert to an app if pills are not dispensed, and a home equipped with multidimensional monitoring sensors, medication support system, and data integration to and from the electronic medical record of the patient.

Supportiveness. The second key aspect is the amount of support the technology offers. The most effective technologies are those that support the individual to fully self-manage their recovery or chronic condition. The system provides just-in-time information, lowers the cognitive burden on the individual, teaches and activates the patient, and positively reinforces the completion of healthy behaviors. In the cases where an individual has a physical frailty, the system provides the necessary prosthetics to enable the individual to achieve a full quality of life (Sterns and Sterns 2007). With mental frailties, the system provides the necessary cognitive prosthetics to help the individual remain safe and independent for as long as possible. Ideally, the technologies make it effortless to gather data and share summary data with the

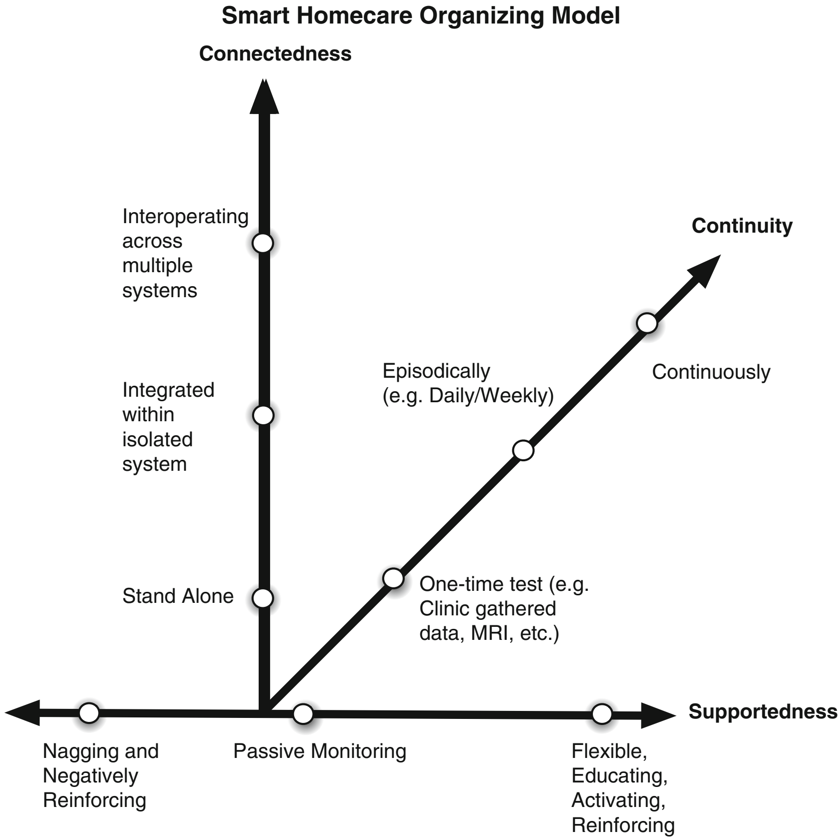

Fig. 3 The smart home-care organizing model consists of three key parameters: degree of connectedness, degree of supportiveness, and degree of continuity

health-care professional team (Sterns 2005). Another aspect of supportiveness is the comprehensiveness and flexibility of a system, the capacity to handle multiple chronic conditions.

From these characteristics that define the highest state of supportiveness, technologies move to a neutral state of supportiveness. Examples of such telecare technologies are those that simply monitor passively (e.g., carbon monoxide alarms). Other technologies are increasingly burdensome nagging the patient and creating negative attributions (e.g., resentment) and negative behaviors. An example of an unhealthy behavior might include eating unhealthy foods or avoiding needed medications. Nagging technologies would include medication reminding services that call each time you are to take medications or a pill-dispensing device with a loud alarm that goes off whether or not a pill for that dose has already been taken.

Continuity. The third aspect of our model is the degree to which a technology monitors an individual. Some technologies provide continuous monitoring and reporting at one end of the continuum, and some technologies provide episodic collection only when initiated by the user. In the case of the fully wireless and integrated smart home-care technologies, the devices are each logged into the network, monitored for power and tampering, and constantly reporting on their status and the status of the individuals within the environment. In the case of the blood pressure cuff, the device only collects information when used. At the low end of this class of devices, it may collect only the last reading or perhaps an average of the past 30-day readings. For our discussion of medication apps, the app may provide only a reminder and not monitoring in any way. Moderate continuity might be represented by tracking and recording the history of medication taking, providing a summary, and receiving updates on when refills are necessary representing basic continuity. And a high continuity app may be interactive with a pill-dispensing system when the app collects heart rate, blood pressure, and activity level of the individual and makes adjustments to the medication amount.

The Complete Organizing Model

Using these three key aspects of connectedness, supportiveness, and continuity, it is possible to fully evaluate a large set of technologies and order them in terms of their ability to fully integrate and successfully achieve smart technology-based care. To best consider these technologies, we begin by examining the challenges of the very difficult case of individuals with chronic conditions resulting from acute care episodes (e.g., recovering from stroke, recovering from cancer, recovering from a fall-based injury, living with heart failure, living with diabetes) and also living with dementia. Individuals living with these comorbid conditions are at the highest risk for being moved from an independent setting to long-term care. Therefore, they are also the most challenging to discharge from the hospital, to return home safely, to remain safe in the home, to maintain a high quality of life, and to control the cost and burden of care. Failure to properly take medications is one of the most common triggers that end the independence of these individuals living with dementia and comorbid conditions; the other is wandering outside the home. It is also a group for which connected, supportive, and continuously monitoring technologies can have the most impact. Now we have a framework to approach and consider the development of an app that might help a person be more independent in a smart home setting.

Translating the Problem to an Intervention

With a conceptual care framework, a behavioral framework, and an organizing model, we can turn our attention to discussing the process of translation to an app that functions within a smart home platform. At this point, the challenge is to have the design team, consisting of the health domain experts, the health-care professionals, health behaviorists, and potentially the business management experts, communicate a set of requirements to the technical team. The technical team consists of designers, architects, programmers, database experts, and engineers or at least to the folks that manage them. It is possible that these roles are handled by one or two people, but in a commercial setting, it is likely that these are one or more persons in each category. That app is also to be used by a person living in that smart home setting, so they are the eventual audience for the software. They play a key role in use testing and as the arbiter of its adoption and usefulness. Generally, in commercial settings, there will be extensive interaction and iteration as the basic features are implemented and then additional features added to increase its usefulness.

Because of the many constituencies between the design and technical groups, the communication challenge is far from trivial. The best way we have found to overcome this communication challenge is the use of an approach utilizing user stories and drawing pictures (Cohn 2004).

User stories. To balance the input of the users and experts with their ambitious ideas and demands with the technical team, and their collective and constrained skills and availability, we recommend a management method that utilizes user stories. This method provides a way to rank and order the best ideas so that the technical team can apply the available resources to the most important and interesting development objectives. It provides a common ground using language both groups understand and removes the emotionality and politically charged struggle between the user and technical constituencies.

If you have never developed software, it may be difficult to appreciate how unpredictable it can be. But it makes sense that it is, because in essence you are creating something from nothing. It's an undiscovered path, and it doesn't always allow you to go where you want. There are always technical obstacles and barriers that send you in directions you didn't plan on going, taking longer than you can afford, and causing you to alter and abandon your original plan and design as you go.

User stories start with just two pieces of information, each goal to be satisfied by the system and the rough cost of satisfying that goal. In terms of effort, it is easy for the user team to generate a goal in just a few sentences, and similarly, the technical team can look at the clear goal and make an estimate on implementation. This approach also relies on the adoption of an agile programming approach known as "last responsible moment." The team waits to write down details of the features until just before implementation. These time-shifts have two important impacts on the development process.

First, it makes clear the most important or useful or core or interesting features so that the technology team can dig into those first. The core innovation and architecture are the early focus, and with the use of proper unit testing, automated coding, and value checks that are part of the agile development process, these features will be assured of working as other elements of the implementation are developed.

Second, because the price of the feature is an element of the user story, the resources are always part of the conversation throughout the development process. They avoid the usual panic and cutting and degrading of goals as the delivery date and budget constraints are imposed on a very detailed feature map developed from the beginning.

What makes a good user story are three elements: (1) a written description, (2) a conversation that serves to flesh out the details, and (3) the creation of tests that convey and document the details to determine when the story is complete. We can draw on our experience on medication adherence for an example (Fig. 4).

User Story: The app user has a goal of maintaining 80% adherence or better, which has been demonstrated by research to be effective and maximizes the likelihood of positive outcomes. When the user looks at the app icon, they see a green badge 80% or better, yellow badge if 70% to 79% compliance, and a red badge if 69% or less. This would be written on a card. The card might include a hand drawn picture of the icon and a small circle in the upper right corner with an arrow and note saying "badge can be green, yellow, or red."

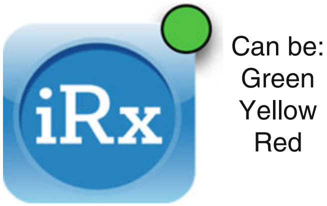

Fig. 4 Sample user story card and picture illustrating the idea

The card would be shared with a technology team member. The team member should ask questions about the idea. One question might be about the sensitivity, if it's important to have the badge updated in real time, or maybe just every 24 hours; and how taking one, few, or many drugs might impact on this high-level indicator. The technical person would think about if this feature was easy, moderate, or hard. If there is currently a graph on the home page of the app with the overall percentage, this feature might be easy. There is a clear unit test to be done to determine if the percentage and the badge are synchronized. But if there is no structure to generate the percentage yet, a lot needs to be done to figure this out, including the unit tests that need to be developed. So in the former case, it might be 1–2-day effort, but in the latter case, it might be 10–15-day effort. Now this can be weighed among the pile of cards with other user stories, such as having that percentage of adherence summarized on the home page.

What the team ends up with is a nice wall of cards that generate constant discussion about the features that are important at the moment. And that discussion is done in the context of what is already done and what we might like to do once our current work is complete. It makes for a very smooth process and keeps the language of the user team and the technology team out of the technical weeds, so communication is "mostly" calm and clear.

App Design Guidelines

Development of the user interface and what the user will experience are closely related. To deliver an exceptional user interface for a mobile app, there are a number of universal design principles that need to be followed. When the user interface is for a mobile app, there are some important differences from other product design. There are a set of standard interface approaches that are dictated by the platform, and these should be leveraged to increase the familiarity and intuitiveness of the user. The challenge is to manage the standard interface elements well across multiple platforms. A second challenge is to integrate new features and interface methods and elements such as force touch and voice control, which become available and may offer an advantage to the user.

The smart device running the app will also have potential access to hardware elements, and these can enhance the functionalities of the app. Such hardware might include incorporating the use of the front camera, gyroscope, fingerprint unlocking, GPS/network location, high-resolution HD display, and communication with other peripheral devices, among others. The challenge for any design team is that nothing remains static for long and the various platforms (iOS and Android, today) are heading in very different directions in key elements that effect apps focused on health-care applications. For example, alerting is handled very differently within the operating systems, and this has a big impact on the app infrastructure and interface.

The main focus of your user interface design needs to be the interactive elements. So the interface should have clear action triggers, and buttons should have clear functionality. This can be accomplished with the help of existing icon conventions (tabs bringing up a hidden screen) and clear feedback (a switch highlighted with green when on and white when off).

Key App User Interface Design Principles

Focus on content. The content presented is always the most important consideration. A task analysis should be conducted to ensure that the information is presented optimally. Often some customization need to be allowed to ensure that the content is applicable to a variety of users. Content optimization is particularly challenging in health-care applications in general and specifically for smart home development. There are going to be a lot of options in the home setting, so many options mean a significant challenge to how best to present and control content. Figure 5 shows two different approaches to presenting information about drugs. Information elements include a picture, dosage, and guidance for taking the medication.

Smooth interactive elements. It is imperative to make all interaction opportunities clear to the user. Buttons, tabs, switches, and sliders must have indicators and anchors that make it clear what they do and the state they are in. This is often aided by standard icons, but in health-care applications and in the smart home setting, it can be more of a challenge. The home icon is generally used to take you to the main page in most apps. You might modify the home icon by embedding a light bulb shape to indicate light control for the entire home.

Figure 5 illustrates a number of interactive elements. One thing to point out between the two medication apps is that they offer a set of choices for each drug. The iRxReminder app offers four choices (take, skip, snooze 5, and snooze 15), while the iRxCapture app offers only two (take and wait). In fact, when wait is chosen, it brings up a window that gives the three choices (skip, snooze 5, and snooze 15). This choice is important because it allows the user to be in control and make a choice about how to behave. When they choose take, the healthy behavior, the user is reinforcing picking the healthy decision each time. Both do this, but the iRxCapture app does it more efficiently.

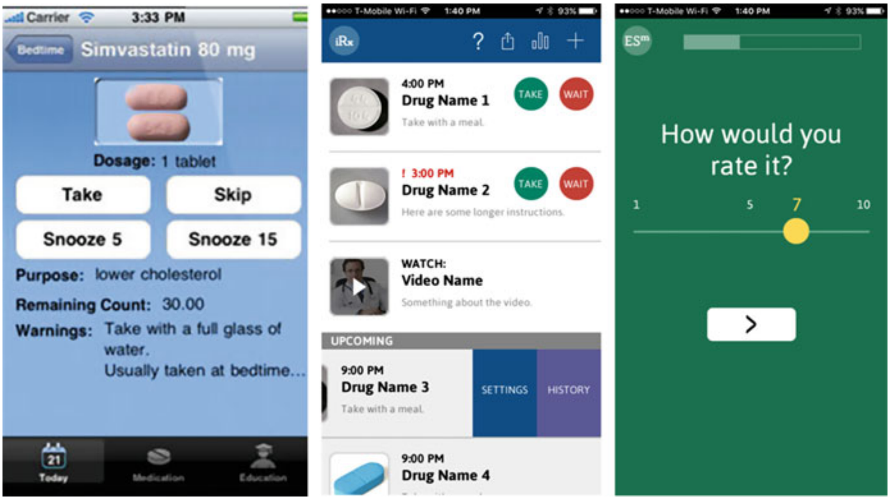

Fig. 5 The left screen is an image of the iRxReminder™ app which uses shadowing, textured background, buttons, and bottom tabs. The middle screen shows the iRxCapture™ app, with a modern flat interface with white backgrounds, scrolling, sliding, and touch targets. The right screen shows the ESmCapture™ app, an experience sampling survey app, illustrating a very simple flat interface with various cues such as the progress bar at the top, the simple line and circle for the slider to set the rating, and a white button with arrow for going to the next screen

Clear, clutter-free interface. I like to create elements that are present when I need them and are hidden when I do not. For example, it is often useful in testing to be able to see the data you are collecting and confirm that it has been transferred. But a simple toggle in the settings can hide this information, so it's not distracting to the user who is likely only interested in the latest reading and a summary (e.g., current blood pressure and 7-day average). Figure 5's ESmCapture app interface illustrates a clean, clutter-free interface.

Color and placement cueing. Color and order should be used to direct emphasis to the most important interface point at the right time. The best interfaces help softly direct you and train you to follow patterns and establish correct behaviors. These interfaces have a more intuitive feel and grow more so over time. They are the very definition of user-friendly.

Flat and tiled design. A number of trends are impacting the look and feel of apps. While texture and blurring can be used to help persuade and attract interaction, more recently, there has been a move away from texturing, gradients, and use of shadows that create a strong 3D feel to the app's interface. This trend has also manifested with more use of tiling, a small number of functions accessed by touching a panel in a set of frames. The advantage is that the flat interface is highly readable and the limited number of options clear.

Synchronization. Perhaps the most important trend for smart homes is the synchronization with other systems and platforms. The synchronization can extend to many integrated smartphone systems. Alerting from an app can be experienced by a kinetic alert from a wearable such as watch, seen on a room display, or heard from a connected speaker. The synchronization go both ways, so a voice command can be used to add or check off an item on a to-do list; standing on a scale can record and chart your weight on an app, or dispensing a medication can record the event and be added to a database monitoring your adherence.

Components of a Successful Intervention Development Team

UI design. Design researchers, interaction designers, and visual designers are required for comprehensive interface design. Wireframes are their tool of choice for contributing to illustrations of the user stories.

Coordinated team. Product management, design, and software development need to work as one team. User stories are the tool for integration, and dedicated resources to carry out design and technical tasks are what need to be managed to achieve as many developed and working elements within the time and budget of the project.

Clear roles and responsibilities. Understanding other team member goals, motivations, and priorities is key to ensuring overall success of the project. Product management is responsible for the business end of the product and ensures the product is supporting a revenue-generating business model. The model defines the key elements that must be present to have a successful business outcome. Designers are tasked with delivering an engaging user experience, empowering the users, and bringing joy to the users with the use of the app. Developers are the engine mechanics and are measured by how fast and how well the engine is assembled and how well the engine performs. Delivering bug-free code on time and on budget for something that is new and innovative is something you must give very long odds too. But with well-balanced design and technical efforts, the likelihood of a successful project is greatly enhanced.

The right amount of planning. The balance of features and the time to produce them is why user stories are a successful approach. User stories set the balance and make detail planning done at the right moment. What is important is right sizing the effort. Too few people will limit the progress, but too many people may cause even great delays as conflicts proliferate among different modular efforts.

Work in parallel. Steps are not sequential. Each team member needs to understand the key features, work the back end to make those work, and build in a buffer for creative exploration and innovation.

The iRxReminder Platform as a Model

Better adherence monitoring would improve research. The gold standard in clinical trials for measuring medication adherence is electronic bottle openings. However, this technology varies in its ability to monitor in real time and in its accommodation of real-world medication taking because an electronic cap is needed for every medication. To date, electronic pill bottle caps have been prohibitively

Fig. 6 The iRxReminder iLidRx™ medicine cabinet is a system designed to integrate into a home setting to support complex medication schedules. The system is managed from a cloud-based control center, and each pill-dispensing device holds a single medication. The devices communicate via Bluetooth LE when medication is dispensed. If the medication is not dispensed on time, the system sends the app on the smartphone an alert. The alert can also be directed to any display in the home (e.g., television display), and an alert from the voice interface could also alert the person (e.g., Amazon Echo)

expensive to use on a day-to-day basis outside of clinical trials. The iLidRx pod offers several technologic advantages over currently available electronic pill bottle caps or pill bottles. These advantages include: *(1) the pod needs total control of the medication dosage, no overdosing possible (compared to a wireless cap;* e.g., *GlowCap, MEMS); (2) each pod holds a 30- to 90-day supply and no sorting or sorting errors possible (compared to a wired pillbox;* e.g., *MedMinder, MedSignals); (3) it enables remote medication schedule changes (compared to blisters other pre-packaged solutions (*e.g., *PilPak)); (4) real-time monitoring of multiple pods support complex schedules; and (5) the pod operates seamlessly with a smartphone app for reminding support, following symptoms and side effects, and patient education.* These advantages make it an important, highly innovative product, which significantly advances the state of the art for medication monitoring in this increasingly competitive marketplace of electronic medication monitoring (Fig. 6).

Looking Toward the Future

The future likely means further integration between acute care settings and the home. Integration among apps and synchronized devices, sharing information with the person's health-care team, better use of behavior support approaches, more invisible and invasive technology, and greater use of effortless data collection approaches will continue.

One such vision is the wander control system envisioned by integrator RealHelp using the EV2 system (Realhelp.net). The EV2 system is part of the Tycho family of technology products (Elpas.com).

Ethical, Safe, and Quiet Home-Based Wander Control

Caregivers are often trapped at home with individuals with dementia whom they cannot leave alone. They cannot sleep soundly for fear of the individual getting up and causing an accident or leaving the residence. Many individuals resort to dead bolting all doors, even bedroom doors, to stop wandering, particularly at night.

The wander control system gives the caregiver the ability to sleep soundly and to perform daily activities with the knowledge that the person in their care is safe and at home. Unlike other systems available, the proposed system can work silently if the homeowner chooses, preventing egress for only the individual with dementia and allowing others to operate doors normally. This allows doors to be locked to only those individuals with the Personality™ Bracelet. Another unique feature is that doors will allow egress to individuals with a bracelet when a smoke alarm component tied to the system is triggered. This way, caregiver and person with dementia are never at risk of being trapped.

Safely go outside. The system for the home proposes a new feature that utilizes low-frequency wire technology to create zones around the yard and home, similar to that used for pet control systems. As a result, the proposed system provides individuals with greater freedom. They can go throughout the house, deck, and yard in zones determined to be safe. Like some other commercially available systems, it will inform the caregiver of the person's location as they move to outside zones. However, an alarm (if desired) and escalating alerts will be issued only if the person leaves the designated safe zone.

Condition-based control. The home system's door control panel is sophisticated enough so that with additional sensors, it is possible to control access for individuals. The access control system is weather and time-of-day sensitive, allowing doors to be programmed to deny exit if it is too cold, too hot, or raining, and at nighttime. This allows more able individuals to wander around the yard and on walking paths when the weather is appropriate. As they approach areas not approved for walking, the person can receive a warning through their smart device app (watch or smartphone), and caregivers will receive an alert as well and can act. If unsafe areas are being approached, such as a pool, an alarm and alert can be triggered when urgent action is required.

Care accountability. Another unique advantage is that the same wireless door control system, in conjunction with a personalized smart device running an app, can be used to control access into the home by home health-care workers. The time of day that health-care workers have access to the home can be controlled. The access system will document who they are, when they arrive, and will document when they leave. The home health-care company can utilize this information for improving quality of service. The information can also be made available to distant family members to provide peace of mind that services are being delivered.

This kind of system presents a comprehensive model that meets the criteria at the high end of the scale of each of our organizing model components. The system provides strong cognitive prosthetics for the individual; the system provides safety and peace of mind for the caregiver and provides a summary of important information to and about the care team that is shared and available as needed. The system provides help with mastery of complex self-management tasks, self-esteem from successfully carrying out those tasks and remaining substantially independent, providing social support when needed and clearly defining where and when support is needed, and results in reinforcing a positive health trajectory for the supported person. Most important, the system helps the individual and their family members safely recover from acute care episodes and remain independent in their home. And when this independence is considerably lengthened, it allows the individual and family a better quality of life. This is made possible through app-integrated and synchronized technologies that are continuously monitoring, supporting healthy behaviors, and fully interconnected with the health-care professional network. We are ever closer to this ideal system, and we will need it to take care of the many older adults who need this type of support in the near future (Sterns and Collins 2004).

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Monitoring Everyday Abilities and Cognitive Health Using Pervasive Technologies: Current State and Prospect

Prafulla N. Dawadi and Diane J. Cook

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Abstract

In this chapter, we provide an overview of technology-driven approaches to performing in-home cognitive assessment based on sensor data using measures of everyday function. We present examples of clinical findings that relate measures of everyday functioning to cognitive health and highlight different sensor-based approaches to monitor them. We argue that the sensor-based everyday behavior data can capture early indications of decline in cognitive health, and we present possible future research directions to develop an in-home sensor-based cognitive health monitoring system.

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Smart homes • Cognitive assessment • Everyday functioning • Activities of daily living • Learning algorithms

Introduction

Recent advancements in pervasive sensor technologies and learning algorithms have made continuous and unobtrusive monitoring and analysis of human activities in the home environment a reality (Cook and Das 2012). For example, sensors are embedded in a person's home environment and in everyday objects. These sensors often unobtrusively monitor and collect human behavior data. By analyzing and visualizing such sensor data with algorithms, we can understand a person's behavior. For example, we can determine their sleep pattern by analyzing when they go to sleep at night and when they wake up in the morning, or we can identify the typical timing for activities of daily living such as eating breakfast and washing dishes. Understanding everyday cognitive abilities and performing cognitive assessments are two uses for this sensor data.

Sensors that continuously collect everyday data of an individual offer a wealth of information about their everyday behavioral events. Analysis of sensor data can reveal patterns of daily activities that can be studied to identify regularly completed activities and activities that were completed with difficulty. Similarly, information about whether the individual is regularly taking their medication or is having difficulties with sleep can be found. Furthermore, sensor data collected over a time period provides insights on day-to-day changes and trends in activity patterns. The fact that smart homes collect information-rich behavior data under real-life circumstances makes them invaluable tools to understand an individual's real-life everyday abilities.

In this chapter, we review pervasive in-home technologies to monitor everyday behavior in the home environment and perform cognitive assessment using these technologies. In particular, our goal is to highlight current practices for in-home sensor technologies that monitor everyday behavior and perform cognitive assessment and to identify future research directions of these technologies and present the challenges that lie ahead.

Cognitive Assessment Systems

Clinicians use cognitive assessment systems to assess the cognitive health of an individual. They diagnose the type and severity of cognitive difficulties. Clinicians can use outcomes of the assessment systems to recommend treatments and decide on the required level of care and support. In addition, the treatments for cognitive decline are more effective when treated at early stages, before a cognitive disease causes irreversible damage to the brain. Thus, cognitive assessment systems can be

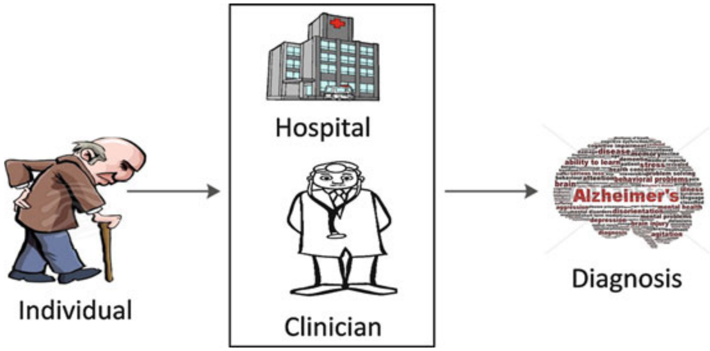

Fig. 1 Traditional cognitive assessment systems

used for early detection and management of cognitive decline. This slows the progression of the disease and consequently prolongs the individual's independent living and allows family members and caregivers more time to make appropriate decisions (Woodford and George 2007; Snyder et al. 2011).

In traditional cognitive assessment systems, conventional methodologies such as pen-and-paper-based tests are used to diagnose the type of cognitive difficulties (Woodford and George 2007). Patients often visit the clinician who evaluates their cognitive health by administering various tests and using different scoring methods. Figure 1 illustrates this concept. Some examples of such standardized and validated tests are the Mini-Mental State Examination (Folstein et al. 1975) and the Modified Mini-Mental State Examination (Teng and Chui 1987). However, traditional clinical tests are administered in a laboratory. As a result, they require an individual to travel to clinics. They are often administered at an advanced stage when there are concerns of severe difficulties. In addition, they are administered infrequently since they have a long testing time and are expensive to administer. Since they are administered outside of the individual's home environment, i.e., in laboratories, they have limited ability to capture everyday difficulties of an individual. In another word, many of these tests are not considered to be ecologically valid (Chaytor and Schmitter-Edgecombe 2003). These limitations in traditional settings have prompted researchers to pursue new directions of more ecologically valid methods of detecting difficulties in individuals in real-life settings using pervasive computing solutions.

Cognitive Health and Everyday Functioning

Everyday functioning in an individual is an important neuropsychological construct that clinicians try to understand. There exists a relationship between decline in everyday functioning of an individual and decline in cognitive health (Schmitter-Edgecombe et al. 2011). While functional decline in at least one of the domains is a criterion for diagnosing dementia, individuals diagnosed with mild cognitive impairment, a transition between normal cognition and dementia, also have difficulties

Table 1 Everyday functioning measures affected by cognitive health

Categories	Measures
Computer usage	Keyboard and mouse usage, typing speed, performances in computer games
Mobility	Ability to move around, climb stairs, stride length
Gait	Gait velocity, gait balance
Everyday functioning	Ability to initiate and complete activities of daily living such as bathing, toileting, and eating

completing complex activities of daily living such as managing finances. In addition, decline in everyday functioning is associated with reduced quality of life, risk of institutionalization, caregiver burden, and financial costs (Spector et al. 1987; Hope et al. 1998). The systematic characterization of everyday functioning and understanding the course of decline improve understanding of cognitive deficits that affect everyday abilities (Hope et al. 1998). This can pave the way for development of new methods to overcome the difficulties associated with impairments that can consequently prolong independent living (Jefferson et al. 2006). Thus, early detection of decline in everyday functioning has important clinical and research applications that help clinicians understand patients' difficulties in everyday life and the decline in their cognitive health.

Table 1 lists various everyday functioning measures that are affected by decline in cognitive health. With decline in cognitive health, patterns of decline in these measures such as difficulties in completing activities independently and diminished ability to move around can be observed.

Technology and Cognitive Assessment System

Environmental, motion, and object sensors and video cameras are installed in an individual's home. They can continuously collect everyday behavior data that is rich in information. For example, analyzing this data can provide detailed information about the individual's sleep pattern such as when and for how long the individual sleeps and how many times he goes to the restroom during the night (bed to toilet transition) (Wang et al. 2012). The insights that smart home technologies provide help researchers and clinicians better understand a person's everyday abilities and make informed decision about their cognitive health. In addition, electronic devices such as smartphones, tablets, and computers are technological gadgets that we continuously use in our daily routines. The embedded sensors including accelerometers, gyroscopes, and touch pads collect data when the individual interacts with these devices (Jimison and Pavel 2006). Analyzing the collected data reveals how the person behaves daily and as well as fluctuations in routine behavior. These concepts are illustrated in Fig. 2.

The information that technologies collect in real-life settings has motivated researchers to use pervasive in-home technologies to measure a person's everyday

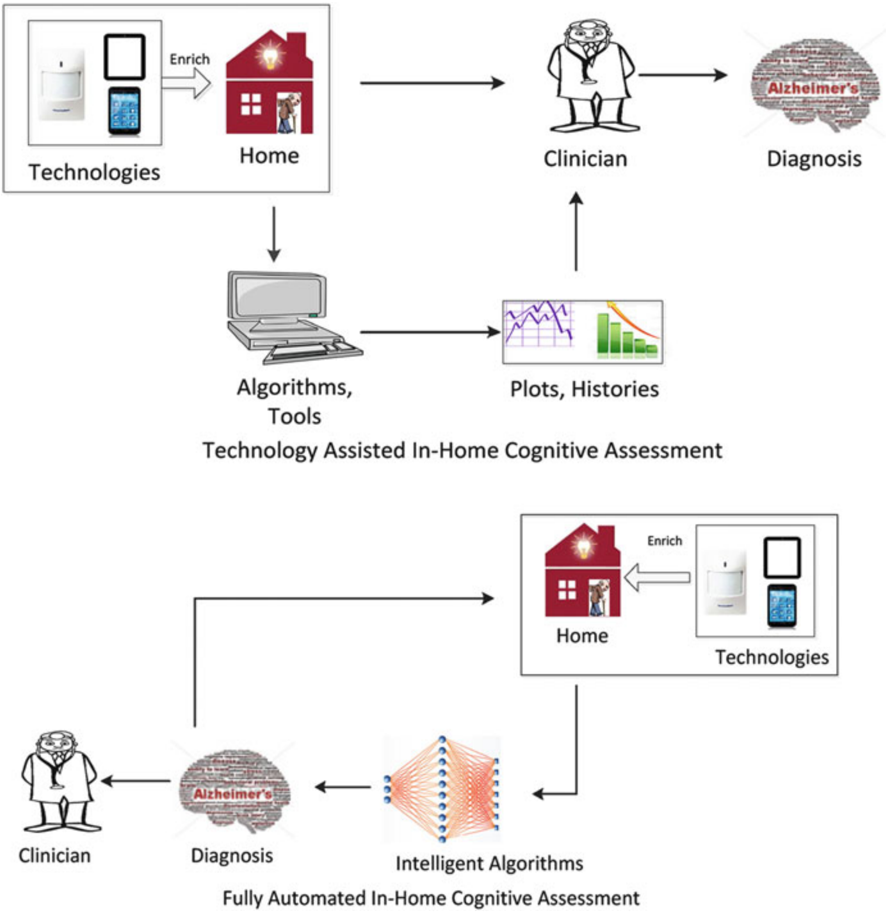

Fig. 2 Technology-based cognitive assessment system

abilities and have insights on their cognitive health. Formally, we define *technology-assisted cognitive assessment system* as a cognitive assessment system that uses technology to measure everyday functioning measures and assists clinicians to make informed decision by providing in-depth real-life data. Typically, in-home cognitive assessment systems use sensor technologies to collect the data. Intelligent algorithms analyze this data to provide valuable insights.

We can view technology-assisted cognitive systems as an *intelligent agent* in which modern technologies enhance the traditional testing environment providing new perceptions to the learning agent, clinician, or intelligent learning algorithm, as illustrated in Fig. 3 (Cook and Das 2004; Russell and Norvig 2003). Table 2 lists various components of the agent. Based on the role of technology, we classify them into three different categories:

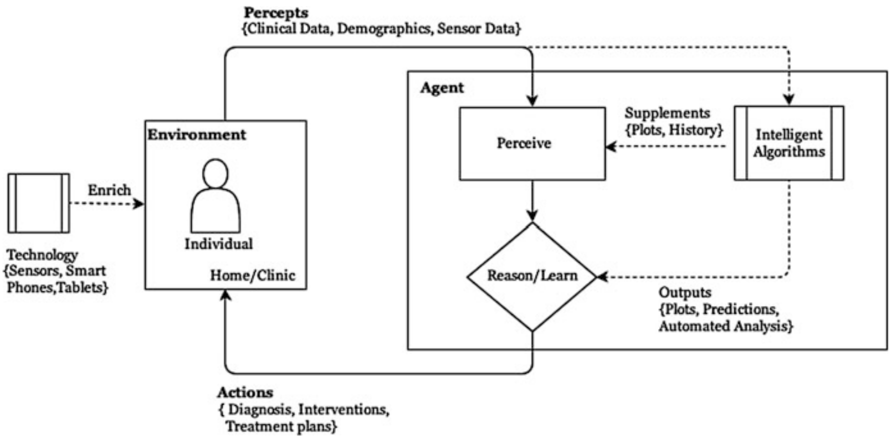

Fig. 3 Technology-based cognitive assessment agent

Table 2 Elements of technology-assisted assessment agent

	Traditional agent	Technology augmented agent	Automated agent
Agents	Clinicians, nurses	Clinicians, nurses	Learning algorithms
Perception	Standardized tests, care giver questionnaires	Standardized tests, sensor data, tablet and smartphone data	Sensor data related to daily behavior, tablet usage data
Actions	Diagnosis, medication, level of care	Diagnosis, medication, level of care	Interventions, diagnosis, alerts
Environment	Clinical labs	Traditional environment enriched with technology	Home

- In a *traditional agent assessment system*, clinicians are the agents who administer clinical tests and collect information. They perceive this information, reason and interpret them using their own expertise, and take actions such as conducting diagnosis and planning treatments.
- In a *technology-augmented agent assessment system*, sensors are added to the traditional clinical environment. Intelligent algorithms provide their own perception of the individual's task performance based on sensor data, which expands the set of information passed to the reasoning/learning agent. Clinicians or caregivers act as learning agents. Figure 2a illustrates this concept.
- In a *fully automated technology-assisted agent assessment system*, the agent perceives information from its environment (sensors) and uses this knowledge to take actions (perform assessment) without human assistance. For example, these agents perceive sensor information related to an individual's everyday behavior in their home environment and alert the residents or caregivers when they detect significant deviations in everyday behavior. Figure 2b illustrates this concept.

Technology-Assisted Cognitive Assessment

The technology-based cognitive assessment systems monitor various every day functioning measures and help one evaluate the cognitive health of an individual. Below we describe measures that technology-based cognitive assessment systems monitor continuously.

Cognitive Assessment Using Computing Devices

Cognitive assessment using computing devices can be an alternative to the traditional pen-and-pencil-based tests. Clinicians can perform cognitive assessments by (i) utilizing data collected from computerized cognitive test suites that a participant completes on those devices and (ii) by monitoring the personal "cognitive digital behavior" of a participant. These systems utilize sensor technologies present in the device and make assessment process flexible by making it accessible at home. Individuals can complete them online and multiple times on any supported platform with limited cost and burden.

Compared with traditional testing systems, computerized cognitive assessment testing systems offer several advantages (Noyes and Garland 2008). In contrast to traditional "paper-based" interface, computerized test systems can leverage "digital" interface to present end users with interactive and dynamic contents. The test systems can be customized according to end user's requirements or testing methodologies. For example, tests can be adapted based on how a user responds to test questions, or they can be geared toward testing a particular cognitive difficulty. Measurement constructs such as reaction time can be accurately measured while the system collects additional test metadata such as time spent in each component of the tests and the total number of pauses and breaks taken (Noyes and Garland 2008). Overall, the computerized cognitive assessment tests offer the flexibility of taking the tests at home, enhance the traditional testing environment with resources, and supplement measurements with metadata. Therefore, they are "in-home" alternatives to traditional "clinic-based" pen-and-paper tests.

The other class of assessment systems that uses computing platforms performs nontraditional assessment based on an individual's cognitive digital behavior. The cognitive digital behavior data are everyday computer usage behavior characterized according to how the individual interacts with the computer. Examples of these behaviors may include the person's keyboard or mouse usage pattern and their playing games on tablets and computers. It is hypothesized that changes in cognitive health change the cognitive digital behavior. We explain both of these methods next.

Cognitive assessment systems can use computers to perform cognitive assessments. Generally, the traditional pen-and-paper tests are adapted to computers. For example, finger-tapping test, Stroop interference test, and CERAD word list learning test are implemented in computerized assessment battery in computer self-test (Dougherty et al. 2010; Dwolatzky et al. 2003). However, these tests have different sensitivity and specificity in classifying cognitive health of the participants.

They also have different completion times. Some of these tests can be completed online while others require trained clinicians to be present (Snyder et al. 2011; Noyes and Garland 2008).

Cognitive assessment systems can utilize mobile platforms such as tablets and smartphones. Researchers have developed both tablet versions of the traditional pen-and-paper-based tests and completely new test suites on mobile computing platforms.[1] Using these portable devices, users can complete tests at any place and in any time. For example, users can complete the CANTAB test suite[2] that includes tests on attention, visual memory, and executive functioning on their mobile devices. Often, these tests provide information that traditional pen-and-paper tests cannot. For example, in addition to the information about the correctness of the clock elements, the tablet version of a clock drawing test provides "real-time pen interaction" data such as pausing tendency, pen pressure-exerting patterns, and drawing sequence (Kim et al. 2012). In addition, these devices are equipped with sensor technologies that provide additional methods of input. Possibilities include sensor-based inputs such as stylus, digital pen, and digital paper. One can exploit different sensors in the phone to develop a generic assessment suite or test suites that measure specific constructs. For example, Fouchenette (2010) developed an iPod application to test long-term memory. In this application, users can either use the touch screen to tap the correct answer, or type on a virtual keyboard, or use the microphone on the iPod to record the answer. These devices offer a sensor rich platform that provides researchers with an opportunity to develop tests that target specific cognitive domains while providing accurate measurements of the underlying constructs.

Virtual reality-based assessment systems are the other category of cognitive assessment systems that use computing devices. In virtual reality-based methods, participants wear special devices to manipulate entities in a virtual environment. Participants complete everyday activities in the virtual environment or complete the virtual reality-based cognitive tests (Zhang et al. 2003; Kang et al. 2008). The review of the virtual reality-based assessment systems are out of the scope of this work as they require specialized equipment and are not readily available at home.

Similarly, another variant of computerized cognitive assessment systems uses cognitive digital behavior data. The data is collected during the time individuals use computers in their home environment playing computer games or using keyboard and mouse. Assessments can be performed by deriving c*omputer cognitive metrics*, which serve as proxy measures to standardized neuropsychological tests (Jimison et al. 2007). For example, finger-tapping test measures motor control. In this test, participants repeatedly press a switch at a given time. Finger-tapping test can be simulated based on how individuals use keyboards at home. Typing speed during login can be used as a consistent and reliable proxy for measuring motor speed (Jimison et al. 2008). It was reported that individuals with cognitive difficulties have

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[1] www.penscreen.com

[2] http://www.cantabmobile.com/

lower average scores and higher variability in typing speed compared with healthy individuals. Similarly, mouse and keyboard usage data can serve as a proxy for motor speed measurements. Cognitive digital behavior data collected over a period of time can be used to identify cognitive health trends and day-to-day variability and compare within subjects measured across a period of time (Jimison et al. 2008).

Cognitive computer games are another approach to computerized assessment of cognitive health. Cognitive computer games are computer games with embedded algorithms to infer cognitive processes. Often, popular computer games such as FreeCell and Solitaire are modified to create cognitive computer games. When users play those games, the algorithms calculate different cognitive metrics that possibly correlates with measures obtained from traditional clinical measures. For example, Jimison et al. (2004a, 2008) designed word games to obtain proxy measures correlating with the measures obtained from verbal fluency test. A verbal fluency test measures a person's ability to recall from long-term memory and their semantic processing ability by asking individuals to produce as many words as possible. To simulate this test, a computer game presents user with letters of scrambled words and asks them to make as many words as possible with incentives on longer words. The authors argue that game metrics such as word complexity (a mix of word length and frequency of use in the English language), the total number of words created, and the speed of generation of words approximate the standard verbal fluency measures. Using a similar concept, one can approximate other cognitive parameters such as memory, planning, and divided attention (Jimison and Pavel 2006). Such approximations can classify cognitively healthy subjects and those with mild cognitive impairment (Jimison et al. 2004a). Cognitive computer games have also been implemented in mobile devices[3] to assess the cognitive health of astronauts, who operate in a complex environment.

Cognitive assessment-based computer usage is a promising alternative to traditional pen-and-paper-based assessments given that it is unobtrusive, home-based, inexpensive, and likely pleasant to complete. More importantly, it provides frequent measurements. However, the high initial cost of buying a computer and the limited ability of older adults to use computers or to adapt to new technologies are factors that can limit the wide-scale adoption of this system.

We categorize computer assessment systems as intelligent agents. The sensor technologies such as touch displays, mouse, stylus, and keyboards enhance (or substitute) the traditional pen-and-paper environment with several added capabilities and expand the perception of the agent by collecting diverse information from the environment. The clinicians are the agents who take necessary actions after interpreting their perception (the collected data) using their own experience. Alternatively, the intelligent algorithms can study the data history and provide real-time feedbacks and recommendations to the user or the caregiver.

[3]http://designinteractive.net/coggauge/

Cognitive Assessment Using Smart Home Sensors

Smart home sensors continuously monitor and collect data related to everyday abilities, for example, completion of activities of daily living, circadian rhythms of daily behavior, and ability to move around. Clinicians can use sensor data to better understand the course of decline in everyday abilities. Such understanding helps them to design treatment plans, develop measures to overcome difficulties, and prolong an individual's independent living. In addition, using the sensor data, one can develop a more ecologically valid assessment system using data collected from real-life events and predict a person's ability to live independently.

We explain smart home-based assessment systems using agent framework in Fig. 3. The environment in the framework is the participant's home enhanced with sensors. These sensors continuously monitor everyday behavior of the resident and provide data and precepts to the learning and reasoning agent. Agents act and reason by interpreting this data and recommend or administer treatments. The agents can be clinicians, caregivers, or intelligent algorithms. Smart home sensors can perform cognitive assessment by monitoring key features of daily routines such as mobility and activities of daily living.

Monitoring Mobility

Mobility is the ability of an individual to move around their home environment and the community, while completing activities of daily living and maintaining an active social life (Webber et al. 2010). Mobility impairments limit an individual's ability to maintain independence and quality of life and are one of the predictors of institutionalization among older adults (Hope et al. 1998).

Several cross-sectional and longitudinal clinical studies have investigated the relationship among mobility, gait disorders, and cognitive decline. They have shown a relationship between gait speed and risk of lower Modified Mini-Mental State Examination (3MSE) score (Fitzpatrick et al. 2007); gait abnormalities, such as unsteadiness and frontal gait disorders, and non-Alzheimer dementia (Verghese et al. 2002); and time to walk 9.14 m and the onset of cognitive impairment (Marquis et al. 2002). Similarly, other studies have investigated relationships among cognitive dysfunction, risk of disability, ability to walk few feet and climb stairs, ability to get out of bed and chair, and upper extremity strength (Fitzpatrick et al. 2007; Waite et al. 2005). These studies concluded that mobility and gait impairment are associated with cognitive decline and prediction of dementia, future risk of hospitalization (Studenski et al. 2003) and disability (Guralnik et al. 2000), and loss of executive function (Coppin et al. 2006). These studies demonstrate the importance of mobility and their relationship with cognitive health. However, the data in clinical studies are usually collected using traditional methods of self-report, informant report, and performance-based measures. In contrast, sensors continuously monitor in-home mobility for longer duration and provide frequent measurements. Therefore, they can be valuable in understanding mobility in real-life (Hagler et al. 2010).

The mobility of individuals can be monitored using wearable sensors such as accelerometers and gyroscopes (Williamson and Andrews 2000) as well as pressure sensor-wired shoe insoles (Zhu et al. 1990). The possibilities to recognize mobility and gait parameters also include ambient sensors such as passive motion sensors (Austin et al. 2011a), indoor sensor mats (Middleton et al. 2005), laser scanners (Frenken and Govercin 2010), and video cameras (Stone and Skubic 2011). The measured parameters using PIR motion sensors have been validated with the standard systems. Hagler et al. (2010) collected in-home walking speeds using PIR motion sensors and validated it using GAITRite system. Ambient sensors are preferable to wearable sensors since they are unobtrusive. However, installing ambient sensors requires prior knowledge of the layout of the room and may pose difficulties for multiple-resident homes (Jimison et al. 2004b).

The initial work that monitored mobility and predicted possible cognitive decline using mobility parameters analyzed continuously monitored sensor data using semi-Markov model to make estimations (Pavel et al. 2007). Other researchers predict decline in cognitive health based on the gait speed estimated from sensor data (Austin et al. 2011b). In the home environment gait speed is estimated based on the timing of sensor events arranged in a straight line down a hallway or narrow corridor. Studies have shown evidence for a relationship between in-home gait speed and abrupt changes in health condition, as well as a relationship between weighted correlation estimates of the gait speed and cognitive health (Austin et al. 2010). However, estimating gait velocity using this technique poses challenges in multiple-resident homes. As one solution, Austin et al. (2011b) proposed modeling gait speeds using Gaussian mixture models for multiple residents in a smart home. They show the effectiveness of their technique by correlating the results from sensor data with the standard clinical assessment data. Researchers have also studied the relationship between the longitudinal trajectories of walking speed and speed variability and the cognitive health using latent trajectory modeling technique (Dodge et al. 2012).

These modeling techniques use passive infrared motion sensor systems and require explicit arrangements of sensor systems to measure walking speed. Alternatively, one can use a Kinect system to measure walking speed, stride length, and stride time. The measurements using Kinect sensors were validated using marker-based motion capture system (Stone and Skubic 2011).

Monitoring Everyday Functioning (Activities of Daily Living)

Every day functioning is the functional ability of an individual to complete daily activities to live competently and independently. Functional abilities such as eating, maintaining hygiene, and using bathroom are called basic activities of daily living. They are cognitively less demanding but are fundamental to living. Similarly, independent activities of daily living (IADL) are another set of functional abilities. These cognitively demanding activities include driving, using telephones, and managing finances. For independent living, a person needs to complete activities of daily living. Measuring and understanding difficulties in everyday functional abilities are therefore important parts of gerontology research.

Previously, clinical studies have shown that individuals diagnosed with cognitive difficulty have more difficulties in completing IADLs when compared with healthy controls (Artero et al. 2001; Farias et al. 2006; Pedrosa et al. 2010). With incidence of more severe cognitive problems such as AD, individuals have difficulty in both initiating and completing basic activities as compared with healthy and MCI controls (Farias et al. 2006). Often, with progression of cognitive difficulty, a pattern of decline in abilities to complete higher-order functional abilities (IADL) followed by basic functional abilities is observed (Gross et al. 2011). Such pattern indicates that detection of functional changes may help detect early stages of cognitive decline or identify individuals with greater risk of decline (Pedrosa et al. 2010). Predicting cognitive health based on the performance of activities of daily living is an active research area in neuropsychology and clinical research (Schmitter-Edgecombe et al. 2011, 2012).

Activity recognition and discovery algorithms can be used to study a person's everyday functioning using sensor data. The raw sensor data does not contain activity labels, and therefore it requires annotation before it can be used further. Activity recognition and discovery algorithms can annotate sensor events with activity labels. While activity recognition (Cook 2010) algorithms map a sequence of raw sensor readings to a label indicating the activity that is being performed, activity discovery (Rashidi et al. 2011) algorithms discover sensor patterns of frequently conducted activities but cannot provide specific activity labels. These algorithms can accommodate various sensor modalities including environmental sensors, wearable sensors, and object sensors. They can also recognize complex and interweaved activities of daily living (Singla et al. 2010). The output from activity recognition and discovery algorithms can be used to develop activity-tracking algorithms to track an individual's daily behavior.

Activity-tracking algorithms monitor activities in daily life. They flag abnormal changes in activity patterns after discovering frequently completed activities (Rashidi et al. 2011). They may also use domain-specific rules to detect changes in circadian rhythms of the daily activities (Virone et al. 2008). These abnormalities and changes in circadian rhythms are hypothesized to indicate problems in cognitive health. The activity-tracking algorithms are particularly useful to track an individual's activity over a long period of time and detect decline in their everyday abilities.

In other works, researchers hypothesized that individuals with cognitive difficulties have significantly lower *activity quality* than healthy controls. This hypothesis was drawn assuming that individuals with cognitive difficulties commit more significant errors while completing activities. The focus of this research is on the development of intelligent algorithms that can predict activity quality and study the relationship between cognitive health and quality of activities of daily living. The data is usually collected under a constrained laboratory environment while groups of people with different cognitive difficulties perform predefined set of activities.

In one of such works, Hodges et al. (2010) hypothesized that patterns of errors made while completing daily activities correlate with type and severity of cognitive difficulty. The authors assumed coffee-making activity as a proxy to everyday functioning and monitored the object usage using wireless RFID sensors while individuals with TBI completed the activity. They found a correlation between extracted set of features that characterized the task performance based on the object usage data and neuropsychological assessments tests. Researchers have also used ambient sensors to derive the quality of completed activities. Cook and Schmitter-Edgecombe (2009) developed a Markov model to assess the completeness of five different activities of daily living: telephone use, hand washing, meal preparation, eating and medication use, and cleaning. Their model detected certain types of step errors, time lags, and missteps. Both of these studies were conducted while participants performed simple daily activities. Researchers have also developed algorithms to monitor a specific activity such as dressing (Matic et al. 2012).

Monitoring activities with sensors have shown that activity quality and cognitive health are related in complex and real-life activities (Dawadi et al. 2013a, b). The authors classify individuals into cognitively healthy and cognitively unhealthy using activity quality as an input to learning algorithms. They also show a fairly strong correlation between direct observational scores that were observed on a set of activities of daily living and the sensor measurements of the same activities by trained neuropsychologists. The latter indicates that by using sensor data, learning algorithms can predict activity quality of both simple and complex activities and that such predictions correlate with activity quality measurements performed by trained clinicians.

All the abovementioned studies present tracking everyday functioning using sensor technologies as a promising candidate to monitor cognitive health. The shortcoming of these studies is that they were conducted under a laboratory setting using a limited set of predefined activities. Future research in this area must be focused on investigating the relationship between everyday functioning and cognitive health in real and unconstrained environments.

Longitudinal Monitoring

In contrast to the cross-sectional studies of everyday functioning in which researchers collect data from a population at a certain time point, longitudinal studies collect repeated observations of everyday functioning of individuals continuously over a long period. These studies are better suited to address the questions related to within-individual changes and interindividual differences in changes, trends, and trajectories (Singer and Willett 2003). Using longitudinal data, one can detect changes in data by taking a person's past as a baseline. Thus, to detect early indications of cognitive decline based on continuous monitoring of everyday behavior, analysis of longitudinal everyday functioning data is ideal. However, longitudinal analyses require data collected over a long period and pose additional challenges such as missing data and dropouts.

Previously, clinical researchers have studied patterns of changes and their trajectories in everyday functioning measures and their relationship to cognitive health.

For example, Artero et al. (2001) studied the relationship between the ability to perform everyday activities (functional abilities) and cognitive disorder in 368 participants for 3 years. They found that individuals with mild cognitive deficits have more difficulties completing everyday activities when compared with cognitively healthy individuals. In a similar work, Wadley et al. (2007) examined trajectories of changes in everyday functioning of 2,358 participants over a 3-year period and found that the rate of decline of everyday functioning is higher in individuals with cognitive difficulties (mild cognitive injuries). Similarly, Pérès et al. (2008) followed nearly 1,000 healthy individuals and individuals with dementia for 10 years and found that among those healthy individuals, the ones who developed dementia at a later time had worse performance in complex IADLs compared with the healthy controls that did not develop dementia. They conclude that changes in daily pattern may constitute early markers of decline in cognitive health. The relationship between changes in mobility patterns and cognitive difficulties has also been studied in O'Connor et al. (2010).

However, clinical studies often use self-report and informant report-based methods since behavior simulation and direct observation methods of data collection procedures are expensive and labor intensive to carry out repeatedly. In contrast to self-report scoring, smart home sensor systems can continuously monitor and collect measurements of everyday behavior of the residents in their home environment.

A limited number of studies have investigated longitudinal monitoring of everyday functioning parameters using sensor data and studied their relationships with cognitive health. While some researchers have developed visualization techniques to visualize gait, sleep, activity densities, and circadian rhythm over a long period, other researchers have used statistical modeling techniques to model the relationship between longitudinal sensor data and cognitive health. We discuss both of these approaches next.

Often, visualization techniques represent sensor data in a way that clinicians and caregivers can comprehend and visually detect changes in activity patterns and activity rhythms of the patient. In one of such works, Wang et al. (Wang et al. 2012) used motion sensor data to plot an activity density map, which is a visualization plot that represents levels of activities with different colors. Using a dissimilarity metric among activity density maps, the authors demonstrated techniques to track changes both in daily activity patterns over time and in physical and cognitive health. In another work, Virone et al. (2008) presented techniques to model and visualize daily circadian rhythm of the activities and their deviations. They calculated time spent in each room of the smart home and the number of motion sensor events triggered per room. Such visualization technique has also been developed to visualize deviations in activities of daily living. Similarly, Kanis et al. (2013) developed techniques to visualize activities in order to detect early indications of diseases with feedback from medical experts. These works focus solely on the development of an effective visualization tool for long-term data monitoring.

While visualization techniques are helpful tools for both caregivers and clinicians to derive quick conclusions, they neither model the statistical relationship between health events and sensor data, nor do they generalize the relationship across the population. Thus, other researchers have quantified the relationship between sensor data and standard clinical scores. In one such work, Paavilainenet al. (2005a) found lower daytime and higher nocturnal activity levels in individuals with dementia compared with healthy individuals. They also found statistically significant correlations between self-assessment of sleep quality and daytime vigilance. The activity signal data was collected using IST Vivago Wrist Care system. Similarly, Paavilainen et al. (2005b) study changes in circadian activity rhythm using the same technologies as clinical observations of health status of the subjects and concluded a relationship exists between the two. Researchers have also investigated the direct relationship between sensor data and standard clinical scores. For example, while (Robben et al. 2012) found a correlation between data obtained from the motion sensors and standard clinical assessment, the Assessment of Motor and Process Skills (AMPS) scores, Dodges et al. (2012) studied the relationship between longitudinal trajectories of walking speed and speed variability and cognitive health using latent trajectory modeling technique. Suzuki and Murase (2010) have shown a relationship between MMSE scores, health, and in-house movements. All these studies provide valuable evidence that longitudinal monitoring data can be used to make inferences about cognitive health.

Future Directions and Conclusions

The recent advancements in sensor technologies and learning algorithms have made continuous monitoring of daily human behavior in their home environment a reality. We presented cognitive assessment systems as intelligent agents and discussed in-home technologies to monitor an individual's cognitive health. We highlighted clinical findings that suggested a relationship between everyday behavior and cognitive health and discussed smart home-based approaches to monitor everyday functioning. Interdisciplinary research effort among clinicians, neuropsychologists, and engineers is required to move this field forward.

In particular, future work on cognitive assessment based on computing platforms can utilize mobile platforms. By exploiting this sensor-rich platform, scientists can develop test suites that can be completed in an individual's home environment and can accurately measure the underlying cognitive construct. One can also adopt novel platforms such as full-body gaming systems (e.g., Nintendo

Wii and Microsoft Kinect) to perform cognitive assessments. Recent research suggests that full-body gaming systems are becoming widely accepted among older adults (Aarhus et al. 2011). Previous researchers have studied the acceptance of these gaming systems and their applications for physical rehabilitation for older adults. Future research should address the question of whether or not the data from these gaming systems can be used for cognitive assessment or to simulate standard clinical tests.

Similarly, monitoring everyday abilities with smart home sensors has several research possibilities given the importance of understanding everyday abilities of older adults and the immense amount of information that sensor data contains. The initial studies have shown potential for sensor technologies to monitor daily activities in constrained laboratory setting and predict their quality. However, how their methods extend to unconstrained settings remains unanswered. In addition, extending activity recognition algorithms, which are well-studied problems in pervasive computing, to develop activity-tracking algorithms to track changes in activity patterns for a period of time is an open research question that needs to be addressed.

Recently, with the availability of longitudinal data, researchers have focused on development of algorithms to analyze long-term sensor monitoring data and detect early indications of cognitive decline (Dodge et al. 2012). Modeling of everyday functioning parameters and types of statistical and learning models required for detection of early indications of cognitive decline is an active area of research. The outputs from the models are valuable to end users, especially to clinicians and caregivers, as they allow them to better understand a person's behavior. In addition, the data from large-scale studies can be used to answer questions about the population behavior. For example, one can answer the questions of whether or not an observed trend for a dementia group can be generalized across the population or if MCI and dementia groups exhibit similar trends.

Cognitive decline is a gradual and slow process. Researchers require continuously monitored data over a long period of time to detect cognitive decline. Currently, there are very few openly available long-term behavior sample data that researchers can use to develop algorithms. Very few of them have instances of known incidence of cognitive decline. Such lack of publicly available data complicates algorithm development and is an ongoing challenge for the field.

Ideally, a cognitive decline detection algorithm performs trend detection on longitudinal behavioral data. Such algorithms would take the individual's history as a baseline and perform the analysis. This algorithm requires convergence of traditional time series and longitudinal data analysis techniques and machine learning algorithms. In addition to analyzing each individual separately, it is also desirable to generalize the trend to the overall population and to observe if a detected individual trend can be generalized to the population. Still, this poses a great challenge since it requires large datasets. Thus, we stress the necessity of publicly available clinical ground truth data along with long-term sensor monitoring data to advance and motivate researchers to develop algorithms for performing in-home

Table 3 Pervasive technological approaches to monitoring everyday functioning measures

Measures	Studies	Technologies
Computerized cognitive assessment		
CERAD, CANTAB	Dougherty et al. (2010), Snyder et al. (2011)	Desktop computers, tablets, smartphones
CANTAB mobile		
ClockMe	Kim et al. (2012), Zhang et al. (2003)	
Virtual reality		
Computer usage		
Typing speed	Jimison et al. (2004a)	
Mouse usage		
Computer games		
Solitaire	Jimison et al. (2007, 2008), Jimison and Pavel (2006)	
Word scramble		
Mobility and gait		
Gait velocity	Hagler et al. (2010), Austin et al. (2011a)	Motion sensors
Everyday functioning		
Object usage	Hodges et al. (2010)	RFID
Simple activities	Cook and Schmitter-Edgecombe (2009), Dawadi et al. (2013a)	Motion sensors
Complex activities	Dawadi et al. (2013a, b)	Motion sensors
Longitudinal data		
Visualization tools	Stone and Skubic (2011), Aarhus et al. (2011)	Motion sensors
Statistical models	Dodge et al. (2012), Paavilainen et al. (2005a), Suzuki and Murase (2010)	

cognitive assessments. After analyzing the results obtained from sensor measurements, the final step is to verify that the obtained results *align* with the results obtained from clinical data that are accepted by the community. This step ensures that the results have indeed captured some existing underlying trends on a validated standard clinical dataset (Table 3).

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Architectural and building services requirements for smart homes

Joost van Hoof, Wim Zeiler, and Rob van Bergen

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Abstract

Smart home technologies are a large potential market for the construction and building services industry. This chapter discusses the topics consultants, installers, and suppliers of home automation systems encounter when working in the field. Improved communication skills and more flexible approaches to the design and installing of building services leads to many new opportunities for new products and services. There are a large number of requirements from the perspective of architectural design and building services engineering, which

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relate to the infrastructure that is needed for smart homes. An overview of these electrical engineering and ICT requirements is discussed. When working with clients, it is important to consider the additional set of rules of working in their homes. Clients may have additional needs in the field of home modifications that can also be addressed when doing retrofitting projects. An outline of steps to get stared and essential questions for professional care organization is given.

Keywords
Building services • Architecture • Home automation • Networks • wireless • Infrastructure

Introduction

The concept of lifetime housing, which allows older people to age in place, is closely related to the use of various home modifications, home automation, and information and communication technologies (van Hoof et al. 2011a, b). With the ever-increasing numbers of older people and other people with a temporary or permanent demand for care, home automation technologies are a large potential market for the construction and building services industry in Europe. It also allows the sectors to expand their horizons and markets. Within the domain of health care, there are numerous subgroups of clients in need of care. All these potential users of smart home technologies have their own set of requirements that can be expressed in user profiles. The actual needs can be met by the implementation of a wide array of different technological solutions, which also go together with different approaches to infrastructure and a large complexity of the work. Smart home technologies can either be (1) supportive technologies for the activities of daily living, such as automated lighting systems and on-and-off switches as well as (2) surveillance technologies used for monitoring, detection, and communication. These two types of technologies can be used for a wide array of functionalities such as:

- Improvement of the sense of safety and security: automated switching on-and-off devices, nighttime orientation, fire and burglar alarms, and assistance with medication intake
- Warning: fall and wandering detection systems that warn care professionals after accidents/incidents
- Improving the productivity of care professionals: technologies that can serve as an additional means of surveillance
- Collecting data and vital signs
- Distinguishing between acute and nonacute alarms and need for care/assistance

Many older people, in particular, deal with multimorbidities and can be part of various user scenarios and profiles, for instance, an old lady with cardiovascular disease and also early-stage dementia, requiring a set of functionalities as way to support. It is therefore of the utmost importance that various user profiles match as much as is technically feasible. Consultants, installers, and suppliers of home automation systems are often imprisoned in their own professional domains, given the technologies and infrastructure they advise, install, or sell. Too often, they do not communicate efficiently with one another which leads to a suboptimal approach to tackling the complexity of home automation (Zeiler 2009).

Towards a New Approach in Home Automation

Making the process of design and installing building services more flexible leads to many new opportunities for new products and services (Zeiler 2009). Any building services company should offer its customers a sustainable and careless future. By focusing on innovation, the development towards system integration has been made, and some successful smart home products have made it to the marketplace. A system integrator is a person or company specialized in bringing together various subsystems or components in order to create a system that works flawlessly. The next step is the professionalization of the development of an environment that responds to the user, who in turn is leading in the control of the various technological systems. In the domain of smart homes, an important leap forward can be made when we collectively star comparing the process of building design and construction to that of cars and other vehicles. Modern cars are actually mobile computers, fully equipped with a seemingly endless selection of computers to control the functions as breaking, climate control, and acceleration. In order to star thinking about dwellings as we do about cars, it is important to follow a fitting development strategy. The tuning between the many disciplines involved in such processes asks for a cooperation which is embedded in an integrated approach of the design process as a basis for product development.

Infrastructure and Communication

Apart from the operational aspects and control concepts which are essential for a correct operation of the smart home technologies, there are a large number of requirements from the perspective of architectural design and building services engineering, which relate to the infrastructure that is needed for smart homes. Such requirements concern the positioning of devices in the dwelling, connection points (sockets) for electricity and data communication, and the way installers work with their clients.

Most of the smart home systems consist of one part for infrastructural communication and of one part for local communication:

1. The infrastructural communication is the communication connection between a (nursing) home and a health call center. This connection is often wired.
2. The local communication between sensors and the central home system, which is either wired or wireless.

The wired systems can be divided into two groups or typologies: the BUS structure and the star structure systems.

- A BUS (binary unit system) communicates with the central home system via its own fixed wires (mainly UTP, unshielded twisted pair). It is a data communication system that allows the communication between various technologies, including switches and controls. A BUS is in fact a main artery or spinal cord, which connects all the technologies in a home or building to the central home system.
- In a star structure system, each sensor or actuator is connected to the home system via its own wire. The devices need their own secure location for positioning.

When choosing for a BUS, potential savings can be made when using multiple main arteries for the connection of sensors and actuators. When one of the main arteries gets damaged, communication to the home system is no longer possible. When a cable gets damaged in a star structure system, it does not lead to a total standstill of (a part of) the system. A star structure system does require more and longer wires to connect all devices to the system. Loose cables in rooms and corridors should always be installed in such a way that they are covered by plinths in order to prevent damage or cause complaints in relation to aesthetics.

Wireless systems have a large advantage over wired systems, namely, the fact that no wired infrastructure is needed, which is costly and time-consuming to install. Wireless systems also allow a flexible placement of sensors and actuators. Security can be guaranteed through closed communication protocols. Potential disadvantages are the risk for disturbances and interference and, when devices are battery powered, power outages. Wired systems are reliable and the operation of such systems is more secure because of the use of its own infrastructure and protocols. Producer-independent extensions of the systems are possible when choosing for a standardized system. Wired systems are labor intensive and expensive when installing in existing buildings. Moreover, the flexibility of such systems is limited when retrofitting or moving.

Infrastructure and the Building

Mohammadi (2014) concluded that two thirds of the smart home projects in the Netherlands were implemented in the existing building stock. These projects required substantial modifications to and retrofitting of the homes and the infrastructure, mainly due to the lack of shafts, ducts, and suspended ceilings. Such actions may be conflicted to the image of smart home technologies as being plug and play and advanced (Mohammadi 2014; Kort et al. 2012; Kort and van Hoof 2012). According to Mohammadi (2014), half of the projects took measure to make the dwellings more future proof, meaning that empty tubes and shafts were put in place for future modifications.

ISSO, the Dutch Building Services Research Institute, published a document which deals with the role of the building services sector in relation to lifetime homes

Fig. 1 Room for improvement: a meter cupboard of a home automation demonstration dwelling in the Netherlands

(ISSO 2004). This document deals with smart home technologies for healthcare and the infrastructure that is needed at home for the proper operation of these systems. For instance, the meter cupboard or storage space should be spacious enough to allow for the installation of devices, such as BUS technologies, controls, and other switchboards (Fig. 1). One could also consider placing an additional plug socket for charging the batteries of a mobility scooter or electrical wheelchair, which goes together with sufficient space for positioning the mobility aid in the first place without blocking the pathway. One should consider the wired communication systems and connections for the Internet, audio, television, video telephony/intercom systems, and the traditional telephones. Sometimes, users can ask for multiple telephone connections per dwelling, even in the era of mobile phones. In order to be able to track and trace people, for instance, older persons with dementia, systems based on GPS,[1] Wi-Fi,[2] or RFID[3] can be installed for alarming and assistance on demand. In order to provide these devices with electricity and to control them, two types of infrastructure are required: one for electricity and one for data. The wired

[1]Global Positioning System.

[2]Method for wireless communication between electrical devices and the Internet.

[3]Radio-frequency identification.

infrastructure for electricity is needed as long as the devices are not battery powered. The infrastructure for data transmission can be either wired or wireless.

Another point of discussion is that of providing empty tubes in the home, which allows for putting cables in the home at a later stage when needed. This allows the installation of electricity and data cables without the need for drilling and demolition. Modern systems are increasingly based on wireless communications and a centralized processor. Still, there are various reasons why one should consider applying empty tubes in homes during the construction phase. First of all, the costs are limited compared to adding tubes in a later phase when cables are needed. It is still difficult to predict the future: people can get a (higher) demand for care or, with new occupants, can move in requiring an extensive network of wired solutions. At the same time, there are critical voices regarding the application of empty ducts. Verheul (2011) stated that home automation technologies are as transitory as an average mobile phone. The latest technology is, so to speak, out of date the moment the technology is being installed. Verheul further mentioned the application of wired systems, as it would be unaffordable for social housing organizations to design and install a basic infrastructure for smart home technologies. Verheul also stated that about 70 % of all infrastructure remains unused or is outdated at the moment an occupant wishes to use smart home technologies. The current wireless systems, on the other hand, are often considered not to be a true and reliable alternative for wired solutions.

Home Automation in Practice

The possible advantages of empty tubes can be illustrated by an example of the installation of a fire alarm system as part of a larger smart home system for older people. The unattended autonomous surveillance (UAS) system (van Hoof et al. 2011a) includes fire alarms which are connected to a 230 V power supply. In new systems, designers can choose to install fire detectors which are operated by batteries (and which can be positioned near light sources in the ceiling). This is much cheaper in its installation, but during the operation phase, it requires a regular check of the battery status. In the same UAS project, the ZigBee[4]-based sensors were equipped with batteries, which required a regular change of the batteries. Technicians had to pay additional visits to the homes of the older people in order to change the batteries. These visits were either appreciated as a social event, or as a breach of privacy. In apartment blocks with a concrete structure, a loss of signal strength can be found when using ZigBee-based devices. The UAS project further showed that many users are reluctant to accept technologies with lose cables in their homes. These cables have a negative impact on the aesthetics of the interior design and gather dust. The best position for any processor is the meter cupboard, as long as it is large enough to accommodate the technology. When having to place computers in

[4]ZigBee is an open standard for wireless connection between devices over a short distance.

the living room, one has to cover up the technology. When home care technologies are too visible, for instance for visitors, it can be stigmatizing. At the same time, some users regard the technology as a surrogate burglar alarm and communicate that message to friends and relatives when being asked about the technology. Distracting sound effects and flickering lights, for instance, LEDs, can also be considered as unwanted. Most of all, the newly installed home automation systems should not interfere with other technologies in the dwelling, such as portable (DECT) telephones. Additional automated detection of faults and interferences may be considered. Last but not least, not all walls are suitable for mounting sensors, for instance, gypsum board walls.

More than Smart Technologies

Apart from having a wide array of home automation technologies at home, occupants may have other needs that fall within the domain of building services engineering. For instance, they may want additional plug sockets in bathrooms to allow for so-called shower toilets (with a built-in bidet function), burglar alarm systems, or taps operated by infrared sensors in order to improve the hygiene at home. Additional electricity or data connections may be wanted in upper corners of homes, for instance, for installing sensors and cameras, as well as automated curtains. In large apartment blocks inhabited by older people, back-up power units may be a valuable option to guarantee power supply during power outages, for instance, for people who are dependent on medical technology at home. Home switches, allowing people to turn off all electrical devices when leaving the home, should be designed in such a way that critical technologies, like sensors and refrigerators, are not switched off when leaving the home. For people with mobility impairments living in regions with cold winters, having electrical heating in the pavement around the home to keep it free from snow and ice can be a desirable functionality. Nighttime orientation lights showing people the way from the bed to the bathroom at night may be designed and installed near the plinths or in the floors. This, however, requires additional infrastructure.

In short, there are numerous technological innovations available within the domain of building services which allow people to age in place. With the right basic choices for the home's infrastructure, end users can install these technologies (or have them installed) with limited effort. This maximizes cost-effectiveness in healthcare and opens up a new line of innovation.

Steps to Get Stared

When implementing smart home technologies as a professional care organization, the following questions should be asked and answered (Cbz 2006):

- How can smart home technologies contribute to the improvement of the care processes and well-being of the user?
- What are the operational and economic benefits of smart home technologies?
- Which guarantees (technological, functional, and operational) are desired or considered essential?
- How do the new smart home technologies fit within the existing ICT systems and policies of the organization?
- Which technologies are available on the market place?
- Do these new technologies meet the requirements of the “new” process of care?
- Which technological solutions are offered by the producer/supplier?
- Are you going to design or develop a new set of solutions or do you select existing technologies?
- What are the architectural consequences of the smart home technologies?
- What are the needs and desires of the organization in relation to the control software?
- What are the estimated costs and the expected financial benefits?
- Are best practices available that allow for a comparison?

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Standards for Smart Living: A Historical Overview

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Abstract
This chapter provides an introduction into the current state of acceptance of smart home technology and its history. It starts with examining four stages of domestic technology, the current situation, and the future of smart home technology. This

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chapter aims to apply concepts from literature on the diffusion of innovation on the past, present, and future of smart home technology. Lastly, this chapter examines the analogies between technology adoption discussed in the first three stages of domestic technology with the present and future situation of home automation and robotics.

Keywords
Smart homes • History • Innovation process • Adoption • Home automation

Introduction

Smart living is a concept that has developed rapidly over the past decades and the technology itself has changed immensely in the last decennium, from the first usage of electrical appliances like the smoothing iron (1903) and the toaster (1909) (de Rijk 1998) to the use of vacuum robots and smart thermostats today. In the nineteenth and early twentieth centuries, the concept of a "smart home" was advertised as a futuristic notion. At fairs and in showrooms, different parts of the house or complete apartments were packed full of electric (and later also automated) appliances that functioned independently from each other. These appliances were meant to make domestic labor lighter and more pleasant and were subsequently marketed as such (de Rijk 1998). From these showrooms full of independently functioning appliances, we have moved to complete systems that can be installed in the home. Nowadays, the "smart home" is a concept in which innovations do not only function autonomously within the home but are also interconnected and as such form an integrative system or whole. Today, smart homes are residences where computing and information technology aim to provide a safer, healthier, cleaner, and more socially connected environment for the occupants. Smart housing technology has evolved significantly over the past decennium. It has moved from just easing housework for housewives to many types of applications today. The focus of the development of smart home technology currently lies on healthcare applications in healthcare and living facilities and adoption of energy saving or sustainability innovations (for instance, smart thermostats). For example, in the Netherlands, there is no widespread implementation of this domestic healthcare technology yet (Mohammadi 2014), even though the ageing population and budgetary measures in the healthcare sector make this technology highly relevant for Dutch society. This limited implementation can be partly attributed to the technology itself: especially in "new" technology, some flaws and bugs are expected to arise when just entering the market. Nevertheless, some technology has been around for years and has not (yet) seen success. Also, the price of new technology is initially higher and therefore not accessible to everybody.

However, research has shown that price is not the most important determining factor for older adults in the Netherlands in the decision-making process surrounding smart home appliances (Mohammadi 2010, pp. 224–225). When examining the factors for successful or failed technology implementation, several aspects are important: (1) the technology itself, (2) the stakeholders involved in any part of the production or consumption process, and (3) the social, cultural, political, and economic context. The interplay of these aspects is a critical success factor for technology implementation (Mohammadi 2014).

In this chapter, we will first go into the history and development of domestic technology in the late nineteenth and twentieth centuries. Secondly, we will report on the current situation of smart home appliances in the Netherlands and examine the possibilities of robotics in the future. In addition, we will examine the general process by which innovations are adopted by society and apply this knowledge to the development of domestic technology, in the past, present, and future. Lastly, the analogies between adaptation of domestic technology in the twentieth century and smart home technology in the twenty-first century will be treated.

We will start with the history and development of domestic technology. We do this for several reasons:

1. The developments in home technology in the last century have provided the seedbed for modern smart and intelligent homes (Aldrich 2003).
2. Through examining the historical evidence, one can illustrate the process by which innovations are adopted by the general public (or not) and at what pace. The underlying drivers of this process can be relevant for current adoption of smart home technology.
3. With this knowledge, we can examine whether history provides us with lessons for overcoming and/or understanding the current "adoption lag" of smart home technology.
4. The importance of overcoming this adoption lag lies in the applications for smart home technology in relation to the demographic and sustainability challenges the world faces today (ageing society and global warming). In short, this technology is essential in "future-proofing" houses.

Four Stages of Domestic Technology

As mentioned in the introduction and paragraph above, successful implementation of a technological innovation does not only depend on its technical attributes. Whether a product moves from one adoption phase to another (or stagnates) is only partly dependent on the *technology* in question. It is also largely influenced by the *stakeholders* involved in using the product and the specific social, cultural, historical, political, and economic *context*. Often the combination of these three factors can give an explanation for the course of the innovation process, i.e., when and why specific products are widely implemented and used (or not). In order to structure this historical overview of domestic technology, we have identified four different time periods, where we will explore the development of adoption of domestic technology and the influence of the factors named above. It is important to remark that the technology associated with the different historical stages, like mechanization and electrification, is not mutually exclusive. In fact, these technologies build on each other and are eventually combined in later stages, i.e., in the robotics stage. Furthermore, we argue that we are now somewhere in the late stages of automation or early stages of robotics. In order to make the distinction between past, present, and future, we have added a paragraph on the current state of smart homes in the Netherlands.

Mechanization

The first major stage in the development of domestic technology is set off by the Industrial Revolution. The Industrial Revolution started in the UK at the end of the eighteenth century; however, other countries (among which the Netherlands) followed almost 100 years later during the late nineteenth century and early twentieth century. The introduction of the assembly belt by Henry Ford in 1913 is a clear example of how the production process changed during this period. The process of mechanization allowed for faster and cheaper production of goods (mass production). Not only did the Industrial Revolution have an impact on the production process, which resulted in the cheaper supply of goods through mass production, it also set in motion major social changes. Instead of the self-sufficient, rural family life of preindustrial times, production of goods moved from inside the home to factories. It meant that, primarily in the poorer families, men as well as women and children started working outside their home. Whereas families from the poorer classes often worked in factories, in the emerging middle class society, working outside the home was a predominantly male affair. The role of the man became increasingly more important financially, and the "female" domestic chores were perceived as inferior to the "male" job outside the home (Aldrich 2003).

Electrification

The usage of electric power and its applications rose in the middle and late nineteenth century. However, it took more than 50 years for the technology to become more widely adapted into consumer's homes. In quite some (more affluent) households, domestic appliances were introduced during the beginning of the twentieth century. This was possible due to a combination of factors (Fig. 1):

1. *Connection of houses to the electricity grid* – By the beginning of WW II, around 65 % of all households in the UK were provided with electricity (Aldrich 2003, p. 19), but not all these connections were suitable for domestic appliances and were only used and fit for lighting. Nevertheless, the use of electricity for domestic purposes made it technically possible for domestic appliances to be used in the home. Compared to countries like Germany, Britain, and the USA, the Netherlands was rather slow in the initial adoption of household appliances powered by electricity. However, in the Netherlands, where the Industrial Revolution took place almost 100 years after its start in the UK, almost all households in the city of Amsterdam had access to electricity in 1920. That made Amsterdam

Fig. 1 The cover for the catalogue of domestic appliance of the Amsterdam municipal electricity company (GE). It makes buying household appliances even more appealing by offering a fixed tariff ("vastrechttarief") for the use of electrical household appliances (Prijs Courant Elektriciteitswerken Amsterdam 1930)

the "most electrified city" in Europe at that point in time (de Rijk 1998, p. 25). This was due to the government's involvement in the electricity supply. As seen in most other Western countries, by the end of the nineteenth century, electricity was provided by private companies and was mainly sold to factories and other companies. During the first decennium of the twentieth century, municipalities in the Netherlands withdrew the contracts they had with these private companies and started building their own power plants for electricity. The municipalities started extensive marketing campaigns[1], and some even offered free installation of connections in private homes (including in poorer neighborhoods). The government was not only helping to fulfill the requirement of installation of sockets in the home, it was also important in the promotion of electrical household appliances. Its motives were primarily economic in nature, for their measures aimed to increase the consumption of energy in domestic environments. With the price of electrical appliances being fairly high in the early twentieth century, the government's involvement (by selling these appliances below their retail value) gave a boost to the sale of household appliances. The municipalities hoped that families would start using more energy when they had more appliances that were powered by electricity. So whereas the adoption of household appliances was

Fig. 2 "Let Electricity be of use to you in the household where your maid abandons you" [translated] (de Rijk 1998, p. 66)

initially more widespread in countries like the UK and the USA, the Netherlands quickly became highly electrified after the municipalities started concerning themselves with the energy market. Consequently, a fertile market for electrical household appliances arose.

2. *Shortage of domestic help* – A shortage of domestic servants in the early twentieth century called for a way to alleviate the housewife of her domestic burden. Vacuum cleaners, washing machines, and electric fires did just that. The rise of the middle class and general growth in income had increased the demand for domestic servants (Pinchbeck 2004), but fewer young women wanted to be employed as domestic servants and preferred factory jobs instead (de Rijk 1998)[2]. Furthermore, by the end of the nineteenth century, the household tasks that were previously shared between husband, wife, and children now shifted to burden only the housewife (Bowden and Offer 1994, p. 734). Electrical appliances were marketed as a way to liberate the housewife and (partly) relieve her of her domestic burden (de Rijk 1998, p. 65). Ironically, with the introduction of this time-saving technology into the home, the housewife spent more time on household chores than ever before, due to higher hygienic standards and the woman being solely responsible for the household (Aldrich 2003) (Fig. 2).

   The combination of the increasing shortage of domestic help and women becoming the primary caretaker of the household transformed electrical appliances into "Cinderella technology" (Mohammadi 2014, p. 23). The applications for technology in the house were mainly aimed at making the domestic tasks of

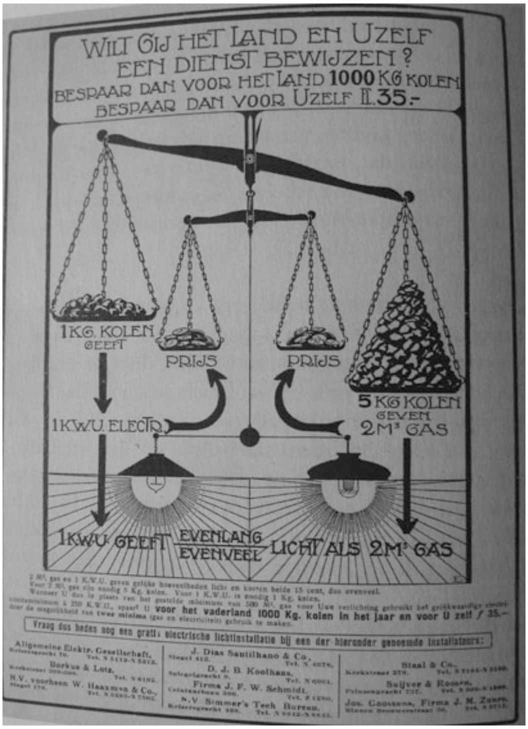

Fig. 3 "Serve your country and yourself" by using electricity rather than gas (de Rijk 1998, p. 34)

housewives easier and more pleasant. As such, the Cinderella technology tried to find a solution for the scarcity of the domestic servant.

3. *WWI and resource scarcity* – Within the historical context of World War I, resources in Europe became more scarce. Especially the scarcity of conventional resources like coal accelerated the use of electricity in the home. Within the house, electricity competed mainly with the use of gas for lamps and cooking. To generate this gas, coal was used. The same was true for electricity; however less coal was needed for the same amount of energy in kWh (electricity) than in m^2 gas. Next to physical shortage of coal, the electrical companies appealed to the consumer's patriotism. For example, in the Netherlands, using "Dutch" electricity was promoted by the municipality-owned electrical companies as being patriotic and cheaper than gas[3] (de Rijk 1998, p. 35) (Fig. 3).

As mentioned before, the technology in the different stages does not stand alone but rather builds on previous discoveries and innovation. An example of where electrification in combination with mechanization brought about immense changes in the built environment is the elevator. Whereas the mechanical elevator had been around since the Roman period, electrified elevators opened up a range of architectural possibilities (Mohammadi 2014, p. 24).

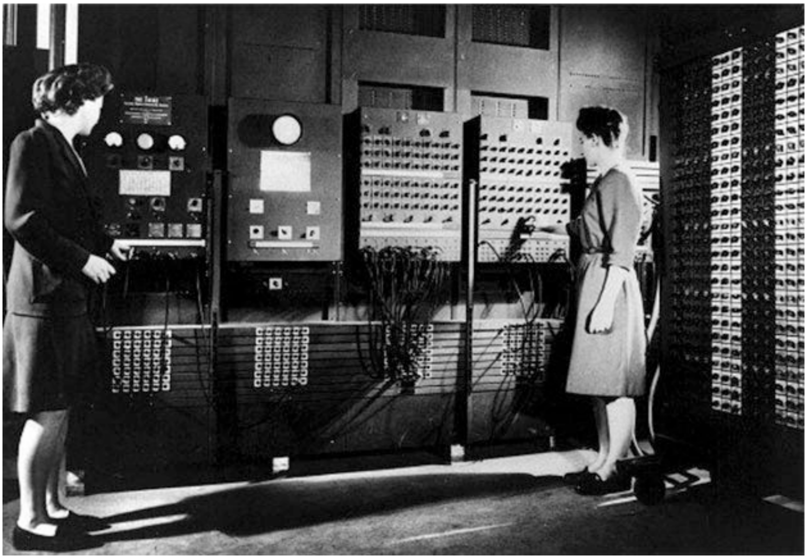

Fig. 4 ENIAC, the first electronic computer, built by the US army during the World War II (Computer History Museum 2014)

Automation

The automation of the household was inspired by several historical factors. As mentioned above, the electrification in the first half of the twentieth century and the changing modes of employment that arose from the Industrial Revolution were two important prerequisites for the start of the automation phase. Other factors that were crucial in this phase were:

1. *Technology push after the war* – World War II gave an impulse to technical innovations due to the rapid development of technology during the war. These developments, first invented for military use, slowly entered the domestic market after the war. Examples of this type of technology are the computer (first developed by US military under the name ENIAC[4]) and the microwave (also developed by the US military), both in 1945 (Fig. 4).
2. *The "efficient" housewife* – The type of technology found in households during the interbellum and 1950s was still mainly focused on the housewife (Cinderella Technology, see above). Inspired by offices and factories making their professional spaces more efficient, efficiency in the household became a topic of debate. Several associations for housewives propagated efficient lay out of the kitchen and the use of electrical appliances in the home. They derived their ideas from the workplace and played into the idea of the "housewife" as a modern professional. The efficiency movement is a rather contradictory one, as it combines elements of both modernism and traditionalism. As the president of the "Nederlandse Vrouwen Electriciteits-Vereeniging (translation: Dutch Electricity Association

for Women)," Mrs. Wolthers-Arnolli stated in 1935: "…[we should]… ask ourselves…what is the *housewife's task*. Whatever the change in the nature of the activities [of the housewife], now, more than ever, we can specify the housewife's task: *the material and idealistic care for the family*" (translated from de Rijk 1998, p. 69). The distinction between material and idealistic care is important here. With the rise of electricity and automated appliances, the task of the material care would ideally start taking up less time (modern view). With this extra time, the housewife could pay more attention to the idealistic care for the family (traditional view). The layout of electrical appliances changed drastically during this period. These appliances looked "professional" with clean lines and shiny surfaces that allured a sense of hygiene and competence. Here, the influence of dominant values within society on technology is seen.

3. *The house as a showroom* – During WW II, women started working outside the house to do the jobs formerly executed by men, who were now enlisted as soldiers. Women became financially important in the household and more aware of their technical competence. After the World War II women were encouraged to return home and tend to their domestic tasks once more. Whereas the view of this "professional" or "efficient" housewife was dominant during the years after the war, in the 1960s contraception increased women's flexibility and allowed them to start working away from home once more. The idea of the stay-at-home housewife was more and more rejected by women. They wanted to be seen as independent and no longer as "just a housewife." Especially during the 1970s, electrical appliances did not take a step back in its overall penetration of the market but rather were designed to look more old fashioned. The "open kitchen" as a concept provided a way for women to put "their" view of the rejected housewife on display in their home (de Rijk 1998, pp. 79–81).
4. *Influences from development in the workplace* – Furthermore, around the mid-twentieth century, blue-collar (factory) jobs made way for more white-collar (office) jobs. During the 1950s, "the office" as a space and office jobs became more mechanized. The introduction of computers at workplaces gave rise to the process of automation and the field of information technology. Eventually, together with the aforementioned "inspiration" that was derived from the efficient workplace, these technologies were adapted for domestic use too.

The combination of income, the changing role of the housewife, and further evolvement of the technology consolidated the adoption of electrical domestic technology like washing machines, toasters, coffee makers, etc. Furthermore, the efficiency movement in the interbellum and 1950s encouraged the use of automated electric appliances in the home, inspired by the usage of automated machines in the workplace.

While the *time-saving domestic technology* almost took half a decade to reach its "tipping point," after which widespread implementation took place, another domestic technology stream started emerging. With the rise of computers (specifically the PC) and information technology (IT), different entertainment technologies entered the market. This *time-consuming technology* needed only the last quarter of the twentieth century to become mainstream. Adoption of time-consuming technology like television, radio, cinema, and computers was quicker and not as dependent on income as time-saving technology had been in the centuries before. Furthermore, not only housewives (and by default women) were concerned with this technology, men also became more involved in household technology. Bowden and Offer (1994) suggest that the television offered a way to substitute social interaction and to keep feelings of loneliness at bay. These feelings of loneliness might have emerged from the changing society in which traditional social structures were becoming rapidly less important (the de-compartmentalization of society). Furthermore, they argue that television offered a "vivid form of immediate gratification" that humans find hard to resist as another reason for this fast implementation (Bowden and Offer 1994, p. 739). Of course important prerequisites that were not met during the early implementation of household appliances had already been met when time-consuming technology entered the market (for instance, electricity).

Current Situation

During the twentieth century, societal processes shaped the use of appliances within the home as "Cinderella technology," a way of making housework easier and more enjoyable. In the twenty-first century, society faces different problems: an ageing population with an increasing number of noncommunicable diseases has shifted the technology from technology to support the housewife to technology to support the nurse. As such, this new type of technology empowers and supports older people living in their own home for a longer period of time. This "new" technology is what we named "Florence Nightingale technology" (Mohammadi 2014). Big steps have been made in this "Florence Nightingale technology" in the past decennium. In the beginning of this century, companies were "forcing" their products on users in pilot projects. The inhabitant became a customer with no say in the development and implementation of products in his or her own home. This resulted in protest and rejection of the technology, exacerbated by the sometimes flawed and often malfunctioning technology itself. The recent shift from "technology push" to "market pull" has incorporated the user's perspective and needs. With the consumer's perspective in mind, the technology can be adapted or "tamed" for use in the home. The technology moves from a superfluous "gadget" to an appliance fulfilling an actual need. Within healthcare organizations in the Netherlands, implementation of a couple of these smart healthcare appliances or products is taking place. However, this is not the case for all (types of) products and not at an individual level, the level of the consumer (Pragnell et al. 2000; Leppänen 2003; Friedewald et al. 2005). Research in the Netherlands found that the average use of "smart" applications in different types of living formations for older people was 55 % in health and care appliances, 45 % in security appliances, and 30 % in both energy saving and comfort and e-services. It goes to show that whereas some adoption of smart health appliances is taking place, this is not commonplace for all living facilities for seniors (Mohammadi 2014, pp. 46–47).

Robotics

The word “robot” originally meant “artificial worker” and hints at the origin of this type of technology (the workplace). Its definition is muddled by the different types of applications for robots nowadays. At the very least, it implies some form of (artificial) intelligence and interaction with its environment. The quick rise and implementation of entertainment technologies in the last quarter of the twentieth century and the introduction of the Internet in that same period were important for the development of the field of robotics. Robotics combines the developments made in technology during the period of mechanization, electrification, and automation. It gives intelligence to technology from these earlier periods. In work environments like factories, robotics is already widely used. However, in domestic environments, this is much less the case. The slow adoption of these kinds of innovations may be due to the fact that this type of technology originating from the workplace needs to be “tamed” or “domesticized” before it can be implemented in the home, just as we have seen above in the case of other domestic technology. By design, these domestic appliances require to be physically present in the “private” domain of the home, which makes the technology acceptance more complex (Young et al. 2009, pp. 96–97).

Looking back at the different periods described above, one can identify two important developments where the societal context has shaped technology: Cinderella technology and Florence Nightingale technology. A similar development that we predict will happen in the future is that of the second machine age. The introduction of robotics and the omnipresence of technology (where technology becomes as “normal” as oxygen) are key elements in this second machine age (Fig. 5).

Three Phases of Innovation Adoption

With the adoption of a new technology, like household appliances or smart home technology, three phases can be recognized. In the first phase, the technology is still developing. In the second phase, the product is spread among potential users and the process of individual decision-making takes place. In the third phase, the product can be used and eventually becomes part of daily life (Rogers 2003; Wejnert 2002).

Research and Development Phase

The first stage of innovation adoption is research and development. In this stage, an idea is translated into a tangible object or product that can be converted into a prototype for testing. An example of this is the hydrogen car, which has been

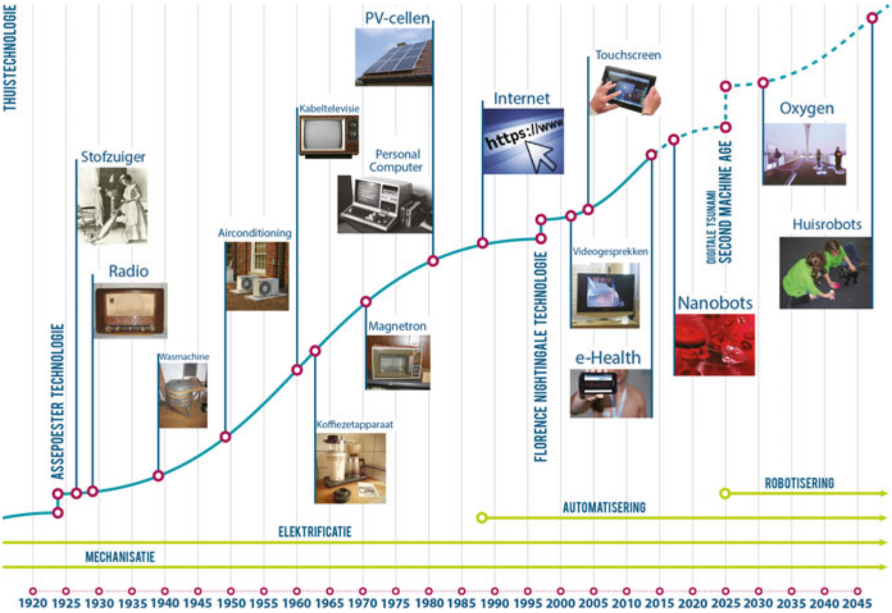

Fig. 5 Timeline domestic technologies (Mohammadi 2014, pp. 26–27)

manufactured on a small scale but has not yet seen massive production. This is due to the nature of hydrogen (highly explosive), the infrastructure (where to get "fueled up" on hydrogen), and the competition with electric and traditional transportation. Another example, also from the automotive sector, is the Google car: a car that can drive without somebody operating it. Road tests have been done and technologically the Google car is a success; however, the technology is not available to the general public (yet).

Transfer Phase

The second stage is the transfer phase, in which the technology becomes available for the general public (Fig. 6). Within this stage, there are two substages: firstly, the introduction into the market (diffusion), where small-scale adoption of the innovation takes place, and, secondly, the adoption by consumers, where consumers and households have access to the technological innovation. In this first stage, the product is introduced to potential user group, which describes a group phenomenon on how technology spreads. The second phase is the adoption phase, which deals with the individual decisions of the consumers on if they want to adopt the new technology or not. Several types of adopters can be recognized: (i) innovators, (ii) early adopters, (iii) early majority, (iv) late majority, and (v) laggards (Rogers 2003, p. 298). These types can be summarized in an S-shaped curve, in which there

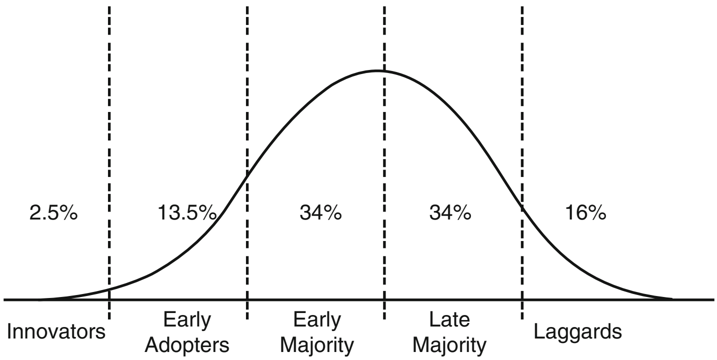

Fig. 6 Types of adopters (Rogers 2003)

are relatively few innovators, slightly more early adopters, after which the numbers rise exponentially with the early and late majority, to flatten off to the laggards (Fig. 5).

In the two earliest stages, the product or service is not yet mainstream. An example of adoption by consumers is the fitness tracking devices like the Nike fit or Jawbone that can be worn like a bracelet and whose main function is the tracking of the wearer's activity. Even though the technology is accessible to the general public, only 11 % of the US population reported using a fitness tracking device of any kind (Technology Advice Research 2014). This implies that this wearable technology has reached the early adopters at the present.

Implementation Phase

During the third stage, a tipping point is reached, which indicates that the innovation has reached enough momentum to sustain itself. Logically, the third phase is called the implementation phase, and in this phase, varying degrees of widespread adoption take place (Bouwman et al. 2002). This phase also consists of two subphases: in the first subphase, the product is available to the public and knowledge dissemination on the product is taking place. Obstacles preventing widespread adoption can be addressed in this phase as well. Solving the problems and issues with the technology might enable the technology to eventually move on to the next, and last, phase of the innovation process. An example of products in this introduction phase are laptops and computers; US census data reports that 83.8 % of US households own a computer or laptop, with only older (65+ years) and less affluent (>$25.000) households dropping below 65 % (File and Ryan 2014, pp. 2–4). The second subphase can lead to an innovation being so embedded in society that people are not consciously aware of the object or innovation anymore. An example of this (in most developed countries) is the availability of clean drinking water or electricity.

Nonlinear Phases

Even though a model of "stages" and "phases" suggests a linear model in which only one-dimensional movement is possible (from R&D, to transfer to inevitably implementation), this is not necessarily true in three respects:

1. The model can move in a cyclical fashion: a product or innovation can move back to another phase (Mohammadi 2014).
2. The model is not linear in time: a product can be "stuck" in a particular phase for a long time or never get out a certain phase at all (Rogers 2003, p. 345).
3. In traditional innovation studies literature, there is often no difference in types of non-adoption, just a gradual curve from "introduction to the market" to "adoption by the masses" (Rogers 2003).

Yet, research by Kleijnen et al. (2009) suggests that there are different types of reasons for people to not adopt a certain technology. Three types of "non-adoption" are identified: rejection, opposition, and postponement. Underlying these types of non-adoption are different arguments and motivations. Knowing these motivations can help to address the question of why certain types of technology did not become mainstream. These objections or motivations can be addressed in the first implementation stage: introduction. These objections may be overcome and lead to the second phase of implementation, namely, incorporation. If these signs are ignored, the innovation may not reach that phase at all. In the case of *rejection*, non-adoption is often driven by an unwillingness of consumers to break with their patterns of daily use. When consumers *oppose* a certain innovation, they do not adopt it for ethical or moral reasons. Obviously this is driven by tradition, personal ethics, societal beliefs, and norms. *Postponement* is very often found when examining technological innovations: consumers are afraid that the technology will change in the near future (and that they will have bought an obsolete or dated product). They are waiting for more information on the performance and risk of the product or until a newer version hits the markets (Kleijnen et al. 2009).

In this article, we have examined the development of smart home technology and Roger's theory on the diffusion of technology. What we can conclude is that electrification, mechanization, and automation have reached the last phase of the process, i.e., the incorporation phase. Most of the Cinderella technology addressed in these paragraphs (for instance, access to electricity, elevators, vacuum cleaners, the fridge, television) have become a natural part of everyday life. However, when we look at the status of the Florence Nightingale technology in the paragraph "the current situation," we see that this technology is still in the transfer stage. Instead of forcing technology onto the user and trying to skip ahead to implementation, it is important to incorporate user's view on technology. Here, research on the types of non-adoption of smart home technology and the underlying drivers can give a user's perspective on the technology. With this knowledge, smart home technology and smart homes can be designed *with* the inhabitants instead of *on behalf of* the inhabitants.

What Can We Learn from History?

What we have seen in the previous paragraphs is the influence of society on the technology. The need for domestic workers sparked Cinderella technology, and the ageing society calls for more Florence Nightingale technology. Technology development is influenced by a number of elements: the technology itself, the stakeholders, and the social, cultural, economic, historical, and societal context (Mohammadi 2014, p. 21). In this paragraph, we will examine the most striking parallels found in the history of many types of Cinderella technology (as discussed in the paragraphs on mechanization, electrification, and automation) with the current situation of smart home technology and future developments in the field of robotics.

1. *Technological infrastructure* – As with the introduction of electrical appliances, the right infrastructure needs to be in place before widespread adoption of smart home technologies can take place. As we have seen, the technology itself has developed significantly over the last few decades. Already, many innovations in the field of smart home technology are ready for domestic use according to its producers. However, the domestic environment needs to be able to accommodate these new technologies. Two prerequisites for smart home appliances and robotics that are (nowadays) quite common are electricity and the Internet. Whereas we assume that most people have access to the Internet, this might not necessarily be the case. Especially in homes of older adults, Internet is not a given (File and Ryan 2014), whereas the Florence Nightingale technology is often aimed at enabling older adults to keep living in their own houses. In Europe the extent of Internet usage ranges from countries like the Netherlands, Scandinavian countries, and Luxembourg with 92–96 % coverage, to Eastern European countries like Ukraine or Armenia with, respectively, 37.4 % and 43.5 % coverage nationwide (ICT Data and Statistics Division Telecommunication Development Bureau 2014). Next to Internet and electricity, smart home technology sometimes requires adaptations in the building infrastructure as well. If these requirements are not met, the infrastructure is not suitable for the adoption of smart home technology. Furthermore, standardization is an issue in smart home technology. Not all types of infrastructure and systems accept all types of smart home appliances (Miori et al. 2010).
2. *Added value for consumers* – As seen in both early electrical appliances and gaming technology nowadays, market actors can have a big impact on technology. In the Netherlands, municipalities earned money off of the usage of electricity. To increase the *potential use* of electricity, they sold electrical appliances under their market value. The same is happening in gaming technology nowadays. Collaborations between game makers and gaming devices (like Playstation, Xbox, etc.) result in "packages" where buying a separate device is more expensive than buying a game in combination with a device. This may be important when price is a barrier; however, more importantly the combination of two elements (the device/infrastructure and its applications) shows the user what the added value of a specific type of technology is. A Playstation or Xbox on its own

does not offer any added value, but a game that can be played on these devices does (entertainment value). The same can be said for electricity. Whereas people did not see the use of a connection to the electricity mains at first, combining it with electrical appliances, it shows the added value for the consumers. When applying this knowledge to smart home technology, it might be useful to show the added value of a smart home infrastructure to the consumer. As we have seen in history, an example of showing the added value might be demonstrating or marketing the applications that need this specific infrastructure.

3. *Emotion* – A second analogy is the emotions experienced by the different stakeholders. Returning to types of non-adoption, one can see how different emotional reasons can underlie these types of non-adoption. In the case of *rejection*, one can see an unwillingness of consumers to break with their patterns of daily use, the underlying emotion being the nostalgia experienced by consumers. This does not necessarily need to be an obstacle for the use of technology, as we can see in the case of household applications in the 1970s. During this time, many households increasingly resisted the idea of technology development becoming more and more important in households. However, this had no effect on sales of household appliances; in fact, they still rose during that period. It influenced the design of the appliances more than anything Aan elkaar, ook ingesprongen, hoort bij 3. emotion namelijk.

In the case of *opposition*, a certain innovation is not adopted due to ethical or moral reasons. Regarding electrification this was mainly a matter of health and safety (some people believed gas-fueled lamps were better for ventilation and health than electrical lamps) (Noort 1993). Consumers see some smart home technology as an assault on their privacy and autonomy when previously human tasks are taken over by smart home technology or robotics. However, where it was rather easy to debunk the myth that electricity would be more detrimental to health than gas lamps (de Rijk 1998), scientifically proving that smart home technology will not invade privacy and pose a threat to autonomy is much harder to do and might hinder current widespread implementation. *Postponement* is associated with the fact that technology changes fast and consumers are afraid they will have bought outdated technology. They are uncertain in what direction the technology will go and are waiting for more information on the product and its risks. The fact that there is no clear standardization of smart home technology and infrastructure only adds to this uncertainty.

4. *The taming of technology* – Technology that might be readily adopted in the workplace is not always successful in penetrating the domestic market. Here we refer to the taming of "hard" technology into the "soft" environment of the home. Another important cultural and historical aspect coming into play is the traditional association of the woman attending to the household. She is associated with "soft" values with which she takes care of the family and the home. In contrast, technology is often seen as harsh, stiff, unforgiving, and more "male" oriented. Still today, a large proportion of the women do most domestic (unpaid) work in the homes and spend relatively more time on domestic work than their male

counterparts (regardless of their respective income) (Bittman et al. 2003). What was crucial for the large-scale adoption of electrical appliances was the way marketing targeted the housewife (rather than the man). It addressed issues that were relevant for them in that specific historical context (chronological examples: the domestic help shortage, the "efficient" housewife, the emancipated woman). Despite the fact that women are often responsible for most household purchases, women are not always involved in the design process, which is still a male-dominated field (Cockburn and Ormrod 1993). Especially in the area of healthcare and nursing, the role of gender is highly relevant, since that it is traditionally associated with a caring (for instance, nursing) role, also today performed by primarily female employees (Landivar 2003). Ideally not only marketing but also product design should take into account that the domestic environment is (still) highly influenced by gender.

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Business Case for Smart Homes

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Abstract

The application of home automation in "smart homes" has been successful from a technological point of view. In practice, however, few projects seem able to survive after the initial financing period has ended, failing to establish a positive business case. This chapter addresses why the *positive business case* for smart homes is hard to establish. Insight into business cases of smart homes is provided, helping to formulate what could be done to help realize more benefits, thus improving the business case. Before doing so, a definition of a business case is presented. The approach chosen will first focus on the three key effects that interventions in smart homes are likely to have on an aging population that is in need of some form of care. Secondly, it demonstrates how interventions can be observed and reformulated in a societal business case by using two case studies. Finally, the implications on how to successfully launch the business case for smart homes are provided. The chapter is based on relevant literature and practical experiences from working with healthcare providers and SMEs, trying to build positive business cases for smart homes for older adults.

Keywords

Business case • Smart homes • Societal business case • Smart homes • Financing

Introduction

The application of domotics in what is often referred to as "smart homes" has encountered an odd obstacle. Many people agree that domotics are a highly promising development. They make life easier, can help the elderly continue living at home for a longer period of time, and can reduce the involvement of professional care providers and case managers, causing healthcare costs to go down. You'd expect to see massive growth in domotics applications. However, that is not the case as of yet, particularly not in extramural healthcare in the Netherlands (Genet et al. 2011). Applications in intramural institutions regularly involve infrared sensors, noise-level sensors, bed mats, door locks, cameras, speaker-microphone systems, alarm buttons, and chips in clothing. Figures on the amount of extramural application of domotics do not appear to be available in the Netherlands. Applications in the extramural setting appear to primarily involve the personal alarm button (RIVM National Institute for Public Health and the Environment 2013).

We argue that most of the projects so far have dealt with technology-push developments, adding or increasing the technological dimension of smart homes and the implications for service or healthcare providers. Most of these types of projects have had some sort of (external) financial stimulus, allowing the technology to mature, as these projects mainly covered new development of technologies, systems, or software.

Question and Structure of this Chapter

This chapter addresses why the *positive business case* for smart homes is so hard to establish. We hope to increase insight into business cases of smart homes and to formulate what could be done to help realize more benefits, thus improving the business case.

The approach we take will first focus on the three key effects that interventions in smart homes are likely to have on an aging population that is in need of some form of care. Secondly, we will demonstrate how interventions can be observed and reformulated in a societal business case by using two case studies. Finally, we will provide implications in how to successfully launch the business case for smart homes for the aging population. Before doing so, we will first present a definition of a business case.

The chapter will be based on relevant literature and practical experiences from working with healthcare providers and SMEs, trying to build positive business cases for smart homes for the elderly.

What Is a Business Case?

A business case is a description of the business considerations involved in an investment in healthcare innovations. A business case systematically assesses the advantages and disadvantages of healthcare innovations by describing how the costs and efforts involved in an innovation compare to the benefits and effects of its application. In our opinion, a good business case also addresses the risks, support, and feasibility of the proposed healthcare innovation. Business cases are often used to decide whether or not to launch an innovation, continue its application, or develop the innovation in a more specific detail.

The figure below outlines the different aspects of a business case (Fig. 1).

When using the term "business case," we should distinguish between two different types of business cases: an organizational business case and a societal business case.

The organizational business case has a limited scope that comprises costs and benefits over time for a specific stakeholder. The costs of the investments are calculated and the effects of the investments are monetized for that individual stakeholder. For example, an SME selling a smart-homes product to an end-user at a profit would have a positive business case.

The "societal business case" looks at the situation from the perspectives of all the various stakeholders, comprising all key actors that are affected by the initial investment. As costs and benefits are spread out over time and across multiple stakeholders and are harder to predict and monetize, it is at this level that we need to pay more attention to the business case.

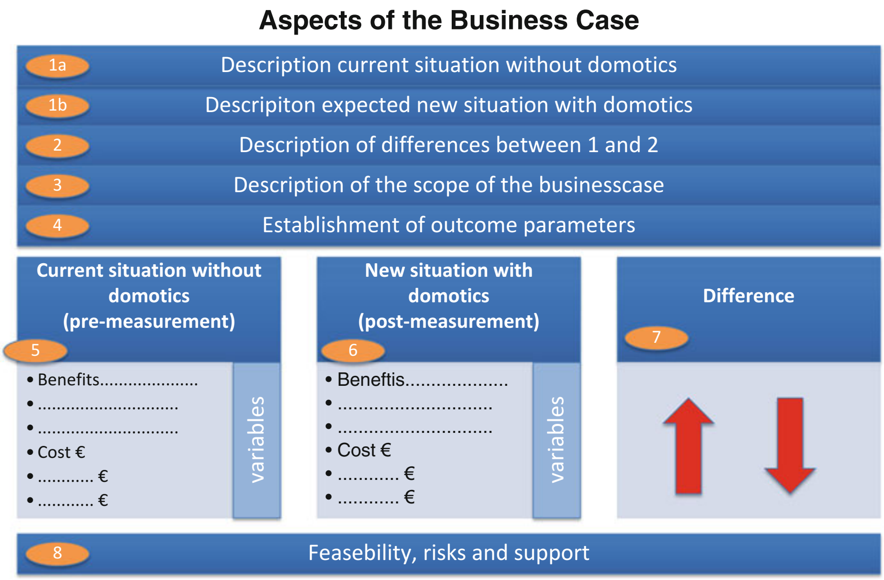

Fig. 1 Aspects of a Business Case; a step by step approach

What Is the Problem in Assessing the Effects of Domotics for a Business Case?

We can summarize the key effects of domotics in three categories:

1. Saving labor in healthcare processes (improved efficiency or substitution; both are "short-term" or direct savings)
2. Effects on the quality of life and effects on the quality of care
3. Long-term effects (which include postponement effects)

We will look at each of these categories below and list what makes it difficult to establish its contribution to the business case:

1. Labor Saving
   Labor saving is the easiest return for financiers to understand. It is not difficult to explain to financiers that there are costs involved in scheduling employees to provide care or nursing – and that everything that could reduce employee hours or be done by less expensive staff will cut costs. What is difficult is determining exactly how many employee hours are saved, since no one knows where to start calculating how many hours are saved. Yet these types of calculations are easier to make in other sectors. It is a long-standing practice in the chemical and industrial sectors to conduct thorough analyses of how labor is deployed in the production process; the effects of automation or robotization on production

process efficiency are subjected to careful consideration. Very bluntly stated, that is to some extent what domotics is about: automating healthcare tasks. Geriatric care has less of a tradition of thoroughly analyzing the production process, in part because healthcare is said not to lend itself for measurement or analysis. Healthcare is provided on an instinctive basis and is tailored to each individual person receiving it. In the healthcare sector, so this line of reasoning goes, each healthcare activity is unique and difficult to automate. However, when taking a deeper look at geriatric care, it becomes apparent that it involves many repetitive activities. Employees open and shut the curtains in a room every single day. Alerts are sent to a central control room every day, notifying a nurse to go check on the person in question. Home care staff prepares meals for clients living at home on a daily basis. And medical aids and devices *are* used in the healthcare sector. For instance, lifting aids and chairlifts are commonplace these days. And dust is no longer swept up by hand but hoovered up with a vacuum cleaner. In point of fact, there are a number of repetitive tasks that could effectively be automated using domotics. Various assessment tools are also available to help identify how many employee hours can be saved. The website www.businesscase-longtermcare.com (TNO 2013) offers an example. This tool offers a systematic assessment of the steps that need to be taken in order to identify labor savings resulting from domotics. Calculating labor savings may take more getting used to in the healthcare sector than in other sectors. This may be due in part to the fact that employee hours are not all that changes; the quality of care or quality of life also changes.

2. Improvement in the Quality of Life or Quality of Care
   Healthcare requires personal involvement. That means that the work also evokes a certain "emotion" in the client who perceives how the care is provided. In marketing terms, this is known as the "experience." A meal prepared centrally in large quantities using modern kitchen equipment is produced much more efficiently than a meal prepared in the kitchen of a small-scale residential unit. However, the latter may be the preferred option, since that self-prepared meal improves the quality of life. In this situation, the residents are there during the cooking process; they can see or hear how the meal is being prepared, which is a fun activity for them. It not only evokes pleasant memories of being young in their mother's kitchen but also ensures that residents remain mentally and physically active. That constitutes quality of life. And that quality of life is worth something in healthcare. At the same time, quality of life is very difficult to assess objectively and difficult to compare with improved efficiency.

   However, there are methods available for assessing quality of life, such as various questionnaires. On the website www.businesscase-longtermcare (TNO 2013), for instance, questionnaires are used that are based on the "Standards for Responsible Care" that were established after extensive consultation with professionals working in the field. The easiest way is to ask clients themselves, or their informal care providers, what experiences they have had with different approaches with or without domotics.

If you have then managed to assess labor saving and the contribution that domotics have made to the quality of life and care, there is still one more return on investment to consider – and one that is even more different to assess.

3. Long-Term Effects
   An important third effect is the contribution to preventing or postponing the need for care. For example, domotics may make it possible for clients to continue living at home for a longer period of time, avoiding the need to use more expensive intramural facilities, or domotics may make clients more self-sufficient, avoiding the need to rely on care providers.

   These effects may be the most complex to identify. Almost no (validated) studies have been conducted that show how domotics can contribute to allowing the elderly to continue living at home independently for a longer period of time or dare to state that costs are saved as a result. That is unfortunate indeed, since domotics offer major benefits due to long-term effects.

Obstacles to Drawing Up the Societal Business Case

Even if you can provide a substantiated estimate of the three effects discussed above for each stakeholder, the societal business case is still more than the simple sum of the costs and benefits of the three effects per stakeholder.

The relevant obstacle here is caused by the Dutch system of healthcare funding. It is compartmentalized and complex and primarily pays for direct, client-oriented care activities. This issue is not limited to the Netherlands, either. All European countries have complex and compartmentalized systems of healthcare funding, paying for client-oriented care activities to a greater or lesser extent. The consequence of this complex funding system is that many investments in domotics involve costs for one stakeholder, e.g., a healthcare facility, and benefits for another, e.g., the health insurer or municipality.

As a result, healthcare facilities have, more often than not, no incentives to save labor, improve quality of life, prevent healthcare demand, or resolve healthcare needs in cooperation with other care organizations.

Practical Applications

The following section looks at two case studies of how domotics have been applied in practice. The case studies offer tangible examples of the obstacles that occur in practice in making a positive business case for domotics.

The first case study is about the use of an alarm system in assisted living facilities. The second case study examines the use of cameras and sensors for elderly people living independently.

Case Study 1: Use of Alarm Systems in Assisted Living Facilities via a Video Link to a Control Room

The Homes and Residents

The healthcare facility provides extramural residential accommodations for elderly people with mild health problems (230 residents in 207 apartments). These elderly people live in assisted living units that are attached to a nursing home. Nursing staff and care providers have an indoor connection to walk from the nursing home to the assisted living units. The residents rent the apartments from a housing cooperative. During renovations, a camera with a video link was installed in a fixed central location in the living room of all the apartments. The domotics panel (with a 5 × 5 cm screen and audio link) and the associated nursing assistance call system (alarm button in the apartment and around the residents' necks) replaced the old nursing call button and are intended for emergency use.

The 110 residents who use remote care pay €15 a month for a mandatory alarm response system. The subscription is required by the landlord.

Old Call System Versus New Alarm System with the Video Link

The new alarm system works as follows: when a resident presses the alarm button, it establishes an audiovisual link to a control room several kilometers away in the same city. This control room responds to all calls, logs them, and takes action as needed; the notification is forwarded to the coordinator of the extramural care team, who then sends a nurse to the person requesting care. The control room is staffed by healthcare professionals (up to the expertise level of a nurse). In the previous situation, an audio-only link was established with the reception desk of the adjoining healthcare facility. The receptionist at the healthcare facility answered the person requesting care and notified the care coordinator. Outside the receptionist's office hours, the call was forwarded directly to the care coordinator of the extramural care team.

The expectation was that the domotics would change a number of processes. First, the receptionist would be under less pressure, since the control room handles the alarm calls and can assess whether assistance is needed in the home via video contact (audiovisual link). The process of reassuring the client changes, since the video link also offers a visual connection between the client and the care provider, giving the care provider a clearer impression of the situation than they might get via an audio-only/telephone connection. Moreover, the video contact may also increase the residents' sense of security, allowing them to continue living independently for a longer period of time. The control room handles all calls and only sends a care provider to the client's home as needed; employees on the extramural care team know that they're not being sent out for no reason, preventing "unnecessary" trips. Moreover, if the healthcare facility wants, the control room can provide "remote care" thanks to its professional staff. This reduces the immediate need to deploy the extramural care team, since "remote care" can take over some tasks, thus saving walking/travel distance.

Although the equipment used here could also be used for other purposes, it is not, since the facility wants to use the control room's services as little as possible due to cost considerations. The analysis of the case study only looks at the measurable effects on the work processes that were studied. The chart below shows the difference between the old and new situations (Fig. 2).

Analysis of the Reports

In order to gain a better understanding of the added value provided by domotics, the facility analyzed the residents' calls. The data logged by the control room and -follow-up actions between 1 January 2010 and 8 December 2010 were used to analyze how the services were used. The logs kept by the control room also included what the resident's question/report was. This results in the following overview:

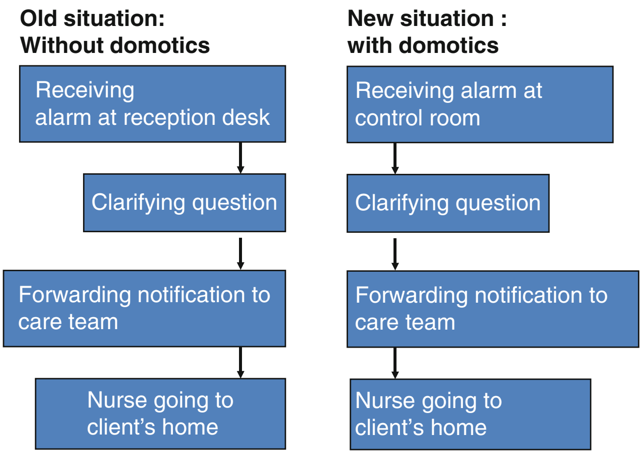

Fig. 2 Mapping the differences in work processes with (*right*) or without (*left*) domotics

Nature of the questions	Explanation	Number	Percentage
Questions related to activities of daily living (ADL)	Assistance with going to the toilet, going to bed, catheter, waiting for regular assistance, soiling, ostomy care, hunger/thirst)	117	15 %
Medication-related questions	Administering, forgot	4	<1 %
Medical nursing questions	Pain, dizziness, injuries, trouble breathing	23	3 %

(*continued*)

Nature of the questions	Explanation	Number	Percentage
Other questions	No verbal contact	245	32 %
Fall-related questions	Client has fallen	10	1 %
Non-alarm-related questions	Nothing wrong, unknown	360	47 %
Total		759	100 %

In that period, the control room received a total of 1,324 calls from 119 residents. 759 of those were emergency calls. This comes to an average of 3.3 calls per resident. However, the frequency distribution reveals that approximately 1/3 of all calls came from eight residents.

Analysis of Labor Saving

It is striking to note that 360 calls were made with no action taken in response; no care provider was sent to the resident. The control room only notes that no action was taken; this definitely means that the call was not based on a request for medical care. However, there is no way to tell based on these records whether the resident was reassured in those cases or whether they pressed the alarm button accidentally. The adjoining healthcare facility noted that the nursing call system was often used for trivial matters in the old system (e.g., ordering extra gravy with meals). Once the residents grew accustomed to the new system, the healthcare facility says, they became aware that they were really only allowed to call for “serious” matters. The more trivial issues are now arranged by calling the receptionist.

A second striking note is that the questions asked were only medical or nursing related in nature in a limited percentage of the calls (approx. 4 %), in which case a video link does save labor. The labor savings come from the fact that the control room can probably handle the call based on resident medical records and the questions asked about medication or other medical or nursing issues, without having to send a nurse to the client’s home. However, this form of savings does not occur more often, because the contract between the healthcare facility, the landlord, and the control room stipulates that this form of service is not included. The potential labor savings (replacing the need to send a care provider for the control room) are not utilized in this case.

Effects Regarding Quality of Life

In analyzing this case, quality of life aspects were not measured:

– Increased sense of contact due to the combination of audio and video compared to audio-only.
– Increased sense of safety and security among residents due to the addition of a video link to supplement the audio link.
– Reduced sense of loneliness, thanks to the video link.

– Higher quality of the response to the call. Instead of the receptionist, there is now a healthcare professional.

There are also advantages for the healthcare facility and the resident:

– The extramural care team only receives necessary nursing calls, thanks to the intervention from the control room.
– When the resident uses the alarm, if the resident is standing in front of the fixed camera and screen, he or she can see that an employee in the control room is answering the call.
– The reception desk no longer has to handle the nursing call system. Although this does not save labor, it frees up the receptionist for other tasks.

Obstacles to Achieving Labor Savings

– The video link does not save time for healthcare staff, due to the fact that the control room is not contracted to provide other care services to the residents, although they would be competent and willing to do so.
– Moreover, the limited distance (the apartment complex is an annex attached to the healthcare facility) means that the potential time saved by reducing travel time is limited; it is often easier to send a care provider to the apartment than to try to help the resident via the video link.
– There is insufficient consideration of situations in which the control room would have been able to provide added value, e.g., a "wake-up service" that checks every morning to see if the client is out of bed, or an on-demand question line for explanations and advice regarding medication use.

Obstacles to Achieving a Positive Societal Business Case

The healthcare facility wants to maintain control of as many extramural care tasks as possible, since it will otherwise miss out on payments for the provided care. When tasks are outsourced, it takes time away from the facility's own staff, thus removing a source of income from extramural care.

The resident is unwilling to pay a monthly contribution for alarm response. Although the domotics application could also be used for other care, welfare, and comfort services, there is no interest in those applications.

The owner of the building, the housing cooperative, pays for the maintenance of the domotics system. However, the benefits for the owner are not financial in nature. It involves an improvement in its image and reputation because the owner can offer potential tenants assured alarm response due to the availability of the domotics application. This could be a selling point for the owner to use in marketing and rental strategies.

Because the equipment consists of a fixed camera with a fixed screen, rather than a mobile device such as a laptop or tablet, the equipment is less suited for, e.g., talking to family members.

Creating Added Value

The control room could take over some of the services from the healthcare facility. For example, the morning checkup for patients who need more care could be replaced, as well as social control, someone to talk to, or assistance in deciding how to structure day-to-day activities. The control room could also offer assistance or support to informal care providers or other care-related staff. Another option would be to make more active use of the video screen to provide information, both for the resident (calendar, activity schedule) and for the care provider (client file). The control room also seems to be the only party involved that could continue providing high-quality alarm response and other services on a 24-h basis, due to the economies of scale it offers.

Case Study 2: Cameras and Sensors for Elderly People Living Independently

The Healthcare Facility

The facility provides intramural nursing home care and extramural home care. The facility has been actively involved for some time in projects that provide alarm response and support for elderly clients living independently with a physical handicap or problems with their memory. The effects of domotics on labor saving, quality of life, and postponement of care needs have been evaluated, and a business case has been drawn up.

The Domotics

The domotics used here were developed in order to provide day-to-day support for people in the early stages of memory problems or dementia, allowing them to live at home independently for a longer period of time. The system "recognizes" fall incidents and immediately calls in the medical care team.

The surveillance system consists primarily of motion detectors and a single camera at a fixed position in the living room. The sensor system detects when a client leaves the house and can tell the difference between different individuals entering and/or leaving the house, thus preventing false "runaway" reports. The "departure" detection makes it possible to allow a client to continue living independently without having to lock them in.

The camera is only turned on if a hazardous situation is detected. These images can only be accessed by the extramural care team, who can, e.g., view the images on their mobile telephone.

Because the system uses fixed sensor points installed in the home, the clients do not need to wear detectors on their bodies. The system is suitable for use in one-person or two-person households. The system is most suited to middle- and end-stage dementia and advanced Parkinson's, when wearing an alarm necklace is no longer functional or preferred.

In the event of an (potential) emergency situation or unplanned departure, the system generates a text message and sends it to a care provider or control room, reporting the nature of the incident and the room in the home where the incident took place. The care provider then checks whether there is an emergency situation or unplanned departure by using a speaker-microphone connection or a camera installed in the living room. If there is an emergency situation or a situation that cannot be verified, then the care provider goes to the home.

The computer program produces very few false alarms, so the mobile care team can be notified directly without requiring intervention from a staffed control room.

Care Processes Affected by Domotics

The potential labor savings due to the domotics have been assessed.

The figures involve *estimated* savings based on estimates of process times and incident numbers reported by care providers.

The domotics affect three care processes, initiated by:

1. Alarm response
2. Straying incidents
3. Falling incidents

The following section briefly addresses these processes and the impact of the domotics:

1. Alarm Response
   Fewer employee hours are needed in the Alarm Response process, since domotics avoid the need for nursing staff to respond to false alarms. When an alert comes in, it is standard practice to use the speaker-microphone connection to contact the person reporting the alarm and verify the situation. However, remote verification is not always possible, e.g., if the resident does not respond to the nurse's call.

   In that case, the nurse goes to the home to verify what's happening; in some cases, it turns out that nothing was wrong and the alarm was false. The domotics could prevent unnecessary alarm responses by using the video camera on the domotics system to inspect the living room.

   The team leaders estimate that false alarms occur about 130 times annually in a group of 35 clients suffering from dementia. The inventory of process times shows that an average of 9.5 min per call is saved on unnecessary alarm response This brings the total employee hours saved annually due to the use of domotics to over 19 h.

2. Straying Incidents
   Care staff are sent to the location when a straying client is identified, as reported either by people in the surrounding area or by a family member or a nurse making a house call. When the client has been located, the client is generally picked up and brought back to the home. If the client has not yet been found, secondary organizations (e.g., the police) should be notified, and a search of the surrounding area is generally launched.

   Domotics can prevent some of the straying incidents; if the door opens at an unusual time, domotics can detect that the client is about to leave the home. The system then calls the client, who receives an automated voice message stating that it would be better to stay home.

   With domotics an estimated 25 straying incidents can be avoided annually, saving 12.5 min per straying incident, saving 612 labor minutes per year. This is due primarily to a decrease in follow-up activities such as filing reports and notifying family, since half of the straying incidents can be prevented. It takes less time to find the clients in the remaining straying incidents, since straying incidents are reported earlier. Also nighttime checks are no longer necessary.
3. Falling Incidents
   When a client falls in the home, he or she is generally able to alert the staff via an alarm button on a necklace. This method is less effective for senile elderly clients, since they may forget to put the necklace on or may not remember how to use the alarm button after a fall. In such situations, a client may spend some time after a fall lying helpless on the ground without assistance because no one has been notified. This situation is frequently traumatic for the client and may lead to additional physical complications. As a result, the client generally needs extra care when he or she is discovered during a routine visit or when a family member drops by.

   Domotics are capable of detecting when a client falls or slowly collapses and alerting staff to the situation.

   In the current situation (without domotics), a falling incident without an alarm response is only discovered when the nursing staff make a scheduled house call. In that case, the client receives care, but it can be assumed that additional follow-up care will be needed due to the fact that the client has spent some time lying helpless on the ground. Falling incidents are always discussed with family in order to adjust the client's care as needed. Reports are also filed. In a situation that does involve domotics, the alarm goes out immediately and an extra house call takes place immediately after the incident. This eliminates the need for follow-up care or discussions with the family.

   Despite the extra travel time, the domotics save 43 min per incident in these cases by preventing the need for follow-up care and family talks. With an estimated 43 falling incidents without an alarm annually, this saves 1,832 labor minutes per year.

For the group of 35 relevant clients at the facility, it was calculated that the annual care savings would total approximately 121 h annually.

Long-Term Effect: Postponement of Admission to a Nursing Home

The domotics system was tried out in a longitudinal pilot before implementation at the care facility. Seven clients were monitored during a 2-year period. Three of them were able to stay at home longer (for more than half a year) due to the surveillance of the domotics system (Vilans 2012). Based on this fact, the assumption is that postponement of the nursing home admission would be approximately three months.

Lessons Learned and Suggestions for Domotics Application

The following lessons can be learned from these two examples of how to compile a societal business case:

- Express the employee hours saved in tangible terms by analyzing the work process with and without domotics and by assessing the changes in task frequency and duration.
- Talk to care facilities and brainstorm with them about more effective use of current domotics functions that could save employee time or improve client quality of life.
- Objectify how domotics contribute to quality of life by having clients specify what contributions they perceive.
- Calculate costs and benefits separately for each stakeholder (facility, health insurer, housing corporation, supplier, etc.).
- Identify which costs per stakeholder are not covered according to current care funding rules, such as investments in domotics that make clients more self-sufficient or investments in domotics that postpone or prevent more expensive care, such as intramural care.
- Make sure that there is a transparent overview of which costs and benefits go to which organization. This information can be used to start negotiations with funding organizations, such as health insurers or municipalities.

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Technological Solutions for Smart Homes

Jeedella S. Y. Jeedella and Mahmoud Al-Qutayri

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Abstract

The combination of ubiquitous computing and wireless communication has provided the opportunities to create novel solutions to realize smart environment. The application of smart environments in the field of health care and assisted living is accelerating at a high pace. These systems can provide cost-effective solutions that will improve the quality of life of humans, particularly those regarded as senior citizens or have some form of disability. The realization of smart environments with real-time monitoring will enable such people to lead independent lives in the comfort of their normal homes. This chapter focuses on highlighting the major components and systems that are currently available to deliver reliable technological solutions for smart homes, health care, and well-being. The key sensing devices that form the basis of smart environments are

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discussed. The integration of these devices into wireless sensor networks (WSNs) that can be spread over an area to build smart health and assisted living environments is investigated. The role of power line communication technologies, which complements wireless communications, and the new reliable solutions is also highlighted. Wireless communication technologies and the various options and standards available are discussed. Target localization plays a key role in many of the services supported by smart environments. The various fundamental localization techniques are investigated. The major security and privacy issues related to WSNs and wearable body area networks (WBANs) and their impact on the trust in using such systems are addressed. A case study that demonstrates the integration of various WSNs elements to deploy a guiding system for blind persons is described.

Keywords
Ubiquitous computing • Context-aware • Smart homes • Sensors

Introduction

The world's population, particularly in developed countries, is aging, and the health care costs are increasing at a high pace. Therefore, there is a real need to create opportunities for senior citizens, people with disabilities, as well as those that suffer from health problems that require long-term health care, such as diabetes and certain cardiovascular conditions, to live independently in their preferred environment. This will inevitably have a positive impact on the concerned persons, as they will be able to have control on their environment and activities, live autonomously without burdening their caregivers, and have the feeling of dignity and overall well-being. This will obviously reduce the cost of health care provisions and will enable the redeployment of resources to support other services.

Advances in technological solutions currently make it possible to realize smart environments and homes that will enable older adults, persons with disabilities, and those with chronic health conditions to lead independent lives. Smart homes are ones that are augmented with sensors that sense and observe the environment, communicate the sensed information, and have actuators or devices that can react in a proactive manner. The sensing and the other aspects of a smart environment are becoming highly pervasive, due to the phenomenal advances in integrated circuit technologies and other aspects of ICT (information communication technology), and include wearable devices that can be attached or even embedded in the body of say an older adult whose condition is to be continuously monitored. This enables the formation of a wireless body sensor network, which includes accelerometer sensors for motion, ECG sensor, etc., that will facilitate the acquisition of a person's vital signs information and diagnosis of their state of health remotely (Viani et al. 2013).

The devices and technologies that enable the realization of smart environments are becoming even more sophisticated in their sensing/actuation capabilities, embedded computational power, and wireless connectivity. All these modern devices require very low power, which means internal batteries, where they exist, can run for a long time without having to be replaced. In fact, in some cases the devices are self-powered through their energy-harvesting capabilities. The energy-harvesting/scavenging aspect can be from the surrounding environment or even the body of the person being monitored. Context awareness is an important property of the modern devices used to realize smart environments. Fusion of the device context, the environment context, and the person context will enable all better understanding of the situation and hence improve the decision-making process.

The realization of smart environments for older adults and others in need of monitoring and health care provision is expected to become of a plug-and-play nature. This is driven by the fact that a smart home or ambient will take advantage of the Internet of Things (IoT) world that is starting to take shape. In the IoT world objects with unique identifiers will be interconnected, and information can be transferred between them seamlessly. A person with a wearable ECG monitor or a motion sensor that has connectivity to existing Internet infrastructure is considered an object. This means that billions of ubiquitous objects will be connected to the Internet. This will as stated earlier make the realization of smart homes at a large scale feasible and affordable. Some work on smart environments for persons with disability using IoT architecture has been recently reported in the literature (Domingo 2012).

Therefore, with the advent of IoT and the availability of sophisticated sensors that can monitor a myriad of health as well as other parameters, persons will not need to move from the comfort of their homes when they become senior citizens. Delivering real-time health monitoring and general care while an older adult is at his/her normal home is becoming a reality. Given the vast amount of information that can be gathered and processed, the smart environment systems will even have the capability of predicting some health conditions, such as heart attacks, before they actually occur. These types of capabilities will enable to attend to emergencies much faster than otherwise.

This chapter is organized in eight sections. The first section describes the key sensing devices that can form the basis of smart environments. The integration of these devices into wireless sensor networks (WSNs) is investigated in "Wireless Sensors Networks" section. The role of power line communication technologies, which complements wireless communications, is highlighted in PLC section. The "Wireless Communication Technologies" section discusses the various options and standards available that can influence smart environments. Localization plays a key role in many of the services supported by smart environments; accordingly it is presented in the "Target Localization" section. The "Security" section addresses the major security and privacy issues related to WSNs and wearable body area networks (WBANs). Finally, this chapter ends by describing a case study that demonstrates the integration of various WSN elements to deploy a guiding system for blind persons.

Sensing Devices

Ambient intelligence can be provided to smart home users by making use of a heterogeneous network of smart sensors that actively monitors and collects important information about the home facilities and its users. The type of services provided using this smart home sensors network can be as simple as controlling the environmental condition within its premises. The remote monitoring of health conditions of senior citizens living alone in their home is one of the advanced challenges that could be integrated in this network. Different types of sensors and actuators can be used to implement the different services provided to users of smart home. For example, the integration of temperature, humidity sensors, location-based sensors, and information processing can be used to control the air conditioning and heating systems not only to optimize energy usage but also to adapt the same atmospheric condition to its user based on his/her location inside the home.

For health care monitoring, sensors can be from simple biosensors such as heartbeat, respiration, blood pressure, etc. to more advanced ones such as location, postures, and emotion sensors. Information processing is an important component in the smart home sensors network where data collected from different sources can be combined together to create a confidence about the whereabouts of the smart home resident. The location of the smart home resident for example can be inferred based on the data acquired from his/her location sensor, and by processing the audio data stream from his/her voice, some confidence can be created about his/her current activity. By combining the aforementioned data streams with the face analysis of the video stream monitoring of the smart home user, some judgement can be formed about the well being and emotional state of the person being monitored.

In the future, both wearable smart sensors and implantable medical devices (IMD) can be used to provide remote health care monitoring. For example, pacemaker, implantable cardiac defibrillators (ICDs), drug delivery systems, neurostimulators, etc. are some of the IMDs that can be connected to the smart home networks to provide the constant monitoring of the smart home user. With the advances in flexible sensors, miniaturization technology, low power design, wireless networks, and smart textile, wearable health-monitoring systems (WHMS) (Pantelopoulos and Bourbakis 2010; Kim et al. 2011) can be developed. A senior citizen who needs to be monitored can wear WHMS most of the time. The WHMS is embedding or integrating different types of sensors such as electrocardiogram (ECG), electromyogram (EMG), blood pressure, respiration, heartbeat, etc. (Chen et al. 2011). The collected measurements are transmitted via wires or wirelessly to an information processing unit which produces the information that are displayed on the user interface and transmits the vital signs data to the medical center. Figure 1 shows a possible architecture of a WHMA.

The information processing unit could be a PDA, a smartphone, a pocket PC, or any specialized microcontroller-based device. Thus, it will allow the real-time monitoring of the vital signs of a senior citizen living alone. The collected information can provide feedback information about the user's health condition to the medical center or directly to the professional physician and in some situation alert

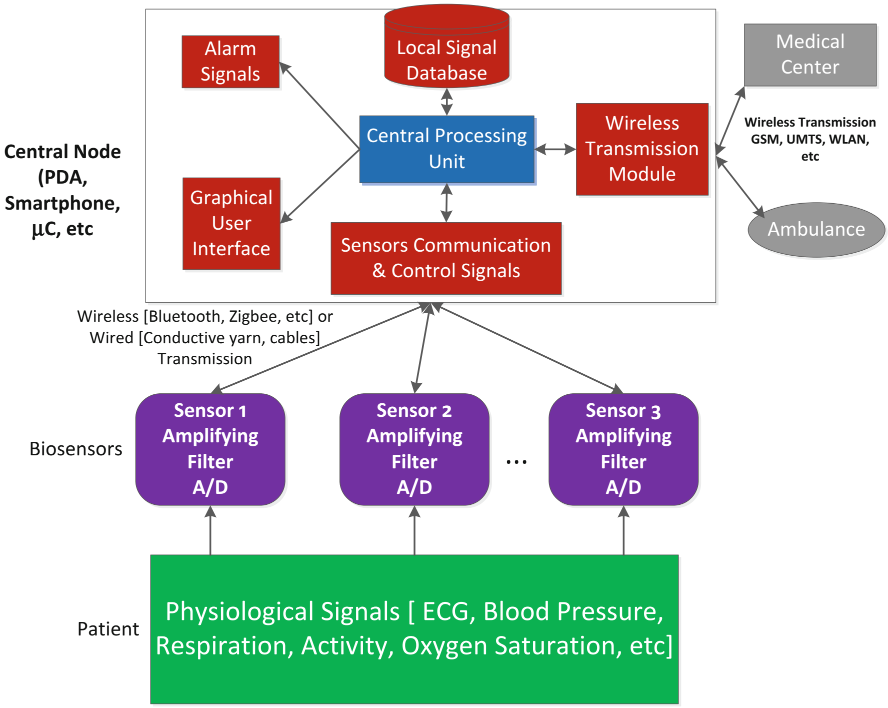

Fig. 1 Architecture of a wearable health-monitoring system (Pantelopoulos and Bourbakis 2010)

the concerned individuals in case of emergency health-threatening conditions. The authors (Pantelopoulos and Bourbakis 2010) reviewed several of the state-of-the-art wearable sensor-based systems for health monitoring that are as research prototypes and also commercially available products.

Wireless Sensor Networks

Wireless sensor networks (WSNs) are the main elements of smart environments. They are the key to gathering sensory information and communicating it for subsequent processing for a myriad of applications that include health monitoring, security, localization, seismic sensing, and many others. A WSN is basically a network of a large number of distributed autonomous tiny devices that are deployed over a geographical area to sense particular physical phenomena such as those stated earlier. Each sensor node in a WSN typically consists of three components: (1) sensing and data acquisition subsystem, (2) processing component, and (3) wireless communication transceiver module.

In addition to the above components, each WSN node normally gets powered from a battery to provide a small amount of energy. In general the battery is not

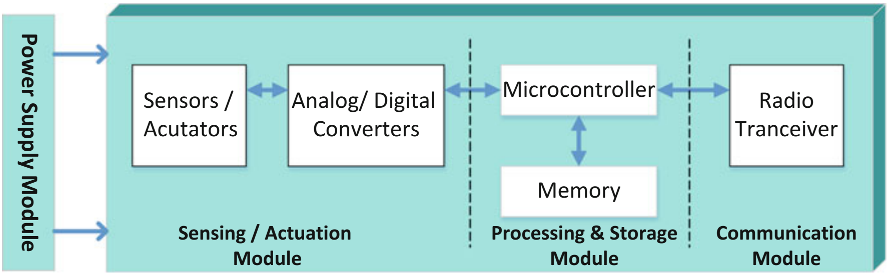

Fig. 2 Wireless sensor node general architecture

expected to be replaced as the sensor node could be deployed in a remote hazardous environment. This requirement puts severe constraints on the design of WSN components and its functionality. The components must have very low power consumption. This has led to many innovative power management designs including those that utilize energy scavenging techniques. Given the limited energy supply, WSNs have severely constrained communication bandwidth and range as well as information processing and local storage capacity. The general architecture of a wireless sensor node is shown in Fig. 2. Wireless sensor nodes are available from a variety of suppliers with various features that depend on the application being targeted.

To build a network, sensors typically get grouped in clusters, with each cluster having a cluster head. The nodes within a cluster forward their data through the cluster head. The routing of the various cluster heads traffic is done using multi-hop wireless communication through a special node called a sink node, which basically acts as the base station. A number of wireless communication standards are used in wireless sensor networks including IEEE 802.15.1 (Bluetooth) and 802.15.4 (widely known as Zigbee).

The use of WSN in health monitoring and assisted living are among the prominent applications of this increasingly pervasive technology. In the field of health, wearable body area networks (WBANs) have been deployed as part of the general WSNs in a number of studies. WBANs include both wearable and implanted devices. The wearable ones enable monitoring temperature, heart rate, blood pressure, etc. The implantable devices get inserted inside the body, and they include cardiac arrhythmia monitor, brain liquid pressure sensor, etc. The range of both types of devices is expanding with advances in materials, MEMS (microelectromechanical systems), and integrated circuit design. A typical architecture of WSNs in health care applications is shown in Fig. 3 (Al Ameen et al. 2012).

In Chipara et al. (2010), the authors presented the design, deployment, and empirical study of a WSN clinical monitoring system that collects pulse and oxygen saturation readings from patients. According to the study, monitoring these vital signs enables early detection of clinical deterioration so that clinicians can intervene before the patient's condition deteriorates. The choice of monitoring the said vital

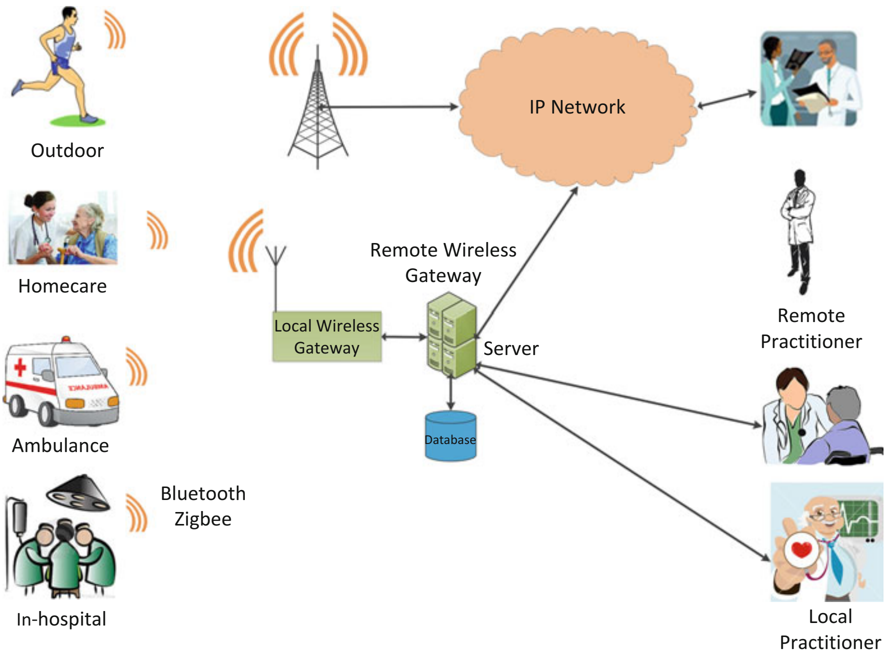

Fig. 3 Typical architecture of WSNs in health care applications (Chipara et al. 2010)

signs is driven by the fact that these parameters do not need high data rates and hence can be easily supported by energy efficient IEEE 802.15.4 enabled WSNs.

In Wood et al. (2008), a WSN-based system called AlarmNet for assisted living and residential monitoring is presented. The system combines many of the features of predecessors including PlaceLab (Intille et al. 2005) and CodeBlue (Malan et al. 2004). AlarmNet is a heterogeneous scalable network that has the ability to integrate new technologies as they become available. The architecture of the AlarmNet system, shown in Fig. 4, includes the following main elements:

– Mobile body networks are wireless sensors that can be worn by the patient or senior citizen being monitored. The devices can sense and transmit physiological and activity parameters such as pulse rate and acceleration.
– Emplaced sensors are used to sense the quality of the environment, such as temperature and dust levels, the person is living in. They can also be used to monitor a person's activities and provide location information that can be integrated for context awareness features of the AlarmNet system.
– Alarm-Gate is an embedded platform to run various applications.
– At the back end of this is a set of programs that perform online analysis of sensory data and use it along with profile information to aid context awareness.

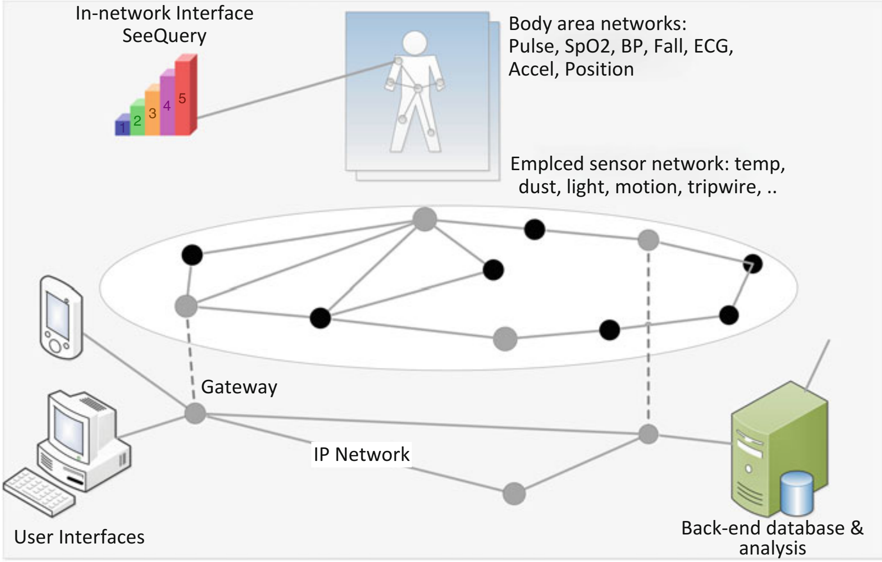

Fig. 4 AlarmNet architecture (Wood et al. 2008)

Power Line Communication Technologies

This technology uses existing power line wires for home communication purposes. Several power line communication (PLC) commercial products are used for home automation and networking such as X10 which is a proprietary technology. It provides low data rate and poor reliability in noisy environment (Nunes 2003). Some of PLC products use LonWorks technology (Jeon 2002). The Consumer Electronics Bus (CEBUS) is meant to define a local area network to exchange control and services among home appliances. Even though it is meant to revolutionize home automation, it has not yet gained much popularity (Jeon 2002).

The HomePlug Alliance released a set of standards for in-home PLC networks with the intention to provide platform to foster the creation of products and services in a cost-effective and interoperable with each other's (Home Plug Alliance). HomePlug 1.0 with data rate of 14 Mb/s intends to provide networking using home PL wiring. Also for high speed Internet, HomePlug BPL was defined. This can provide an alternative to wired network protocols such as Ethernet. HomePlug AV with data rate of theoretically 200 Mb/s intends to support multimedia applications in homes. HomePlug C&C (Command & Control) is intended for home automation since it provides a low data rate at low cost networking. PLC is shared channel such as Wi-Fi; accordingly encryption is required to improve its security. HomePlug uses DES encryption with a 56-bit key. However, it suffers from intrusion and interference from adjacent subnets such as apartments. Since it uses the existing infrastructure, it has tremendous potential; accordingly many companies and researchers are interested to find solutions for the challenges related to technology.

Wireless Communication Technologies

The ultimate goal for wireless communication is to communicate with all types of information, audio, video, data, and control, with anyone and any system, at any time and from everywhere. The emergence of wireless communication standards such as Wi-Fi, cellular technologies, Bluetooth, Zigbee, RFID, and MICS can help in realizing this goal. With the aid of a combination of these standards, smart homes can be constructed. Basically, any wireless communication technology supporting some form of sensing, data transfer, and control can be a candidate to realize some of the smart home requirements.

Wireless Fidelity (Wi-Fi) is a technology that refers to wireless networks; however, it uses the IEEE 802.11 wireless communication standard. This standard defines the standard for wireless local area networks (WLAN) where 2.4, 3.6, 5, and 60 GHz frequency bands are used. Wi-Fi technology allows network users to move around to different locations while they can still access the network from almost anywhere. It can provide an alternative solution for providing network services for old buildings. The Wi-Fi standard defines an access point (AP) and a wireless client as shown in Fig. 5. The Wi-Fi client could be a laptop or a smartphone equipped with a wireless network interface.

Transferring the information between the wireless network and the wired network is the responsibility of the AP, and it can service up to 30 wireless devices. The coverage range of an AP is between 33 and 50 m in indoor situation and can be up to 100 m in outdoor situation. Wi-Fi devices can form together a network using ad hoc infrastructure where a Wi-Fi node can operate as both an AP and a client.

The mobile communication systems have gone through extensive developments since their introduction. This has culminated in the current 4th generation and heading toward Long-Term Evolution (LTE) systems (Astely et al. 2013). The

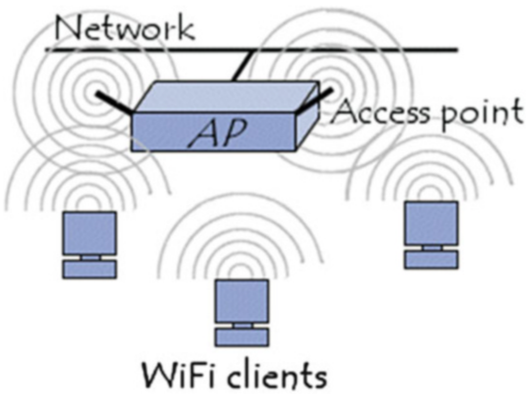

Fig. 5 Wi-Fi standard network architecture

developments brought about an increase in bandwidths and a rich set of services. With the supported data rate, it is possible to provide mobile TV, video conferencing, and fast Internet.

Bluetooth technology uses a short-range universal radio interface to replace the wired communication between various electronic devices, such as mobile phones, headsets, and sensors (Blueooth). The development of many Bluetooth-enabled devices and sensors enabled the formation of personal area networks ubiquitously. Furthermore, many applications were developed based on this technology. It uses 79 channels of 1 MHz in the 2.4 GHz band and it can provide data rates up to 2.1 Mbit/s. It can support a maximum range of 100 m in case class 1 devices are used. Encryption is optional and provided using a 64 or 128 bits SAFER + algorithm; however, Bluetooth is often designated as vulnerable to attacks. Bluetooth SIG announced the addition of two stacks: the Bluetooth low power targeting devices with limited battery sources such as health care devices and sport/wellness devices. The second stack is Bluetooth 3.0 specification that uses Wi-Fi physical/MAC layer for higher data throughput.

Zigbee is a technological standard created for control and sensor networks based on the IEEE 802.15.4 standard (Zigbee Alliance). It is defined for low cost, low data rate, low power, wireless personal area network (WPAN). It can use 868 MHz in Europe, 915 MHz in the USA and Australia, and 2.4 GHz in most jurisdictions worldwide. It can support data rate of 20 (868 MHz), 40 (915 MHz), and 250 kbit/s (2.4 GHz). This technology provides a communication standard for low power, battery-operated sensors and low cost application by providing a compromise between these parameters and the supported date rate. It uses advanced encryption standard (AES) to perform authentication to guarantee communication privacy. The operating frequency, data rate, and network size are all defined by the standard. Zigbee devices operating in the 2.4 GHz band are more often used since it is available worldwide and the supported data rate is higher than other bands. The size of the network is limited to 64,000 devices; however, by using multiple coordinators connected together, large networks can be made.

Radio frequency identification (RFID) is a system where an object can be wirelessly scanned; accordingly it will transmit its identity. This technology defines an RFID tag that holds information about the object carrying it and an RFID reader. The RFID tag will only transmit its data when it is scanned by the reader. In case that the RFID tag is passive, then it will have no battery, and it will be powered by the reader's magnetic field; accordingly it is cheap to manufacture. The passive RFID tag has a low range when compared to an active RFID tag that does have battery powering its circuitry.

The Medical Implantable Communication Services (MICS) technology is an ultralow power, low data rate, and short-range communication for therapeutic or diagnostic functions related to medical devices. This technology uses the 402–405 MHz frequency band with 300 kHz channels. It targets devices such as pacemakers and implantable cardiac defibrillators (ICDs) with limited radiated power to 25 μW. Even though this technology has interesting characteristics, it was not used by many researchers in their prototypes due to the limited commercially available MICS solutions (Pantelopoulos and Bourbakis 2010).

Target Localization

Target localization is an important feature of WSNs. This is particularly the case for WSNs that are used for assisted living, senior citizen monitoring, target tracking, and other tasks in smart environments. In general target localizations enable the computation of the position of a node within some fixed coordinates. By doing so, many applications can be developed. For example, a WSN can be installed in the home of a senior citizen, and a sensor node can be attached to the person. The movement of the concerned senior citizen can then be tracked, and an alarm can, for example, be raised if the person's activity behavior changes from the norm. Node localization can also be used in hospitals to track equipment, patients, and medical staff. This ability to localize a node within a smart environment opens many other possibilities for a multitude of applications and services. For example, the fusion of a target node location with other sensory information and a profile database enables building context aware systems with various degrees of sophistication.

Localization can be achieved in wireless systems using a variety of techniques. A straightforward one is the use of GPS (global positioning system) that requires satellite line of sight. However, such systems are only suitable for outdoor environments and consume relatively high amount of energy. Given these constraints and the fact that nearly all WSN operate with small batteries that are supposed to last for a long time, the use of GPS for localization is precluded in such systems. Many node localization techniques have been proposed in the literature that do not depend on GPS.

Generally location discovering techniques consist of two computational phases: (1) distance estimation and (2) location combining. Depending on the parameter used to calculate the relative position of a target node, distance (or angle) estimation techniques can be classified as: angle of arrival (AoA), time of arrival (ToA), time difference of arrival (TDoA), and the received signal strength indicator (RSSI).

The AoA technique calculates the position of a node by estimating the angle at which signals are received. AoA can give accurate results; however, it requires an array of directional antenna elements which increases the complexity of the hardware. ToA computes the time at which a signal first arrives at a receiver. Distance can then be calculated by multiplying the measured propagation time (be it one way or round trip) by the radio signal velocity. In ToA the nodes have to be synchronized and the signals time stamped. The TDoA technique uses either multi-node or multi-signal to compute the location of a node. The former is based on the difference in time at which a single signal from the target node arrives at the at least three receiving nodes, while the latter uses two signals that have different propagation speeds (e.g., radio frequency and acoustic) generated by the target node and compares their delay. TDoA gives accurate results under line-of-sight conditions. However, the accuracy gets highly reduced in indoor environments due to multiple reflections of radio signals.

RSSI localization technique measures the received signal power, and given that the transmit power is known, the propagation loss can be calculated. This information can be combined with a channel model to translate the loss of transmitted signal power into a distance estimate. RSSI is very popular in target

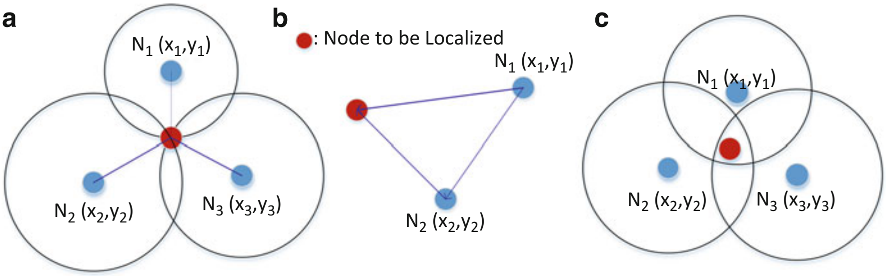

Fig. 6 Localization techniques: (**a**) trilateration (**b**) triangulation (**c**) maximum likelihood

localization in WSNs because the received power indicator is available at no cost at the physical layer of the WSN nodes. However, RSSI technique does not provide accurate ranging estimation, compared with AoA, ToA, and TDoA, due to the multipath propagation effect of radio signal. The accuracy of RSSI can be improved by having more accurate radio propagation path loss models and the use of adaptive computational algorithms (Kupershtein et al. 2013).

The location discovery combining phase normally uses trilateration, triangulation, or maximum likelihood estimation techniques. These techniques are depicted in Fig. 6. Trilateration or lateration, shown in Fig. 6a, is an intuitive geometrical technique that uses the intersection of at least three circles; each represents the aperture distance between an anchor node and the node to be localized. The radius of the circle is equal to the distance measurement. The triangulation method, depicted in Fig. 6b, uses basic trigonometry to find the location of a node. In doing so, it uses angles instead of distance information. The node to be localized estimates its angle to each of the three reference nodes then uses this and the known positions of the reference nodes to calculate its own position by applying trigonometric properties. The maximum likelihood (ML), shown in Fig. 6c, is a probabilistic technique that attempts to mitigate the uncertainty in distance estimation. ML uses distance measurements from multiple reference nodes to estimate a node position. When the unknown node receives a signal from a reference node, it assumes it to be at any place around the reference node with equal probability. The same process gets repeated for other neighboring reference nodes. This results in identifying the probable position of the unknown node. The major drawbacks of ML are the high computational cost and information storage requirement.

Security

The security and privacy in WBANs as well as WSNs in general are of major concern. Both types of networks use wireless communications, and that exposes them to all the security and privacy vulnerabilities associated with such technologies. However, security and privacy issues are much more critical for WBANs as they may affect the lives of the persons involved. In WBANs sensors collect data about the various physiological parameters of a person; however, those devices are severely constrained in their resources and available power, and hence incorporating traditional security schemes is not feasible (Al Ameen et al. 2012; Li et al. 2010; Kaseva et al. 2011).

Malicious attackers can compromise the security of WBANs by gaining access to the data collected by the sensors. This can then be used to launch passive or active attacks at the system and information security levels in ways that could pose serious problems to the concerned individual. An attacker may, for example, change the destination of a data packet containing critical vital signs information, such as blood pressure, and hence deprive the person from receiving appropriate medical attention leading to possible loss of life. Generating routing inconsistencies which leads to identity deception is another possible type of attacks. In such cases the adversary can cause selective forwarding and wormhole and sinkhole attacks (Zhu et al. 2011; Krontiris et al. 2009).

Through eavesdropping to the WBANs or WSNs, an attacker can steal health data about an individual and use it to blackmail or compromise the person. Security attacks on node location information in WBANs/WSNs are critical ones. An attacker may intercept location packets and replay them in different locations. It may also manipulate the intercepted information and use it to distribute incorrect locations for malicious reasons. These forms of attacks may threaten the life of the individual. For example, in an assisted living smart environment node, location is used for context awareness so having the wrong information will lead to incorrect inferences about the state of the person being monitored (Al Ameen et al. 2012; Li et al. 2010; Zhu et al. 2011; Krontiris et al. 2009).

A summary of the security risks in WBANs and their corresponding security requirements are listed in Table 1 (Al Ameen et al. 2012). Security associated with WBANs/WSNs is an active research area, and various solutions are continually proposed in the literature to address new challenges as the technology evolves (Kaseva et al. 2011; Zhu et al. 2011; Hu et al. 2009; Rohokale et al. 2013; Matyas et al. 2013).

Privacy and measures of preserving it are a major concern for individuals as well as organizations that deploy WBANs and WSNs in general. Privacy threats include attacks on content where the meaning of the information being exchanged is understood by the adversary, identity theft which results from revealing the identities of the communicating entities, and location privacy threat which results in identifying the physical location of a node. All privacy oriented attacks, be it in WBANs or WSNs, lead to unauthorized access to information that may be of critical nature such

Table 1 WBAN security risks and requirements (Al Ameen et al. 2012)

Attack assumptions	Risks to WBAN	Security requirements
Computational capabilities	Data modification	Data integrality
	Impersonation	Authentication
Listening capabilities	Eavesdropping	Encryption
Broadcasting capabilities	Replay	Freshness protection

as medical records and hence compromise trust in the system. Depending on the nature of the privacy attack, the life and well-being of the affected person may be threatened. Solutions to overcome privacy threat at all levels of WBANs/WSNs continue to be proposed in the literature. However, the ever increasing complexity of these systems, particularly their distributed nature that extends to the computing clouds, means that the issue of privacy will need to be continually addressed in order to keep an acceptable level of trust in the systems (Al Ameen et al. 2012; Li et al. 2010; Krontiris et al. 2009; Di Pietro and Viejo 2011; Matyas et al. 2013).

Case Study

This section provides a system architecture of a smart home that integrates wireless sensor networks with different types of sensors to help blind or visually impaired person to navigate independently inside his/her home. It is based on a Zigbee network that calculates the location of its user and a digital compass that help to infer his/her orientation. The localization and navigation algorithm is running partially on a remote server and partially on a mobile node carried by its user. This mobile node is a Zigbee end device that requires relatively low power. The server receives the audio command from its user regarding his/her target destination. Accordingly, the system will calculate the optimal path to the requested target using the current user's location and the internally stored virtual map of the house. The required audio commands to help the user navigate to his/her target destination will be generated by the server and received and played back on the mobile node. Figure 7 shows the global system architecture of the prototype system. The system will receive the various input signals and continuously adapt the navigation commands based on the current location and the target destination in real-time.

Based on this architecture, a demonstrator was developed and tested, and its accuracy is highly dependent on the localization engine in Zigbee mobile node.

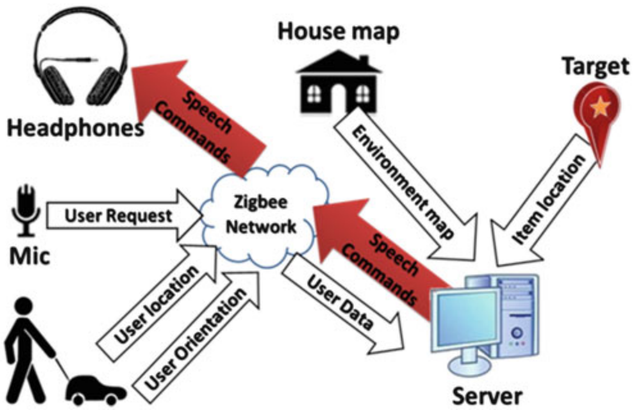

Fig. 7 System architecture (Al-Qutayri et al. 2011)

Furthermore, the system was not fully autonomous, and it relies on the user to do local obstacle avoidance since the household situation can continuously change. With the advances in indoor localization algorithm, we believe that the localization accuracy of this demonstrator can be improved by using better localization engine as was discussed in the "Target Localization" section.

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The Future of Living

E. Slaats

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Abstract

Computers with their staggering calculation and communication capabilities have penetrated virtually everything. This, combined with their evolving pace dictated by Moore's law, presents us with a vista of staggering possibilities. Even within a foreseeable future, a lot of these possibilities will become part of daily life. In this chapter, a number of possible scenarios that exist within the realm of smart homes for health are explored. The focus hereby is "future of living and care."

Keywords

Future of living • Adaptive homes • Computer driven technology • Moore's law

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Prelude

It is the year 2030. An older couple, both aged well over 90, is still living independently. All the help they need is supplied by their intelligent home (Fig. 1). *Their home knows them well and is fully tuned into their needs. Despite the fact that Ann has to walk with a cane and her husband Theo is having problems with his memory and has impaired vision and a yet incurable form of diabetes, they seem to manage well on their own.*

Theo and Ann are also taking care of their young great-grandchildren for some afternoons and two nights a week. Their smart home facilitates them to take care of the kids and makes the experience even more pleasing for both the children and the couple. When the kids arrive, the home modifies itself in order to accommodate their presence.

Theo knows his great-grandchildren love to play a particular board game. Therefore, he sculpted game-character figurines using his 3D printer. When the kids arrive, the floor displays a life-sized game board. They go crazy as great-granddad gives them the action figures. Even though the game itself is rather complicated, the children can play because the environment acts as a coach and guides the kids, while granddad watches the news.

At dinnertime, two of the dining table chairs morph into children's chairs. These chairs can lift the children so the older couple does not have to. During dinner, prepared in a smart kitchen which optimizes the nutritional value of the food, the table itself turns into a projection screen (Fig. 2). *The table continues the game the children were playing some minutes ago. During dinner, the room takes some pictures and shares them through the cloud-based family photo album.*

After dinner, Ann rides the elevator upstairs with her great-grandchildren to give them a bath. The tub is already filled and at the right temperature. She returns to the living room in the knowledge that the bathroom monitors the safety of the children. When the bathroom signals Ann that the children are done, she returns to the bathroom to find the kids had a ball and flooded the floor. The intelligent floor is already rinsing all the excess water and cleaning up. After dinner and water play, the

Fig. 1 A mobile webcam mounted on a robot. Less intrusive and intelligent mobile sensors will become part of our daily life supporting new ways of living (Photography by Cas Slaats)

Fig. 2 Every surface will become a display interacting with us based on our moods and needs (Photography by Cas Slaats)

kids are tired and like to go to bed. The bedroom is dimly lighted and there is some soft music playing soothing the children to sleep.

Satisfied, the couple has a shot of whiskey before going to bed. Theo gets a last message from the home that his glucose levels are in order. The couple goes to sleep knowing that the house is cleaned by robots and breakfast will be ready in the morning.

Introduction

Computer technologies have become ubiquitous in our daily lives. Apart from being an integral part of machines and all sorts of equipment, computer technologies are being embedded in pieces of furniture, lighting systems, doors, walls, and even our own body. The potential of future applications is endless. This chapter explores these developments from three perspectives: being upgradable, being adaptive, and being intelligent. In the exploration of the diverse scenarios and accompanying possibilities, these three themes will be essential. But what do they mean in practice and for the future of daily living?

Upgradability

A product without any embedded ICT only foresees in the predefined behaviors it is designed and developed for. In order to enhance and enlarge the repertoire of behaviors, physical adaptations or replacement needs to be considered. Take the classical washing machine as an example. These machines offer the user a number of fixed built-in programs for washing wool, cotton, and other fabrics. When a new detergent or washing powder is being released, which needs to be used at, say, 16 °C, the machine cannot use it correctly. Adding a so-called 16° program to the machine

Fig. 3 Glass. Optical wearables are here to stay and will become the next generation of personal connected devices (Photography by Cas Slaats)

means to physically amend the hardware. A computer-controlled washing machine can make the necessary adaptations by downloading software dealing with the new 16° program. In an instant, the machine is upgraded for use in a new situation. Through the existence of wireless communication systems, these upgrades will take place without the end user even noticing it.

We consider these procedures as absolutely normal when it comes to mobile phones. Not a single user will be surprised to see that updates are available without having to return to the shop and make physical adaptations to your phone. A simple tap on the screen and the update is being downloaded. Users have come to expect that the machine, in this case a telephone, actually functions better, faster, and more accurately after the update. Supported by the apparent simplicity of wireless communication, this behavior will be encountered in a wide array of future products. From cars for transportation to electric toothbrushes for maintaining oral hygiene, and from sight enhancement implants to the dosing of insulin for people with diabetes, the potential application domains are seemingly endless. Living in an online, connected world will lead to a 24/7 automatic upgrade of our bodies and minds, as well as our environment (Fig. 3). In this scenario, more, better, and new possibilities will become available automatically without further notice.

Adaptiveness

Being adaptive means one can adjust to changing conditions in the environment. Being upgradable is a precondition to being adaptive. Adaptiveness can be something very simple, for instance, it starts to rain, the skylights in the ceiling will be shut, or when night falls, the garden lights will be switched on. Adaptiveness becomes a more interesting phenomenon when it is considered in the light of our ever-changing lives. When parents are taking care of young children, their parental needs differ from those with teenage children or young adolescents. In the end, the living environment will automatically adjust to changing situations and conditions. In the long run, we also want this to happen to objects around us and, perhaps, inside us. The dishwasher recognizes the items put inside and will choose the right program. It would be nice if my armchair can recognize my activity level and mood and adjust itself to my physical and mental conditions. The chair communicates with the lighting and heating systems to make sure conditions are tuned into my needs so I feel more relaxed. The number of scenarios like this is virtually endless. Living room which adjusts to: an evening with the family, watching television while lying on the sofa, a party with friends, a herd of gaming kids, babies crawling on the floor, having grandfather and grandmother coming over for the day, etc. In order to meet the exact needs of these scenarios, the home and the living environment as a whole will become increasingly more adaptive and intelligent.

Intelligence

Intelligent behavior, such as "it is getting dark, so the outdoor lighting needs to be switched on," in itself is not enough. Homeowners wish that objects can determine differences, similarities, and changes based on what intelligent systems see and recognize and that they decide what their behavior will be based on these observations. In addition, an object needs to be able to respond to other stimuli including emotion, language, movement, gestures, nonverbal communication, and the overall atmosphere. This involves types of input that we as humans use as well. This means sensory inputs for smelling, seeing, hearing, feeling, and tasting. All sensor technologies needed for these interactions are already in existence; some of them already are very sophisticated and available and some are in an experimental stage or existing as a prototype. What is special about machines is that they can handle these "senses" in an extended way. Sensors can detect sounds humans cannot hear (<40 Hz or >20.000 Hz), see things we cannot see (infrared, ultraviolet), smell things that seem odorless to us, and sense things we cannot detect as they are below our own sensory detection threshold. Machines, thus, only have to learn how to use their senses within the boundaries of our human context and can provide additional assistance because they can sense thing we cannot without the use of assistive devices and instruments.

Intelligent behavior also encompasses the notion that it is important to learn from each other. Why would I, as a user, have to instruct or program any new device that I introduce in my home environment? A new television set should ask the coffee machine, smart furniture, and the walls who we (residents) are and get tuned in by that information. This means only very specific preferences still need to be learned or taught to appliances.

Propositions

So what dictates the potential possibilities and impossibilities of the aforementioned behaviors? In order to provide an answer, we need to take a closer look at a computer, which is basically a calculator. So it is very good in rapid manipulation of numbers. This means the better we can translate our environment into a set of numbers, the better the computer is able to work with it.

Proposition 1 All human perceptions can be translated into a set of numbers. Images, sounds, odors, and movements are already being digitized. Just think of digital photography and DVDs, as well as robots in large production facilities. By using these digital senses, the environment of a machine can be mapped. This is nothing more than registration. It is more complicated to adequately respond in a truly interactive manner. This requires coming to conclusions from the sensory input. For example, what is the present context (work, leisure, fighting, or love), what are the emotions involved, which nonverbal or verbal communication is encountered, and what is the social composition of a group?

Proposition 2 The faster a machine does computations, the better it is able to solve the detection and analysis problems mentioned in Proposition 1 in real time.

In short, computational power is the driving force behind the possibilities. In order to draw a number of future scenarios and put developments on a time line, it is necessary to understand the speed at which the computational speed has evolved. In 1965, Gordon Moore, one of the founding fathers of Intel, published a white paper in which he described a found pattern in the development of computational chips. The development pattern he described has become known as "Moore's law"[1]. This law describes a periodical doubling of the number of transistors that fit on a certain surface area of a computer chip and thus, implicitly, the improvement of computational power. Moore defined this doubling to be taking place in 24 months, thereafter, to be 18 months. In practice, this prediction was rather accurate. It fluctuates but seems to have an average of approximately 13 months in practice. Moore's law only considers the developments in hardware, not the developments in smarter software. This means that the computational force increases by a factor of 1000 every 10 years. Let us compare this to something more tangible. When a car drove at a speed of 150 km per hour in the year 2005, the same car will drive approximately 40,000 km per hour in the year 2015. Therefore, the conclusion is: The needed computational force to facilitate a wide array of intelligent and adaptive behavior, based on the current state of things, will be available within the next decade.

The end of Moore's law has been predicted several times, but it still stands. Every time technology seems to stall, a new technology emerges and makes new growth possible. Futurologist Ray Kurzweil describes this in his book *The Age of Spiritual Machines*.[2] He calls this phenomenon the law of accelerating returns[3]. In his vision

[1]Original paper: http://www.monolithic3d.com/uploads/6/0/5/5/6055488/gordon_moore_1965_article.pdf

[2]Ray Kurzweil 1999

[3]http://www.kurzweilai.net/the-law-of-accelerating-returns

this exponential growth will continue far beyond technology getting smarter than humans (the technological singularity[4]).

It is a remarkable thing that humans adapt almost instantly to the extra potentials their environments have to offer, rely on them, and, more importantly, trust them. When we hit the brakes, the car slows down. The driver is completely unaware of the chain of actions and reactions that take place when hitting the break. In a modern car, the driver no longer controls a physical cable but is actually interacting with a computerized automated break system, which, based on the road conditions, speed, and force involved in using the brake pedal itself, decides in what manner the car will slow down. The driver probably thinks in vain that he or she is the one who decides. Such a trust in and surrender to technology are increasingly considered to be normal, even when surrendering control over our physical functioning to so-called thinking machines.

A Wireless World

Power and communication infrastructure will become wireless. Objects that become intelligent, start to think, make decisions, and communicate do need certain conditions to function, just like us human beings do. A first primary need is food. All labor consumes energy, and for computers this usually is electrical energy. At the moment, most equipment needs to be connected to the power grid or supplied with batteries, which, in turn, have to be recharged. An equipment that does not use batteries usually has a mobility issue. They are literally stuck to the grid by a cable. Battery-powered equipment is mobile on the one hand but needs a regular change of batteries or needs to be charged. In order to overcome these challenges, the energy supply of new equipment, in combination with batteries, will increasingly become wireless. Within the promise of zero power computing[5] devices will become better in extracting the needed energy from sources in their environment such as light, warmth, or radiation.

Zero-power devices enable us to freely move our equipment and (interactive) furniture throughout the home with these devices still functioning and not being attached by wires. For instance, you can take your television out into the garden; you can also bring your interactive chair along or move around the light fixtures. Every position will be possible without having to look for a socket for communication or power. Owners of electrical cars no longer need to look for specialized parking lots with charger poles but just need to park their car in a designated area and it will charge by itself.[6] Plug sockets will slowly disappear from the home, just like wired

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[4]https://www.singularityweblog.com/17-definitions-of-the-technological-singularity

[5]http://www.extremetech.com/computing/136043-intel-predicts-ubiquitous-almost-zero-energy-computing-by-2020.

[6]http://www.fraunhofer.de/en/press/research-news/2014/august/charging-electric-cars-efficiently-inductive.html

communication has. In the 1980s, it was fashionable to equip your home with a BUS system, which supplied a sufficient amount of power and communication access points in every room for telephones, televisions, radios, computers, etc. This kind of infrastructure has disappeared in favor of mobile solutions including Wi-Fi. Intelligent products in our living environment will become fully wireless, which enables us to use devices in any way we want or like.

Explorations

Based on the insights mentioned above, a small number of explorations are presented. These explorations are (partly) based on existing technologies and focus on the further development of these technologies and the meaning they have to our lives.

Nonintrusive Intelligent Devices (New Interactions)

We do not think much about it, but we adapt quite easily to new technologies. The interaction we have with technology usually is being dictated by the interfaces used by that technology, for example, a keyboard, a remote control, or a steering wheel.

These interfaces do not automatically understand natural interaction, let alone respond to nonverbal communication. To us humans, it is still normal to adapt to technology and not the other way around. So we accept the fact that an equipment does not respond as fellow humans would. Technology develops into ever-smarter and adaptive devices. This implies they can start to adjust to our natural means of interaction. A trend like this is already visible in the ways tablets deal with user interaction. The turning of a page is done by a natural swipe gesture similar to the motion of actually turning the page.

We are on the turning point that devices will adjust to humans instead of the other way around, a huge paradigm shift!

Our environment should be able to recognize emotions[7] and use this to our benefit. Machines are not (yet) programmed or equipped to respond to emotions as stress, joy, sadness, or relaxation. The context of a given emotion should also be detected. The detection of emotions (emotion sensing) and their context (work, relaxation, etc.) will create a home environment which learns to react in a natural way depending on context and emotion, just like fellow humans. Various devices will learn together and from one another and act together in response to emotions and their context. This will be done in a nonintrusive way, meaning that a user does not have to manipulate the device, there are no sensors (intrusively) attached to the body, or the user is hardwired to devices (Fig. 4). The environment will learn simply by observing.

[7] http://tinyurl.com/qemhm48

Fig. 4 Connected body-worn sensors will monitor our health and support us to lead a healthier lifestyle (Photography by Cas Slaats)

Relax!: I am at home, working; my room knows I like daylight. By sensing my emotions and actions, my home simulates daylight through a light-emitting ceiling. I am seated behind a laptop and I am very busy working on my stock market portfolio. The portfolio results are not encouraging, and my stress levels are skyrocketing. The room recognizes this mental change and starts to project light patterns onto the wall to calm me down and warn me. I am annoyed at first but finally calm down and will be able to make more rational decisions with my stock.

Sleep tight: My grandchildren are in bed. They have had a very exciting day. The bedroom detects the children's stress level which comes with processing the emotions of the day. The lights are adjusted, relaxing melody is heard, and a soothing subtle scent is released. The room detects the children relax, dims the lights and the music, and supplies a fair amount of fresh air. Soon, the children fall asleep relaxed.

New Interfacing and Display (All Is a Display Interface)

Virtually, any surface can be turned into a display, for instance, textiles, floors, walls, tabletops, and pieces of furniture. This also is of particular interest in the domain of lighting. People have an innate preference for visual stimuli, so multi-surface displays offer a fantastic array of possibilities.

Dinner: The in-laws are coming over for dinner. We just printed our own new posh dishes. On the table, some animations are displayed who support the dinner being served. As a tease, I ask the table to project cockroaches running around my mother-in-law's dish.

Show me the way: I finally arrive in a huge conference venue after a day of traveling. I do not have a clue where to go for my keynote lecture. The building recognizes me, the floor starts lighting up, and I am being guided through the hallways to the room where I am supposed to have my keynote lecture. This is done by an animation on the floor and a voice which softly welcomes me and gives me guiding. In order to improve my mood, flowers pop up wherever I step on the floor.

Art**:** Art does not have to be static and noninteractive at all. The large art object in the hallway sees who is coming in and challenges the visitors to contribute to the art experience based on their personal appearance. This eventually leads to an interactive work of art, in which the basic design is still maintained but is enhanced by individual contributions. The art object also recognizes returning visitors and can adjust itself to these special guests.

Newspapers and mail**:** The classic paper mail slowly disappears from our mailboxes. In the morning I sit down at the dining table to have breakfast. I ask the table for the newspaper. The latest news is displayed on the table in a newspaper-like interactive fashion, including a list of messages. Through a combination of speech, touch, and gestures, the newspaper can be read. In the meantime I can respond to my messages.

Programmable Matter

The explorations lined out above are based on the assumption that the environment itself is rather static. A chair can be adjusted somewhat but still remains a chair. It will be more exciting if objects in our environment behave like a sort of electronic clay or play dough[8]. This clay is composed of very small intelligent elements which can change color, and, together, can form any shape we like or even become mobile.

Modeling the environment**:** Programmable matter will enable elements in our environment to freely adjust their shape. This is more than just a chair that moved its armrest. Image a cluster of furniture objects that can transform from a desk into a sofa, a dining set, or a lounge environment. During the transformation, the color and texture of the elements can change as well. Connect this to nonintrusive ambient intelligence and the environment cannot only change in terms of atmosphere but also in terms of shape.

Human distant interaction**:** Programmable matter can move, evoke color sensations, and take on textures. It is, therefore, possible to model someone else, and the model can do whatever the original person does. Its huge difference from a hologram is that the model can be touched and has a full three-dimensional presence. This will create a sensation like someone is really there with you. This will enable interactions to be very humanlike and realistic.

[8]http://www.cs.cmu.edu/~claytronics/

The Meaning of Home Manufacturing

Consumer goods like clothing or kitchen appliances are usually being mass-produced. The production means are tuned to what is being produced and, aside from minor changes in the product, cannot do anything else. Rigid production systems coupled with costly distribution systems makes for a limited choice of product designs. Home manufacturing creates an environment that will support seemingly endless design options compared to mass-produced goods. A specific design can be changed and produced in a specific number and shape. The logistical challenges only have to deal with distributing base materials. All these products are potentially recyclable. When a printed object is broken or no longer needed, the material can be reinserted into the printer and used again for the production of new objects. 3D printing[9], the printing of spatial objects, holds a big promise for the future. These machines will develop into devices that can manufacture anything, even objects with moving parts, as long as there is a digital design available. As a consequence, trade will move from products to models, in which the models can be modified to a certain degree set out by the original designer. The modification can take place within a preset range of needs and tastes.

***Hey look, I created a shoe*:** Shoes are usually mass-produced ordinary objects which are used on a daily basis. This means personalization of shoes or the production of shoes for people with deviating shoe sizes or impairments requires a lot of manual labor. A scanner can create a scan of one's foot and produce a model that can be uploaded to a printer in order to produce an ideally fitting shoe. Moreover, the shoes' design can be adjusted to the personal needs, tastes, and wishes of the wearer.

***Creating appliances*:** The printing of objects does not have to be limited to static objects like shoes, kitchenware, or light shades. Objects with moving parts like a drilling machine can be produced, too. A future where virtually all tools can be printed is near.

(Nano)robotics in a Home Environment

Smart devices that are autonomous and mobile inside our homes and can decide independently are within reach. Think of robots assisting in household activities but, at the same time, can be a friend or a virtual pet. Robots will make our lives more pleasant by helping in any way they can. Robots can also assist with the provision of care, lifting people from their beds and driving them around. Using robots is not science fiction anymore. At a large scale they are already being deployed in the

[9]UNfold.be: Printing Things 2014 C. Warnier, D. Verbruggen / Unfold, S. Ehmann, R. Klanten. http://unfold.be/pages/projects/items/printing-things-book-for-gestalten

industry. Self-driving cars are the talk of the day, and the discussions concerning human labor vs robot labor are becoming political issues.

Clean windows: Robots do not need to be large. Very small robots can be just as supportive. Image a colony of microrobots living in the corner of your window. They feed on sunlight during the day. At night, they become active, walk around across the window pane, and clean it. A similar colony of nanobots dwells in the corner of the bathtub, the toilet area, the kitchen sink, and so on.

Vacuum the floor: Household tasks like vacuum cleaning will quickly become a thing of the past. Cleaning will be done by devices and robots. The vacuum cleaner drives around the home at night when the residents are asleep, powered by wireless electricity. When the dust reservoir is full, it drives to the waste container and empties all by itself. These devices are already on sale. Future forms of these devices will become increasingly intelligent and nonintrusive to our environment.

I want to get up: Every robot has its specific shape and appearance, just like the bed. The bed of the future helps you to get out of bed if you have trouble getting up. My shower is a robot too; it senses how I like to shower, standing up, sitting, etc., and will adjust itself. All kinds of objects that are at the moment lifeless will become intelligent and can and will anticipate my needs.

Growing Older

What is the meaning of all these potential technological options in the care of older people?

Signaling: An environment that has awareness means that signaling happens automatically. My grandmother does not have (and does not want) to walk around with a neck-worn personal emergency response system. The home environment itself can recognize a fall, a heart attack, or any other event and will react with the right intervention.

I forget, my room does not: Losing stuff, forgetting where you left your keys, and not knowing what medication to take. Your home can supply the answers; it will tell you where your belongings are and help you trace it. Your home will be your personal assistant, keeps your habitat in the right condition, and knows where you left your stuff or what actions you should take.

Happy: Your home knows who you are, recognizes your needs, and will adjust. This process of adjustment will develop along with you as you grow older. The home is a personal diary. The environment will be fully adaptive, in terms of the furniture, lighting, care assistance, household activities, and so on.

Technology has brought humankind a plethora of possibilities and, most of all, wealth. Anyone can afford buying an exoskeleton called a car, an interactive TV set, or devices for mobile communication. In 20 years from now, interactive adjustable homes in which lifelong living is made possible through adaptiveness will be the trend. Future homes will become increasingly intelligent, mainly because they will be upgradable. In addition, homes will use all the knowledge they have gathered over the years and so become even more personal and reliable. This scenario does not even include the potential of self-modification of the environment. Modern and ever-progressing technologies will support the physical decline of our aging bodies and keep us healthy and in wellness for a longer period of time. What started with a dentist filling cavities and an ophthalmologist providing contact lenses to better our physical well-being will evolve into active modification of organs and senses for a longer life in good well-being.

Wireless Sensor Networks for Aging-in-Place: Theory and Practice

Lawrence Normie

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Abstract

This chapter introduces wireless sensor networks (WSNs) and appraises their potential for enabling and supporting aging-in-place. A person aging in place (i.e., independently within the community) usually will experience one or several age-related medical conditions that frequently may also manifest as physical and cognitive impairments leading to functional disability in performing basic and

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instrumental activities of daily living (ADL/iADL). The role of WSNs in this context is to enable older citizens to age in place with autonomy, security, dignity, and reasonable quality of life, whereby medical status and general welfare is constantly yet unobtrusively monitored. Family, social, or emergency services intervention is automatically initiated based upon a situational assessment drawing upon a variety of sensor data. In the following sections, wireless smart sensor networks will be described for their technical characteristics and capabilities, the range of applications and services currently deployed through WSNs for the welfare of populations aging in place will be identified, and new and emerging capabilities will be discussed. In addition, the role of standards and regulatory requirements are considered, in particular regarding the ethical implications of WSN deployment.

Keywords
Active Assisted Living Joint Programme (AAL-JP) • Android smartphones • Apple iPhone • Digital signal controller (DSC), Network topologies • Passive infra-red (PIR) • Smart home technology • Smart homes • Smart phones • Smart sensors • Wireless sensor networks (WSNs) • Affective systems • Aging • Context awareness • Data fusion • Elder abuse • Gateways • Generalized anxiety disorder • Middleware • Neglect prevention • Network topologies • Physiological parameters • Privacy considerations • Security • Smart homes • Smart sensors • Technical standards • Transceivers • ZigBee

Introduction

Policy changes in favor of decentralized healthcare provision worldwide are driving the migration from secondary and tertiary care frameworks toward enabled primary and community delivered care (Augusto et al. 2007). For the growing older population, there is a corresponding shift from in-patient and institutional care to home-based managed care. These trends are facilitating "ageing in place" as the preferred option for many older citizens living with chronic medical conditions and disability. This evolution in community healthcare doctrine has been greatly facilitated by revolutionary advances in information and communication technologies (ICT) exemplified by ubiquitous intelligent sensor networks, which are dynamically responsive to a wide range of measured environmental and physiological parameters. In recent years, wireless sensor networks (WSNs) have been replacing sensors connected via wires, owing to better flexibility in sensor network architecture design, scalability, and minimal infrastructure costs.

A key challenge for successful transition from senior care institutions to home-based medical care and independent living support is the provision of economically sustainable and reliable community-based care programs for the welfare monitoring of aging-in-place subscribers.

In the last decade, community-based health care delivery has been considerably bolstered by major advances in embedded intelligent wireless sensor networks.

Intelligent sensor networks, wirelessly incorporated into the domestic living environment, constitute one of three main pillars of the "smart home" concept, the two other pillars being networked home appliances and interactive user interfaces. This chapter introduces the technical attributes, functional capabilities, and health and well-being benefits of WSNs and assesses their potential benefits when deployed within home environments specifically adapted for aging in place.

WSNs in Smart Homes

Despite more than a decade of media exposure and marketing hyperbole, during which "smart home" has become part of the popular lexicon, there still exists no official standard definition or consensually agreed list of attributes concerning what actually constitutes a smart home. To be sure, a plethora of de facto industry technical standards has evolved with the development and commercialization of enabling sensor and actuator technologies for smart homes. Though these standards and guidelines have contributed substantially to the domain, substantial obfuscation still permeates the domain resulting in diverse conceptual frameworks for smart home technology and associated interoperability incompatibilities, especially in sensor network and data communication infrastructures. In the context of aging-in-place within smart homes, the appropriate choice of wireless sensor network type therefore demands careful consideration. We shall see later on in this chapter how heterogeneous wireless protocols operating side by side is not necessarily an impediment and in fact may even provide functionality and performance benefits when mediated via gateway controllers linked to the internet.

Although automated control of smart home systems and appliances (for instance, in lighting, HVAC,[1] and security systems) typically is transacted through WSNs, this fact neither necessarily nor sufficiently qualifies a personal living space as a smart home. Beyond potential benefits of automation, for example, through improved energy efficiency, time and labor saving, and security, to achieve a comprehensively facilitating environment for aging-in-place, the smart home's intelligent controller must be capable of personalized responsiveness and adaptability to current and changing needs and capabilities of the older resident, including sensory and cognitive needs, as well as physical. In other words, the older person must be considered actually as the governing control element of the entire smart home system.

This leads to a pragmatic working definition of the "smart home" to be introduced here that is especially appropriate to the theme of independent living for older citizens and aging-in-place, facilitated by WSNs: "*A smart home is a domestic living space that is rendered dynamically and adaptively responsive to the immediate, imminent, and predicted future needs and capabilities of those living within it*." This particular definition emphasizes the functions of monitoring, situation evaluation,

[1]Heating, Ventilation, and Air-Conditioning

and contextual response to the physiological, cognitive, and emotional status of the older subject (Rowe et al. 2008). A complementary ethical perspective of the smart home role in this sense is that it must be supportive, responsive, and preventative, and, in all three of these qualities, adaptive to changing circumstances, while respecting privacy and choice. The practical realization of these essential attributes is mainly thanks to the capabilities of WSNs.

Smart Sensor Basics

To fully appreciate the potential of WSNs for aging-in-place, it is first necessary to understand the key technical and functional attributes of smart sensors and how individual sensor nodes cooperate with each other to create scalable intelligent sensor networks that are capable of composing a richly textured data representation of the built environment and those living within it.

The fundamental functional building block of a WSN is a single smart sensor node (also known as a "mote").[2] Each sensor node is designed to measure one or several environmental parameters. If in proximity to the older person (for instance, embedded in clothing) the sensor node may be dedicated to measuring and monitoring physiological signals such as heart rate, body temperature, and possibly also movement, walking gait, and general activity.

Besides the primary task of measuring the specific environmental or physiological parameters assigned to it, the smart sensor node includes embedded circuitry that performs some initial filtering and processing operations on the raw sensed parameters in preparation for transmission via the wireless network to a central data-processing hub. Additionally, local processing of the data by the sensor node can include some basic inference or decision-making operation. In this configuration, with onboard signal processing capability, the sensor node is said to be "smart." A concrete example is the rudimentary motion detection capability of passive infrared (PIR) sensors that are typically installed in home security systems. The basic PIR sensor will produce a changing voltage in response to an object moving across its field of view; the object has to be at a different temperature to the background in order for movement to be detected, so a moving person or any living creature with a sufficiently strong body heat should trigger the sensor. Even basic PIRs usually are tuned to a particular infrared spectral distribution corresponding most closely to the subject of interest that enables them to discriminate between the movement of, say, a house pet and a human subject. To this extent of movement discrimination, not special signal processing circuitry beyond a rudimentary voltage threshold detector is required. With the addition of several more PIRs situated at different locations in

[2]List of sensor nodes. http://en.wikipedia.org/wiki/List_of_wireless_sensor_nodes (Retrieved on 01/12/2015)

the room, it is not hard to imagine extending the basic motion detection capability to determine whether a human subject has fallen or collapsed rather than merely sitting or lying down. In this scenario, each PIR might contribute its signal input to a central processor; and the monitoring and analysis of the PIR signals as they occur over a short time interval could in principle track the progress of fall event.

Sensor Data Fusion

Such independently performed pattern recognition capabilities require an onboard microprocessor or digital signal controller (DSC) housed within the sensor unit, though many sensor motes still incorporate a simpler microcontroller with limited signal processing ability. Nevertheless, even with an onboard DSC, it is usually insufficient for a sensor mote in isolation reliably to perform everything required in the example scenarios of the previous section.

To improve the detection and estimation reliability of sensors, the data from different sensor nodes often are merged in combinational algorithms, a process known as sensor data fusion (Kansal and Zhao 2012). For example, the probability of correct identification of a genuine fall event (and minimization of false alarms) may be considerably enhanced by combining, through a multivariate estimation algorithm, the data streams of several sensors measuring, for instance, inertial parameters of the falling subject (by means of embedded accelerometer sensors), posture (by means of video or infrared sensors), acoustic qualities (through vibration sensors), and physiological signs such as change in the subject's blood pressure and pulse rate.

Algorithms employed to perform sensor data fusion typically are based on Bayesian predictive filters; a popular choice is the extended Kalman filter (EKF) which requires remarkably low computing resources to combine data from numerous sensors and output optimal filtered estimates of observed parameters.

Such multicontextual capabilities are feasible only with multiple cooperating networked sensors, each providing a unique and independent perspective of the sensed environment. Only once these independent sensed perspectives have been algorithmically integrated (or fused) is it feasible to produce a composite fiducial picture of what actually is occurring. For instance, in the previous section's example of fall detection, a combination of acoustic, optical, and thermal sensors is required to create a reliable picture of the fall event as it develops.

Wireless versus Wired

There exist both advantages and disadvantages for wireless sensor networks when compared with sensor networks with hardwired connection to a remote controller (Table 1).

Table 1 Comparative advantages and drawbacks of WSNs

Advantages	Disadvantages
Unattended operation	Requires periodic replacement of battery
Can be situated virtually anywhere and repositioned at will	Limited maximum transmission distance (requires repeaters for long distances)
Requires no wired infrastructure	Higher unit cost because of transceiver component.
Requires no external power supply	Higher power consumption owing to wireless transceiver operation and batteries
Mobile – can be worn on body or in clothing	Susceptible to radio frequency interference (RFI), multipath signal drop-out, packet loss, etc.
Autonomous and self-organising	Lower data rates
Ease of deployment and removal	Security vulnerability (e.g., packet sniffing)

Classes of Wireless Transceivers

Two principal characteristics distinguish the various wireless technologies used in WSNs: the radio (RF) center frequency and the network stack protocol; the former is determined primarily by hardware components and the latter by software coding.

The RF center frequency is a physical determinant of maximum range, where, in general, higher frequencies have shorter range but potentially higher effective data rate. The stack protocol is a software-coded determinant of the maximum data rate. Generally, the lower the data rate, the smaller the power requirement.

Sub-GHz protocols and the open ZigBee standard are among the most commonly used wireless protocols for applications that require a combination of energy efficiency and extended range for WSNs. Sub-GHz wireless sensor nodes typically are suited for long-range, low-power, and lower data rate applications, such as domotic sensors (e.g., smoke, gas, temperature, and motion detection).

The Bluetooth® protocol does not require a preexisting infrastructure (such as a hub) as it is not designed or intended for complex networks and is used primarily for short-range, point-to-point connectivity between a limited number of nodes. A common application of Bluetooth® in WSNs is in personal area and body area networks (PSN and BAN). WiFi is the protocol of choice for high-bandwidth applications such as video streaming and therefore this protocol commonly is used for communication with remote video sensors.

Wireless Sensor Network Topologies

Several possibilities for network configurations (topologies) exist; the main ones typically employed are point-to-point "star," "cluster tree," and "mesh."

The star configuration (Fig. 1) simply has all of the sensors in bidirectional communication with a central coordinator hub. The key advantage of the so-called star point-to-point network is that the individual sensor nodes require very

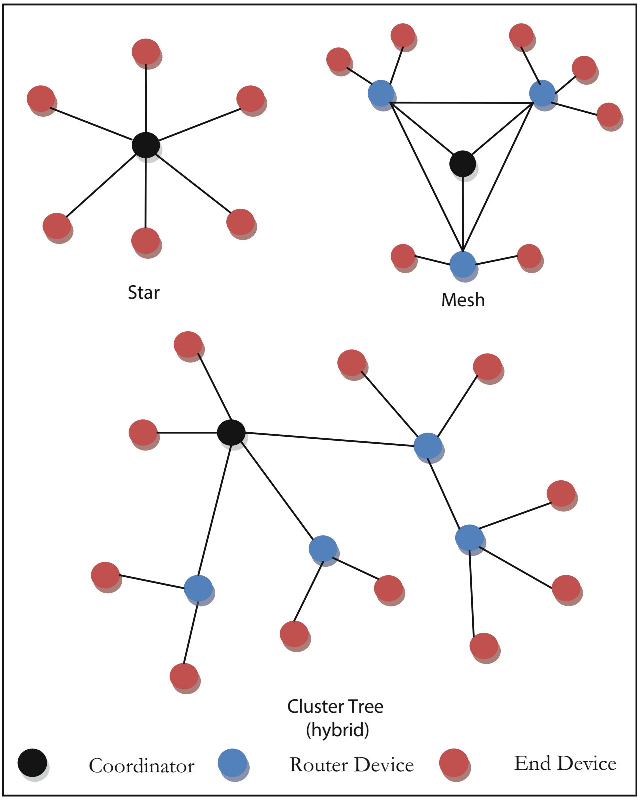

Fig. 1 Wireless sensor network topologies

rudimentary and inexpensive transceivers. The main disadvantage of star networks is that the power requirement for remote sensor nodes is an exponential function of the distance from the hub. For battery-powered sensors, this obviously is a major practical constraint for the deployment of large-scale networks.

In a cluster tree topology, particular nodes are designated as routers, which manage the routing of data across the network as whole and the central coordinator. Each router (also termed a "repeater") essentially acts as a star network coordinator for the sensor nodes in its vicinity and routes the consolidated data from sensors in the local cluster to the central hub coordinator. The key weakness in a cluster tree configuration is that if a given repeater fails, all sensor nodes on the local cluster are effectively disabled from the network.

The topology of choice for most modern WSNs is the wireless mesh network configuration. Here, each sensor node is able to communicate with every other node in the network that is in range. This means that a remote sensor can communicate with the coordinator hub by routing through the other nodes. The individual power requirement for each node therefore is substantially reduced.

The true power of the mesh-based wireless sensor network protocol, however, is the embedded intelligence to administer autonomously, on the fly, ad hoc network self-configuration and network healing. Consider the case where one or more sensor nodes fail, say owing to a dead battery or hardware fault. In this situation, the network will automatically reconfigure to bypass the faulty sensor node, thus maintaining network functionality and integrity. As more sensor nodes fail, the network will continue to function in manner of graceful degradation, until the minimum number of functional nodes is reached to sustain network operability.

Heterogeneous Wireless Sensor Network Attributes

Integration of smart home wireless sensors from multiple vendors usually depends on the existence of heterogeneous communication architectures that seamlessly support diverse hardware, firmware, and data transmission protocols on the same network (van Bronswijk et al. 2007). Typical wireless network protocols embedded in smart sensors include ZigBee, Bluetooth®, ANT, and WiFi.

Smart home sensors are many and diverse; the following is indicative of those commercially available:

- Presence, motion, and activity sensors
- Acoustic and vibration sensors
- Body temperature remote sensors
- Fall detection sensors
- Door opening sensors
- Water faucet use sensors
- Oven, refrigerator, and other white goods status and use sensors
- Environmental temperature, humidity, and air quality sensors

Autonomous smart home sensors share several basic characteristics that are independent of their individual functions (such as measuring environmental conditions, proximity sensing and motion detection, physiological vital signs, etc.). These common features are provided by modern low-cost microcontrollers, which include a rich set of processing and power management capabilities.

Wireless sensors manage their own power consumption (often battery powered), so that minimum energy is expended. This is enabled by multilayer "sleep" protocols, which ensure that only system resources and peripherals that currently are required remain actively powered. In battery-powered sensors, this intelligent power management facility can extend nominal battery life from days to weeks, months, or even years.

Wireless sensors are capable of communicating through ad hoc wireless networks, based upon heterogeneous technologies and communication protocols. The standard way of achieving this is through the intermediary of "gateways," which provide seamless connectivity between different networks (Faludi 2011).

Mesh type WSNs are capable of autonomous network self-organization on the fly. This means that if one or more sensors in the network fail to communicate, the network automatically will reconfigure itself.

Middleware

At the sensor network level, centralized middleware, located in a local or remote server and/or distributed at various levels of abstraction among the various components of the smart home hardware, including networked home appliances and the wireless sensor nodes. Centralized middleware functions, besides polling between and coordinating data from disparate sensor nodes, may perform cross-correlation and time trend analysis data from selected sensors, from which may be derived longer-term changes in health status.

A key advantage of distributed middleware, as opposed to strictly centralized, is that the local sensor network may continue to operate autonomously when communication with the remote central server is temporarily unavailable. Another benefit is that local preprocessing and integration of raw sensor data offloads some of the computing burden at the central server, which may be handling data from numerous sensor networks, for instance, in an aging-in-place community of many independent residents. This requires a modicum of local intelligence supporting the contextual adaptability of individual sensor nodes and the local sensor network. Software agents of this type may employ Bayesian predictive filters, including extended Kalman filters that can integrate highly heterogeneous sensor data having possibly nonlinear relationships to observed parameters (Yang and Li 2008).

WSN Gateways and the Internet of Things

A WSN can operate as a local area network or communicate with applications and other end devices hosted on the Internet. Sensor or actuation nodes sharing data and control with Internet host applications are essentially part of what is popularly known as the Internet of Things or IoT (Perera et al. 2013). Communication with the Internet can be established through interoperability with the Internet's network layer protocol (TCP/IP), either directly or through the intermediary of gateways. Gateways are interface devices that provide connectivity between different network architectures and communication protocols. Heterogeneous wireless sensor networks (i.e., networks of sensors employing different wireless transmission protocols) require special interfaces to be able to communicate and integrate with each other. In particular, for the Internet of Things (IoT) gateway sensor aggregators are essential.

For local sensor data processing, an embedded control gateway provides shared intelligent processing resources and high-level management functions, whereby the gateway performs tasks – signal filtering and decision threshold monitoring – that would otherwise occur within the remote sensor nodes; this removes the necessity

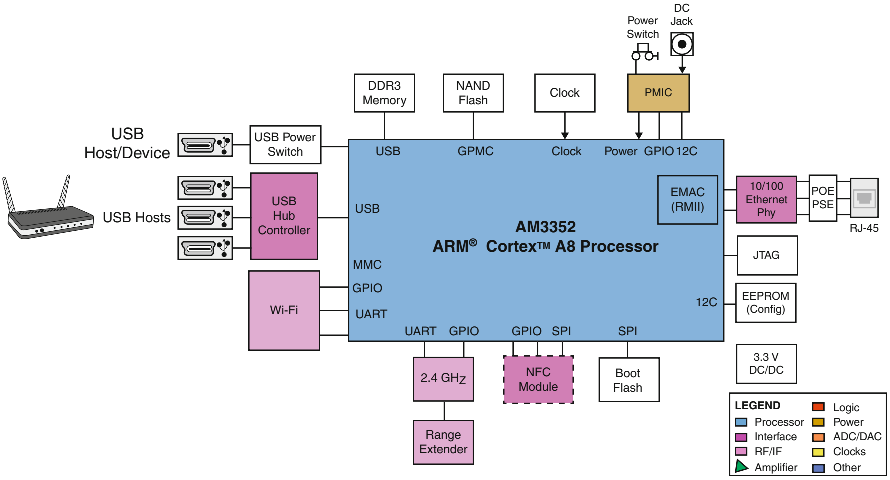

Fig. 2 Texas instruments home automation IoT gateway solution showing interfaces to heterogeneous wireless protocols (Wi-Fi, ZigBee, etc.) (© Copyright 1995-2015 Texas Instruments Incorporated (Retrieved 01/05/15 http://www.ti.com/solution/iot_gateway))

for onboard sensor processing, minimizes transmission data rate, and power consumption requirements, and also reduces sensor node architecture complexity and cost.

There is a further important advantage gained by maintaining native communication protocols, such as ZigBee and Bluetooth, at the sensor nodes rather than have every node use TCP/IP. Internet Protocol carries higher memory and power overheads than many other data communication protocals. Reducing the complexity of nodes also reduces overall power consumption for applications where nodes have limited battery life or operate on energy harvesting sources.

Enabling intelligence in a gateway addresses both wireless and wired interoperability issues on a local level while minimizing the changes required for connecting to home appliances (Fig. 2). Rather than require full intelligence in each appliance, the gateway can provide the base intelligence for all devices. Additionally, provided with appropriate onboard software, an intelligent gateway can continue to support the functionality of sensor nodes even when Internet communication is interrupted.

Context Awareness

The critical ingredient in smart home technology is *context awareness* within the data processing architecture. Smart sensor networks exhibit context awareness (Castello et al. 2013), being responsive to the needs of the older dweller according to present location, the time of day (and possibly knowledge of temporal behavior patterns of the subject), as well as the monitored environmental and physiological data concerning the subject (Andò et al. 2014). Context awareness can be implemented by a set of rule-based or heuristically self-adaptive algorithms that derive the context from parameters including the time of day, ambient temperature, humidity and light levels, a time-stamped history of the subject's movements and behavior within the living spaces, and possibly personal medical information from the electronic health record.

The performance of context-aware systems ultimately is governed by the fidelity of the raw input data, much of which is furnished by wireless sensors. Data fidelity is a function both of the accuracy, precision, and timeliness of the data, but also its richness; in other words the diversity and multimodality of independent sources composing the consolidated data stream feed the smart home decision algorithms.

WSNs for Aging in Place

Having in the preceding sections established the technical and conceptual framework for wireless sensor networks and their key structural, functional, and performance attributes, in the following this information is instantiated and operationalized to illustrate several potential real application scenarios in WSN-enabled independent aging in place.

Miriam, a widow in her mid-80s, still lives in the home where she raised her family. Miriam takes daily medication for osteoporosis, diabetes, and atherosclerosis. The latter condition is responsible for a noticeable decline in Miriam's cognitive function and she is increasingly forgetful and disorientated. Miriam's children live overseas and she refuses to enter institutional care or sheltered accommodation. With the help of local authority grants Miriam's house has undergone some structural modifications to help maintain her independence, including a stair lift and grab bars in the bathroom. Last year Miriam subscribed to a community alarm service and she wore an emergency response button on wrist (when she remembers to put it on). Six month ago, Miriam volunteered as a subject for a smart home project run by the local university. Several items of technology were recently installed in the house. These include microphone and vibration sensors, fall detection sensors embedded in the floor of the bedroom, kitchen, and bathroom. Miriam also now has an upgraded community alarm which is connected to the fall detection system just described. In the bedroom, pressure sensors have been inserted under the mattress; these automatically cause night lights distributed between the bedroom and bathroom to illuminate when Miriam gets out of bed during the night. As with the fall detection system and community alarm, information from the bed sensors is wirelessly routed to the TV set-top box which in turn is connected via ADSL to a 24 hour call center. Wall-mounted television flat panel screens in the bedroom and kitchen also are routed wirelessly to the set-top box.

In the kitchen, the refrigerator door has been fitted with a sensor which logs when and how frequently the door is opened. The cold water faucet also has a sensor monitoring the volume of water used. If the faucet is not opened at least twice in a 12 hour period, an automatic alert is flagged at the call center.

Application in Affective Systems

A prominent consequence of aging is the propensity for depression and generalized anxiety disorder. Part of this owes to social isolation experienced by many older people living alone, but the aging process also has been established as a risk factor for clinical depression and anxiety, ensuing from changes in the aging brain, in particular diminished or imbalanced production of mood-related neurotransmitters such as dopamine (common in Parkinson's disease), norepinephrine, and serotonin.

Affective systems are responsive to the emotional state of the subject by detecting signs of depression or agitation through, for example, pattern recognition algorithms for gestures, facial expression, and movement activity (Silva et al. 2008). Affective systems currently being researched employ a variety of interventions that by various stimulatory means attempt to ameliorate episodic depression and anxiety. These include the modulation of temperature, humidity, ambient lighting, and the production of soothing music or recorded sounds, and even pleasant aromas. The affective system also, where appropriate, can automatically establish an audio or video link with a family member or caregiver. Additional modalities include the use of functional materials (which modify their properties according to environmental or system predicated conditions), for example, to modify the visual scheme of the subject's surroundings, including the color of wall coverings and the displayed images on "smart" picture frames.

Implementation of affective systems depends on smart sensor networks that include video and acoustic recorders and ambient luminance thermal, and humidity sensors (which may be permanently wired in the person's living space, as well as physiological sensors (incorporated in a wireless body area network) monitoring heart and breathing rates, and possibly also electrodermal activity (skin conductivity).

Applications in Elder Abuse and Neglect Prevention

The application of remote monitoring and detection for neglect of an older adult (including self-neglect) is a high-priority research imperative in developed countries. To date, much of the research progress in this area is a result of academic-industrial-governmental shared cost initiatives in the EU and USA. Deployment of validated systems to monitor and respond to self-neglect, however, is minimal; several small to medium pilot installations have been or currently are being evaluated in the USA, Europe, and Australasia in the context of smart home environments and the Ambient Assisted Living Joint Programme (AAL-JP)[3] initiative of the European Commission's Article 189. A common feature of many AAL projects is a mechanism, mediated by heterogeneous wireless sensors, to detect and identify signs of self-neglect, for example, presence sensors in the bathroom or kitchen that monitor the

[3]Since 2014, AAL-JP is now officially the acronym for Active and Assisted Living Joint Programme; the term "Ambient Assisted Living" has been derogated.

frequency and time distribution of occupation by the subject. A simple door open sensor on the refrigerator often suffices to flag a warning (say via a dedicated smartphone app) to formal or informal carers that the older subject has not eaten within a prescribed period.

A key challenge with reliable detection of self-neglect is rooted in the diverse yet interrelated modalities in which the neglect process can occur, for example, malnutrition, personal care and hygiene, and self-medication compliance. A holistic self-neglect monitoring protocol therefore is mandated in order to provide effective monitoring and intervention protocols. The potential role of WSNs in this scheme is considerable, since a diverse variety of networked sensors can be quickly and flexibly installed in the living environment to monitor the older subject's welfare from a multimodal perspective.

Concerning the detection of potential abuse of the older person by other agents, including family members as well as hired caregivers, the problem at hand is considerably more complex. The categories of sensor to employ in such situations where abuse is suspected is dictated essentially by two parameters: the nature of the abuse being monitored (e.g., verbal, physical) and the degree of privacy intrusion that is acceptable to the older subject themselves and the family. Video monitoring has been reported in the popular press as having successfully exposed elder abuse by hired carers, but in almost all situations this mode of surveillance is unacceptable. Less intrusive modalities of abuse detection include acoustic sensors that monitor for key words and phrases (think Homeland telecommunications surveillance) and the identification of distress markers based on speech power spectrum analysis employing algorithms based on fast Fourier transforms (FFT) with principal components analysis (PCA) and blind source separation (BSS) of the voice waveforms (Vacher et al. 2013), and also analysis of word rate (Aman et al. 2013).

Wireless sensor networks are amenable to the logistic demands for the deployment of multiple acoustic sensors such as microphones to attain the required area coverage, sensitivity, and specificity for elder distress identification. However, the hardwiring of these sensors restricts the latitude and flexibility for optimization during installation and commissioning, whereas wireless sensor nodes can be installed and modified in location on an ad hoc basis.

Smartphones as WSN Platforms

The advent of the Apple iPhone and Android smartphones has been a game-changer in ubiquitous wireless sensing. Even the most basic smartphone is equipped with a host of sensors, for location, motion, orientation, and ambient environmental conditions. The smartphone is almost the ideal platform for locally acquiring data on the owner's health and well-being status and information about his/her surroundings. A smartphone even can function as a data aggregation hub for intelligent networked home appliances and transmitting all of this information in a meaningful format to designated formal and informal carers. This considerable potential and versatility is made possible by the free availability of open application programming interfaces and software development kits.

The smartphone can be networked with other wireless sensor nodes worn by the user or embedded in the living environment and household appliances. For body area or personal area networks, where sensor nodes and wireless-enabled devices typically will be in close proximity to the user, the Bluetooth® Low Energy- BLE (marketed as Bluetooth® LE or Bluetooth® Smart) protocol will often be the most appropriate networking solution. For networking over a larger area with other Wi-Fi-enabled sensors and devices, the Wi-Fi Direct protocol will be a good choice. For both BLE and Wi-Fi Direct, a separate wireless access point (WAP) is not required because these protocols operate according to a peer-to-peer network architecture.

In practice, however, WSN solutions based on a smartphone hub are substantially limited because of battery drain and the requirement for the user to have the device constantly on or in proximity to his/her person. With continuing improvement in power storage technology, especially recent breakthroughs in low-weight high-density energy storage technologies based on nanomaterials, the battery drain limitation is likely to be mostly solved within the next few years. The issue of user compliance (to keep the smartphone at hand) is a harder challenge that might be overcome in the future by wearable devices based on flexible or textilized electronics. In the immediate term, watch-type smartphones could be a workable solution for many use cases.

Technical Standards

In the European Union, several attempts have been made over the last decade and half to establish a commonly recognized standard communications infrastructure for smart home sensor networks. The Batibus architecture of the early 1990s was rapidly superseded by wireless alternatives. The present drive is toward a standardized process for the full plug and play interoperability of heterogeneous communication networks that are transparent to the architecture and protocols of the system application and service layers.

Several de facto industry standards exist for commercial installations of WSNs in smart and automated homes. In the USA, the wireless extension to the X10 standard is pervasive, though it has limited capabilities for functions beyond conventional automated home environmental control, surveillance, and security functions. Other popular (but non-interoperable) architecture standards include UPnP, HomePlug, and HomePNA. More recently proprietary open standards low data rate and short-to-medium range communication protocols incorporated in smart home installations include IEEE 802.11 (Wi-Fi), Bluetooth® and Bluetooth® LE (BLE), as well as low-power mesh-based protocols such as IEEE 802.15.4 (ZigBee) (Fig. 3) and Z-Wave (Table 2). Each implementation has its particular benefits and disadvantages with respect to range, energy requirement, capacity, and cost. At any rate, a holistic and truly extensible WSN architecture should be capable of incorporating most of the above communication standards in a seamlessly integrated way, providing true universal plug-and-play capabilities.

Fig. 3 ZigBee transceiver module

Table 2 Selected communications protocols for wireless personal area networks

Protocol designation	Remarks	Web site
IEEE 802.15.4	Specifications for PHY and MAC layers, forming the basis for ZigBee and other low data rate wireless protocols	http://standards.ieee.org/about/get/802/802.15.html
ZigBee Alliance	Official specifications of the ZigBee protocol	http://www.zigbee.org
Bluetooth® / BLE	Adopted Bluetooth® core specifications	https://www.bluetooth.org/en-us/specification/adopted-specifications
Wi-Fi Direct	A peer-to-peer network protocol not requiring a wireless access point	http://www.wi-fi.org/discover-wi-fi/wi-fi-direct
ANT™, ANT+	ANT+ is an open source interoperability function that can be added to the base ANT protocol	http://www.thisisant.com/resources/ant-message-protocol-and-usage/
Z-Wave	Proprietary standards, similar to ZigBee, but operating in the 900 MHz band; MAC and PHY compliant to the ITU-T G.9959 specification	http://www.z-wave.com/
6LoWPAN	IPv6 over Low power Wireless Personal Area Networks. The Internet Engineering Task Force (IETF) working group nascent wireless protocol specifications for the Internet of Things	http://tools.ietf.org/wg/6lo/

Security, Integrity, and Privacy Considerations

Any wireless network potentially is open to unauthorized access. Generally, therefore, it is essential to ensure encryption of all data transmitted or received over a WSN, whether between nodes or to the outside world (e.g., via an Internet gateway). Data security and integrity is particularly important where the concerns of older people or vulnerable people are at stake. In most countries there exist mandatory regulations for appropriate steps to preserve the privacy of such data. In the USA, the federal Health Insurance Portability and Accountability Act of 1996 includes special provisions for the confidentiality of wirelessly transmitted patient data. Similarly, in the European Union, there is the Data Protection Directive 95/46/EC on the protection of personal data. Because of the stricter regulation in Europe, US WSN equipment suppliers are required to comply with the US-EU Safe Harbor Framework [4]. The need for privacy extends not only to prevention of unauthorized or criminal interception of data but also to the allocation access permissions in the care supply chain. For example, only designated medically qualified personnel should be able to access clinical and physiological data captured and transmitted over the WSN.

There are very many competing, as well as complementary, standards and protocols that may be employed to implement WSN integrity and security; only a few examples of more widely used methods will be discussed in this section in order to illustrate the main ideas and principles. In practice, the constraints on choice are determined by trade-offs of complexity, power consumption overhead, security flexibility, and scalability (Iwendi, et al. 2013).

NIST's RSA asymmetric encryption algorithm for many years has been the de facto security protocol for most computer networks and also for WSNs. The "asymmetric" aspect refers to the reliance on codes generated by the multiplication of two very large prime numbers and the virtual impossibility of an eavesdropper determining the prime factors to decode the channel (Gustavo et al. 2012).

More recently, the Advanced Encryption Standard (AES) has become the default choice for many WSN implementations. AES facilitates an additional layer of security over the native WSN key management mechanism (Khambre et al. 2012).

Conclusion

WSN functional capabilities and potential benefits for secure independent living have been presented in this chapter with several real-world illustrations. Obviously, there exist many additional actual and potential applications of WSNs for aging-in-place and a Google search will reveal a considerable number of references to these.

Wireless Sensor Networks are increasingly relevant to aging-in-place, owing to a confluence of market "pull" and technological "push" factors. The technology contribution is due to affordable yet more powerful and peripheral-rich digital

[4] http://www.export.gov/safeharbor/eu/eg_main_018476.asp

controllers with integrated radio transceivers, the wide-scale adoption of self-configurable and scalable mesh-based communication network protocols, and context-aware intelligence systems of rapidly advancing capability and performance. Market accessibility to WSN-based aging-in-place support platforms is additionally fostered by steadily falling component costs, involving virtually no additional infrastructure requirement beyond gateway equipment.

WSNs have in the last several years transitioned from the ascent phase to the maturity phase in the technology adoption life cycle model (Beck 2013). Wireless sensor hardware performance, power management, and affordability are no longer the limiting factors for dependable application within aging-in-place environments, though much still depends upon creativity and innovation by developers. The state of the art in smart homes technology, in particular concerning an accurate and timely automated evaluation of the older resident's well-being status and needs, still remains largely a nascent field. Commercial solutions for aging-in-place applications based on WSNs, though plentiful, are as yet insufficiently grounded in evidence-based research (Pol et al. 2013). The potential for further scientific, technological, and market contributions to the field therefore is considerable.

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Thermal Comfort in Smart Homes for an Aging Population

L. Schellen and J. van Hoof

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Abstract

The number of older adults is increasing rapidly, and the majority of older adults wish to age in place. Furthermore, these demographical changes put a large stress on the healthcare system. Therefore, adequate aging-in-place strategies become significantly important. Appropriate and comfortable housing is one of the key determinants to facilitate this desire. One of the aspects of concern is thermal comfort. Since the thermal requirements differ between young adults and the older counterparts, current models for assessing thermal comfort are not sufficiently accurate to be used for older adults. This chapter provides an overview of thermal comfort in relation to aging and the way smart home technologies including smart thermostats can contribute to well-being and health with respect to aging-in-place strategies.

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Keywords
Thermal comfort • Smart homes • Home automation • Aged population

Introduction

Healthy aging and aging in place become increasingly important regarding demographical changes and the pressure on the healthcare system. In 2025 there will be 360 million people aged 60 or over in the Industrialized World (WHO 2013). This number emphasizes the urge for healthy aging-in-place strategies. Aging in place can be defined as "the ability to live in one's own home for as long as confidently and comfortably possible" (van Hoof 2010). The vast majority of older adults that live independently wish to continue their current lifestyle and, therefore, ask for extra support and guidance at home, as well as assistive technologies including smart home technologies (Korhonen et al. 2003). Healthy aging is one of the key topics of the World Health Organization (WHO) and is included in the WHO's Ageing and Health Program (WHO 2013). Housing directly impacts health; the environmental conditions where we are exposed to are a key determinant of health (Howden-Chapman 2004; O'Neill et al. 2006). With respect to the thermal environment, especially older people are relatively vulnerable to thermal environmental conditions outside the "common" temperature range, for instance, during cold spells and heat waves (Huynen et al. 2001; Garssen et al. 2005).

Since older adults are at greater risk of hypo- and hyperthermia, it is a trend to advise older people to keep the indoor temperature tightly controlled without hardly any fluctuations, both during day and season (Howden-Chapman et al. 1999). These strictly controlled indoor temperatures have their background in thermal comfort research within the built environment. This chapter provides an introduction to thermal comfort of older persons and the way smart home technologies can contribute to their well-being and health.

Thermal Comfort

Thermal comfort is defined by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) as "that state of mind which expresses satisfaction with the thermal environment" (ASHRAE 2010). Within the built environment, the most commonly used model for evaluating thermal comfort is the PMV model (Predicted Mean Vote) of Fanger (1970; Fig. 1). The optimum condition according to Fanger (1970), defined as the thermal neutral condition, is a condition wherein a person does not prefer either a colder or warmer environment ($-0.5 < \text{PMV} < 0.5$).

The model is included in standards regarding the assessment of thermal comfort (EN-ISO 7730 2005; ASHRAE 2010) that are widely used by heating and air-conditioning engineers to prescribe and design the thermal environment

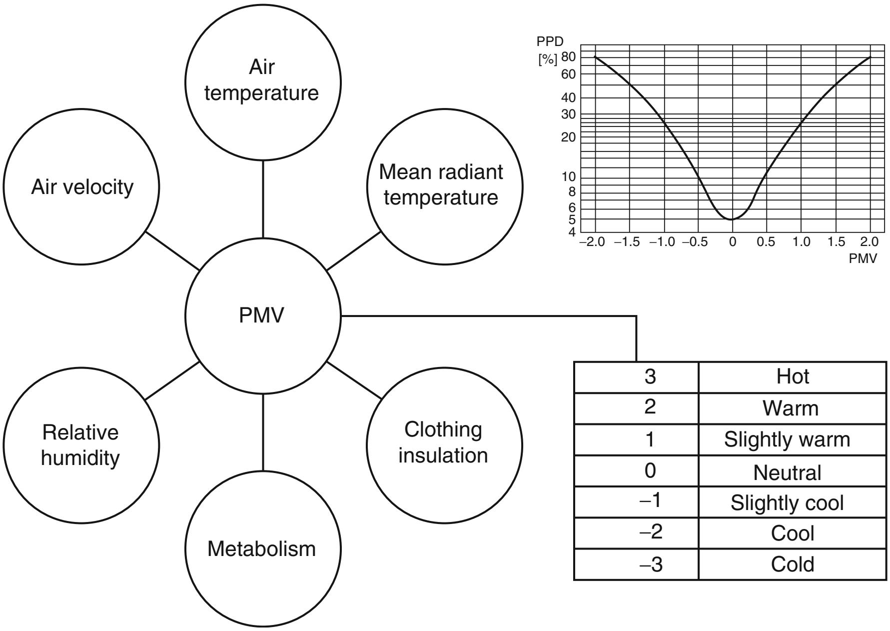

Fig. 1 The Predicted Mean Vote (PMV) is shown with its six input parameters, the relation to the seven-point ASHRAE scale of thermal sensation (Table), and the graphed relation between PMV and PPD (Predicted Percentage of Dissatisfied)

(van Hoof 2008). These thermal comfort standards aim to specify conditions that provide comfort to all healthy adults, including older adults (Cena and de Dear 1997). Application of these guidelines results in an "optimum" constant indoor temperature without fluctuations.

However, the optimal thermal condition is not necessarily equal to thermal neutrality since preferences for non-neutral thermal sensations are common (Croome et al. 1993; Nicol and Humphreys 2002; van Hoof 2008). Moreover, several studies indicate that optimum thermal conditions for the older people differ from those of young adults (Collins et al. 1981; Natsume et al. 1992; Hashiguchi et al. 2004; van Hoof and Hensen 2006; Degroot and Kenney 2007; Schellen et al. 2010). In addition, gender plays a role in perceiving the thermal environment. In general females are more sensitive for cold conditions and deviations from the individual optimum conditions than males. Besides, females frequently prefer higher temperatures (Nakano et al. 2002; Parsons 2003; Karjalainen 2007, 2011). This, however, is contrary to results from studies reported in the ASHRAE Handbook (ASHRAE 2009). These reveal that the thermal conditions preferred by older people and females do not differ from those preferred by younger adults and males.

Furthermore, results from naturally ventilated buildings in practice revealed that satisfaction with the thermal environment does not mean that this environment has to be controlled at a constant indoor air temperature (de Dear and Brager 1998).

These findings lead to the *adaptive* thermal comfort approach and caused a significant paradigm shift away from the heat balance-based approach (de Dear et al. 2013). The adaptive approach accounts for the fact that humans adapt to seasonal variations in environmental conditions. Application of the adaptive thermal comfort approach therefore results in a more varied, depending on the outdoor conditions, indoor thermal climate (de Dear and Brager 1998).

Furthermore, compared to a constant temperature, allowing the temperature to drift will reduce building energy use (Kolarik et al. 2011). The latter is highly relevant since one-third of the primary energy in developed countries is used for heating, ventilation, and air-conditioning (HVAC) of buildings (IEA 2011). A temperature drift is here defined as a transient temperature over time, depending on running outdoor temperature.

In addition to the comfort and energy-saving potentials, a recent study search indicates that the adaptive temperature approach can have significant health effects (Lichtenbelt et al. 2014). Conventionally, thermal comfort and health are often considered as synonyms. Therefore, the tightly controlled PMV approach is regarded as most healthy. However, recent findings suggest that it might be healthier to be exposed to temperatures outside the thermoneutral zone (Lichtenbelt et al. 2014).

Aging and Thermal Comfort

It is generally assumed that older adults do not perceive thermal comfort differently from young, college-age, adults (ASHRAE 2010). For instance, when Fanger (Fanger 1970) created his predictive model through climate chamber research involving approximately 1,300 college-age students, these studies were followed by much smaller experiments involving 128 older subjects to study the influence of age and aging. He concluded that the neutral temperature did not differ between young and older adults, and therefore no difference in thermal preference between those two groups was assumed. However, there are indications that there are differences in thermal comfort between young adults and their older counterparts. Besides, the older population has different physical characteristics compared to younger groups. Therefore, the question arises if thermal comfort guidelines and the PMV model are valid for application to the “healthy” older population.

The effects of biological aging on the perception of thermal comfort and thermoregulation have been reviewed (van Hoof and Hensen 2006; van Hoof 2010; Blatteis 2012), and, until recently, scholars supported the hypothesis that in relation to thermal comfort, older adults did not perceive thermal comfort differently from younger college-age adults. Schellen et al. (2010) showed that the optimum conditions for healthy older adults (age above 67 years) differ from those of their younger (age 18–30 years) counterparts (Fig. 2). These findings are supported by other studies as well (Collins et al. 1981; Hashiguchi et al. 2004; Degroot and Kenney 2007). Older adults are more vulnerable, compared to young adults, in conditions that differ from neutral, because the efficiency of their cold and warm defense mechanisms is declined and the ability to detect, and therefore respond to,

Fig. 2 Older subject in climate chamber in order to study the differences in thermal comfort between young and older adults (Schellen et al. 2010)

temperature changes is reduced. In addition, Poehlman et al. (1994) revealed that their metabolic rate is lower compared to the metabolic rate of younger people due to a decrease in muscle mass which reduces both the basal and resting metabolic rate. In the study of Schellen et al. (2010), the thermal sensation of older adults was in general 0.5 scale units lower on the PMV scale than the thermal sensation of the young adults. The same trend was found for the thermal comfort votes; older adults felt less comfortable than the young adults. This was supported by the fact that the older adults preferred a higher temperature than the young adults. Under the same environmental conditions, the young adults were feeling neutral, while the older ones were feeling slightly cold. The difference in thermal sensation may be explained by a decreased thermoregulatory response (especially the vasoconstrictor response), indicated by the extent of vasomotion measured by the differences in skin temperatures between the young adults and the older adults (Degroot and Kenney 2007; van Someren 2007). For example, during the experiments of Schellen et al. (2010), the older adults were continuously more vasoconstricted compared to the young ones. Although 20% of older adults show no vasocontraction of cutaneous blood vessels, not all of them have diminished control of body temperature. In general, older adults have reduced (i) muscle strength, (ii) work capacity, (iii) sweating capacity, (iv) ability to transport heat from body core to skin, (v) hydration levels, and (vi) vascular reactivity and (vii) lower cardiovascular stability (Havenith 2001).

Concluding, older adults seem to perceive thermal comfort differently from the young due to a combination of physical aging and behavioral differences. Individual differences are too large to draw an unequivocal conclusion on the requirements of older adults regarding their preferred thermal environment. Therefore, emphasis, with respect to the thermal environment, should be on individual level. Furthermore, the indoor climate can have an influence on the health of occupants. Results with young subject showed that mild thermal variations could be beneficial from both a health and comfort perspective (Lichtenbelt et al. 2014). However, such mild thermal challenges can result in both positive and negative physiological responses. From previous studies we know that mild cold exposures can result in increased systolic blood pressure levels in older adults (Kingma et al. 2011). Therefore, it is advisable to further investigate the effects of mild thermal disturbances.

Smart Homes and Thermal Comfort

Thermal comfort in the home environment can be achieved through: (i) passive, architectural solutions, for instance, thermal mass, blinds, orientation, and so on and (ii) more active technological solutions, such as HVAC systems and home automation (van Hoof and Hensen 2006). Passive architectural solutions often form an integrated part of vernacular and modern buildings and in most cases require minimal user interaction to guarantee a comfortable indoor climate. Moreover, most of these solutions do not use extra energy and do not put a strain on the environment. Home automation technologies include all in-home devices and infrastructures that use electronic information for measuring, programming, and control of functions to the benefit of the residents. Through the intelligent combination of noninvasive biological and environmental sensors and actuators, automatic tuning of the indoor climate to individual needs is likely to become possible in the homes of older adults in the Industrialized World in the future, even though no well-evaluated and working systems can be purchased on the marketplace yet. Bottlenecks of current home technologies are inadequate control options for people with decreased muscular, visual, and auditory functioning, the limited compatibility of various systems, and financial aspects. Still, positive trends in society come to the fore. In the Netherlands, smart home thermostats (Fig. 3), including technologies with fancy names as *Anna*, *Nest*, and *Toon*, were being launched on the marketplace in 2014. Such developments in smart home technologies are very recent. For instance, Nest Labs from the USA was founded in 2010 and acquired by Google in 2014.

Smart thermostats can be controlled via smartphones and personal and tablet computers and are said to offer better comfort and provide a means for energy conservation. Some of these thermostats offer options for the hourly control of the indoor (air) temperature. Depending on the brand, a thermostat can be used for the control of the home as a whole or for individual rooms. Anna and Nest contain self-learning algorithms based on the presence of occupants, which allow a room to be controlled according to the wishes of the homeowner. In combination with radiator-mounted thermostats and motion detectors, individual rooms can be controlled, based on time and temperature. Based on the location of a mobile phone (geo-fencing), some systems can detect if the occupant is close to home, and the temperature of the home can be changed if needed. Some more elaborate systems

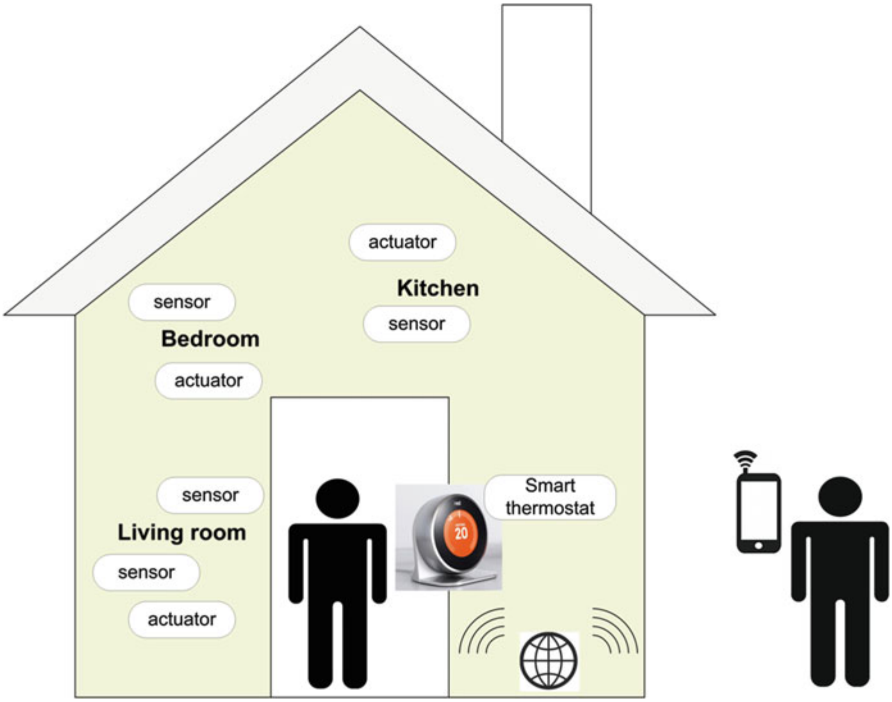

Fig. 3 Overview of smart thermal comfort. Smart thermostats in smart homes can be operated manually inside the dwelling or via applications on smart phones when away. Sensors in the dwelling measure the temperature in a given room and help control the temperature within a range of preset temperatures

also allow the thermostats to be combined with the control of electrical appliances and lighting systems, through the use of plug-in switches. These switches can be controlled online and receive their commands through wireless communication from a smartphone or tablet computer. An additional benefit is that such plug-ins allow for the monitoring of energy use. To date, the Dutch energy market is organized in such a way that each energy and gas provider comes with its own specific thermostat system, and similar trends are also seen internationally. Smart thermostats can be preset to have small control ranges, which may be a solution for households with people with dementia (van Hoof et al. 2010a, b). Some people with dementia may have difficulties operating thermostats and may experience thermal conditions differently from healthy counterparts.

In the near future, dwellings are foreseen to respond autonomously to changing weather conditions and at the same time optimize energy use, for instance, by automatically closing windows when outdoor temperature drops or turning off heating when windows are opened. HVAC systems, which can supplement architectural solutions in weather extremes, could be controlled in compliance with personal preferences. Rooms could have individual temperature profiles. Impairment of thermoregulatory functions due to diminished or absent sweating (Foster et al. 1976) is thought to be one of the factors responsible for increased mortality among older adults during hot summers (Havenith 2001; Rutten and Hensen 2002). This is even more critical for bedridden or bed-bound (institutionalized) older adults, whose clothing insulation is strongly increased by the bed and bedding (Mccullough et al. 1987), and, therefore, they need lower ambient temperatures (22.5–25.5 °C) compared to mobile people (Rutten and Hensen 2002). Adequate HVAC systems at home of the frail are of great importance in periods of extreme weather conditions. Depending on the size, effectiveness, and controls of the cooling system, this reduces or eliminates the number of hours with too high indoor air temperature (Rutten and Hensen 2002).

There is no need for prescriptive standards if individual control is provided in order to optimize the indoor environment to personal needs (Fountain et al. 1996). Although passive architectural solutions are preferred to guarantee thermal comfort, rooms of frail older adults may be actively controlled for the "average" occupant (Havenith 2001) based on a PMV algorithm using real-time measured input data. Additionally individuals should be given direct control for fine-tuning environmental parameters, in time supported by intelligent technology substituting frequent user intervention. Easily operable technology, characterizing the future housing of older adults, is expected to increase user autonomy and provide optimum thermal comfort for everyone.

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Part III

Practical Examples and Lessons Learned

House of the Present: Doing Is Believing

Erik Zwierenberg, Evelyn Finnema, Ate Dijkstra, and Robbert Sanderman

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Abstract

The “House of the Present” is located at the NHL University of Applied Sciences in the city of Leeuwarden in the province of Friesland in the Netherlands. It is a 90 m^2 apartment with a kitchen, living room, bedroom, and bathroom. In the “House of the Present” more than 100 objects, solutions, gadgets, and “quick-wins” are presented, which can support elderly people in their daily lives in their own homes. The “House of the Present” is a living lab: a presentation and communication instrument. It is designed to inspire students, professionals, and elderly people to use innovative solutions for supporting “staying at home longer” with the use of technology that lessens the care burden for caregivers, increases the quality of care, decreases the financial impact of care, and increases the quality of life for the elderly. The name “House of the Present” was chosen to reflect the fact that the eHealth and home automation technology and solutions on show are already available today.

The technological innovations in eHealth and home automation services are identified as part of the solution for supporting elderly people faced with the challenge of a changing society. Society is asking the elderly to take on more responsibility. Platform GEEF has been initiated to support elderly people in the choices they have to make about solutions that can help them. Platform GEEF developed the “House of the Present” and related projects in order to reach its goal of supporting the elderly in their own homes.

The information gathered in this chapter provides an idea of what a living lab like the “House of the Present” and its supporting projects can do to support the elderly, nursing assistants, nurses, and caregivers in creating smarter homes equipped to support the elderly in their last years.

Keywords

Home automation • eHealth • Infrastructure • ICT services • Education • Communication • Living lab • Smart home • Deployment

Introduction

The “House of the Present” is a facility built to inspire and help the elderly in Friesland to adapt their homes using modern technology that fits their needs. The elderly population in Friesland is growing, from 115,000 aged 65+ (18 % of total population) in 2012 to 171,000 (26 % of total population) in 2030 (Chorus et al. 2013), and often they have not prepared their dwellings for their needs when mobility or cognitive problems arise. For a few years now, only elderly people with a high requirement for care are allowed to make use of government-supported nursing homes (van Vliet

Fig. 1 Layout of "House of the Present," a semiopen apartment with living room, kitchen, bedroom, and bathroom

et al. 2013). The Dutch government is promoting a policy of the elderly living in their own homes for as long as possible, and elderly people are being held responsible for preparing their environment for those last years and months of their lives. This policy of "living at home as long as possible" is new for Dutch society, and the implications for the elderly are not yet commonly known. With the "House of the Present," this gap in knowledge can partly be resolved. In the "House of the Present," the elderly and their caregivers can learn which modern tools can support them in old age.

The "House of the Present" (Fig. 1) is equipped with more than 100 technological solutions that are on the market today. There is a full-time employee who looks after the technological solutions available in the house, who is in contact with technology providers and gives guided tours and presentations to scholars, students, professionals, and elderly people. Every year more than 1000 people visit the facility and are inspired and learn about smart home technologies and how to improve their home environment for their old age.

The idea for the "House of the Present" originated in 2007 when Platform GEEF[1] was initiated by a care organization and a housing association. The goal of Platform GEEF was to stimulate the use of "standardized" eHealth and home automation technology. The vision behind the initiative is that eHealth and home automation technology can support the elderly in their daily lives at home. Platform GEEF is

[1]GEEF = Gezondheid Expertise en Educatiecentrum Friesland (Health Expertise and Education Centre Friesland)

currently (2015) supported by 16 organizations consisting of local communities, care organizations, housing associations, and educational organizations in Friesland (www.platformgeef.nl). The organization has three main focus areas:

1. Dissemination of the innovative solutions provided by eHealth and home automation via the "House of the Present"
2. Sharing knowledge with its partners about eHealth and home automation technology
3. Initiating projects to support the use of eHealth and home automation technology

Although eHealth and home automation services are evolving rapidly, they are fulfilling needs that have in fact not drastically changed. To gain insight into how ICT solutions (eHealth and home automation) presented in the "House of the Present" fulfill these universal needs of the elderly, we start by categorizing these needs and mapping the ICT solutions that fit these needs.

Structure in ICT Services for Life at Home

To be able to give a coherent guided tour of the "House of the Present," it is necessary to categorize the selected eHealth and home automation products in such a way that visitors understand what need each product addresses. NICTIZ (Nationaal ICT Instituut in de Zorg) described in a white paper (Krijgsman et al. 2012) a practical model for ICT platforms in welfare and care. The service layer of the model is presented in Table 1. This model connects the needs of people to the products that might support them. The four categories briefly explained (see Table 1 for examples) are:

1. *Convenience services* ease the difficult daily tasks. They automate the home, share agendas, and so on.
2. *Welfare services* are a collection of services that support making contact with other people to prevent loneliness and to share experiences, and the support network of friends, family, neighbors, and other caregivers.
3. *Security and surveillance* are services and products that support the elderly, who are often home alone. All kinds of solutions can help prevent being afraid of unwanted visitors with the wrong intentions. This fear of their vulnerability can often lead to resistance for care-at-home on the part of the elderly, when a health care problem occurs and self-support seems no longer possible.
4. *Treatment and care* is a collection of services that supports contact with professional care, and makes it easy to obtain the right medicine and treatment at the right moment. These services support the need for proper care.

When the "House of the Present" was founded, a selection was made of eHealth and home automation technologies to support the elderly, and these were subsequently categorized. With the support of the technology providers, these solutions where incorporated and presented in the house. Each year a selection is made of

Table 1 Categorization of technologies for the service layer of the practical model for ICT Platforms in welfare and care (2012)

Convenience services	Welfare services	Security and surveillance	Treatment and care
Local events calendar	Video communication	Contact alarm	Contact care center
Local radio/ TV	Social network	Fall, smoke, water detection sensors	Contact with medical professionals
Municipal services	E-mail	Emergency camera	Medication counseling/ encouraging medication adherence
Marketplace services	Chat services	Automatic autonomous monitoring	Health sensoring
Delivery services	Good-morning services	Lifestyle monitoring	Shared-care planning
Games	Shared-care agenda	Surveillance cameras	(. . .)
Meals/recipes	Coaching (motion, diet)	Key management services	
Health information	(. . .)	(. . .)	
Home automation			
(. . .)			

6–10 of the newest and most promising products that can be demonstrated, alongside the existing solutions. Products and services that become obsolete or are no longer available or which do not deliver the services or quality expected are removed from the house and no longer presented in the guided tours.

The above categorization connecting the needs and the products that can support them is the basis for the explanation given in the guided tours. In the next section, the target audience for the tours will be described.

The Target Audience for the "House of the Present"

Three kinds of visitors can be distinguished: students, professionals, and the elderly. For each type of visitor, we determined a separate goal.

Students: Preparing for Their Profession

The two universities of applied sciences and the two schools for secondary vocational education in Leeuwarden are using the "House of the Present" in training future nursing assistants and nurses. In the "House of the Present" students can experience and learn which tools they can use to support their future clients. These students were mostly born in the digital age and, as digital natives, should be able to internalize the solutions that are presented and be able to communicate these solutions to their future colleagues and clients. They should become “ambassadors of eHealth and home automation solutions”. Because students are the nurses and nursing assistants of the future, their knowledge and way of working will have a huge impact on the use of eHealth and home automation services in the future.

Nurses and Nursing Assistants: Know-how and Communicating with Clients

Each nurse or nursing assistant serves 5–20 clients on a daily basis. When professionals have developed the right training and skills, client assistance is greatly improved. Unfortunately professionals themselves often feel uncomfortable with eHealth and home automation solutions. Often they have chosen their profession in order to help other people, not to work with technological products. There is a natural resistance toward tools, products, and services that are new and change their way of working. The guided tours in the “House of the Present” focus on the support that technology can provide to professionals and their clients, thus bridging the gap that impedes the implementation of support technology. If the guided tours succeed in spreading innovative solutions and motivating professionals, the direct effect of the tours could lead to a multiplier effect in the communication of these innovations to the elderly and increase effective use of these products.

Elderly: Seeing and Experiencing What Could Be Useful to You and Your Peers

Elderly people often come in groups of 5–15 persons to look at and experience the possibilities that are available in the “House of the Present”. The caretaker of the house explains how each item can be used and tells stories about how other people have benefited from certain solutions. The stories often lead to interesting discussions among elderly people about their own personal experiences. In addition to the guided tour and discussions, they also have a chance to try out each device and see how it works. After their visit, elderly people know what the latest developments and products are that can support them in their daily lives and often state that they intend to buy certain products or that they have seen certain good solutions for their peers.

With this target audience in mind, we will describe in the next sections how to keep the audiences interested during their visit and what will be shown and presented.

How to Interest People in Visiting the “House of the Present”

When the first version of the “House of the Present” was launched in 2007, the initiators expected that people would come spontaneously to the facility, but this did not happen. Currently (2015) there are 1000 people each year that visit the “House of the Present.” To reach this goal, steps were taken to interest the target audience.

Fig. 2 The caretaker presenting the available smart solutions in the guided tour

The four educational organizations that work together in Platform GEEF have adapted their curricula, and all trainee nursing assistants and nurses pay at least one visit to the "House of the Present" during training. Furthermore, professionals in care organizations are encouraged via newsletters to visit the "House of the Present." A third way to encourage visitors is via presentations on location. The caretaker of the house travels to where the participants are located and attends meetings that are organized by municipalities or local organizations in Friesland. These presentations often lead to visits to the "House of the Present."

Housing corporations and care organizations in Platform GEEF often use their own communication channels (newsletters, magazines, and websites) to communicate the possibility of visiting the "House of the Present" to their customers. Another channel that is used to encourage elderly people to visit involves the so-called elderly associations and the Alzheimer's café.

The Guided Tour

There are two kinds of users that can benefit from the eHealth and home automation solutions that are presented in the guided tour (Fig. 2). In the first place, we have elderly people whose needs are fulfilled by the solutions already available. In the second place, there are the nurses, nursing assistants, and caregivers who use the installed technologies to support the elderly. Both viewpoints (elderly and those who care for them) are presented and explained in the guided tours.

A guided tour in the "House of the Present" normally takes 45–90 min. The tour starts at the front door and leads the visitor from the living room to the kitchen, bedroom, and bathroom. In each area certain solutions are available, and these are discussed and demonstrated. The optimal group consists of 5–15 visitors.

The ultimate goal of the guided tours is for people to become aware of the possibilities that are presented and take the necessary steps to make their dwelling, or the homes of people they care for, smarter.

To be able to give value-free information and preclude any commercial end, there are no products on sale in the "House of the Present." Providers of home automation and eHealth services are asked to provide their products for free, with each product being promoted equally. Both the positive and negative experiences with them are shared with visitors to the premises.

The different solutions and how they impact the needs of the elderly will be briefly described below, using the four categories described above. When appropriate, the impact for professionals and caregivers will also be described.

Security and Surveillance

The first element that the elderly consider important is security and surveillance services. Starting at the door of the "House of the Present," (Fig. 3) there are several products that help provide a better feeling of security. When a visitor rings the doorbell, a 180° bird's eye view camera makes it possible to see the visitor at the front door without any chance of someone hiding somewhere near the door, out of view. This solution provides the security of knowing who is at the front door and offers the possibility of either opening the door or recording a visitor for future analysis.

Front door security: The front door can be opened in different (electronic) ways (Fig. 4). It is possible to open the door with a small remote control that can be carried at all times within the house.

Front door app: Employees of homecare organizations are able to open the front door from outside the house via an app on their smartphone. Only nurses who are scheduled to visit can gain access via the app. The nurse's schedule is linked with the app on the smartphone.

Front door listening support: If someone presents themselves at the front door but the elderly person, home alone, does not trust the situation, they can ask for listening support. A connection with a care center can be initiated; there, an operator can listen to the conversation that is being conducted at the front door. Via the audio connection, the operator can explain to the visitor that he or she is monitoring the situation, and, if necessary, the operator can directly contact a police car in the neighborhood to take action.

Fire, water, and gas sensors: With a totally secure front door, the next step in the security and surveillance services is to detect anything strange happening in the house. In the "House of the Present," there are examples of sensors that can detect

Fig. 3 Front door of “House of the Present”

Fig. 4 Front door with electronic key

Fig. 5 Carebelt

flooding, smoke, gas, and more. These devices are connected directly to a care center to ensure fast response, when a problem occurs in the house.

Personal safety sensors: As important as the security of the home is the security of the person living there, should a potentially dangerous care problem arise. In the house there are sensors in the bedroom, bathroom, and so on, which can trigger an alarm. There are also devices like a watch with an alarm switch and fall detection that have the ability to trigger an audio connection to a care center for immediate contact with a nurse, who can give verbal assistance or take action by sending someone to the house.

Geofence and GPS: A relatively new development is the smartphone, or its equivalent, tailored for specific functions. These devices (e.g., carebelt) can generate alarms and transmit the GPS location data along with it. It is often possible to program a *geofence*. If the owner of the smartphone moves outside the programmed area, an alarm is triggered. The alarm can be configured to alert a caregiver or a care center. Several of these devices are available in the "House of the Present" (Fig. 5).

Lifestyle monitoring: More recently, there has been the development of lifestyle monitoring, which is innovative due to the fact that it increasingly makes it possible to rapidly analyze data generated by sensors. There are two types of lifestyle monitoring. The first solution works with five to seven sensors in a house (Fig. 6). These sensors are located in different rooms and measure the activity in each location. The second solution works with a camera. Both solutions analyze

Fig. 6 Lifestyle monitoring

the data generated by these sensors and cameras. The software triggers an alarm if the activity in the house changes from the normal day-to-day activities. If, for example, the inhabitant is visiting the bathroom and does not return within a certain length of time, an alarm is triggered.

Each person experiences various levels of insecurity, depending on their own condition, the house they live in, and other considerations that depend on individual circumstances. Sensors that can detect nearly every kind of security issue are available and can be demonstrated. Once there is a sense of security at home, the next step is getting support for treatment and care at home.

Treatment and Care

Video communication: Care organizations often visit elderly people at home more than once a day and sometimes more than one nurse visits at a time. If, for example, someone needs to take medicine, which can be life threatening if the dosage is wrong, one nurse is not enough. One nurse can prepare the medicine, while the other nurse checks the dosage. With a video connection, it is possible for a second nurse to check the prepared dosage from a distance. In the "House of the Present," devices for video communication are available, and it is possible to give a live demonstration with a video connection to a care center (Fig. 7). Products like the videophone have been developed for those elderly people

Fig. 7 Videophone

who recognize this as an updated version of the fixed-line phones they are accustomed to. The same functionality can be delivered with, for example, Skype or Facetime, but elderly people from another technological generation find these services difficult to use (Rama 2001). Elderly people also often experience cognitive and motor problems like tremors. These problems can lead to difficulties in using technological solutions. For these reasons, products in the "House of the Present" sometimes look old fashioned.

Medicine dispenser: Another solution that is demonstrated is a medicine dispenser. This device delivers the medicine at preprogrammed times and signals when it is time to take the medicine. When no action is taken, the medicine dispenser can send an alarm to a caregiver or care organization.

Uploading blood pressure and weight measurements: With self-monitoring services for blood pressure and body-mass scales, the measured results can be uploaded to a portal monitored by a doctor. This type of device has been around for a while, working with GSM and GPRS, and can be demonstrated. Just recently there has been a switch to apps that connect with external devices for measurements. These possibilities will be demonstrated in the near future.

Fig. 8 Living care platform

Welfare Services

Welfare services are, in general, delivered via a computer or tablet. There are a few providers that have built portals to combine services, such as video conferencing, e-mail, chatting, good-morning "visits," live connections with a church group, games, and scheduling and coaching options (Fig. 8). These portals often depend on the lively support of volunteers, which makes or breaks the success of this solution. A few of these solutions are available in the "House of the Present."

Convenience Services

A broad range of convenience services and products are available these days. A robot can clean the floor and another type of robot can mow the lawn. Other devices are able to determine when to switch the lights on and off or can regulate the temperature at a certain time of the day or week. There are digital marketplaces where you can ask a neighbor for help or ask for a product you want to borrow for a certain length of time. All of these services are available in the "House of the Present." These briefly described devices and services are currently the most important components of a smart home that can support elderly people in living in their current homes as long as possible. In the coming years, a lot of new solutions will be developed and, as soon as they are available on the market, will be presented in the "House of the Present."

From Awareness and Observations to Platform GEEF and its Theoretical Foundation

Around a decade ago Dutch society began changing in terms of how to support elderly people in their final years. The social system became too expensive due to the aging population. The government began a policy of stimulating elderly people to support themselves and began to close expensive elderly homes. The elderly became more and more dependent on their own abilities and power to support themselves. Communities, care organizations, housing associations, and educational organizations were sensitive to the upcoming changes and decided on a joint effort to support elderly people with knowledge about eHealth and home automation solutions that could ease the burden of care by automating certain homecare tasks. They envisioned that a new communication channel was needed to support elderly people in their lives in their own homes. The organizations realized that the challenge was too big to solve alone. The vision to help elderly people organize their surroundings so they support a high level of Health-related Quality of Life (HrQoL) with a reduced need for governmental support was the reason for founding Platform GEEF.

Elderly people are willing to use smart technology to support their daily lives. They require the technology to be reliable, nonintrusive, and to allow them control over their personal information, and they need adequate support for learning how to use the information (Jacelon and Hanson 2013). The technology has to take into account what skills have been developed, along with the cognitive and motoric capabilities available. When the technology delivers what is intended, it then requires communication channels that can support the diffusion of innovation by supporting elderly people through knowledge transfer and providing assistance for the choices they make.

From the diffusion of innovation theory (Rogers 1987), we know how new innovations spread via communication channels. The major explanatory factors regarding the rate of adoption are relative advantage, compatibility, complexity, ability to try the products out, and viewing the products. The first three factors fall within the control of innovators, researchers, and the industry that produces the new innovations and should be judged by them. When the innovations are useful according to the developers, they market these. As for viewing and trying out products, a gap has been identified: for nursing assistants, nurses, caregivers, and elderly people, there was no place where they could view, try out the products, and experiment with those innovations that could support the daily life of elderly people. There was no collection of “best practices” or a knowledge center for this topic that they could visit. Another problem was the technological fear on the part of nurses and nursing assistants, which leads to reluctance to use and communicate to elderly people that there are solutions that could support their daily lives. We also learned that nurses did not know enough about which solutions could support their clients; nurses were found to be reluctant to talk about the options available. In other words, the conclusion can be drawn that although there is a potential communication channel between nurses and clients for home automation and eHealth solutions, this is not working properly for the reasons mentioned above. Another observation we made was that technology providers were unable to communicate about their solutions in terms of the other solutions available so that users would then have a holistic overview of what combination of products and services might work for them. Each provider tried to develop his own communication channel to promote his products and solution. For all of these reasons the "House of the Present," which opened its doors in 2007 in Heerenveen and was moved to Leeuwarden in 2010, was established.

Platform GEEF Initiatives "House of the Present" and Supporting Projects

The "House of the Present" is a unique and visible tool in the communication mix that Platform GEEF developed to enhance the use of home automation and eHealth solutions in the support of the elderly in their own homes. There are three other projects that the participants in Platform GEEF worked on together. The projects initiated by Platform GEEF together with the "House of the Present" are all helping to accelerate the implementation of home automation and eHealth solutions that can support elderly people in their own homes and enhance their HrQoL, with limited use of government-supported care and nursing homes.

To encourage nurses, nursing assistants, and social workers to use eHealth and home automation solutions that can support their work and empower their clients, a project called "eHealth suitcase" was developed. In this project a selection of useful eHealth services is made together with nursing assistants and nurses. The eHealth services selected either enhance their work or can support their clients. Via an e-learning program, nursing assistants and nurses can learn how to use the eHealth solutions in their work (www.ehealthkoffer.nl).

In the second project, nurses and nursing assistants defined three types of elderly people with different levels of care needs. For each cluster of elderly people, solutions were selected, which could support them. The result was translated into a document that nurses could use in communicating with their clients. In the near future an e-learning module will be made available to support nurses in explaining the solutions selected.

In the third project, the municipalities that participate in Platform GEEF have been building an awareness campaign called "My custom home." Part of the campaign is communicated via print media, meetings, and the website: www.mijnhuisopmaat.nl.

House of the Present and Future Research

With the "House of the Present," a facility has thus been created that is loaded with modern eHealth and home automation solutions. In this living lab it is possible to learn what the effects of the guided tours are, and this can be used to do further research on the products that are presented in the facility. Students are working, for example, on research projects that identify missing tools, establish how the presented solutions can work together, and so on.

The ultimate goal of the “House of the Present” is to allow the residents of Friesland to familiarize themselves with solutions that can support their daily lives when they become older. The following questions are the ones asked:

– Are the products and services that are presented in the “House of the Present” supporting elderly people in their daily lives? In other words, do these products and services increase the quality of life?
– Is a guided tour the best way to transfer knowledge to students, nurses, elderly people, and caregivers?
– Are the opportunities to view and try out products provided in such a way that this leads to a transfer of knowledge?
– Are visitors taking steps to support their daily lives by using the innovations they came in contact with during a visit?

Students of the NHL University of Applied Sciences are working on these questions so as to continuously upgrade the quality of information that is being transferred to the visiting guests.

Some Final Thoughts

The “House of the Present” has evolved over the past 8 years. It began with the realization that the Platform GEEF participants were unable to address a social problem on their own. The fact was that elderly people have to remain living in their own homes, even when they need care, without knowing which eHealth and home automation solutions could provide support. With 1000 people a year visiting the premises and together with the other projects of Platform GEEF, the total effort should pay off in a higher quality of life for all elderly people in Friesland and in prolonging the period in which elderly people can remain living in their own homes.

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Smart Home: A Learning and Development Environment

Kari Vehmaskoski and Toni Pekkola

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Abstract

JAMK Smart Home application is a unique concept. It is owned by JAMK University of Applied Sciences and it is located in university campus area in Jyväskylä, Finland. This application and its technical solutions are presented in

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this article. JAMK Smart Home is a real test environment for accessibility and usability for architects and technology providers as well as disabled and aged people. It is also a test environment for the usability of the technology. In JAMK different degree programmes are using it also as a multiprofessional learning environment. This possibility is also offered to other student groups from local schools, when they visit smart home to see what possibilities latest technology has to offer.

Keywords
Smart home • Accessibility • Usability • Learning environment • Test environment

Concepts

As a concept, smart home seems to be rather new and needs further research, and there is a need to collect experiences of end users and their acceptance (Demiris and Hensel 2008).

In the past, different kinds of smart home associations have used definitions where smart home consists of the integration of the technology and services through home networking for a better quality of living. From the literature, it is hard to find the original article or reference for this definition, although it is useful.

Sometimes, professionals in architecture and building industry think about technical solutions only, when they write or talk about smart home. Technical solutions may consist of network, which transfers information produced by smart devices (Ricquebourg et al. 2006). Technology may include sensors and wireless technology. In Northern Europe, this often means computer-based control of temperature, electricity consumption and ventilation, etc. Nowadays, it can also mean safety control with the help of cameras or other devices. First impression of the technical definitions is that the idea of accessibility is not included.

Smart home supports the everyday life of disabled people, thus can be considered as an important area of research. Smart home will also increase the independence of disabled people (Ojasalo et al. 2010). In this case, the idea of accessibility is included to the smart home concept.

Accessibility is also included as one of the functions of a smart home, designed for aged people (Stefanov et al. 2004). Smart homes for disabled people may include small village or society structure, where the use of mobile technology and the Internet has a key role although the users seem to like more face-to-face contacts (Mikkola and Halonen 2011).

In many real-life situations, smart home technology is integrated into normal homes but may be not as widely as described below.

JAMK Smart Home Application

JAMK is a short version of JAMK University of Applied Sciences, in Jyväskylä, Finland. At JAMK and in Jyväskylä Region, there was a need to put up a real environment supporting projects, enterprise cooperation, and student learning. Support from the European Union made it possible to build a smart home to the university campus area. The JAMK smart home is more like a smart apartment, because it is located in the blockhouse bottom floor. Within an area of 89m2, the smart home includes a living room, kitchen, bedroom, and bathroom. Also, the front yard and garden is part of the smart home, because it is necessary to take care of the accessibility within the environment. There is also a storage room and a monitoring room included to the smart home facility from where all the smart home technology and cameras can be operated.

Smart Home as a Technological Environment

The smart home is equipped with various accessible and useable solutions supporting safe and independent living, and there is more to come in the future. Some technologies and devices have been purchased through separate funding, but, since the project, new solutions of the smart home are presented through cooperation agreements with companies. All solutions selected for the smart home are fully functional, and they can be used and tested by the visitors. However, smart home is not an example of a home designed for a single group of customers in real life, which means that smart home also has parallel and sometimes overlapping solutions (Pekkola 2013).

Colors and Contrasts

The design of the smart home aims to take people with visual impairments or perception problems into consideration. With the help of colors and contrasts, for example, it is easy to see where the support handles are in a bathroom and where the line is between the wall and the floor (Pekkola 2013). There are plenty of examples such as this in the smart home.

Environmental Control Devices and Cognitive Tools

In the smart home, nearly everything can be controlled with environmental control devices or remote controllers. The smart home has a “talking” environmental control device transmitter, a transmitter which works with picture buttons and a transmitter with a touch screen; if necessary, these can be controlled with one separate button. The environmental control devices operate using an IR signal, and they make it possible to control home electronics, blinds, lights, kitchen, elevator, doors, windows, and wall sockets, among other things. A robotic vacuum cleaner has also been connected to the environmental control system. As an alternative to the traditional environmental control devices, it is also possible to test iPad control for home electronics (TV, Playstation, radio) and lighting in the living room (Pekkola 2013).

In connection with the environmental control devices, cognitive and communication tools were also purchased for the smart home. On the memory panel next to the front door, one can see if a device (such as the coffee maker) has been left on or if a window has been left open. The connection works with a radio signal between the memory panel and a sensor connected to the device. The same reminder information follows persons outside the home in a key fob so one can easily check if it’s necessary to return to home and turn off the coffee maker, for example (Pekkola 2013).

Among other things, the smart home has a communicator that repeats recorded speech or sound to facilitate communication. The user interface consists of several interchangeable cards, where buttons that repeat the desired message or sound can be defined in different places and under different icons or images. With separate computer software, additional cards can be created. It is also possible to practice communication with the family using a computer or a mobile phone with an easy-to-use user interface (Pekkola 2013). Same solutions are also available as mobile phone applications which make them even more portable and versatile.

The Solutions that Support Safety

The smart home features several safety-related solutions. The most extensive one is the sensor floor, which informs the care personnel or a family member, if something happens to the inhabitant. The sensor floor observes exiting an area, entering an area, getting out of bed, and falling down, and it can also be connected with a nurse call system. The floor operates using capacitive sensors placed under the flooring. The equipment visible to the inhabitant are the skirting boards, which are slightly bigger than usual. As a parallel solution to the sensor floor, the smart home has a movable bed sensor operating with motion detectors, which can be used to observe getting out of bed, exiting an area, entering an area, and falling down (Pekkola 2013). The benefit of this movable bed sensor is that you can take it with you when you decide to move to another house.

With a mobile bracelet, a person can call for help easily and carry out voice communication with helpers, even when moving outside the home. The users can be private persons as well as workers in the health-care sector. The device sends location information automatically to the assistant, a colleague, or an emergency central, which can alert help to the right location. With the safety bracelet, one possibility is that the user can only move in a predetermined area. The device will send an alarm if the user leaves the area. The system includes an RF base station, which can be used to charge the bracelet. The base station also shows when the bracelet is within a range. Alternatively, another safety bracelet solution can be used to monitor the inhabitant's activity and well-being (Pekkola 2013).

The Yard

The passage to the smart home through the inner courtyard of the building is designed accessible. The yard area has two customer parking spaces (large), which are marked as disabled parking. There is a heating system under the paving in the yard, which keeps the yard free of snow and ice in the winter and makes it easier to move around using assistive devices (Pekkola 2013). This is to prevent falling accidents caused by weather conditions during winter. In Nordic countries this is important, because we have hard and long winter.

Customers with impaired vision are guided to the smart home with the help of a sound beacon and the raised figures on the paving, which help in finding the right direction. At the yard it is also possible to practice gardening with the help of raised planters (Pekkola 2013).

Teaching Facility

Due to the educational aspect, there is a teaching facility in the smart home where lectures can be arranged for up to 20 or so people. Contrast has been taken into account in the student seating. A person with perception problems can find a light chair more easily against a dark floor. There are also fixed writing pads on the lecture chairs for both right- and left-handed people (Pekkola 2013).

The teacher's workstation has a desk with electric height adjustment and a saddle chair, which helps in finding an ergonomic working position. The computer has a touch screen, but lecturers can also use the interactive whiteboard if they wish (Pekkola 2013). It is also possible to connect a game console to the whiteboard or use the wheelchair simulator in testing to make the scenery more realistic. Wheelchair simulator is useful when the therapist want to evaluate users' capacity in electrical wheelchair driving or just train those skills before real driving.

The Living Room

In the living room of the smart home, people can play physically active games with game consoles regardless of their level of functional capacity. One can also watch films in 3D, with film theater-quality audio.

In the living room sofa set, the rocking chair and active chair can be distinguished from the other furniture by its color. The seats in the sofa set support the posture and balance the seating pressure. The sofa, the recliners, and the rocking chair also have removable, washable covers with hygiene protection. The active chair assists a person when he or she starts moving, and it can be also used as training equipment to promote muscular strength and balance (Pekkola 2013). A training program, designed by physiotherapists, is already available.

The waste container is also hygienic, because it operates with a motion detector (Pekkola 2013). There is also another waste container that is specially designed for odorless storage of waste materials.

The weather station in the living room describes the current weather with information presented in images and numbers (Pekkola 2013).

The Kitchen

In the smart home kitchen, the height and distance of the cabinets and kitchen island can be adjusted electrically and can be brought close to the user. In addition, the drying and corner cabinets have shelves that can be pulled out manually (Pekkola 2013). This is one example of a solution where the same function can be achieved in different ways.

The extinguishing hood communicates wirelessly with the stove and cuts off the power when recognizing dangerous situations like overheating or flames. The stove is an induction stove with easy-to-handle knobs; it only heats up when an induction stove compatible vessel of the right size is on the stove. It is also possible to prepare food in a combination oven, which includes a microwave oven, a convection oven, and a grill function (Pekkola 2013). Even though this kind of oven saves space and is easy to use by a wheelchair user, it might not be suitable for a person who has difficulties with their memory. When taking the hot food out of the oven, you can set it down on a surface designed for the purpose, located under the oven (Pekkola 2013). Actually, it is possible to operate with one hand.

For storing the food, there is a fridge with drawers and a freezer, both integrated into the kitchen cabinets. The dishwasher is also with drawers and integrated into the cabinets. They are chosen and located in a manner that they are accessible and easy to use (Pekkola 2013).

Small assistive devices can be used to facilitate food preparation and eating. The height of the dinner table can be adjusted electrically (Pekkola 2013). The adjustment can be done with remote control or environmental control system. Seating comfort and ergonomics have been taken into account in the chairs for both the inhabitant and the assistant (Pekkola 2013).

In the smart home, unlike in many other Finnish homes, laundry has also been brought to the kitchen. The washing machine and the dryer have been raised above floor level and brought into an area with more space to work in more ergonomic working positions (Pekkola 2013).

The kitchen has a safety floor with a friction surface, and there are sensors under the flooring that make it possible to observe, if a customer leaves the room or they can send an alarm if the customer falls (Pekkola 2013).

The audiovisual modeling and recording system in the kitchen can be used for purposes such as occupational therapy, where the expert and the client receive feedback in a video format on the client's skill process in preparing food, for example (Pekkola 2013).

The Bedroom

The bedroom has a cork-based safety floor with sensors under the flooring that make it possible to observe if the client falls of or gets up from the bed and moves into the toilet facilities, for example (Pekkola 2013).

The parallel system to the safety floor is the bed sensor which increases the level of security: it monitors the inhabitant's movements with motion detectors and raises an alarm if the client happens to fall off the bed.

The adjustable bed has comfort features as well as various positions for care. This ensures that elderly persons can continue using their own familiar bed, even if they move into assisted living at certain stage of their lives. The bed also has smart bed sensors installed under the mattress, which allows the monitoring of the heart rate and respiration without attaching separate sensors on the person's body. This wireless system is also able to register body movements during the night. This makes possible to analyze sleep and the quality of relaxation. With the sensors, mobile phone, and the mobile application or online service, the inhabitant or the care personnel receives feedback immediately in the morning on how well the inhabitant has slept the previous night. With this solution, athletes and trainers can also monitor the recovery process of an athlete after a performance or training (Pekkola 2013).

It is easy to eat and read in bed with the help of an adjustable bed table. It is also possible to work with a laptop or a tablet in bed by using a separate stand (Pekkola 2013).

The drawers of the bed table open in both directions. This makes the items in the drawers easily accessible when the client is lying down or when he or she is leaving the bed (Pekkola 2013).

A bar to assist in getting up has been installed in the smart home bedroom to make getting out of bed easier. When the client moves out, the bar can easily be taken along, because it does not need to be mounted permanently (Pekkola 2013). There is also another bar installed into the bed side to help the person to get up.

Ergonomic assistance and moving between the bed, wheelchair, and bathroom can be accomplished easily with the help of the ceiling hoist system (Pekkola 2013). The same system can be used to lift the person up from the floor in case he or she falls.

Clothes in the wardrobe are easily available with the electrically adjusted clothes rail. There are also assistive devices for dressing up and taking medication. Someone with a memory illness can even be reminded of taking his or her medication at the right time with a special medication reminder or medication clock (Pekkola 2013).

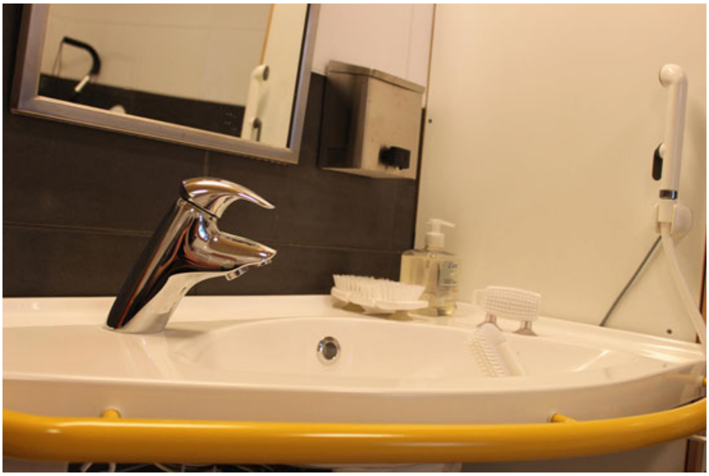
The audiovisual modeling and recording system in the bedroom can be used in teaching situations, where the student receives feedback in video format on issues such as working positions when moving the patient (Pekkola 2013).

The Bathroom

Different users and groups have been taken into consideration also in the smart home bathroom. People with a low vision, issues with identifying and remembering colors due to aging, or other perception problems have been taken into account in the color and contrast choices (Pekkola 2013). One example of this is the different coloring between the walls and the floor. Once this is added, the contrast and color of the fixed handles, the surroundings are easily perceived.

A person using a wheelchair can easily move with assistance from the bedroom into the bathroom with a ceiling hoist system, which can be used to move the person to the toilet seat or into a shower chair equipped with a height adjustment function (Pekkola 2013).

The height of the sink can also be adjusted. Fixed handles have been installed on the bathroom walls to provide support for the elderly. Some of the handles also have a quick release function, which makes it easy to take them along to the summer cottage, to the hotel room, or a visit to friends (Pekkola 2013).



A washing and drying bidet has been installed into the smart home toilet seat as an accessory. With a remote control or environmental control system, the device washes intimate areas when necessary, making the work of informal carers easier. The bathroom also contains a range of small assistive devices for taking care of personal hygiene (Pekkola 2013). The toilet seat lid has been colored yellow with tape to make more contrast to the surrounding environment.

In case of emergency, the inhabitant or customer can call for help by using the nurse call system. This alarm can be received outside the bathroom and is also integrated to the smart floor system.

The audiovisual modeling and recording system can be used in teaching situations, where the student receives feedback in video format on issues such as working positions when providing assistance (Pekkola 2013).

The Monitoring Room

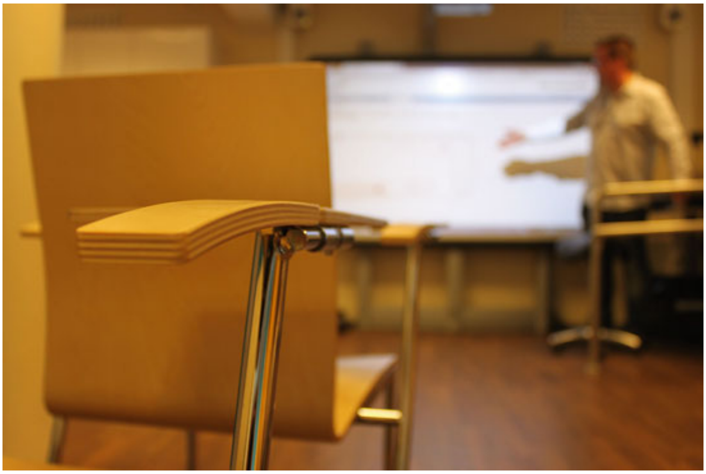
From the smart home's monitoring room, it is possible to control the audiovisual modeling and recording system, which can be used in distance learning, in assessment of the students' skill demonstrations, in different therapy situations, and in product or service development and testing. The smart home has a camera system that covers all rooms for this purpose. In addition, the system includes one movable camera that can be used in various areas. In different kinds of guidance and teaching situations, the person or group working in the area can be given instructions via loudspeakers from the monitoring room, if necessary (Pekkola 2013).

Smart Home as a Learning Environment

According to Ferrari et al. 2009, creativity and innovation are coming more and more important for the twenty-first-century knowledge society. In strategy speeches, creativity, innovation, and continuous renewal are seen as critical success factors and enablers of economic growth throughout the European Union (Lautamo 2013). One practical solution for these efforts is problem-based learning used in engineer education (Vehmaskoski et al. 2007). Training an engineer is a multiple task where varying multiple skills must be developed. Maybe this is not enough, because innovation pedagogy has been highlighted as a method for developing the competence of students. The goal of JAMK University of Applied Sciences is to promote the competences of students in entrepreneurial and international activities (Kantanen 2013).

Kettunen (2009) defines the so-called innovation pedagogy as an operating model based on a social–cultural understanding of learning. Innovation and creativity are in important role in this kind of learning. According to Lautamo 2013, we do not just need individual competence, we also need the development of community competence. As a platform for these kinds of skills and competencies, smart home is ideal, because it offers multidisciplinary environment for project works and examples of practical innovative solutions. Learning through activity has been found to be an efficient way to promote the competencies of students, in a university of applied sciences that combines the application of information with customer situations (Kantanen 2013).

JAMK offers education in engineering but also education in other fields, which can benefit from smart home's solutions: different health and social care degree programs like nursing, social work, physiotherapy, occupational therapy, etc. Smart home functions as a multidisciplinary learning environment for these types of degree programs. Assistive devices for different kind of impairments and simulation goggles can be tested within the smart home environment. With them, the students can learn about the everyday life of a visually impaired person in a homelike environment. The simulation goggles, for example, can also be used to test the usability of different products.



The smart home environment of JAMK has been utilized in international projects of the well-being sector and technology units. For example, with funding from German DAAD, West Saxon University of Applied Sciences and JAMK arranged intensive courses 2011–2013 "User friendly design and innovations for senior citizens." Also, the real-time camera system was utilized in summer courses 2012–2013 with the Utrecht University of Applied Sciences to demonstrate the smart home's operating environment to the participants (Vehmaskoski 2013).

Since its opening, students have had some opportunities to carry out their bachelor's thesis utilizing smart home environment. One example is an illustrated cookbook written in plain language which was created especially for the smart home to make cooking easier, to be used as a support in occupational therapy.

Smart home has made possible for students of JAMK to find a place for their practical training. Due to local cooperation, some companies have even employed students after their graduation due to positive work experience.

Smart Home as an Environment for Development

Obviously, smart home is a meeting place for students, but it is also a showroom for companies and new enterprises and their clients. Original purpose of the JAMK is to develop the client's well-being from a need-oriented basis and to produce entrepreneurship based on new competence (Heimovaara-Kotonen 2014). JAMK has selected technology, which is promoting independent living at home; thus, all companies do not have the possibility to use smart home for their marketing.

The smart home was also built to serve for the development of new technologies and services in cooperation with educational institutions, research institutions, and companies, without forgetting the end users. The smart home facility and the activities established therein will in the future serve to develop user-driven technological applications and cost-effective service concepts.

Some companies may take an advantage of the home environment in testing their new service products (Heimovaara-Kotonen 2014); therefore, smart home is not only a just testing environment for technology. Cooperation with institutional partner Validia has been also important in the development of JAMK's smart home. Validia offers accommodation, rehabilitation, and education services for disabled people. The goal of Validia is their client's independence – also with the help of technology. At JAMK's smart home, Validia has carried out cooperation with JAMK students, lecturers, and clients, for example, in the assessment of housing training.

JAMK's smart home makes it also possible to record and livestream simulation learning, due to its camera system. The camera system makes it possible, for example, to record a client situation or record students' activities and simulate their learning and training during therapy session. The camera system is capable for streaming live feed from smart home via the Internet. The same camera system makes it possible to investigate and evaluate the usability and applicability of existing or new technology and assistive devices. So far, several live video sessions to countries all over the world have been organized.

Good Practices and the Future

JAMK smart home has gathered visitors from all around the world. In January 2014 JAMK smart home received recognition from the Ministry of Foreign affairs in Finland when smart home was invited to an exhibition: “How EU is visible in everyday life of the citizens,” organized by the ministry. During the exhibition JAMK smart home was one of the visiting places of EU road show.

Experiences from the smart home project are utilized when designing the living lab operation to the new Kangas area near the Jyväskylä city center. The Kangas project is the main urban development project in Jyväskylä for the next several decades. Together with the city of Jyväskylä, JAMK is designing the living lab as a part of Kangas area living center for the elderly. The history of the area is around the paper mill which was closed in 2010. After that, the area became a property of the City of Jyväskylä in November 2011 (The Kangas Project 2015) (http://www3.jkl.fi/blogit/kangasjyvaskyla/?page_id=489).

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Networked Seniors

Dov Sugarman

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Abstract

Social isolation and loneliness are increasingly prevalent among older adults in Israel, as in the rest of the world. Loneliness is associated with a wide range of negative physical, emotional, and cognitive effects. This chapter describes the "Senior Network," a pilot program that allows socially isolated older people to participate in social programming from the comfort of their own homes, discussing topics such as current events, religion, health promotion, and music appreciation. The primary goal of this nation-wide program is to reduce loneliness by turning the home computer into a gateway to engagement, intellectual stimulation, culture, and friendship.

Keywords

loneliness • Social isolation • Ageing in place • Socialization • Wellness • Active ageing • ICT for ageing • Social network • Video conferencing • Elearning

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Introduction

As of the end of 2012, the population of Israelis aged 65 and above was 833,000 (Government of Israel Central Bureau of Statistics 2013b). The percentage of elderly in Israel has been stable at about 10 % of the total population since 1995. While this demographic is relatively low compared to other Western countries, it is expected to rise sharply in the coming years. Average life expectancy in Israel is 81.8 years, significantly above the OECD average of 80.1 years (OECD 2013). A very high percentage (96.7 %) of people aged 65 and above continues to live in the community and age in place (Brodsky et al. 2013).

There are two unique demographic factors that characterize the older population in Israel. The first is that 87 % of Jewish elderly 65 and over were born outside of Israel, with 27 % of these having immigrated to Israel in the last 20 years (Government of Israel Central Bureau of Statistics 2013a). This means that the older population is highly heterogeneous, making the development and delivery of culturally appropriate services complicated. The second factor is that nearly 25 % are Holocaust survivors. The average age of a survivor is 79, with over a quarter who are 85 or older (Brodsky et al. 2013). As time passes, the consequences of advanced aging are compounded by the haunting memories of the physical and emotional horrors they endured during the war.

Research has shown that a significant number of older people report that they experience feelings of loneliness with varying levels of frequency. In Israel, 47 % of persons aged 65 and older report that they experience feelings of loneliness (Shiovitz-Ezra 2011). It appears that loneliness increases with age, which is likely due to an associated deterioration in social networks and decreased ability to function independently. Loneliness is a subjective experience which directly impacts on a person's quality of life. Many factors have been identified as contributing to feeling lonely including socioeconomic status, living arrangement, education levels, age, and gender (Sundström 2009).

Loneliness has been shown to have a negative impact on both physical and mental health in older people. Loneliness and social isolation are associated with a range of health issues including heart disease, diabetes, hypertension, depression, cancer, and stroke among people aged 60 and above (Tomaka et al. 2006). Additionally people who feel lonely are 64 % more likely than those who do not feel lonely to develop dementia in old age; in particular, the risk of developing dementia depends on the *feeling* of loneliness and not simply the fact of living alone or being socially isolated (Holwerda et al. 2012) (Table 1).

Table 1 Prevalence of feelings of loneliness over the last week among SHARE participants aged 65 and over (Israel)

Feeling of loneliness	Israel (N = 708)
Almost all of the time	45 (6 %)
Most of the time	61 (9 %)
Some of the time	240 (33 %)
Almost none of the time	371 (52 %)

Background

We are witness to rapid technological developments that potentially may improve the daily lives of people all over the world. However, while most people can take advantage of new technology, elderly individuals are often left out and cannot keep up with the pace and scope of technological changes in society.

In this context, JDC-Eshel, the Association for Planning and Development of Services for the Aged in Israel, set a priority to develop technology-based services for the benefit of the older population in Israel. There are a variety of frameworks and programs in place in Israel to support older people who are aging in place in the community. These include social day care centers, senior clubs, and community centers, among others. All of these programs have among their goals the reduction of social isolation and loneliness among their participants. However, a relatively small number of older people actually avail themselves of these services. According to the most recent data available, less than 20 % of people aged 65 and above participate in these programs. Additionally, when compared to the general population, older people spend more free time watching television and reading and less on attending sports events or visiting the cinema or theater (Brodsky et al. 2013). Possible explanations for this include difficulty with transportation to and from activities, schedule conflicts, physical and/or cognitive impairments that may inhibit participation, and a perception that these activities are not appropriate for older people or do not fit their individual needs or interests.

Our assumption at JDC-Eshel is that it is possible to introduce advanced technologies into the realm of health and social services, thereby improving quality of life by reducing social isolation, promoting wellness, and providing better access to community services, while potentially reducing the cost of services. In particular, we believe that seniors can directly benefit from the use of the Internet, which would enhance their access to health and consumer information, sources of entertainment, and opportunities to socialize online. While on the rise, the use of the Internet among persons 65 and older in Israel is still lower than that of the general population, and the higher the age, the lower the knowledge and usage. While 70 % of the general population uses the Internet, only 39 % of those aged 65–74 do so, with that number dropping to one in five of those aged 75 and older (Government of Israel Central Bureau of Statistics 2013c). By using technology, older people can stay in touch with friends and family, and they can enter into dialogue with past and new acquaintances even when it is not possible to be physically present. We seek to encourage Israeli elderly to become more active online by raising awareness among seniors of the benefits of the Internet and by connecting them with age-appropriate content and online services.

Pre-pilot

The first such service developed is the "Senior Network." The "Senior Network" initially launched as a pre-pilot in 2012, with the name "Virtual Day Care Center," from a senior day care center in a metropolitan setting in the Tel Aviv area and targeted homebound elderly living in the community. Suitable participants were identified and recruited into the program in cooperation with the municipal social services agency and other local senior service providers in the area. Among the target population were former participants in the day care center who were no longer able to leave their home for various reasons and as a result were prevented from enjoying the social activities taking place at the day care center. Our pilot was based in part on a new service being trialed in New York by Selfhelp Community Services called the Virtual Senior Center. That program was launched in 2010 with the support of the New York City Department for the Aging, NYC Department of Information Technology & Telecommunications, and Microsoft, as a mechanism to connect with and engage socially isolated, vulnerable, homebound elderly.

In the first stage of the pilot in Israel, a group of five elderly participants in the community were connected to bespoke activities broadcast out of an office at the day care center. Contact with the participants was established via computer, using "Skype." A key requirement for participation was possession of a computer with a high-speed Internet connection and at least minimal ability to operate the computer. All participants, as well as the session facilitators, had web cameras, microphones, and speakers, to enable them to be fully part of the activities.

Initially programming was delivered twice a week, on Mondays and Wednesdays, between the hours of 11:00 and 12:00. The day care center's social worker and activities coordinator were tasked with facilitating the sessions, which included brain and memory games, guided discussions about current events and literature, and workshops that focused on communication skills, assertiveness, and coping with loneliness, among others. Volunteers from Israel's National Service Program were recruited to provide technical support to the participants in their homes as needed (Fig. 1).

Fig. 1 A participant at home in one of the pre-pilot interactive sessions

After the first 4 months of operating the pilot, it was decided to increase the number of participants by launching a second group and to run the pre-pilot for another 4 months. In an attempt to better utilize day care center resources and to increase the number of participants, each group met once a week, including day care center participants along with the online group members. A large-screen television was installed in one of the activity rooms. Each group consisted of three to five participants at home and three to five participants in the day care center.

Conclusions from the first stage of the pilot were that the program should continue but modifications were required. Overall, the participants reported enjoying the programming content and the opportunity to communicate with others and make new friends. While no one withdrew altogether from the pilot, there were some ongoing issues with attendance due to illness, medical appointments, and other scheduling conflicts. We selected Skype based on its being a universal application, with the idea that once we taught participants to use it, they could expand their usage to include conversations with family members and friends. Unfortunately Skype is not designed for larger group sessions, and there were frequent audio and video quality problems when we had five or more participants. We understood that in order for the service to be feasible for a larger number of participants, a different technology solution would be required. Finally, despite our having recruited participants with basic knowledge in the use of a computer, there were ongoing user issues that demanded a lot of time by the day care center staff and volunteers. More experience is required to help us determine for whom participation in the program would be appropriate.

Pilot

Following the pre-pilot results and in recognition of the fact that Internet-based activities need not be location specific, it was decided to remove the program from the adult day care setting and to recast it into a national operation. The idea was to create an offering that would consist of as many varied activities as possible, at different times of the day, in order to appeal to participants' personal preferences and needs.

With regard to the video conferencing technology, it was decided that a more robust platform was needed. Technical requirements included the ability to share video and other media, to enable as many participants as possible, all of whom would be seen and heard. User-friendliness was also a key requirement. We have decided to limit the groups for now to 12 participants (to enable the most meaningful interaction as possible for each of them); in principle, we did not want the video conferencing solution to create the ceiling on number of participants. Following a review of several leading video conferencing solutions, we selected Watchitoo (www.watchitoo.com) as our technology provider.

In May and June 2013, we piloted two series led by volunteer facilitators. Each series consisted of four weekly meetings of one hour each. The topic of the first series was "Current Events, History and where they Meet," led by a former high school teacher who frequently facilitates discussion groups for seniors in senior clubs. The second series, titled “Health Services – a Peek Behind the Scenes,” was led by a well-known Israeli journalist. Both were attended by eight participants. Our main goals were to test the format, check the usability and dependability of the video conferencing solution, receive input from the facilitators, and obtain initial reactions from the participants.

Following on the success of that stage, we launched a full pilot in the autumn semester. The offering currently consists of six topic-based series and runs between October and January. Initial program activities consist of a series of 6–10 weekly meetings, each lasting 1 h. The series are based on specific topics and are facilitated by a mix of volunteer and paid facilitators, each of whom is a domain expert in their topic. Unlike classic webinar or eLearning formats, sessions are interactive and participatory with a focus on active social engagement by all participants. Sessions are scheduled for morning or afternoon hours. Current programming is limited to the Hebrew language, but we expect to add additional languages such as Arabic and Russian in the future. We also plan to include additional types of activities, such as support groups, armchair travel, and virtual museum-hosted tours. To that end, we are building partnerships with cultural institutions and relevant not-for-profit organizations.

Technical support for the participants is provided by volunteers and family members. Currently we have a technical supporter in each session so that the facilitator is able to focus exclusively on content and group interactions. These technical supporters are able to communicate with any of the participants who might be experiencing technical difficulties, and thus we avoid the whole session being taken off track by participants in trouble. These volunteers have been drawn from a pool of scholarship students in colleges and universities across the country, who are performing community services in accordance with the terms of their scholarship. Training on use of the system for both the participants and the facilitators takes place online via the Watchitoo system. Users are required to have a computer with broad bandwidth connection of at least five megabits per second, web camera, microphone, and speakers. We encourage all participants to use a headset, as it significantly reduces background noise (Fig. 2).

We have marketed the program via a variety of online and offline channels. This has included local web portals for older people and family caregivers. Traditional offline outreach efforts have included articles in local newsletters targeting older people and coverage in national publications read by aging services professionals. Referrals to the pilot have also come from social workers from municipal social service agencies and other local senior services providers. The response from the market to the offering has been outstanding. We limited enrollment to 12 participants in each series and each of the courses is full. Discussions in the series that have started have been animated, personal, and highly dynamic. Moreover, on several occasions, the participants remained online and continued the discussion even after the facilitator left the virtual room. Participants have already begun reaching out to us offering to volunteer to facilitate future series.

Fig. 2 Participants in the "Find the Hidden Meaning in Photos" series

As part of our evaluation of the program, we are tracking attendance via the Watchitoo system. Facilitators submit a weekly journal noting their overall impressions, particular issues, and positive highlights from the session. At the end of the series, we will conduct satisfaction surveys of participants and facilitators to include feedback on the format, quality, and ease of use of the software, effectiveness of the facilitator, interest in continuing to participate, and suggestions for future topics. We also intend to investigate participants' willingness to pay for the service, since the program will need a sustainable business model to reach full rollout (it is offered free of charge during the current pilot). In the second half of 2014, we will perform a formal evaluation of the project, with a particular interest to see if we are achieving a measurable impact in reducing social isolation and loneliness among program participants.

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The Role of Culture in Adopting Smart Home Technologies

Jane Chung

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Abstract

With the increased attention to independent living and healthy aging, smart home technologies are widely adopted in various communities. Technology adoption is a first step to successful diffusion of proven technologies; however, there are still challenges to the adoption of smart home technologies among older individuals or people with disabilities who are a main target user group. Also, there is a growing interest in using smart home technologies in various cultural groups in Western countries and the developing world. However, we do not know what factors

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influence user perceptions of and preferences for smart home technologies in these diverse populations. There is a need for examining the role of cultural context in the acceptability of smart home technology. This chapter proceeds as follows. Definitions of culture and national cultural theories are reviewed. The technology acceptance models and their limitations are discussed in the context of culture and smart home technology. This chapter reviews studies that examine the relationship of cultural factors and technology acceptance in general IT field and health-related disciplines. Then we present a case study as an exemplar to show how the context of culture can be critical to the successful adoption of smart home technology. Finally, recommendations for future work are provided.

Keywords
Culture • In-home sensors • Smart homes • Technology adoption

Introduction

With the population aging worldwide, there has been an increasing interest focusing on how to support the aging population in maintaining health and independence in the community as long as possible. The increased attention to healthy aging recognizes the necessity of adopting smart home technologies into the home or community settings. Smart home technologies have the potential to assess health parameters and deliver care in real-time, accessible, and minimally intrusive way.

Despite advances in technology implementation to facilitate independent living, fundamental challenges to the adoption of smart home technologies still remain among a large proportion of older adults or people with disabilities. Although there have been many efforts to examine what factors influence older adults' perceptions of and intentions to use smart home technologies, much of the research has been conducted in developed Western countries. The feasibility and acceptance among users from various ethnic and cultural groups have not been systematically examined. Given that different groups of people may respond differently to new technology according to their sociocultural context, it is challenging to apply the knowledge on smart home technology acceptance of primarily white people in the Western world to other cultural or ethnic groups in other parts of the world. Therefore, examining the role of contextual issues is necessary to facilitate better smart home implementation that aims to support independent living in culturally various populations.

To date, there have been a few attempts to examine the linkage between culture and technologies for health. Since user acceptance predicts the usage and successful implementation of technology, it is necessary to understand which factors contribute to user acceptance of technology and how cultural differences can determine the level of technology adoption in various ethnic and cultural groups. An understanding of technology experiences among smart home users in the context of culture can provide insights into the knowledge about how to help older individuals from diverse cultures overcome technological challenges and accept technologies proven to be useful and effective.

Technology Adoption

Challenges in Technology Adoption

Information technology (IT) evaluation studies have addressed the importance of technology adoption among users, because adoption is the first step to diffusion of technology that is proven to be effective. The term of *adoption* is often interchangeably used with *acceptance* in IT field. Adopting new technology requires a user's motivation as well as investment in time and efforts to be an adept user. A large number of studies have identified various factors influencing end users' technology adoption including age, education, socioeconomic status, access to technology, attitudes toward technology, or perceived benefits of technology. However, despite advances in technology implementation to facilitate independent living, how to increase technology adoption is still a pressing issue.

Technology Acceptance Models

The Technology Acceptance Model (TAM), developed by Davis (1989) is a widely used framework that addresses the issue of how an end user accepts new technology. The model focuses on relationships among attitudes, beliefs, behavioral intentions, and actual usage. The two main predictors of technology adoption in TAM are *perceived usefulness* and *perceived ease of use*. Davis explained that perceived usefulness is a more important factor than perceived ease of use because users often have a willingness to deal with difficulty of a new system that provides critical functions. In many studies, perceived usefulness is suggested as a strong determinant of an individual's intention to use new technology than perceived ease of use.

TAM has evolved with the efforts to validate and extend the model, and thus, it has been adapted in many ways in different disciplines. Several constructs affecting perceived usefulness are suggested in an extended model of TAM (TAM2), including user experience, image, output quality, job relevance, result demonstrability, subjective norm, and voluntariness (Venkatesh and Davis 2000). For older adults, one systematic review seeks to identify several factors affecting the intention to use technologies that are designed to help older adults remain independently in their homes and community (Peek et al. 2014). These include technology-related concerns, perceived benefits of technology, perceived need for technology, alternatives to technology, social influence, and user characteristics.

Limitations of Technology Acceptance Model in the Context of Smart Home Technology

Over the past three decades, TAM has become one of the popular frameworks in technology acceptance research, yet the model has inherent limitations when we attempt to apply this model to smart home technologies. First, TAM has not specifically focused on technologies used in the health domain. Therefore, when explaining and predicting smart home technology acceptance by consumers, in its generic form, TAM may fail to address unique considerations, such as smart home user need, health status, self-management challenges due to chronic conditions requiring technologies in home, etc. Second, we need to consider features of the home where home-based sensors are installed, which shape user perceptions and behaviors toward smart home technologies. For instance, these technologies are implemented in private residences of users with an aim of 24-h monitoring, which potentially raises privacy and obtrusiveness concerns. Also, individuals who live with sensor technologies in their homes may feel uncomfortable about monitoring personnel or engineers being in the process of data transmission and sharing. Third, given that in-home sensors are put in the home for a long period of time, there is a possibility that user perceptions and concerns can be changed during the technology implementation. It may thus result in a situation in which there is a difference in the level of perceived benefits of smart home technologies before and after the technology implementation. More significantly, TAM may not capture contextual features related to users' intention to adopt home-based sensor technologies, such IT-related policy (interoperability, reimbursement, or regulations), peer influences, access to resources, or sociocultural factors.

The access to emerging and novel technologies is often limited among those who are older and those from racial and ethnic minority groups. Among these factors, cultural factors are not fully considered in the implementation of information and communication technologies for health not to mention smart home technologies. Thus, research regarding cultural issues can enhance our understanding on the pattern of people's behaviors toward new technologies.

Definitions of Culture and National Cultural Theories

What Is Culture?

Understanding the linkage between culture and technology adoption necessitates examining definitions and theories of culture. Culture is defined in various ways according to disciplines. Hofstede (1980), one of the most cited authors in cross-cultural organizational studies, defined culture as "the collective programming of the mind which distinguishes the members of one human group from another" (p. 25). Culture is defined in nursing as "the learned, shared, and transmitted values, beliefs, norms, and lifeways of a particular group that guides their thinking, decisions, and actions in patterned ways" (p. 47) (Leininger 2001). Although there are many other definitions of culture, those definitions converge into one meaning: certain basic beliefs and assumptions commonly shared by members of a certain group.

Culture plays a critical role in forming basic assumptions among a group of people, but at the same time it is shaped by individuals in the group. Culture is not static; rather a lot of internal and external factors transform culture. Culture is manifested through attitudes, beliefs, customs, norms, and other psychological constructs, consequently defining the way in which human behavior is governed such as rituals, rules, and laws. Cultural manifestation differs according to the levels and types of groups, which are categorized by age, ethnicity, gender, nation, organization, profession, etc. Culture is reflected in certain artifacts, art, books, costume, music, and technology. Given that technology is not culturally neutral, people's behaviors and reactions toward technology vary according to their culture. Therefore, examining cultural issues helps to facilitate better IT research and implementation that aims to support the application and diffusion of technology in various cultural groups.

Theoretical Approaches to Culture and Technology

National Cultural Values

There have been considerable interests in culture theories to explain an end user's intentions and behaviors related to technology adoption and usage. In a number of IT studies, culture is often operationally defined at the national level. There is a criticism that cultural heterogeneity among individuals from a country is sometimes greater than intercultural heterogeneity (Lee et al. 2007). Nevertheless, this chapter discusses culture at the national or ethnic level, assuming that individuals in one country or ethno-cultural group show similar patterns of cultural profiles.

Hofstede's Cultural Dimensions Theory

Among several national culture models, Hofstede's *Cultural Dimensions Theory* has been widely used in cross-cultural studies. Based on a study with 116,000 IBM employees from more than 40 countries, he identified four dimensions as a framework of national cultures: (1) individualism vs. collectivism, (2) power distance, (3) uncertainty avoidance, and (4) masculinity vs. femininity (Hofstede 1980). The dimensions are recognized as useful for investigating cross-cultural issues in communication and organizations. This section briefly summarizes each dimension and relevant studies as to how people in each cultural dimension respond to a new technology.

First, *individualism* vs. *collectivism* refers to the degree to which an individual puts emphasis on his or her own needs over group needs. An individual with higher individualism tends to perceive him/herself as "I" rather than a group and behave as an individual, while a person in collectivism considers cohesiveness and loyalty more importantly. Compared to the collectivism culture in which collective decisions often result in delayed technology adoption, new technology is more likely to be acceptable in individualistic countries (van Everdingen and Waarts 2003).

Second, *power distance* is the extent to which individuals accept the fact that there are large differentials of power and inequality. High power distance is characterized by centralized decision-making and the use of formal rules. Individuals in cultures of higher power distance accept that their superiors have more power. Due to hierarchy, individuals are often reluctant to share information and suggest innovative ideas to solve problems or develop strategic plans in their organizations. For the same reason, adopting new technologies might not be easy in this culture.

Third, *uncertainty avoidance* is the level of avoiding unnecessary risks, which can be characterized as an uncomfortable feeling caused by ambiguous situations. Many people are often unwilling to accept innovations and tend to adopt innovations that are already proven to be effective in other organizations. Therefore, individuals in a higher uncertainty avoidance culture are more likely to resist adopting novel technologies (Abdulrab 2011).

Fourth, *masculinity* vs. *femininity* refers to culture differentiation according to the level of preferences on masculine or feminine goals and attributes. Individuals from masculine cultures are likely to put more value on achieving work goals such as competition, ambition, material values, and performance achievement. On the other hand, in feminine cultures, personal goals are more pursued including warm personal relationship, comfortable work environment, equality, and quality of life (Srite and Karahanna 2006; van Everdingen and Waarts 2003). Therefore, in masculine cultures, adopting innovations that are considered to help achieve work goals is easier compared to feminine cultures.

Later, results from several surveys conducted by other investigators lead to the addition of two more dimensions to his model: (1) *long-term orientation* vs. *short-term orientation* and (2) *indulgence* vs. *restraint*.

Despite its extensive use, Hofstede's theory has been criticized for some reasons. First, his study was conducted in various countries, but it only included employees from a single organization. Gallivan and Srite (2005) pointed that cultural representation by the employees might be the unique characteristics of the organization. Second, it is uncertain that employees were representative of the cultures in their own countries (Gallivan and Srite 2005). Third, a group of people scoring high or low on dimensions did not have the same level of cultural characteristics of those dimensions (McCoy 2002). Despite the criticism, Hofstede's approach is arguably the most widely used framework of national cultures.

Hall's Culture Classification

The second model regarding national cultures is Hall's culture classification (Hall 1983). The first classification, *context culture*, refers to a preferred speaking style to convey meaning in usual communication. According to this model, people in high-context cultures (e.g., Japan, China, and Italy) prefer indirect communication and use a few words in which they can easily identify contextual meaning of the communication. In high-context cultures, interpretation depends on implicit information. In contrast, individuals in low-context cultures (e.g., Germany, Switzerland, and Austria) tend to depend on direct communication and explicit information.

The second distinction is *monochronism* vs. *polychronism*, which refers to attitudes toward the use of time. The tendency of individuals in monochromic cultures is to plan ahead and perform one task at a time. On the contrary, people from polychromic cultures do many things at once and they are less likely to be punctual. One study supports this model by showing that individuals from low-context and monochromic cultures had a higher rate of technology adoption than those from high-context and polychromic cultures (van Everdingen and Waarts 2003).

Limitations of National Cultures

We have reviewed two national culture theories that have been widely used to explain technology adoption in the context of culture. One thing to remember is that national culture is not the only factor explaining technology adoption at a national level. It is necessary to consider other national-level factors such as economy, political situation, government regulations and laws, and physical distance from the origin of technology when examining technology adoption in any country (Press et al. 1998).

Need for Considering Cultural Factors

As described above, culture substantially influences the way technology applications are designed as well as how they are received by users. In order to appropriately design, develop, and apply smart home technologies, it is necessary to meet the needs of different target individuals from various socioeconomic and cultural groups, given that the access to these technologies is often limited among older adults who are from racial and ethnic minority groups or who live in developing non-Western countries.

Many researchers and clinicians seek to identify facilitators and barriers to the adoption of smart home technologies, but the majority of smart home project participants are members of highly developed countries. If we simply transferred the knowledge on technology acceptance obtained from these studies to other ethnic and racial groups, this in turn might serve to obscure the real reasons of adoption and utilization of smart home technologies. Given that culture and people interact each other reciprocally, examining cultural factors provides plausible explanations as to why it is often challenging to implement technology transfer from developed societies to developing countries or simply from one culture to another.

Examinations of Cultural Influences on Technology Adoption

IT Field

Many information systems researchers have studied the concept of national cultures associated with a user's response to technology. Gallivan and Srite (2005) reviewed studies on cultural issues in relation to technology adoption. In their review, about 20 out of 56 studies employed a theoretical framework of national cultures to examine technology adoption and usage of IT professionals from different countries. The most frequently used model was Hofstede's cultural dimensions theory. The authors also found that a large number of studies compare individuals or organizations from various countries or apply an existing theoretical framework of national cultures developed in one culture to another culture.

Srite and Karahanna (2006) conducted two studies to examine how national cultural values categorized by Hofstede's framework moderate the relationships between elements in the TAM. Data were collected from students from 30 countries at one college in the United States. The target behavior was the use of personal computer and personal digital assistants. For individuals from feminine and high uncertainty avoidance cultures, social norms were found to be a stronger determinant of intended behavior. Masculinity or femininity cultural values did not have a moderating effect of perceived usefulness on behavioral intention, but the values moderated the effects of perceived ease on behavioral intention.

Ezezika and his colleagues (2012) identified cultural issues as critical to supporting the successful diffusion of biotech for agriculture (agbiotech) among farmers in sub-Saharan Africa. The authors, through interviews with agbiotech stakeholders, found that women's opinions are not reflected in decision-making about purchasing agricultural products although women are key agriculture personnel. Thus, encouraging women's participation in decision-making is suggested as a critical factor in successful agbiotech adoption.

Health-Related Field

In health disciplines, a few studies have investigated the acceptance of health information technologies among health consumers from various cultures.

Jen and Hung (2010) investigated how family's intentions in adopting technologies for aging could influence their older adult's use of mobile healthcare service in Taiwan. One of the interesting findings is that Taiwanese family's attitude plays a significant role in adoption of mobile healthcare services by older Taiwanese individuals who are in need of affordable and accessible long-term care.

Shore et al. (2008) examined the interaction between an interviewer and American Indian veterans during telepsychiatry services. In this study, the authors assessed how culturally competent interactive videoconferencing was as a tool for assessing psychiatric symptoms and clinical interactions. The study found that American Indian veterans see telepsychiatry interviews as culturally acceptable. However, a few participants indicate that lack of exposure to technology or lower comfort level with the technology might be a barrier to technology-based therapeutic interactions. Even though this study measured user's satisfaction as the degree of technology acceptance, questions about intention to use of telemedicine and those about comfort level with using video system for the interview reflected the TAM's construct of behavioral intention.

Similarly, in a study of Lopez et al. (2011), satisfaction with real-time telemedicine consultation was surveyed among rural residents in Colombia. About 40 % of participants answered they perceived easiness when talking to telemedicine provider and want to use telemedicine again. Despite the latter two studies did not specify cultural factors affecting the use of telehealth in Indian people or Colombians, study findings may indicate the potential influence of culture on the acceptance of telehealth.

In sum, many studies reviewed in this chapter do not focus on national cultures or cross-cultural differences in perceptions of and intention to adopt new technologies. Given the lack of such investigations, there is a need for considering the context of culture to better understand the complexity embedded in people's perceptions of and preferences for smart home technologies among diverse groups of users. Moreover, it is necessary to conduct an ethnocentric inquiry that uses existing national culture theories to test them or develop a theoretical model of incorporating contextual factors with regard to better explicate the process by which new technologies for smart homes are adopted by users.

A Case Study: In-Home Sensors to Monitor Activities Among Korean American Older Adults

The following section shows an example of smart home implementation in residences of Korean American older adults and describes key characteristics of socio-cultural context that were identified as factors influencing perceptions of and intentions to use smart home technologies among these people, such as perceived usefulness and willingness to purchase a technology. The following descriptions do not provide an exhaustive list of cultural factors, and they will continue to evolve as further cultural investigation is sought with regard to smart home technology adoption. Please note that the extent to which any one of these factors affect the way people perceive and behave toward smart home technologies will vary depending on the context, purpose, and participants involved in the technology implementation.

Overview of the Project

A smart home project was implemented in a group of Korean American older adults in 2013–2014 as a result of collaboration between the University of Washington School of Nursing, College of Engineering, Korean American elderly associations, and Korean American churches in the greater Seattle area in the United States. To the best of the author's knowledge, This is the first documented attempt to use smart home technologies for an Asian ethnic group.

Smart home project participants were independent and mobile, free of assistance from others, except for one man who was diagnosed with Parkinson's disease. The home-based sensor networks were installed in the private housings of elderly residents who volunteered to participate in this project. This project was focused on ambient monitoring, without requiring residents to wear any sensors or use other devices. The system consisted of a set of passive infrared motion sensors, a water consumption sensor, a laptop, a wireless Internet router, and a receiver. Motion sensors were installed in every place of the household such as bathroom, bedroom, living room, kitchen, dining room, and entrance to detect whether there is a movement in the space. The water consumption sensor was installed in the bathroom (Fig. 1).

Fig. 1 Motion sensor in the bathroom

Mrs. Kim, a 75-year-old widow, decided to participate in this project because she felt loneliness and lack of support from her adult children and also because her friends in a silver college persuaded her to be a test user of in-home sensors. Although she was an active participant showing enthusiasm about the research project, she sometimes said that she would not be in the study if her children visited her often and took care of her. As an immigrant who came to the United States just 5 years ago, she was considering an option to go back to Korea as a result of limited interactions with her children. One day, she talked about her opinion with a little bit of hesitance that she is not a big fan of novel sensor technologies and showed an uncomfortable feeling about the laptop and router placed in the living room. After several weeks, during an interview, she confessed why she was uncomfortable about the sensor system. It was due to a negative response of her son who visited her but could not foresee the value of the technology (Fig. 2).

In contrast, Mr. and Mrs. Hur, who immigrated to the United States 35 years ago, enjoy hiking and singing. They were active participants of church activities and community involvement. Their children were born in the United States and not fluent in speaking Korean. Mr. and Mrs. Hur, who regard independent living as what they should do as an older individual, showed interest in sensor technologies at a recruitment session as a tool for health management. Through regular meetings of senior associations, they learned how to use a computer and the Internet. It encouraged them to get interested in new technologies and become a smart phone user. After being enrolled in the project, they wanted to see their in-home activity data obtained from sensors and expressed a willingness to purchase smart home technologies if the technologies were affordable.

These two cases illustrate how members of one ethnic group respond smart home technologies and several cultural factors interplay in determining perceptions of smart home technologies. Based on the exemplar, cultural and contextual variables are identified below that could potentially affect the acceptability of the technology. It is important to note that not all the factors are derived from the cases (Fig. 3).

Fig. 2 Water consumption sensor installed under the bathroom sink

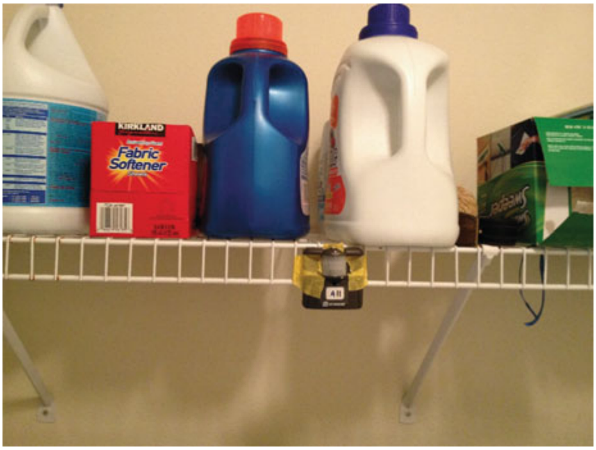

Fig. 3 Motion sensor in a laundry room

Cultural Factors Identified as an Element of Smart Home Technology Acceptance

Factor 1: Sociocultural Norms of Living Independent

Different cultures hold different norms around living arrangements of older individuals. The difference can easily be observed between Western and Eastern cultures. For instance, in some cultures like East Asian countries, it has been the norm for a long time that older adults reside with their married children. Adult children are expected to take care of their elderly in an effort to repay parents' efforts and sacrifices. This is called as the *norm of reciprocity*, based on the notion of filial piety. Such a norm can be a major challenge to promoting technology use for older adults. Older people may feel abandoned by adult children when children decide to have smart home technology in homes as a tool for continuous monitoring health of older adults. Similarly, children may have a guilty feeling that they cannot meet the expectations of parents by allowing technologies to replace family-based care or social contact for the older adults.

Weakened family ties could be a strong motivator for smart home use by older adults. Because of social changes such as industrialization, low birth rate, urbanization, or weakened filial responsibility, changes are made in family structure in some Asian countries. Thus, older adults willingly or unwillingly accept the situation in which they live alone or with a partner but with a lesser expectation of getting care from children. The sociocultural change in modern world can be a factor influencing older adults' acceptance of smart home technologies. On the one hand, older persons who feel lack of support from children may support the idea of adopting technologies in the home setting, which can help to maintain their health, such as technologies for monitoring their health parameters or communicating with their healthcare providers. On the other hand, acculturated elderly immigrants accept their current living arrangements – living alone or separately from adult children after their immigration. Consequently, they are less enthusiastic about adopting sensor technologies in the home setting.

Factor 2: Cultures of Community

In some cultures, decisions regarding whether purchasing smart home technologies are greatly influenced by their community's attitudes toward those technologies. The decision to live in a home where their health and behaviors are monitored by sensors is subject to not only the individual's but their care providers' (physicians, nurses, social workers, and physical therapists), peers', or community members' views on the usefulness of smart home technologies.

Another important consideration is the extent to which how a group of people defines wellness or healthy aging. Do people consider longevity important? Do they value healthy behaviors for disease prevention and health promotion? Because the aim of using smart home technologies is to promote safety and healthy aging in the home or community setting, perceptions toward healthy living through home-based sensors may determine the level of perceived usefulness and intention to adopt smart home technologies.

Factor 3: Family Value

It is often difficult for older adults to make a decision about adopting smart home technologies if they are unfamiliar with independent decision-making or if the technology is expensive. For instance, older adults have a cultural background in which the family has a duty of providing care to their elderly member including expense payment; thus, the increased cost of healthcare for elderly often becomes a financial burden for the family. Thus, the family may not be able to afford the technology or may not have a willingness to purchase the technology for their elderly due to a financial reason. Determining whether these smart home technologies are acceptable requires assessing the family's value of the user, given that there are accompanying costs related to smart home technologies – system itself, maintenance, monitoring personnel, etc.

Factor 4: Context of Place

Where they live or where they are originally from determines the level of knowledge and perception of smart home technologies. In countries with strong IT development, people are likely to have a high level of motivation to adopt innovative technologies regardless of their age. For example, in these countries, new IT products are advertised through media frequently and thus permeated through the society. Also, IT infrastructure is well equipped, such as Internet connectivity, quality service for the operation and management of technology, hardware, and software, resulting in reduced barriers to active adoption of technologies for health. In addition, it is natural for citizens of these countries to expect governmental efforts to expand the access to health information technologies or smart homes. They may have a lower level of fear or concerns about novel technologies.

Conclusion

With the increased interest in adopting smart home technologies for aging in place, the role of cultural factors needs to be addressed to identify facilitators of and barriers to adopting smart home technologies among people in a particular culture. It ultimately will help achieve greater acceptance of technologies that are believed to be effective for supporting independent and healthy living. When considering the use of sensor-based monitoring technologies in homes, it is important to remember that factors affecting smart home user's acceptance extend beyond the personal realm. Without considering cultural differences, it may not be possible to simply transfer knowledge on smart home technology acceptance developed in one culture to another culture. We may not succeed in designing technology applications to meet the needs of various groups of users. Due to the significance of patient-centered care, it is necessary to develop a new theoretical framework that addresses the role of culture in achieving greater adoption of smart home technology. This model will facilitate better understanding on how to meet consumer demands and reduce concerns regarding the technology while implementing the technology for individuals from multicultural and ethnic groups.

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Promotion of Rehabilitation Practice for Elderly People Using Robotic Pets

M. Naganuma, E. Ohkubo, and N. Kato

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Abstract

Trial studies of the application of robotic pets in therapeutic rehabilitation at several hospitals and geriatric nursing homes are ongoing. In these settings, a variety of robotic devices have been introduced and implemented, mainly for physical rehabilitation. In contrast with rehabilitation using living animals, robotic animals have advantages in that they avoid the problem of infection, can be controlled, and can sense and record healthy human states in conjunction with information communication technology. The key issue in the promotion and

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successful completion of rehabilitation by older people is how to cultivate feelings of self-efficacy. With this in mind, this chapter describes the results of a study with two aims: first, to introduce a feeling of play and games and, second, to reverse the participant's role from passive to active by giving them control over the robot rather than it being controlled by a therapist or operator. The robotic pet used in this study was the Sony AIBO, and all other components used were commercially available, allowing the easy implementation of these activities by any interested medical or welfare institutions.

Keywords
Robotic pet • Rehabilitation • Dementia • Nursing home

Introduction

Interactions between robots and older people produce effects in the physical, mental, and social domains. Although industrial robotics technologies are being applied in the physical domain to provide assistance with walking, bathing, and other daily physical activities, research on the application of robotics in the mental and social domains has been limited. Recently, robot-assisted activities and therapy have been receiving considerable attention in all three domains (Shibata 2004; Tamura et al. 2004; Ohkubo et al. 2006; Naganuma et al. 2008, 2013). One issue in robotics research is how to make the robot show elements of a living creature. While there is a long history of research on animal-assisted activities and therapy, which has accumulated substantial findings on its utility and effectiveness, this practice has some limitations. These limitations arise from the fact that the animal is a living creature and therefore poses problems of infection, feeding and excretion, and the need for a handler. In addition, we must be mindful of animal conditions and animal abuse. Because these problems can be avoided when the animal is replaced by a robot, we have been conducting studies on robot-assisted activity to overcome the limitations of animal-assisted therapy (Ohkubo et al. 2003). The present study used Sony AIBO doglike entertainment robots with onboard wireless LAN equipment and evaluated their possible implementation in robot-assisted therapy.

Promotion of Exercise by Introducing an Element of Fun

Rehabilitation of paralyzed persons, such as after brain hemorrhage, normally consists of repeating exercises. These exercises can be painful and may cause them to react negatively to the rehabilitation program. Physical or occupational therapists can provide encouragement during these exercises, but in a rapidly aging society like in Japan, provision of such dedicated person-to-person care will become increasingly difficult. Machine-assisted rehabilitation is one approach to reducing the amount of labor involved in care; however, it is not always enjoyable.

Fig. 1 The "AIBO Derby" game using AIBO robotic dogs

Here, we propose the concept of robot-assisted rehabilitation (RAR), in which a robot is used instead of a simple machine, with the aim of increasing the willingness of participants to engage in machine-mediated exercise.

As an example, Fig. 1 shows a robot walking game called the "AIBO Derby" that uses the AIBO robotic dog manufactured by Sony Corporation. The robot is programmed to chase after pink-colored objects. Four AIBOs are placed at a starting line, as in a horse race, and they "run" on a course prepared on a table-tennis table toward their "owners." Participants hold and show a pink ball to their own AIBO to prompt it to walk toward them faster. Competing in the race leads to positive feelings among participants, and most of them are unconsciously doing physical exercise through standing, holding the ball, and waving the ball as a stimulus. In this exercise, not only are the desired physical effects produced, but participants' socialness is improved as well through mutual communication during the game.

Promotion of Exercise Using a Therapist-Controlled Robot

Rehabilitation Using a Robot as a Gaze Target

Since a robotic pet is usually not encountered in an older person's daily life, it can serve as a strong gaze target. This principle was applied to improve spatial recognition ability in persons with unilateral spatial agnosia. Figure 2 compares the trajectory of an individual's head movement during rehabilitation with and without a remote-controlled robot. Spherical markers were applied to the participant's

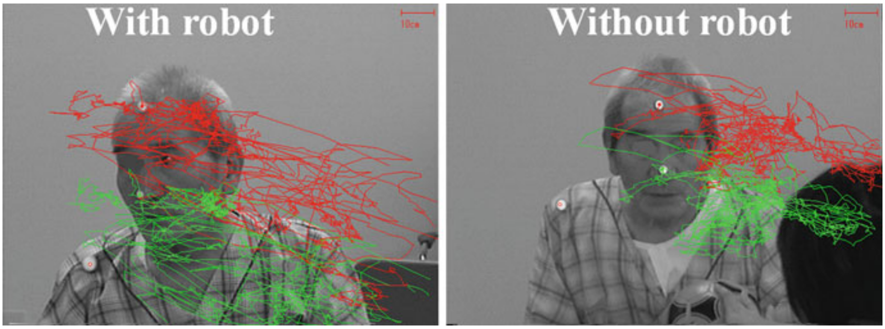


Fig. 2 Motion tracking of a participant's head. *Left* exercise using a remote-controlled robot *Right* conventional exercise

forehead and nose, and an infrared video of him during rehabilitation exercise was produced. The movement of his head was analyzed using motion tracking software, and the resultant trajectories were overlaid on the last frames of the produced video, which is shown in Fig. 2.

The right and left panels correspond to rehabilitation using conventional instruments and an AIBO, respectively. In rehabilitation without a robot (Fig. 2, right), the occupational therapist instructed the individual to transfer a small prop from his left side (with intact recognition) to his right side that was affected by spatial agnosia. In rehabilitation with a robot (Fig. 2, left), an AIBO was controlled remotely by an operator using vender-supplied software (AIBO Navigator 2 and AIBO Entertainment Player) to guide the attention of the individual from the left to the right side. AIBO sends stimuli to the participant by raising its forelimb, shaking its head, or barking on the left side of the participant and then moving to the right side to keep his or her attention. As shown in the figure, AIBO succeeded in guiding the movement of the man's head to the right side, implying that it attracted his attention more easily than a simple transfer exercise. The trajectories with and without the robot were integrated with respect to time to give the total movement. A comparison of the distances is shown in Fig. 3. Total movement during a 12-min exercise with AIBO reached as much as 4 m, representing a 30 % increase over conventional exercise.

Rehabilitation Exercise Using a Therapist-Controlled Robot

Compared with the insufficient AI technologies that exist currently, remote-controlled robots have been found to be effective in aiding rehabilitation, as shown above. However, a robot operator as well as a therapist or other intervener is needed in such forms of therapy. Moreover, the shortage of caregivers can be problematic. To address these issues, we developed a simple handheld operation console for use instead of the standard personal computer console to enable the therapist to take direct control of the robot during the rehabilitation therapy.

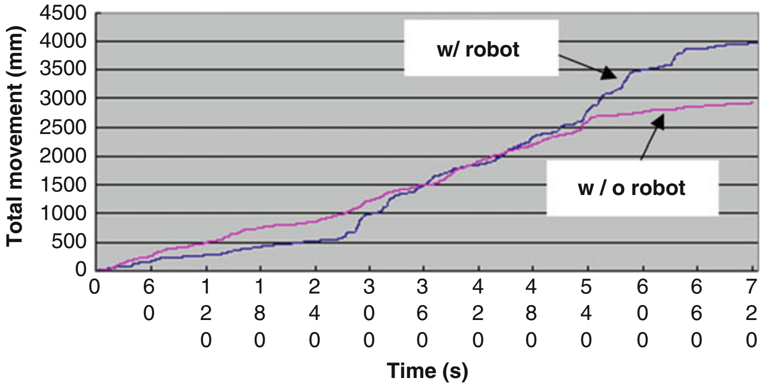


Fig. 3 Total movement of the participant's forehead

Fig. 4 Remote control system developed for use by the therapist

A schematic of the developed remote control system for therapists is shown in Fig. 4. Fifty-two motions were categorized into seven groups corresponding to seven pages of a Web-style console with a touch screen input device, as shown on the left-hand side of Fig. 4. Double tapping a command twice with a finger or stylus would issue the command to AIBO via a direct, server-less system. Moreover, a simple categorized log of the participant can be recorded with a single tap simultaneously along with sending of a command.

Preliminary results using this system at three geriatric nursing homes are shown in Fig. 5. The results were divided into three simple categories: (1) the participant moved physically in response to AIBO (pleased reaction), (2) the participant remained still but showed a pleasant reaction (fun), and (3) the participant showed no reaction (no response). From the results, it can be inferred that the average activity level of residents at a nursing home clearly depends on their average care degree, as

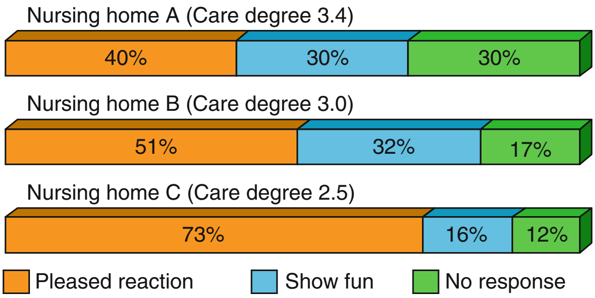


Fig. 5 Evaluated reaction of subjects at three different nursing homes

designated and approved by the relevant public office. Activity levels ranged from 1 (lightest) to 5 (heaviest), and an increase of 0.9 in the degree of care resulted in a decrease in the activity level by a factor of 2.

Rehabilitation Exercise Using a Participant-Controlled Robot

In this section, we discuss an approach to rehabilitation exercises for walking, using the arms, and manipulation with fingers, using a setting in which the participant either walks with a robotic dog or directs it to walk. The key concept is the reversal of the actor and object in assistive technology (Naganuma et al. 2013). More specifically, the goal is not for the machine to act on or carry out an action for the operator; instead, he or she controls the machine and thereby unconsciously engages in the rehabilitation program. In this case, the motivational force for continuing the rehabilitation exercise comes from the participant's feeling of self-efficacy as well as from robotic stimuli.

Experimental Setup

An experimental trial system in which an older person with dementia operates a robotic dog was established, consisting of three elements: a human interface device (HID), the control server, and the robot. It should be noted that because the AIBO robotic dog is not a simple walking machine but behaves like a living dog and also speaks basic sentences, participants tend to have a feeling of empathy toward it when petting it before rehabilitation. To ensure participant mobility and safety, data transfer between the elements was conducted mainly using conventional wireless systems such as Bluetooth and wireless LAN. Because of the advanced age and mild dementia of the participants operating the dog, the control method needed to be very simple. The block diagram of the proposed system is schematically shown in Fig. 6. All the components were commercially available.

Three types of HID were employed: a handheld accelerometer, an electronic balance board, and a touch panel. The first two HIDs were video game input devices manufactured by Nintendo and are safe, robust, and cheap. The signal from each

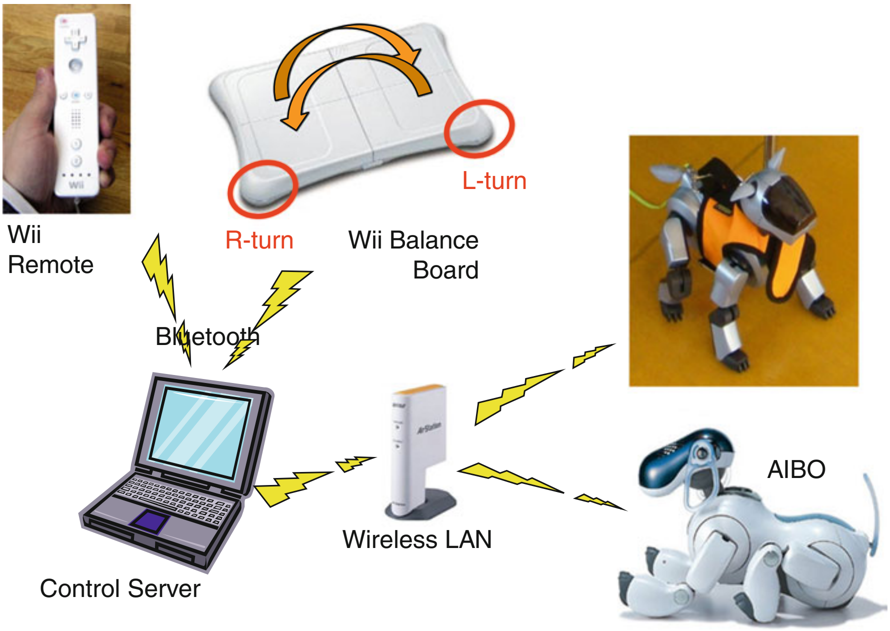


Fig. 6 Block diagram of the proposed system

HID is sent to a server and converted to a gait signal that is then sent to the robot. When the accelerometer is held by hand or attached to the torso, the robot's gait is triggered by the participant's motions. The touch panel HID was used in two modes. In one mode, the participant's finger stroke on the panel is sensed as a straight backward/forward motion or as a clockwise/counterclockwise arc, directing the robot in the corresponding direction. In the other mode, the participant points to the written characters "back," "forward," "right," and "left" to direct the robot. Lastly, when the balance board was used, the participant's steps on the board were used to direct the robot. Whether the participant makes a step or not was determined from the measured movement of their center of gravity, as calculated from weight sensors at the four corners of the board. The conversion from the steps of the participant to those of the robot is tunable. For each of the HIDs, the numerical data sensed by the device and the converted gait command was recorded every 100 ms on the server's disk for later analysis.

Participant-Directed Control with the Accelerometer

When using the acceleration sensor, the participant's motion causes the robot to move and the person then follows the robot, as shown in Fig. 7. This feedback cycle could sustain continuous walking with the robotic dog, providing the conversion ratio of the signal intensity sensed by the HID to the number of steps of the robot was

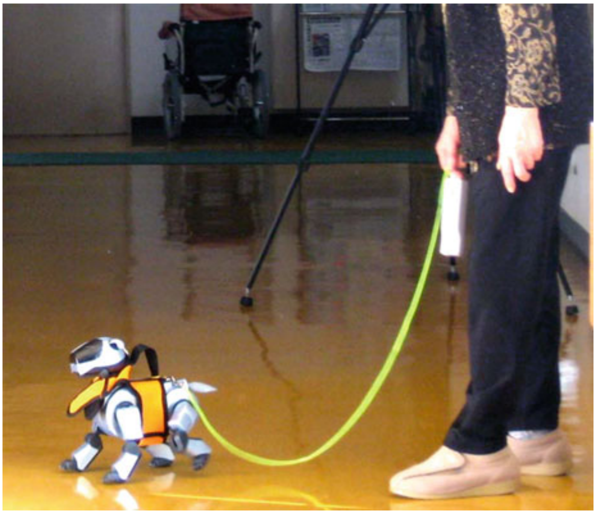


Fig. 7 Walking with the AIBO robotic dog, using the accelerometer

adjusted appropriately. A substantial number of the residents in the nursing home were accustomed to walking with a living dog before moving into the home, and the topic of their own dog came up routinely in dialogue during the walking exercise. Thus, in-house walking with the robotic dog appears to be helpful for reminiscence therapy. The AIBO's gait speed is not very high, so this form of rehabilitation therapy is good for older people who have difficulty walking.

Participant-Directed Control with the Touch Panel

Figure 8 shows the locus of finger strokes on the touch panel. A guideline and circle are drawn on the panel for the participant's convenience. The extent of deviation from the drawn line and circle depends on the participant's level of physical function. The deviation was about 1–3 cm, which is more than three times that of elementary school children. A number of participants could control the robot more easily and made fewer mistakes when they pointed to command characters written on the control panel. This shows that older people with dementia do not lose knowledge that has been repeatedly learned.

Participant-Directed Control with the Balance Board

The use of the balance board is shown in Figs. 9 and 10. Figure 9 shows its use by an older person who could stand, while Fig. 10 shows the exercise performed in a sitting position. The individual shown in Fig. 10 could not raise her knee during daily exercise. Using our system, the physical therapist guided her attention to her knee by tapping and simultaneously lifting up the knee (see Fig. 10, left), and after

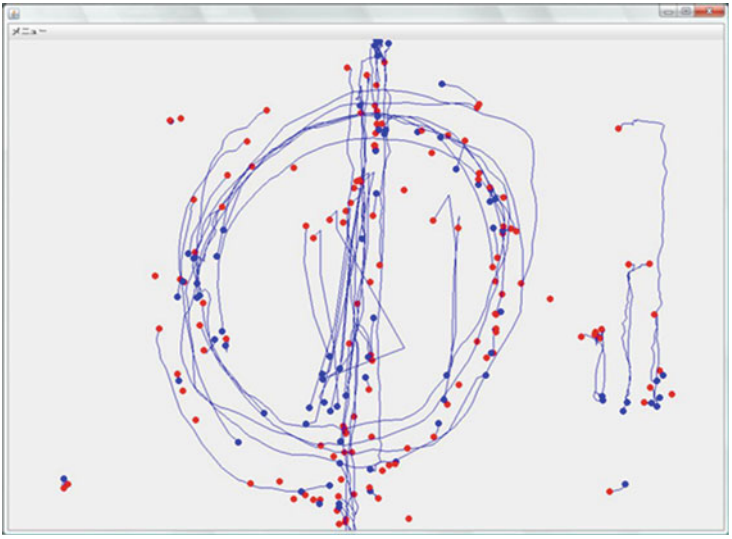


Fig. 8 Locus of finger strokes, using the touch screen

Fig. 9 Walking exercise using the balance board

several repetitions, the participant recognized that raising and lowering her knees caused the robot to move. She then continued the up/down motion without the therapist's assistance (see Fig. 10, right).

Center-of-gravity movements from the left to the right-front and from the right to the left-front caused the robot to turn right and left, respectively, enabling the robot to be directed in any direction. As shown in Fig. 9, the participant tried to move the robot toward another resident, who was motioning for the robot to come closer. Since turning the robot requires use of a mental configuration map, this exercise is

Fig. 10 Walking exercise using the balance board with (*left*) and without (*right*) assistance from a physical therapist

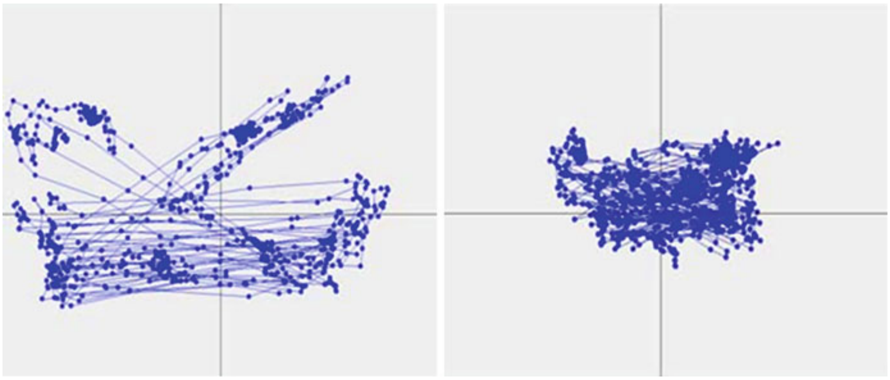


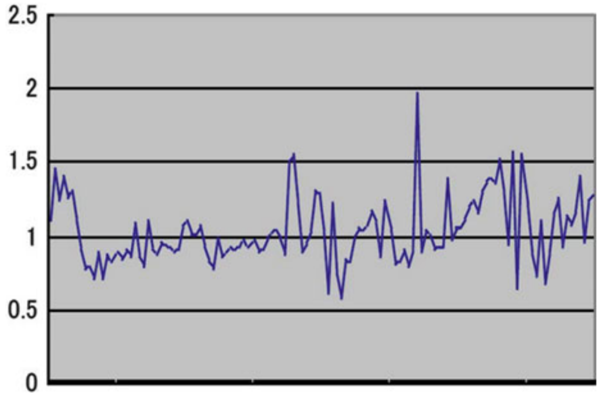
Fig. 11 Loci of center of gravity on the balance board *Left* younger, healthy male user. *Right* older user

also applicable to spatial perception rehabilitation training for higher brain dysfunction.

The recorded loci of the center of gravity for a younger, healthy male user (90 kg body weight) and for an older user (45 kg body weight) are shown in Fig. 11. Loci corresponding to the position recorded every 100 ms are connected by lines. In the case of the younger user, clear weight shifts can be seen to the right upper and left upper quadrants to turn the robot, and normal shifts between the right and left sides of the board enabled the AIBO to walk straight ahead. For the older user, however, the weight shift was insufficient to complete turns of the robot, and making the robot walk continuously in a straight line by weight shifting from right to left was clearly very difficult.

Figure 12 shows the change in stepping rate over a 4-min period for an older person. Stepping began with a slow cycle rate of 1.4 s and then became stable at a rate of about 1 s, before becoming disordered about midway through the period. Simultaneously recorded video images show that the user initially took rhythmical

Fig. 12 Temporal change in step interval (s) over a 4-min period



and stable steps elevating the foot, but this elevation gradually reduced, and weight was then shifted by moving the trunk toward the right and left.

An important point in each of these cases is that participants did not feel forced or obligated to undertake the exercises and were not necessarily aware of performing the exercises while enjoying the operation of the robot. These results suggest the proposed RAR is effective for eliciting a positive attitude necessary to start and maintain a rehabilitation program, particularly among older people with mild dementia.

Because the proposed RAR includes an entertaining component and because it is easy to operate multiple robots simultaneously, it would be possible to implement this RAR as a game where residents compete using their robots against others on a course to imitate dog racing. Such an activity would be valuable not only for older people with dementia but also for healthy people wishing to delay the effects of aging.

Conclusion

The application of the AIBO robotic dog in rehabilitation was examined from several viewpoints. Given the present status of robotic AI, a remote-controlled robot is still much more reliable and effective than an autonomous robot for use in rehabilitation. Although more experiments are needed, these preliminary results show that operation of a robot by participants is effective for eliciting a positive attitude toward rehabilitation. Moreover, the entire system including the HID could be made from commercially available products. Therefore, the preliminary trial of this RAR shows its possibilities for use among older people with severe physical and cognitive decline and for assisting their rehabilitation.

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Translating Smart Home Research into Practice

A Survey of Current and Past Smart Home Researchers

Shomir Chaudhuri, George Demiris, and Hilaire Thompson

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Abstract

Smart homes, namely, residential settings with technological infrastructure that supports passive monitoring of residents, are continuously growing domains with healthcare implications. This chapter explores the current status and lessons learned from smart home design and development worldwide to assess what designers and researchers perceive as facilitators and barriers to smart home adoption. A cross-sectional anonymous web survey assessing goals of projects,

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target audiences, team expertise, and barriers to translation to practice was conducted of smart home project or facility administrators and researchers identified through systematic search of scientific literature and online material. Response rate was 36.7 %. Fifteen usable surveys were included in the analysis. Findings indicate that several smart home projects exist with the aim of supporting communication and independent living. However, there are many challenges to their incorporation into the real world, including lack of funding support beyond the research phase, technology issues, and difficulty gaining widespread recognition as a valuable tool. Proper planning and design strategies are necessary to ensure the success and translation of such projects.

Keywords
Smart homes • Survey • Older adults • Remote monitoring

Introduction/Background

Recent trends suggest that both the population of older adults and people with physical disabilities are rapidly growing around the world (Administration on Aging 2011; Saito 2000). As such, there have been efforts to utilize technology in a way that will allow for people to continue living independently and safely within their own homes. One such approach focuses on enhancing residential infrastructures to facilitate passive monitoring of inhabitants. In doing so, one can detect and in some cases even proactively address individuals' needs in order to ensure their safety and well-being. Homes with such infrastructures are often referred to as "smart homes", which have been defined as a residence equipped with technology that facilitates passive monitoring of residents with the goal to promote independence and improve residents' quality of life (Demiris and Hensel 2008). According to Reeder et al., 77 % of studies investigating smart homes were published in 2005 or later, suggesting a recent upswing in smart home development. Rialle et al. describe three main forces that may be contributing to this development: (1) economic trends to contain health costs, (2) the desire of patients to stay at home while being clinically supervised, and (3) the availability of newer technology that can enable such services (Rialle et al. 2002).

Globally there are several ongoing and completed smart home research projects as well as commercial implementation efforts. Each project has different scopes, goals, and technological features (Bal et al. 2011; Demiris and Hensel 2008; Frisardi and Imbimbo 2011; Reeder et al. 2013; Rialle et al. 2002). One such example is the Georgia Tech Aware Home whose goal is to enhance the social connectedness of seniors to the outside world using various innovative technologies (Georgia Tech Aware 2011). This project has designed various multimedia instruments for communication and indoor tracking technology to monitor the residents and detect specific events. Another case with different goals is the CASAS smart home project at Washington State University (Washington State University CASAS Smart Home Project Website 2011). This project's aims have been to enhance the home and to not only help monitor the residents but also to maximize the residents' comfort while minimizing cost. The CASAS project has designed various activity recognition sensors that allow it to create profiles for its residents in order to identify and adjust for trends or anomalies in the residents' activity. As a further example, the ENABLE project in Europe examined technologies specifically for persons with dementia to enable them to participate in activities of daily living (ENABLE project 2008). The project used several technology tools including sensors to monitor the environment, object finding devices, and multimedia programs to support memory, communication, comfort, and independence. These examples are just a few of many ongoing research initiatives that explore a wide range of possibilities to ensure the safety of older adults and promote quality of life.

Smart home research is an emerging field with the potential to revolutionize the way people choose to live. While there are many projects and publications describing and evaluating the potential uses or quality of smart homes, little is known about the steps necessary to create and, as importantly, maintain a smart home project. For current and emerging researchers in this field, it would be useful to know what funding opportunities have been/are available as well as what kind of skills and expertise are necessary for research teams to develop, maintain, and grow smart home projects. This information could help future developers and researchers to better understand and prepare for the challenges involved in smart home projects in order to successfully implement them in widespread practice. The goal of this chapter is to explore these issues globally with current and past smart home designers and researchers.

Methods

In order to assess researchers' and practitioners' perceptions on smart home implementation challenges and strategies for successful deployment, we conducted a cross-sectional anonymous web survey from March to May 2012. This study received University of Washington Institutional Review Board approval.

Sample

Smart home administrators and researchers were identified using a systematic search of indexed scientific literature and online material. The review consisted of a search of terms such as "smart homes," "smart house," and "assistive technology for older adults" on both Google and Medline.

For the purposes of our review, in order to be included in the survey, we defined smart homes as health-related technology that is either partially or fully embedded into a home infrastructure in order to passively monitor or track an individual or set of individuals. Projects that were excluded included conceptual projects that had yet to be implemented or any projects that used stand-alone telemonitoring devices (e.g., home blood pressure monitors, wearable motion devices).

Project selection was conducted by examining relevant work produced by the project which included but was not limited to websites, papers, and abstracts.

The initial search strategy resulted in 90 projects describing themselves as "smart homes." Several projects were eliminated using the exclusion criteria listed above, leaving 65 smart home projects that fit our criteria. Further scanning of the respective websites and papers associated with these projects allowed us to acquire contact information for 57 of the projects. The remaining projects either did not have contact information available or were deemed to be duplicate projects. Information on the subject's email was generally obtained from the contact information section of the project's website. However, if unavailable through those means, the contact author's email address was extracted from the most recent research paper involving the specific project.

Starting in March of 2012, three rounds of emails were sent to the 57 available projects over a period of 1.5 months inviting participation in the online survey.

Survey

The anonymous survey was created using WebQ (Catalyst Web tools; University of Washington, Seattle, WA). The survey contained 12 items aimed to assess the overall goals of the project, the project's target audience, the partnerships necessary to engage in such a project, and any barriers or challenges faced by the project. The survey also asked specific questions about the funding sources for the projects and the current status of each project (ongoing, completed, no longer active, etc.). Location data were extrapolated either from websites provided by the respondents or through a search of the project's name. Before being implemented online, the survey was reviewed by members of our research team in order to address face validity, and edited to maximize readability.

Results

Survey Distribution

Of the 57 emails that were sent out, 8 were returned as undeliverable. From the remaining 49 emails, we received 18 completed responses (36.7 % response rate). The descriptions of 3 of the 18 responses did not fit our definition of a smart home. Instead, these projects carried out research that examined interoperability and data integration challenges that could ultimately pertain to smart home applications, but did not involve an actual smart home project. A total of 15 projects remained that were included in this analysis. Summaries of responses to selected survey questions are provided in Table 1.

Current Status and Location

Of the 15 projects, respondents for 13 of them identified themselves as ongoing. Two projects were described as no longer active, citing lack of funding and overall

Table 1 Summary of responses for the smart home projects

Project	Summary of project goals	Target audience	Location	Participants	Intent to commercialize	Ongoing
1	To promote social inclusion of older adults	Older adults, family	Europe	29	Parts	Yes
2	To test the feasibility and acceptability of a system that promotes well-being and safety in older adults	Older adults, people with dementia	United States	40	Unknown	No
3	To investigate how technology can address the needs of individuals at home and the technologies impact on society	Older adults, people with disabilities, general public	United States	N/A	Yes	Yes
4	To design a tool that improves the experience of the user in their environment	Older adults, general public	United States	500	Yes	Yes
5	To promote independence and support of care givers and patients with chronic diseases	Older adults, people with disabilities	France	50	Yes	Yes
6	To detect behavioral anomalies related to depression, Alzheimer's, and epilepsy	Older adults	United States	10	Unknown	Yes
7	To use sensors to monitor people at home	Older adults	Europe	16	Yes	Yes
8	To propose, build, and evaluate a technological solution to help people stay at home	Older adults, people with disabilities, general public	France	0	No	Yes
9	To produce preventative medicine with evidence-based health by collecting long-term monitoring data	Older adults	Japan	50	Yes	Yes
10	To increase quality of life	Older adults, people with disabilities	Japan	10	Yes	Yes
11	To raise awareness	Older adults, people with disabilities, family, care givers	Australia	200	No	Yes
12	To provide context-aware home assistance as well as comfort, security, and a connection to the world	Older adults, family	France	68	Yes	Yes
13	To develop a system to monitor and possibly assist older adults	Older adults, people with dementia, family, care givers	Canada	20	Yes	Yes
14	To help people with dementia remain in their homes for longer and to provide support for care givers and family	People with disabilities, family, care givers	United Kingdom	300	No	No
15	To develop technology that promotes aging in place	Older adults, families	United States	3,000	Yes	Yes

support. As one participant stated, “Funding ran out. . .I enjoy the academic investigation, not the marketplace aspects.” Another participant explained, “Sadly though, the obstacle we faced was that the worth of the project was not fully recognized by senior managers from the County Council.” These two inactive projects were located in two separate countries, one in the United States and one in the United Kingdom. Of the ongoing 13 projects, four are based in the United States, three are in France, two are in Japan, and Australia and Canada each have one project. Two of the projects reported operating across several European countries.

Objectives

The stated goals of the 15 projects were quite varied. Many projects were concerned with older adults being able to age in place. One respondent stated their objective was to “help older people age in place in environment of their choice.” In a similar sense, another project stated, “The objective is to propose, build and evaluate technological solutions to help people to stay at home with good conditions of security, comfort and assistance.” Some of the project goals targeted specific disease states. One such project stated their goal, “To develop a smart home system that can monitor an older adult with dementia during common [activities of daily living] ADL and provides prompts and assistance as necessary.” Another project’s goal was “to detect behavioral anomalies that are related to depression, Alzheimer’s, and epilepsy.”

Three projects (20 %) aimed to promote social inclusion of older adults to the outside world. One such project stated its objective as “social inclusion of older adults via social web technologies.” Another project described a similar objective, “to provide easy connection with the outside world.”

Respondents for another two projects (13.3 %) were concerned about the technological capabilities of their devices, with one stating that their goal was “to investigate how technologies can address the needs of individuals at home and mobile, as well as solve larger issues of significant societal impact.” Finally two projects were meant to test the feasibility of such systems, “First-generation study was to determine the feasibility and end-user desired utilities to promote well-being and safety in older adults residing in independent living facilities” and to see “if technology worked reliably, if the use of telecare supported unpaid carers and relatives and if the use of telecare was cost effective.” One study succinctly stated, “increase in [quality of life]” as their goal.

Target Audiences

Not surprisingly, the main target for these projects was either “older adults,” “the elderly,” or “old people” as reported for 13 of the 15 projects. Of these 13 projects, four included the families of the subjects, while another four also targeted “people with disabilities,” “handicapped people,” or “persons with chronic illnesses.”

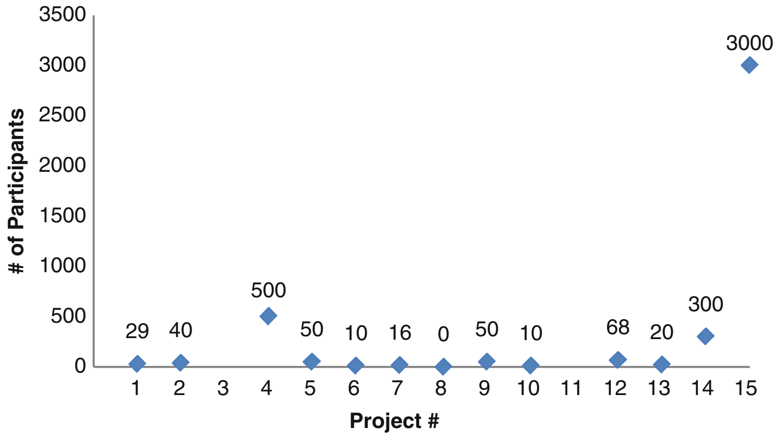

Fig. 1 Number of participants to date cited by each project

Three of the 13 projects stated the "general public," and another three specifically mentioned "people with dementia." Other targets included healthcare providers, governments, educators, students, and funding agencies.

Participants

The number of participants reported across projects varied greatly with some projects stating that they had currently enrolled up to 3,000 older adults and other projects having no subjects as of the date of the survey (Fig. 1). Participants were identified in many different ways including "elders," "older people," "relatives," "professional careers (carers)," "people with dementia," "students," "faculty," and "participants." One smart home served as a demonstration unit rather than an actual living environment, and when asked to describe their participants, the respondent stated, "around 200 people each year visit the smart home."

Partners

Survey respondents reported working with an assortment of partners, most of which could be broken up into five categories: academic, industry, nonprofit, government, or healthcare. Many participants cited multiple types of partners who collaborated with them on their project. The most cited partners were academic (5) and industry (4). Nonprofit were listed by projects located in the United States and France (2). Government was also listed twice by projects located in Japan and France. Finally healthcare partners were listed twice each by projects located in the United Kingdom and the United States. Various universities, government facilities, and retirement communities were also described as partners as were research laboratories and companies.

Funding Sources

A variety of funding sources were cited with most naming some sort of government agency. The National Science Foundation (NSF) was listed three times, while the National Institute of Health (NIH) was listed twice. International governmental bodies listed/included the European Union which provided funding for two of the projects, the Agencie National de la Recherché which was listed as the funding source for two projects, and the Canadian Institutes of Health Research which was listed once. Aside from government grants, private funding from various organizations was listed. As an example, the Alzheimer's Association was cited as a source of funding in the United States and Canada.

Design Team Expertise

Respondents cited a variety of expertise or professional disciplines collaborating within their team. The 15 projects averaged 4.7 (SD 2.2) different disciplines per project. The most cited disciplines were computer science along with several health sciences professions (gerontology, nursing, physical therapy, or occupational therapy; $n = 9$ projects each). Other health sciences professions listed were psychologists ($n = 4$) and speech therapists ($n = 3$). The next most cited discipline was engineering ($n = 7$) followed closely by those in social care and social sciences (sociology, social work, etc.; $n = 6$). There were seven other professions listed as part of the research team among the projects including architect, designer, information and communication technology (ICT), ergonomics, business, informatics, and journalist.

Challenges or Obstacles

Survey respondents listed several challenges and obstacles in the design and implementation of their system. Technical difficulties were common among these projects. Whether it was issues with network connectivity, data analysis, or having the system accurately detect subjects, at least seven projects mentioned are being affected by technological problems. One respondent stated, "Analyzing data for environments with multiple residents and with pets is a particularly difficult challenge." Another frequently cited challenge was user involvement. Issues ranged from basic recruitment of subjects to being able to explain what the project was and receiving honest feedback from the subjects. One respondent discussed the difficulties involved with talking to the subjects "...patiently talking to focus group, explaining what is possible, getting out what they want. Making them to say honestly what they think about some technology or idea of us, rather than politely agreeing it is a good idea." Other issues identified included stakeholder buy-in and funding; two different participants explained that it was difficult to be fully recognized by senior managers or even providers as a worthwhile project which caused issues when trying to identify funds. One respondent explicitly stated "Although the project attracted a great deal of attention nationally and internationally, the project ultimately failed to win the support of senior managers in the County Council who remained skeptical about the project's achievements."

Discussion

The results from this survey showcase many elements involved in sustaining a smart home project. Facilitators of these projects are intent on supporting their subject's various needs including communication, entertainment, and independent living. In order to do so, they require multidisciplinary teams and various sources of funding to properly build and maintain a home infrastructure with the necessary capabilities to achieving these goals. Many of these projects created partnerships and collaborations with various industries in the area which help to facilitate the design and possible commercialization of such tools as well as assist in funding these projects.

Translation of research to practice in this area still faces specific challenges, including lack of funding, buy-in from all stakeholders, and insufficient documentation of effectiveness. While inherently requiring a multidisciplinary team for varying technological issues, these projects also require careful community outreach as well as sound legal and ethical guidance in order to be successful (Chan et al 2009; Frisardi and Imbimbo 2011). Future smart home endeavors should consider including individuals with public relations and policy experience in their research team in order to spread recognition and ensure proper incorporation of their research product into a public space. Members familiar in user design methods can facilitate proper procedures in assessing user feedback (i.e., anonymous surveys, focus groups) to better meet users' needs and explore reasons for nonparticipation. Exploring the various available financial options will also be necessary to provide funding for the duration of the project. Further research needs to provide solid evidence documenting the potential effectiveness of smart homes. Reimbursement models that can potentially sustain such systems in the future will rely on solid evidence of the overall effectiveness and cost-effectiveness of such implementations.

Implementation science examining the process of translating innovations from research findings into broad application can better explain the diffusion of smart home research to practice. Several frameworks and strategies can be used to understand and also plan for successful implementation of research initiatives. The RE-AIM (Reach Effectiveness Adoption Implementation Maintenance) framework is one such model that can inform the implementation of smart home applications. It was initially developed to evaluate interventions and later used to plan them (Glasgow et al. 1999). This framework focuses on five key factors for successful implementation which are listed in Table 2.

The RE-AIM framework can guide the design of smart home research in order to ensure target users and all stakeholders are appropriately selected and involved in the process, to address the need for solid evidence on the effectiveness of smart homes and the documentation of outcomes that are affected and strategies to ensure such

Table 2 The five key factors of the RE-AIM framework

Factor	Definition	Smart home implementation
Reach	The proportion of the target population that is involved in the implementation process	Consider and understand all stakeholders that might be affected by a smart home including the target user's family, care givers, and healthcare professionals
Efficiency	Evidence and documentation that a system causes positive effects to the community that is adopting it	Consider and measure all outcomes (even negative ones) that may be caused by a smart home including biological outcomes, quality of life, physical activity, etc.
Adoption	The proportion of individual or organizations that adopt the intervention	Although the participant is living in the home, understand which aspects of the system they and other stakeholders are actually using. Adoption can usually be assessed by observation, interviews of surveys. Barriers to adoption should also be examined (12)
Implementation	The extent to which the program is delivered as intended	Consider and measure not only the participant's adherence to the system but also how well the study staff intervene with the participants. It is important to understand which interventions are necessary and the changes caused by each intervention
Maintenance	The extent to which the intervention becomes routine or standard practice	Continue to meet with stakeholders and measure outcomes for as long as they are residing in or using the smart home

systems will be integrated into the real world. Such considerations include an emphasis on cost analysis and cost-effectiveness studies as well as examination of reimbursement models and policy regulations.

This study has several limitations. We only surveyed projects that were found using our specific search criteria and may not have identified all ongoing projects. Further, we were only able to analyze responses from 15 projects due to the relatively low (36.7 %) response rate. However, the data from our 15 survey respondents still provide valuable insight to the success and challenges experienced by such projects and can inform future developers and researchers.

Smart homes are an emerging technology that can offer safety and independence to individuals desiring to remain in their own home. However, as stated by current and former researchers in this area, these projects still face technological, financial, and acceptance barriers to becoming an effective real-world intervention. Understanding and properly planning for such barriers is imperative to the future success and wider implementation of such projects.

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Visualizing Smart Home and Wellness Data

Thai Le

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Abstract

Smart homes provide a valuable opportunity to collect data continuously and unobtrusively. However, the data come in varied formats and can be challenging to comprehend. Visualizations can abstract the raw data into representations that better support understanding and insight generation. In this chapter, we present an overview of visualization approaches towards representing smart home data. We also provide a discussion of the challenges in visualizing this information.

Keywords

Visualization • Visual displays • Decision making • Visual analytics • Displays

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Introduction

Advancements in smart home technologies provide an opportunity to collect unprecedented amounts of information across broad data sources. A smart home represents the integration of technology and sensor applications into the residential environment. This creates a ubiquitous environment of information, often unobtrusively embedded within the context of daily living. The components of smart homes are varied and can include systems that allow for remote control of electronic devices, security monitoring, intelligent control of resource consumption, and health monitoring. The underlying theme across these applications involves incorporating information available within the residential infrastructure to improve daily living of residents. Alam et al. divide smart home technologies into three functional groups: comfort, healthcare, and security (Alam et al. 2012). For this chapter, we focus on the healthcare component of smart homes and examine different techniques to visualize health data.

Home health monitoring is a growing area of interest for smart home technologies. This is attributed to an increasing older adult population that wants to maintain independence and quality of life along with significant resource shortages within the healthcare system. Health monitoring technologies make it possible to track health and wellness continuously, unobtrusively, and reliably while providing stakeholders with quantifiable feedback. However, it is not enough to have the infrastructure and technology in place to collect copious amounts of data, especially since consumers may not be familiar with the detailed datasets generated, often requiring clinical knowledge and expertise to interpret. Appropriately designed visualizations can bridge this gap between data and information to help promote meaningful and efficient use of data.

In this chapter, we describe the different smart home data available that can be used to assess wellness, along with differing approaches towards visualizing this information. We then discuss approaches towards integrating different types of smart home data into a holistic visualization. A well-designed visualization that translates data from health monitoring technologies into a consumable medium for stakeholders promotes effective communication and active engagement in healthcare. Incorporating smart home health data into visualizations can be a valuable resource for translating raw data into insights.

Data Sources for Visualization

Data collected from smart homes can be grouped into five primary categorizations: infrastructure-mediated sensing data, activity sensor data, cognitive health data, and behavioral data.

Infrastructure-Mediated Sensing Data

Infrastructure-mediated sensing data measures resource consumption throughout the smart home. This often includes utility information such as electricity consumption,

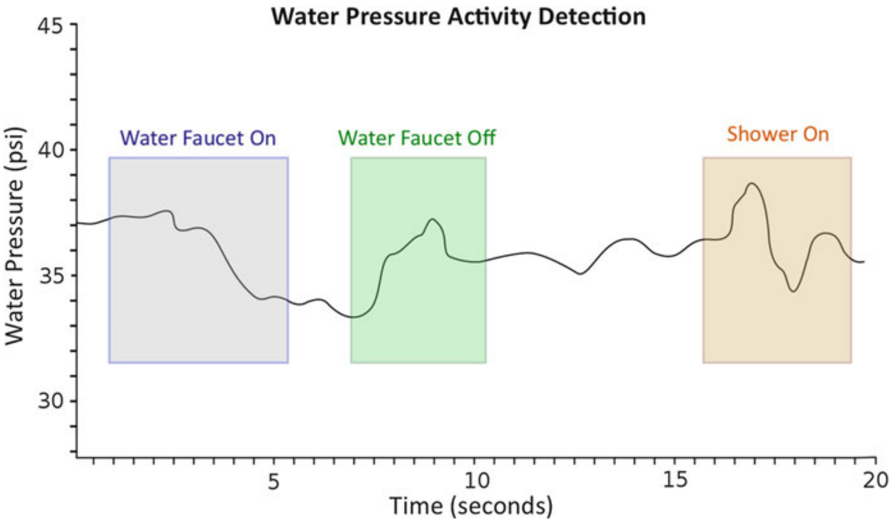

Fig. 1 Example of infrastructure-mediated in-home water activity sensing based on classification of water pressure signals for multiple events. The signals are segmented into the shaded regions and a classifier is applied to identify the activity associated with the unique shapes. This example was modified from Froehlich et al. (2009)

water usage, heating usage, and telecommunication usage. Patel et al. have applied machine learning techniques to infer the use of appliances based on the unique electrical noise signal of devices as they are turned on or off (Patel et al. 2007). This infrastructure-mediated sensing approach has been further extended to detect human movement based on air pressure changes in HVAC system ductworks. Sensors are mounted on the air filter to detect unique airflow changes associated with movement from room to room or from the opening and closing of doors (Patel et al. 2008). Froehlich et al. apply a similar approach to identifying faucet usage based on water flow signals from a water pressure sensor. They are able to identify activity of individual water fixtures at 97.9 % accuracy and are also able to estimate water usage with comparable accuracy to a water meter (Froehlich et al. 2009).

The raw infrastructure-mediated sensing data is visualized as a longitudinal signal of water pressure, electrical current, or air pressure. Fluctuations in the flow are classified as an event (e.g., opening of the door, turning on of a faucet) and annotated on the graph with the event label. Time is represented on the x-axis to provide information on duration of events (Fig. 1).

Activity Sensor Data

These sensors include magnetic contact switches that detect a wide range of functions throughout the home such as opening of cabinet and refrigerator doors, turning on/off of stovetops, and opening of pill dispensers (Tapia et al. 2004; Noury et al. 2000). Pressure sensors can further detect if occupants are in bed or sitting in a chair (Perry et al. 2004). Additional activity sensors include video and motion sensors that are able to detect activity at varying levels of granularity. For example, motion sensors integrated throughout the smart home provide gross level overview of participant location (Hayes et al. 2004). Out of concerns for privacy, these sensors data may be limited to only high-level overview of activities in the home, such as the presence of activity within different rooms of the home. However, these motion sensors have trouble distinguishing the presence of multiple occupants. At finer granularity, Helal et al. describe low-frequency RF, infrared, and ultrasonic sensors for location tracking which would allow the smart home to make more proactive, context-aware decisions based on participant location and movement (Helal et al. 2003). The data consists of position in the home along with velocity data describing participant movement. Another type of activity sensor data includes gait data such as gait velocity, stride length, and cadence as derived from floor or mat sensors (Yamazaki 2006). These data are correlated with measures of balance, activity and mobility status, and fear of falling. Information derived from gait data can be valuable towards assessing risk of falls or changes in gait associated with cognitive disorders.

Given the wide array of activities that can be detected, visualization approaches also differ. One approach for integrating multiple activities, as described by Jakkula and Cook, involves an interval visualization representation. Each activity is listed out, repeated each day on the vertical axis. The horizontal axis displays the time of day with horizontal bars populating the visualization. These bars represent the duration of each activity as detected by the sensor (Fig. 2; Jakkula and Cook 2007). This visualization approach allows the user to compare across multiple activities to detect temporal patterns of events. Interactive components allow users to filter out sensor activities or calculate mean duration of activities across a time interval.

For location tracking sensors, a spatial representation is required to visualize position of the residents within the smart home. Thomas and Crandall describe the use of PyViz, a tool that integrates smart home data into a 2D floor map of sensor activity. The visualization can continuously update to provide a live view of environmental activity (Thomas and Crandall 2011). Historical data over a timeframe can be further represented using a heat map with color intensity corresponding to frequency of sensor activity (Fig. 3a; Chen and Dawadi 2011). This visualization approach has been extended to a 3D simulation of the smart home environment using the Second Life protocol (Szewcyzk et al. 2009). Wang and Skubic describe a density map visualization of sensor activity where hours of the day are displayed on the x-axis and days of the month are displayed on the y-axis. Colors represent density of all sensors that have fired in the smart home within the hour if the resident was present (Fig. 3b; Wang and Skubic 2008). This visualization provides an aggregate measure of activity within the home while also facilitating the easy identification of periodic trends.

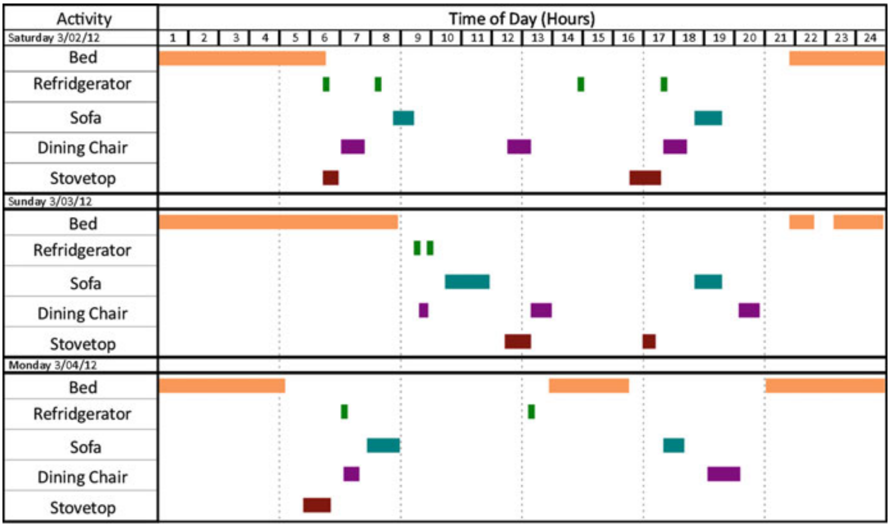

Fig. 2 An example of an interval visualization tool modified from Jakkula and Cook (2007). Different sensor activities are listed on the *left* hand column, repeated for each date. Horizontal bars represent the duration of an activity as detected by the sensor within the 24 h window

Cognitive Health Data

This data source seeks to measure change in cognitive status, important for the early detection of cognitive impairment. Existing approaches to detecting cognitive decline use neuropsychological tests as a gold standard. These tests are administered in a clinical setting and are subject to variability due to the test environment and participant experience. In addition, scores are compared to a population group, making it difficult to address language or cultural barriers. The unobtrusive nature of data collection in smart homes facilitates continuous monitoring of cognitive health referenced to the individual over time as opposed to infrequent neuropsychological exams. Ball et al. found that computer games could be used to assess knowledge, short-term memory, perceptual motor skills, and attention (Ball et al. 2002). This is extended further by Jimison et al. who use keyboard entry and mouse movements in addition to computer games as proxies for cognitive motor health (Jimison et al. 2004). Detecting differences in typing speed or changes in vocabulary composition and sentence complexity over time can provide indicators of cognitive health (Davis and Ball 1989).

Visualizations of cognitive health data involve extracting metrics of performance, such as efficiency on game play or scores that represent reasoning, memory, and processing speed (Jimison et al. 2004). This is shown longitudinally as a scatterplot, with the goal of detecting trends in changing cognitive health.

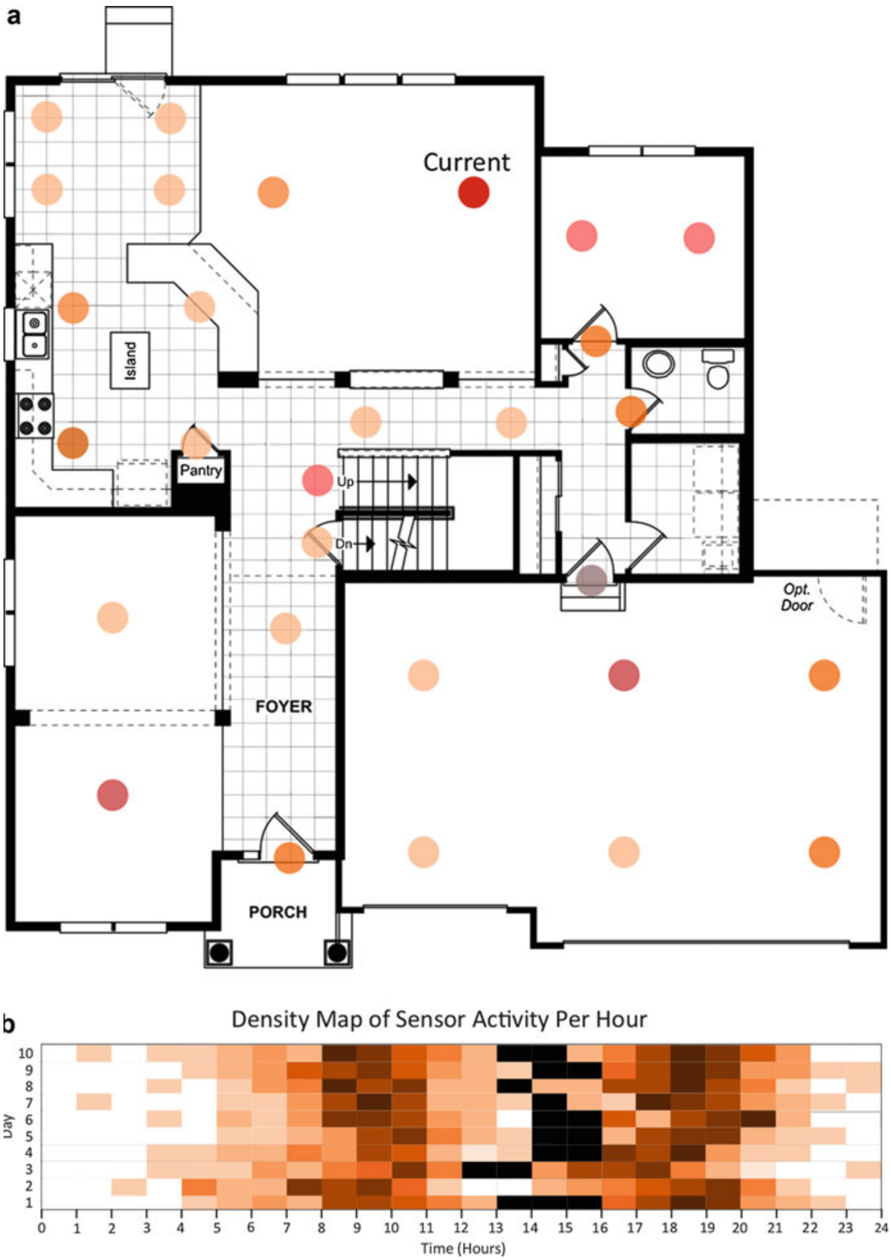

Fig. 3 (**a**) 2D floor map of different sensors within the residence. The *red dot* is the current location of the resident as detected by the sensor. Heat map intensities correspond to frequency of sensor activity. (**b**) Density map visualization of sensor activity modified from Wang and Skubic. Colors represent density of aggregate sensor activity within the home over 1-h periods. Data are displayed as 24 h days on the x-axis and days of the month on the y-axis. *White* corresponds to no sensor firing when a resident is present. *Black* indicates that the resident is not at home (Wang and Skubic 2008)

Physiological Monitoring Data

Sensors embedded in the daily environment can be used to detect physiological data. Williams et al. describe a large array of physiological sensors in a systems analysis of an integrated CareNet telecare system. The sensors include ECG (pulse rate), spirometer (respiration rate), sphygmomanometer (blood pressure), thermometer (basal temperature), photoplethysmography (blood oxygen), galvanic skin response (sweating), colorimeter (pallor), and stethoscope (heart and breathing sounds) (Williams et al. 1998). In addition to sensors that measure blood oxygen and blood pressure, Raad and Yang also describe weight sensors for physiological health monitoring (Raad and Yang 2008). Thompson et al. used commercially available wireless health monitoring devices to capture a wide array of physiological data including blood pressure, heart rate, weight, oxygen saturation, and blood glucose. These were peripheral devices connected to a central health kiosk system. In addition, the researchers assessed activities of daily living through the self-reported Katz Activities of Daily Living Scale and Lawton Instrumental Activities of Daily Living Scale (Thompson et al. 2011).

Behavioral Data

Behavioral data monitor patterns of behavior for the occupants of the smart home. Two approaches have been applied to gather behavioral data. A passive approach uses existing activity sensors to infer behavior. An algorithmic approach is used to identify anomalous patterns such as falls, increased social isolation, immobility, and reaction incapacity. For example, Raad and Young describe an application where sensors in the kitchen detect the water faucet or stove turning on, yet after 5 min, no motion is detected. This is classified as anomalous behavior that would trigger a response from the smart home (Raad and Yang 2008). A more active approach towards gathering behavioral data involves the use questionnaires or a daily activity log. Thompson et al. use different validated questionnaires accessed through a telehealth kiosk to assess mood, social well-being, and activities of daily living (Thompson et al. 2011).

Visualizations of behavioral data often use existing sensor data to predict an activity such as eating, cooking, sleeping, or relaxing. The activity along with duration is visualized throughout a 24 h day in color-coded segments. Variations across days can be shown to identify shifts in behavior. This approach is similar to the interval visualization shown in Fig. 2, however using inferred behavior as activity events.

Integrated Smart Home Visualization

Quantifying Wellness

The breadth of health data available for smart homes is a reflection of the complex and multidimensional nature of well-being. Aging has an impact on many components of health, including physiological, social, cognitive, and spiritual changes. It is important to address the consumer's healthcare needs in a comprehensive manner in order for the smart home to effectively support successful aging. Halbert Dunn's model of holistic wellness provides a framework for integrated health visualizations. During the early 1960s, Dunn emphasized a shift in the dichotomy of sickness and wellness towards a graduated scale where both concepts belonged on the same axis (Dunn 1959). As defined by Dunn, wellness is "an integrated method for functioning which is oriented toward maximizing the potential of which the individual is capable. It requires that the individual maintain a continuum of balance and purposeful direction within the environment where he/she is functioning (Dunn 1959)." This framework considers wellness as a holistic complex concept, broken down into four dimensions of physiological, cognitive, social, and spiritual health as described by Hoyman (1975). It can be difficult to represent the construct of wellness to consumers due to its multidimensional and complex nature; however, the benefits of making this information available include promoting an awareness of holistic wellness, identifying longitudinal wellness trends, and facilitating communication across all members of the caregiving network.

Visualizing Multiple Dimensions of Health

Integrating multiple dimensions of health into a wellness display can be challenging due to the different modalities of data available. Existing work describes the process of aggregating different smart home health data into a common database; however, there has been limited work on an integrated visualization from these data. Cook et al. present a dashboard display of activity level, sleep quality, socialization, and time distribution of different activities as generated from smart home sensor data. An overall measure of health trend is calculated as a function of the prior parameters (activity level, sleep quality, socialization) (Cook et al. 2013). The visualization provides a flexible display of multiple behavioral activities with an overall view of health trend.

Le et al. provide a visualization of smart home data designed with older adults in mind (under review). Existing literature has found that older adults are receptive towards smart home technology, expressing an interesting in the information available. However, at the same time, information needs of older adults and health care providers differ; understanding these differences is important for designing an appropriate consumer-focused visualization (Huh et al. 2013; Reeder et al. 2013). Using a participatory design approach that included both healthcare providers and older adults, Le et al. iteratively designed mockups of visualizations representing multiple dimensions of health. Applying Dunn's framework for wellness, the authors classified data into dimensions of cognitive, social, spiritual, and physiological health. This was presented as a dashboard allowing users to examine holistic wellness compared to community or age populations, against longitudinal trends, and within specific dimensions of wellness (Fig. 4). Evaluation through focus groups found favorable reception to the visualizations, primarily as a tool to initiate conversation with healthcare providers and to promote behavioral changes for affecting wellness score (Huh et al. 2013; Reeder et al. 2013).

Fig. 4 Visualization of data classified into dimensions of physical, cognitive, social, and spiritual health. Overall wellness is an average of the four dimensions, corresponding to overall circle size. *Top* half shows scores compared to community and population averages. *Bottom* portion shows longitudinal trends of wellness

Conclusion

This chapter has presented an overview of data visualization approaches across different modalities of smart home health data. Information visualization is an extensive field concerned with the use of computer supported, interactive, visual representations of abstract data to amplify cognition.

Within the health visualization context, there is a broad body of literature describing the impact of visualizations on decision making from both a provider and a consumer perspective. An appropriate visualization can help reduce the complexity of smart home health data into relevant and valuable information for consumers.

There are some key challenges to consider when visualizing smart home data. The first is the breadth and variety of smart home data. A smart home is able to continuously monitor activity; however, it can be difficult to integrate the data into a holistic concept of wellness. We have described different visualization approaches to presenting multidimensional information with the focus on abstracting raw sensor data into behavioral activities or measures of health over time. The temporal nature of the data can also be challenging to represent through visualizations. Care should be taken not to overwhelm users with a historic timeline of smart home data. Instead, allowing users to specify timeframes for visualizing or overlaying the data in 24 h periods makes it easier to identify differences in circadian behavior. Integrating this with a statistical model makes it possible to detect anomalous patterns of behavior within the home. Finally, the sensitive nature of smart home data raises issues of privacy and confidentiality for the visualizations. In particular, who has access to the data and their visualization interfaces, how may the visualizations be shared with family members and health care providers, and what level of detail should be provided within the visualization? Addressing these issues early on during the visualization development process is essential towards creating not only effective, but usable visualizations.

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Games for Health in the Home: Gaming and Older Adults in the Digital Age of Healthcare

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Abstract

This chapter provides an overview of current research on digital health games and health benefits derived from game play in the home setting by an older adult population. Initially, this chapter presents the current problems of an aging population and a series of gaming trends, game genres, and technology used by older adults are described. This chapter further ascertains previous works, primarily reviews (narrative and systematic), to establish the current stance of utilizing digital games for health among older adults and assesses quality-of-life benefits. Aggregated recommendations across all the reviewed studies are listed and a comprehensive standard digital health game classification system is proposed. Games for health taxonomy and respective technologies are described, in particular the nature of engagement by users. Finally, recommendations for future research on games for health in the home are provided.

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games for health • exergames • video games • gaming, older adults • rehabilitation • digital health

Introduction

Life expectancy has increased in the twenty-first century with older adults (i.e., 65 years of age or older) representing the fastest-growing segment of the population worldwide. This age group is projected to reach 1.5 billion by 2050 or 16 % of total population globally (Haub 2013). The prevalence of disability and risk of developing chronic diseases increases with age (Anderson 2010; Reding 2006). Chronic diseases or noncommunicable diseases, such as cardiovascular disease, cancer, and diabetes, are the leading causes of death and disability, costing trillions and responsible for nearly 60 % of all deaths worldwide (Schwab and Frenk 2011). However, many of these chronic diseases can be prevented (i.e., through diet, exercise, etc.) or efficiently self-managed through changing health behaviors, thus preserving or improving health-related quality-of-life (QoL) factors, such as physical, social, and mental.

Additionally, as people age, they may experience age-related declines in hearing, vision, cognition, and physical strength and mobility (Czaja and Lee 2006). Therefore, activities and interventions that promote health are vital for fostering healthy aging, preventing chronic diseases, and ultimately reducing healthcare expenditure. Finding innovative solutions to reduce risk factors associated with noncommunicable diseases, change health behaviors, and improve the QoL of an aging population is an international challenge (Lim et al. 2012; Reding 2006). In parallel with the aging population, the widespread access and use of technology has sparked growth in digital tools as solutions to increase engagement by older adults in health-promoting activities (Hall et al. 2012b). In recent years, new digital gaming technologies, platforms, and sensors have emerged as valuable health promotion and health education intervention tools.

A systematic literature review of digital gaming for health promotion among older adults found significantly positive physical, mental, and social health outcomes of video game play (Hall et al. 2012a). In this review, 13 published interventions distinctly studied relationships between gaming interventions, older adults, and health benefits; outcomes varied from cognitive function and physical activity measures, but nearly all studies found positive health outcomes in accordance to their predicted outcomes, especially related to mental and physical benefits. Gaming consoles used among the studies in this review were widely varied, yet Nintendo® Wii Sports and Nintendo® Wii Fit were most often used. Studies are showing positive results for the use of digital games as intervention tools for older adults to facilitate rehabilitation, physical activity, and mental acuity and as tools to promote social engagement (Hall et al. 2012a).

Games for Health

The term digital game can be defined as games that are played through technology such as televisions, computers, game consoles, and mobile devices. Prior to the Nintendo® Wii release in 2006, which brought an interactive approach to game play through motion-sensing technology, the act of "gaming" was associated with sedentary behavior (i.e., sitting for long periods of the day). Previous game play involved interacting with video game consoles that utilized pushing buttons and moving joysticks as primary means of interaction (Marston et al. 2013). The Wii uses the Wii Remote, a device that includes built-in motion sensors that wirelessly converts movement into game actions (Marston et al. 2013). This new type of technology created a market of interactive health-based games with games such as Nintendo® "Wii™ Fit" (Nintendo of America, Redmond, WA) and the "Dancetown" Fitness System (Dancetown, Pittsburgh, PA).

In addition to the Nintendo Wii, newer platforms from Sony PlayStation® 3's PlayStation Move with the PlayStation Eye from Sony (New York, NY) and the Xbox 360's Kinect from Microsoft® (Redmond) emerged after the release of the Nintendo Wii. The newer consoles have more accurate motion-sensing technology to detect physical movement in the player. The Kinect offers players a unique experience that does not require the user to physically hold a game pad or remote in the hands, an aspect that becomes difficult as one ages. Instead, the Kinect detects the player's body movements through a series of cameras and microphones through direct interaction (Marston et al. 2013). More recently, the Kinect One, an updated version of the Kinect, was released in 2013. The Kinect One has enhanced audio and visual processing as well as improved joint and muscle tracking (i.e., hand tracking). A few main enhancements of the Kinect One console include the ability to identify a user's heart rate and facial expressions. The new enhancements offered through the Kinect One could prove fruitful for future studies assessing one's health and engagement through digital games. Given these advancements in gaming technology, interactive games (i.e., exergames) and games for health emerged to utilize gaming as a strategy to change health behavior.

More studies have been conducted using the Nintendo Wii than the Microsoft Kinect with older adults. However, a few recent studies tested the Kinect. For instance, an intervention involving older adults with disabilities found improvements in health-related QoL factors and visual performance skills in the intervention group using the Kinect (Chiang et al. 2012; Chen et al. 2012). Other studies have explored the Kinect's motion-sensing technology as a tool to prevent falls (Pisan et al. 2013) and for fall rehabilitation in the home (Uzor and Baillie 2013). Although older adults enjoy interaction with the Kinect compared with other types of gaming consoles (Gerling et al. 2013), a set of guidelines were proposed to inform developers of motion-sensing games to enhance the safety and player experience of games designed for older adults (Gerling et al. 2012; Smeddinck et al. 2013).

Video games immerse players in creative and interactive worlds where players are free to make decisions and overcome challenges without real-life consequences.

Games for health (aka serious games for health) are digital games designed specifically for health purposes and in addition to containing traditional game qualities (i.e., goals, conflict, rules, and ability to win or lose) (Schell 2008) share many of the following characteristics: health content, health messages, behavioral theory-based design, health information, measureable skill gains, ability to set health goals, monitor health-related attitude changes, health-promotion factors, health behavior change outcome measures, and evaluation components.

Studies on games designed for health found positive health gains through game play. These games resulted in health behavior changes on diet, physical activity, and self-management of chronic conditions (Baranowski et al. 2008; Lieberman 2001; Homer et al. 2000; Papastergiou 2009). Games for health comprise design features such as health-related dialogue and tasks, goal setting, and story further contributed to outcomes on health behavior attitude changes and increases in knowledge and skills (Baranowski et al. 2008; Papastergiou 2009). Furthermore, including health behavior theory is vital in the design of games for health for promoting behavior change (Baranowski et al. 2008).

However, Hall et al. (2012) found only one study from their systematic review that based its intervention design or implementation on a theoretical foundation. Currently, there is a lack of theoretically informed research explaining health behavior and digital gaming in older adults. Theory-based interventions have been proven to predict health behavior change in countless non-digital game-related health promotion interventions. Theories and models such as the Social Cognitive Theory and theTranstheoretical Model can provide a comprehensive understanding of the relationship between older adults, health behavior, and video games. Further, it is recommended that evidence-based behavioral theories be incorporated appropriately into games designed and developed for specific health behavior change outcomes. For example, Grimes et al. (2010) designed the game *OrderUP!*, based on the transtheoretical model to teach adults how to eat healthier and found improved health behavior changes on diet habits.

Games, Gaming, and Technology

Playing video games is a favorite leisure time activity of many adults. According to the Entertainment Software Association (ESA), 72 % of US households engage in playing video games, including players of all ages and both sexes (ESA 2011). This phenomenon extends to other countries as well. Worldwide, nearly 667 million people play video games, and this trend is steadily increasing (McGonigal 2011).

Video games are a multibillion-dollar industry, with nearly $21 billion in revenue reported in 2012 (ESA 2013). The most popular video game genre in 2012 was action followed by role-playing, which was the most popular computer game genre (ESA 2013). Further, the most popular online games played include: puzzle, board game, game show, trivia, and card games (34 %), followed by action, sports, strategy, and role-playing (26 %) (ESA 2013). The most popular mobile games include puzzle, board game, game show, trivia, card games (35 %), and causal social games (35 %) (ESA 2013). According to a study conducted by Marston (2012), older adults preferred puzzle and sport genres followed by strategy games. De Schutter (2010) reported similar findings and provided reasons given by older adults for these game genre preferences that included characteristics such as challenging and fun. Additional reasons that motivated older adults to participate in game play were to interact more with their spouse or children, as a hobby, and for enjoyment or as a way to avoid boredom (Marston 2012). Moreover, the LEAGE (LEArning Games for older Europeans) project found that older adults enjoyed digital games, which met their demands for fun leisure activities (Diaz-Orueta et al. 2012).

The Pew Internet & American Life Project reported that 40 % of US adults aged 50–64 years and 23 % of US adults aged 65 years and older play video games (Lenhart et al. 2008). While the majority of younger American generations play video games, older adults aged 65 years and older who play games engage in game play more often than younger cohorts (Lenhart et al. 2008). To provide a perspective of gaming across Europe, The Interactive Software Federation of Europe (ISFE) reports the average percentage of males aged 55–64 playing games is 28 % and 27 % for females (ISFE 2012). Conversely, Pratchett et al. (2005) reported 48 % of gamers were women aged 51–65 years and 52 % were men in the UK. Moreover, from 2004 to 2011 there has been a 12 % increase in the number of adults aged 50 years and older who play digital games (ESA 2011). During the last few years, the ESA has not reported on gaming statistics for people aged 50 years and older. It is unclear why this important statistic is not maintained. The ESA now reports on gaming activity for adults aged 36 years and older.

Technology use and ownership among US older adults is increasing with mobile phone ownership among adults 65 years and older at 69 %, along with other technologies as follows: desktop computers 48 %, laptop computers 32 %, e-readers 11 %, and tablets 8 %. Among US adults 76 years of age and older, technology use includes: cell phones 56 %, desktop computers 31 %, laptops 20 %, e-readers 5 %, and tablets 3 % (Zickuhr and Madden 2012). According to the Pew Internet & American Life Project, 73 % of US adults play games on computers and 50 % use game consoles, with older adults being more likely to use computers (83 % of 50–64 year olds and 81 % of 65+) (Lenhart et al. 2008). Additionally, Pratchett et al. (2005) reports preferences for technology device and game console preferences, showing 84 % preferred a personal computer and 26 % preferred a PlayStation 2 console. Notably, this particular report is 9 years old, and unlike the ESA, there are no annual statistics provided or regular updates on gaming trends across demographics.

Games for Health Genres

The Games for Health Project, an initiative that built a network of professionals and researchers in the games for health industry, developed a taxonomy for health games. The main categories of the taxonomy include: Preventative, Therapeutic, Assessment, Education and Training, Informatics, and Production (Ben Sawyer, Digital,

Table 1 The games for health taxonomy (Ben Sawyer, Digital, Inc. & Games for Health Project)

	Personal	Professional practice	Research/ academia	Public health
Preventative	Health assets: PERMA, exergaming, stress, nutrition	Patient communication	Data collection	Public health policy and social awareness campaigns
Therapeutic	PT/OT sensorimotor rehabitainment disease management	Pain distraction cyber psychology disease management	Virtual humans	First responders
Assessment	Self-ranking	Measurement	Inducement	Interface/ visualization
Education and training	First aid, patient education health literacy	Skills/training	Recruitment	Management sims
Informatics	Personal health record (PHR)	Electronic medical record (EMR)	Visualization	Epidemiology
Production	Personal data collection quantified self	Biotech manufacturing and design	Biotech manufacturing and design	Large-scale data collection and monitoring

Inc. & Games for Health Project). Table 1 provides additional information on the games for health taxonomy. Most game taxonomies aim to address questions related to the expectations of the player and how they act during game play, and additionally, games for health seek changes in players' motivations and behaviors (Xu et al. 2012). A number of other taxonomies exist to categorize exergames and serious games; however, game developers, practitioners, researchers, and industry professionals could benefit from one integrated and comprehensive classification system for off-the-shelf health-based video games (Marston and Smith 2013).

The majority of research conducted on video games and older adults, according to Sawyer's games for health taxonomy, are in the categories of Preventative or Therapeutic. Digital games are being studied for use in rehabilitation treatments, to improve cognitive processes, for physical activity promotion, and for increased social interactions among older adults (Hall et al. 2012). For example, digital games are being studied as tools to improve physical strength in patients with issues such as balance weakness.

There are a number of commercially available (aka off-the-shelf) health-based games. For instance, the Wii Sports Resort includes games on swordplay, wakeboarding, Frisbee, archery, basketball, table tennis, golf, bowling, power cruising, canoeing, cycling, and air sports. The Nintendo Wii Fit comprises programs focusing on yoga, strength/balance training, and aerobics. Many of the Nintendo Wii Fit programs require an additional peripheral called the Wii Balance Board (WBB). The PlayStation 3 and Kinect offer similar sport and health-based games as the Wii. However, given the various types of games available, there is a paucity of research on games preferred by older adults and which games provide the greatest health benefits (Hall et al. 2012; Marston and Smith 2013).

Recommendations

Scholarly activity shows a steady growth of reviews situated around the field of games for health and older adults, including a narrative review (Marston and Smith 2012) and five systematic reviews (Hall et al. 2012; Bleakley et al. 2013; Miller et al. 2014; Primack et al. 2012; Connolly et al. 2012). Common themes aggregated across all reviews were small sample sizes, interventions of short duration, majority of study participants were recruited from community dwellings, and studies mainly focused on balance and stroke rehabilitation. The reviewed studies proposed a series of recommendations that future researchers should incorporate and examine further, which include the following: test feasibility of gaming technology implementation in the home environment, more rigorous experimental and longitudinal study designs, larger sample sizes, equal number of male and female study participants, inclusion of subjects aged 80 years and older, alignment of interventions in regard to frequency and duration, recording of adherence and retention rates to aid in better design methodologies, assessment of games and game console safety concerns, the use of consistent health outcome measures (i.e., for social, mental, and physical factors), behavioral theory-based interventions and games, assessment of game preferences, types of games that provide the greatest health benefits, and testing of newer motion sensing digital video game platforms (i.e., Kinect One). Furthermore, developers of health games should consider suitable themes that relate to the interests of older adults to maintain motivation and engagement, such as their hobbies, interests, and aspirations (Marston 2012). Notably, game features that allow players to record baseline measurements (i.e., heart rate) and skill level coupled with the ability to upload and store game play progress would be advantageous to clinicians and researchers.

In the last 10 years, there has been a growth of research conducted on digital game technologies (commercial and purpose built) for rehabilitation (i.e., physical therapy) and physical activity promotion. Further work is needed by the academic community to identify exact game elements and indexing of exercises to aid with strength, coordination, balance, and fitness, which are crucial for optimal health and wellness. At present, there is limited information on the classification of digital health game features and optimal health benefits and outcomes (Marston and Smith 2012, 2013). Given the influx of studies on the use of digital game consoles and purpose-built technologies for rehabilitation, several recommendations are proposed: an international classification system should be devised and clinicians/researchers need to identify game elements which are most beneficial for rehabilitation (Marston and Smith 2013).

Future studies should consider investigation within the home environment rather than in clinical, laboratory, or community dwelling settings. As reported by Marston in chapter "► Aging in Digital Places" of this book, she outlined problems that may arise when installing digital gaming systems in the home environment. Many people across the world reside in small environments and may not own a television or have high-speed Internet access. Space and technology limitations need to be taken into consideration by researchers when implementing gaming systems in home environments, such as the Nintendo Wii or the Microsoft Kinect One. For example, furniture may need to be moved for the individual to interact with the gaming console and technology installed, which could prove to be problematic and further create safety concerns. Future housing will need to be built to a substantial size to accommodate technology to foster healthy aging.

Conclusion

We described the current state of research on QoL factors of older adults associated with digital video game play. A collection of information and research on digital gaming and older adult characteristics was presented along with current gaming trends and ownership of technology devices. As previously stated, the ESA reports annual statistics based on the following elements: gaming demographics, genre preferences, purchasing habits, and modes of game play. Based on the results of literature reviews presented in this chapter, we provided a series of recommendations for future research that add to the body of work within the games for health field and supply researchers with concepts for future study designs and methodologies. The exponential growth of new gaming technologies, platforms, and sensors, the increased population of older adults who play digital games, the prevalence of chronic diseases, and the aging of the population provide exciting opportunities for researchers to find novel solutions through digital games to foster healthy aging. In summary, digital games are being studied for use as rehabilitation tools, as mental exercise tools, for physical activity promotion, and for increased social exchanges among older adults. We anticipate the continued growth of research and applications of games for health in the home for older adults and the clinical/health benefits derived from studies incorporating the previously stated suggestions and gaming technologies.

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The Rosetta Project

Franka Meiland, Johan van der Leeuw, Irek Karkowski, and Rose-Marie Dröes

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Abstract

To support the growing number of community-dwelling persons with dementia, alternative solutions, such as assistive technologies, are needed. In the European Rosetta Project, three separate ICT systems were improved, integrated, and evaluated with the objective to create one modular system that helps community-dwelling people with mild cognitive impairment (MCI) and dementia in different stages of the disease to retain their autonomy and quality of life that postpones institutional care and that supports the carers.

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The Rosetta system integrates the systems Elderly Day Navigator (EDN), Early Detection System (EDS), and Unattended Autonomous Surveillance–Advanced Awareness and Prevention System (UAS-AAPS). EDN supports persons in daily functioning in the areas of memory, social contact, daily activities, and safety; EDS monitors daily behavior and timely detects changes in functioning; and UAS-AAPS automatically detects emergency situations (like falls) and generates alarms to carers.

The development of the system took place in close cooperation with persons with severe cognitive impairments/dementia, informal and professional carers, and dementia experts. The final prototype was tested in a controlled field trial with persons with severe cognitive impairments or dementia in three countries.

The results from the evaluation study show that participants positively valued the usefulness of the system, but that the user-friendliness could be improved. Though there were no statistically significant effects on outcome measures in this explorative small-scale trial, participants indicated that the Rosetta system changed their lives in some ways, for instance, by structuring the day and by improving feelings of safety and security. Participants had no ethical concerns regarding the (visibility and application of) sensors and cameras.

Future implementation of the Rosetta system may (cost-)effectively support the growing number of community-dwelling persons with dementia during the mild and more severe stages of the disease.

Keywords
Caregiver • Dementia • Emergency detection • Monitoring • Support • User-evaluation

Introduction

One of the healthcare areas that faces many challenges in the coming decades is the care and support for people with dementia. Dementia is a syndrome characterized by an irreversible, progressive decline in cognitive abilities, such as memory, speech, thought, perception, and reasoning. In late stages of the disease, people with dementia are unable to perform even the most basic tasks, like maintaining basic hygiene or eating. Dementia is often accompanied by changes in personality and behavior (Hope et al. 1999; Lyketsos et al. 2000).

The main risk factor for dementia is age, with the prevalence increasing from 5 % to 10 % at 65 years to around 45 % at 95 years or older (Health Council of the Netherlands 2002). Since the global population ages rapidly and life expectancy increases throughout the world, the prevalence of dementia is expected to increase dramatically from 36 million in 2010 to 115 million in 2050 (Prince and Jackson 2009). At the same time, the potential working population will decrease (Health Council of the Netherlands 2002).

Therefore, the role of assistive technology will grow and will be even more important in dementia care in the future. The major challenge will be to continue to adequately care for the increasing number of persons with dementia, of which 70 % will live in the community, mostly taken care of by informal and professional carers. The expected benefits of assistive technologies in dementia care are to:

- Facilitate memory and recall
- Help manage potential risks in and around the home
- Promote independence and autonomy, both for the person with dementia and those around them
- Promote social inclusion
- Improve the quality of life of persons with dementia
- Reduce early admission to care homes and hospitals
- Reduce the stress on carers and improve their quality of life (Alzheimer's Society 2013)

Several positive effects of the use of assistive technologies have been reported in persons with dementia, such as more confidence, enhanced positive affect, increased communication and activities, enhanced feelings of safety and security, and less fear and anxiety (Lauriks et al. 2007; Bemelmans et al. 2012), and among informal carers, such as a reduction in caregiver burden, anxiety and depression, improved competence, and enhanced feelings of safety (Lauriks et al. 2007; Godwin et al. 2013). Additionally, professional carers may benefit from including assistive technology into their daily practice, as it can reduce staff anxiety (Blackburn 1988) and improve their work satisfaction (Engström et al. 2005).

To improve the acceptance of technology by the target group and to promote the effective use of it, it is important to develop technology from the beginning together with the target group and to ensure that the assistive technologies adequately meet the needs of the future users (Nugent 2007; Sixsmith et al. 2007). Studies into the needs of community-dwelling persons with dementia show that persons with dementia have needs for support in the fields of (e.g., preparing) food, household activities, mobility, and personal care (Van der Roest et al. 2009; Miranda-Castillo et al. 2013). For many of these needs, they receive sufficient care and support from informal carers or professional caregivers. In some domains, however, relatively often unmet needs are experienced. These domains are memory, daily activities, social contacts, and safety (Walters et al. 2000; Beattie et al. 2004; Van der Roest et al. 2007; 2009).

The Rosetta Project aimed to develop support for the most predominant unmet needs of community-dwelling people from the early stages of cognitive impairment to the more severe stages of dementia, by developing an integrated assistive technology system (see also www.aal-Rosetta.eu). This three-year European project, funded via the European Ambient Assisted Living (AAL) program, started with three previously developed systems that were improved, integrated, and evaluated.

Development of the Rosetta System

The three previously developed systems that form the core of the Rosetta system are the COGKNOW Day Navigator (Meiland et al. 2010, 2012), the EMERGE system (Storf et al. 2009), and the Unattended Autonomous Surveillance system (UAS) (Jans et al. 2009). Within Rosetta these systems are called the Elderly Day Navigator (EDN), the Early Detection System (EDS), and the Unattended Autonomous Surveillance–Advanced Awareness and Prevention System (UAS-AAPS). See for an overview of the Rosetta system in Table 1. Figure 1 shows a screenshot of the touch screen computer.

The EDN helps people with MCI and dementia in performing daily activities, for instance, by reminding them about activities and supporting them in social contacts via a picture dialling function; the EDS monitors early signs of changes in behavior patterns and functioning and provides alerts for important deviations from a persons' normal behavior; and the UAS-AAPS provides autonomous surveillance with sensors and smart cameras. These three subparts are integrated in such a way that they together meet the needs of persons with MCI and persons with dementia in different stages of the disease. A combination of EDN and EDS will be particularly useful in the early to moderate stages of dementia, whereas in the more advanced stages of dementia, a combination of EDS and UAS-AAPS is more useful.

The subsystems of the Rosetta system were improved and integrated in close cooperation with the target group of persons with dementia and informal carers and with dementia experts (see for more detailed information about this user participatory design process in Meiland et al. 2014). During the development process, iterative workshops and/or interviews were organized with the target group and dementia experts. PowerPoint presentations and mock-ups were used to show the proposed technology to the participants. Also, at Fraunhofer in Kaiserslautern the EDS subsystem was installed in a demonstration house, and in the Netherlands, a demonstration house was equipped with the total Rosetta assistive technology system, allowing for testing the system in a naturalistic environment. Then, after final adjustments and refinements had been done based on users' feedback and with taking into account the feasibility of the proposed changes, the first prototype was tested by persons with MCI/dementia and their informal carers in field tests in the Netherlands and Germany. Participants had the system installed in their own homes for at most 8 months. In Belgium only the subsystem UAS-AAPS was installed and tested.

User Experiences

The Rosetta system was evaluated in a (randomized) controlled trial (see for information about design and results of the evaluation in Hattink et al. 2014 submitted) in three countries. Forty-two community-dwelling persons with mild cognitive impairment (MCI) or dementia participated in this study, as well as 32 informal carers and six professional carers.

Table 1 The integrated Rosetta system with EDN, EDS, and UAS-AAPS

Devices: Video home terminal (touch screen), mobile device, sensors, actuators, cameras, a Domotica Access Point (DAP), and a server
Elderly Day Navigator (EDN)
This touch screen supports persons with mild cognitive impairment (MCI) to moderate dementia in their daily functioning in four areas: memory, social contact, daily activities, and safety. **To support memory**, the touch screen provides reminders (e.g., "you have an appointment with the doctor at 10.00 a.m."). Reminders can be entered remotely by informal or professional carers. The screen also shows an agenda with the planned time to start these activities. Furthermore, an analog clock and the current date are shown. **To support in social contact**, there is a picture dialling function on the screen with a photo address book. **To support in activities**, a person's own collection of digital photos can be shown on the screen. And finally, there are several functionalities **to promote feelings of safety**. Persons may receive safety warnings on the screen, such as "you left the fridge door open, please close it." Also, there is a Help button, which enables easy telephone contact with a relative. The Help button on the mobile device may also be used when persons with dementia have lost their way outside. In that case informal caregivers can direct them in finding the way home using the navigation support on a website that shows the location of the person with dementia and the path he has followed. The EDN allows persons with MCI/dementia and/or informal carers to choose which functions of the EDN they want to use and is thus personalizable
Early Detection System (EDS)
The Early Detection System (EDS) software records the daily pattern of living of the persons with MCI/dementia for several weeks by analyzing signals from the sensors in the house. In case of two-person households, the daily patterns of both persons are monitored together. After this period the software can: • Automatically indicate whether there are significant changes in the day-to-day pattern of living • Generate graphs/indexes that offer a summary of the day-to-day pattern of living and reveal slowly occurring changes in it. These graphs allow professional carers and informal carers to monitor the status of the person with dementia and to decide on the need for follow-up actions. To help analyzing these graphs, colored markers are displayed: green markers indicating no changes in daily patterns, yellow markers for mild changes in daily patterns, and red markers for significant changes in functioning The EDS focuses on sleep–wake rhythms, mobility inside the house and (time a person spends) outside the house, meal preparations, personal hygiene, and number of reminders and emergency alarms. The persons with dementia and/or informal carers individually choose which activities they want to be monitored
The Unattended Autonomous Surveillance System–Advanced Awareness and Prevention System (UAS-AAPS)
This subsystem is able to detect emergency situations and generate alarms to care organizations. By using movement sensors and cameras in the house, emergency situations are detected, such as fall accidents and wandering in the house. In emergency cases, a message is pushed forward on the video home terminal and the mobile device, and the person with dementia is asked to confirm whether he is safe or not. When he is unsafe or when there is no response from the person with dementia, an SMS will be forwarded to the professional carer, who then can assess the situation via the speak–listen unit and the camera in the home of the person with dementia and decide whether help is needed

The actual trial period varied for individual participants from 0.5 to 7.5 months, with an average of 4 months. In total a properly operating Rosetta system could be tested during 50 person-months, divided over different trial houses.

Fig. 1 Screenshot of the touch screen computer with agenda function activated

The persons with dementia and informal caregivers were interviewed before, during, and after the trial. The actual usage of the system was logged and observed by the researchers. The professional carers filled in some online questionnaires.

The user evaluation showed that privacy issues did not seem to be a major concern within the Rosetta trials. Though most participants and informal carers felt they could be themselves with the sensors and cameras in the house and that privacy was warranted, a few participants did seem to somewhat adapt their "normal" behavior.

Despite some criticism about the technical issues in the first months of the trial and about limited user-friendliness of the configuration interface for the carer, the participants considered the Rosetta system as a useful system and felt that Rosetta could indeed give persons more structure and more feelings of safety and security, decrease the burden of caregivers, and enable people with dementia to stay at their own home longer.

No significant impact of the Rosetta system was found on the main outcome measures of quality of life and experienced autonomy of the persons with MCI/dementia nor on the quality of life and feelings of competence of the informal carers. Participants see potential in implementing this system on a larger scale in the future.

After the trial period, people were offered to keep the system in their home, and five of the nine participants in the Netherlands accepted this offer.

Technical Evaluation

The technical evaluation showed that the project succeeded in developing the integrated Rosetta system and installing it in the houses of persons with MCI/dementia. However, the system did not work effectively right from the beginning of the trial, and also during the trial several technical problems occurred.

The EDN worked quite stable during the trial, although some technical issues were encountered, most of which were solved during the trial.

For EDS the general concept (monitoring signs of changes in behavior) was proven to be working during the trial. The activity recognition and behavior monitoring appeared to be highly dependent on the number of sensors installed, which was not always sufficient in the trial to make a good assessment. Based on the trial results, it is recommended that the types and number of sensors are determined based on the environment, the individual behavior of the person to be monitored, and the characteristics and/or progress of the disease. The detection accuracy could not be checked in this trial because there was only limited information about actual, real-life, behavior patterns.

In general the UAS-AAPS part of the AAPS system functioned as expected and generated on average 0,7 false alarms per week. No real emergency situations were detected during the trial period. There were some problems with the bed sensors which were related to type and weight of the mattress used by the participants. The smart camera functionality worked satisfactory in general.

Recommendations and Future Implementation

Based on the evaluation of the Rosetta system, some recommendations were made. For usefulness these were, e.g., to elaborate the agenda function with a messaging function, to improve the technical performance of some functionalities, and to extend the fall detection functionality to cover also other types of fall situations, for example, when a person is still moving because he is crawling on the ground. To improve user-friendliness it is recommended to increase the sensitivity of the touch screen and the battery life of the mobile device. Also the carer Web interface could be improved by facilitating entry of data in the agenda and photo book and by making it possible to check remotely if these data appear correctly on the touch screen in the home of the person with dementia.

When the abovementioned recommendations are being addressed, it is expected that Rosetta will have a good selling point because the system is very elaborate and flexible and combines different functionalities that are needed during the process of dementia, while the existing products on the market focus on separate needs in specific stages of the disease. Another important added value of Rosetta is that the functionalities of the services are in general more advanced than the existing devices due to usage of more and various type of sensors and due to being able to exchange relevant information between the components of the integrated system.

Within the project a social business case for the Rosetta system has been developed, taking into account that the system's most important benefits for the users are the postponement of nursing home admission, prevention of crisis situations, and support in daily life (Van der Leeuw 2012). The most promising social business case is for a combination of AAPS and EDS in one-person households, with an estimated profit of ±€15.000, per system over an exploitation period of 7 years.

Currently, parts of the Rosetta system are already available on the market. The UAS system is exploited via Dutch Domotics (www.dutchdomotics.nl), and the EDS is integrated in the PAUL system by CIBEK Germany and used in home care for the elderly.

Case Study

Mrs. Visser is 79 years old, widowed and living alone. Two years ago she has been diagnosed with mild Alzheimer's disease. She receives support from her daughter, who is married, working full-time, and living at walking distance from her mother. She cares for her mother for about 15 h a week spread over 7 days a week.

The daughter indicated that she is afraid that her mother will fall because this has happened before in the past. She also experiences that her mother is restless, not knowing what to do during the day. Often, the daughter is being called by her mother who asks if there are any activities planned for a particular day. Since the daughter works full time and is not always able to answer her mothers' phone call, this puts quite some burden on the daughter.

The full Rosetta system was installed in Mrs. Visser's home. Her daughter added reminders for activities in the agenda function of the Elderly Day Navigator, such as when to do her shoppings and to prepare a lunch for herself and planned visits to her weekly choir and the doctor. Furthermore, she added pictures from her mothers' family and holiday visits in the past and of course from her granddaughter. Mrs. Visser could view these photos herself, and an automatic reminder that popped-up on the screen to remember her to watch the photos stimulated this activity. Also, the granddaughter used this feature to engage in a nice activity with her grandmother, who vividly started talking about her own younger years when she saw the photos. The intention was that Mrs. Visser would also use the mobile phone for receiving reminders and safety outdoors, but she was not used to a mobile phone and did not learn how to use it.

Thanks to the safety features in the Rosetta system, the daughter felt reassured that any dangerous situation would be detected by the system and she did not feel the need to check this in her mothers' home in the same frequency as she did before. Also, the daughter felt less burdened because she was called less frequently by her mother. She felt the Rosetta system could help her mother in maintaining her independence and being less in need of assistance from other people in maintaining safety. Mrs. Visser was also happy with the Rosetta system; she stated that it is "a good thing, especially for people who are alone." She considered the agenda to be the most useful part of the system.

Conclusion

The project succeeded in the user participatory development of an integrated, multimodular Rosetta system. People with dementia and their informal and professional carers positively valued the Rosetta system in assisting people with mild to severe cognitive problems in their daily functioning, thus helping them to retain their autonomy in daily life and to postpone admission to a residential care facility. They see potential in implementing the Rosetta system on a larger scale in the future, provided that some improvements will be made. These concern, for instance, elaboration of the agenda function, extension of the fall detection functionality, and improvements regarding the carer Web interface and the technical performance of some of the functionalities.

Implementation of the improved Rosetta system may (cost-)effectively support the growing number of community-dwelling persons with dementia during the early and more advanced stages of the disease.

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Property Damage, Purchasing Orders, and Power Outages, Oh My!: Suggestions for Planning Your Next In-The-Wild Deployment

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Abstract

This chapter describe the plan and execution of a 6-week deployment of home-based monitoring technologies in the homes of older adults. Begin by presenting suite of technologies that developed and then outline an original deployment plan, discussing each aspect of the deployment in detail. Next, unforeseen issues encountered prior to and during the deployment. Finally, the lessons learned to produce a list of suggestions for future researchers interested in deploying suites of UbiComp technologies in the wild.

Keywords

Aging-in-place • In-situ deployment • User study

Introduction

Imagine the following scenario: you are an 80-year-old woman and a college student calls asking if she can come over with friends, poke holes in your walls, mess with your computer and home network, and install a camera in your bedroom. To top it off, she wants to make regular visits to your home and call you every day over the next 6 weeks to ask you a bunch of questions! This scenario illustrates – in essence – a study recently conducted by a group of researchers associated with Ethical Technologies in the Homes of Seniors (ETHOS) lab. The goal of this study was to gain deeper insight regarding attitudes toward digital security and privacy held by older adults by situating a suite of prototypes within an actual context of use. While it would have been much easier to install and maintain these prototypes within a controlled laboratory setting, the issues being explored were heavily dependent on day-to-day living and therefore necessitated a full-scale UbiComp deployment *in the wild*.

The sorts of questions that are addressable with *in-the-wild* studies differ from those set within a controlled laboratory, particularly when examining user experience (Rogers et al. 2007, 2010). While traditional lab studies are essential to validate the *potential* impact of new technologies, such studies can only speculate as to how these technologies will function in actual contexts of use. This in no way implies that traditional lab studies are unnecessary; indeed, questions of usability and usefulness are often well suited for study in the lab. However, lab studies may not always provide significant insight into how people appropriate the technology during actual use. To study this aspect of a developing technology requires a push outside the lab so that researchers can observe how people interact when not explicitly prompted with artificial tasks. This is of particular relevance to UbiComp research, which has a strong focus on the study of technology's role in everyday living.

The downside of conducting UbiComp research outside of the lab is the increased costliness and difficulty necessary to make studies effective (Kjeldskov et al. 2004; Hazlewood et al. 2011). This is particularly true in situations when the research question requires studies be conducted over long periods of time. Extended periods of time demand constant observation and maintenance of prototypes and require that prototypes be constructed at a much higher level of fidelity than those housed only in a laboratory.

This chapter begins by briefly describing a study which was conducted to investigate older adults' perspectives on privacy and security in regard to technologies to assist aging in place (Camp and Connelly 2007; Shankar et al. 2012; Huber et al. 2013). This is followed by a more detailed description of the individual prototypes that were installed in the homes of older adults and their informal caregivers. Finally, a detailed description of experiences in deploying prototypes in the wild is provided, including the issues that were anticipated and the lessons learned over the course of the project. The chapter concludes with a set of suggestions for future researchers planning to conduct similar deployments.

The ETHOS Project

ETHOS is an NSF-funded project consisting of an interdisciplinary team of researchers at Indiana University Bloomington whose goal is to design and evaluate home-based computing technologies for older adults. In particular, the ETHOS team is interested in developing technologies that simultaneously enable health and personal safety while preserving privacy (e.g., Caine et al. 2010, 2011). The ETHOS team is dedicated to creating tools that will ultimately help older adults make appropriate decisions about home-based computing (Huber et al. 2011; Shankar et al. 2012; Huber et al. 2013) and guide designers in creating privacy-respecting technologies (Huber and Connelly 2008; Shankar and Connelly 2010; Shankar et al. 2012). The ETHOS project maintains a "Living Lab," in a historic home on the campus of Indiana University Bloomington where new technologies are designed, prototyped, built, and deployed. This allows older adults who visit the lab to interact with these prototypes within a simulated home environment. While every possible has been made to accurately simulate a functioning home environment, there is only so much that can be learned within this environment. Developing a deeper understanding of people's attitudes toward the technologies developed within the lab ultimately requires moving out into the real world.

The Study

This chapter presents a UbiComp deployment aimed at a better understanding of older adults' attitudes toward and behavior with a variety of technologies. To accomplish this goal, a system of prototypes was installed in the homes of four older adults with an accompanying system for each of their informal caregivers. The use of these technologies was then carefully monitored over a 6-week period. Since attitudes toward a particular technology are significantly influenced by perceived usefulness (Davis et al. 1989) and older adults have unique needs, a suite of six prototypes were developed covering a range of different functions (Shankar et al. 2012). Each participant received this collection of prototypes and was observed regarding how they chose to use and avoid different technologies based on their personal circumstances.

Each of the older adult participants lived in independent apartments and cottages within a single retirement community in the Midwestern United States. Each identified informal caregivers to participate in the study along with them, who would receive information collected by the prototypes. All informal caregivers were either family members or close friends who lived within a 30 min drive.

The project consisted of a technologygroup responsible for developing, implementing, deploying, and maintaining the prototypes, and one responsible for designing, conducting, and analyzing the results from the study. The focus of this chapter is on the technology group's experiences with developing and deploying technologies outside the predictable confines of the laboratory.

System of Prototypes

The project deployment contained a system of multiple prototypes designed to share information about daily life between the home of an independently living senior and an informal caregiver. The design and implementation of each prototype within this system is described below.

The DigiSwitch

The DigiSwitch is an application that runs on a self-contained touch screen PC installed in both the elder and caregiver's homes. There were two slightly different versions of the DigiSwitch, one version designed for the older adults and another for the caregivers. The DigiSwitch for the older adult allowed him or her to control all of the devices installed in their home and see exactly what information was being made available to the caregiver. With this interface, the older adults could change the status of each device to either ON, PAUSE, or ME TIME (Caine et al. 2010, 2011). As one would expect, the ON and OFF states control whether or not the devices are sharing data. The ME TIME option, on the other hand, makes the devices stop sharing data but hides this participant's desire to conceal their data by transmitting archived data to the caregiver while still reporting that the device is functioning as usual (Fig. 1).

The Scheduler

The Scheduler is a digital calendar application that runs on the same machine as the DigiSwitch. Its primary function is as a health reminder system that alerts participants to take medications. In addition, participants could add any other events of which they wished to be notified. Medication reminders were handled differently

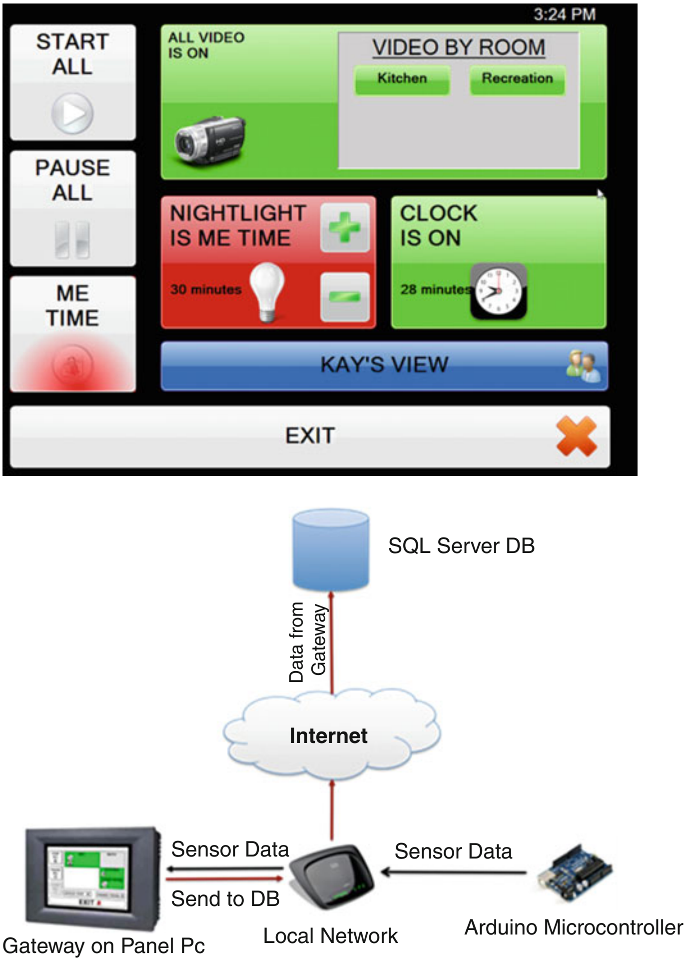

Fig. 1 (*Top*) The DigiSwitch interface. (*Bottom*) A microcontroller using the Gateway to report sensor data to the offsite database

from other notifications in that the older adult would be prompted to confirm whether or not medication was actually taken after the notification was provided. If the confirmation request to a medication reminder was negative, the event was logged and could potentially be reported to the caregiver.

The Gateway

The Gateway is a middleware application that runs in the background on the PC running the DigiSwitch and the Scheduler. The limited processing power of the microcontrollers used in several of the prototypes made it impractical to have them communicating directly with the central server. Since a fully functioning computer system was already being used to support the DigiSwitch and Scheduler in each participant's home, it was decidedly more convenient to run a software daemon from *this* computer that all of the other prototypes could communicate with directly. In this arrangement, the embedded devices within the Presence Clock and Beacon Strip (see below) could easily establish a connection with the Gateway over the local network, which would in turn communicate messages back and forth from a central database over the Internet.

The Presence Clock

The Presence Clock augments a common household object (a decorative clock) with motion sensors and LEDs (Arreola et al. 2014). A version of this clock is installed in both the home of an older adult and the home of an informal caregiver. Each of these devices collects and displays presence information using the motion sensor and presents this information to the other owner using the LEDs. When either the older adult or caregiver is detected by their clock's motion sensor, the paired clock shows this activity by lighting up certain LEDs. Activity is shown by gently pulsating the LED located at the current time of the clock face. Additionally, each clock shows a history of the presence it has detected over the past 12 h by leaving the LEDs on as time moves forward (Fig. 2, right).

The clock was constructed using an array of 48 LEDs positioned around the outside of the clock face, a motion sensor, and a microcontroller. When the motion sensor detects activity that exceeds a certain threshold, it sends that information to a database. The microcontroller also checks the Gateway at regular intervals to determine if any new presence information has been reported from the paired clock. When

Fig. 2 (*Left*) The Beacon Strip illuminates in the *dark* room when the older adult gets out of bed. (*Right*) Clock showing a strong amount of presence between 9 AM until 12:45 PM and a small amount of presence from 5 AM to 8 AM

new presence data is available, the clock illuminates the correct LEDs to represent that information.

The Beacon Strip

The Beacon Strip provides an illuminated pathway between the bed and the bathroom within the older adult's home. When a person gets out of bed during the night, the pathway activates so as to aid in navigating a dark room (Fig. 2, left). The Beacon Strip also collects and shares data regarding sleeping habits (i.e., quality of sleep). This prototype was constructed using heavy industrial carpet, pressure sensors to detect footsteps, two rows of LEDs to create a lighted path, and a force-resistive pressure sensor which could be placed under the mattress of the bed to detect the levels of tossing and turning that occur during sleep. The various sensors, controls, and LEDs are managed using a microcontroller similar to the one used in the Presence Clock, communicating with the Gateway via an Ethernet connection.

The Cameras

The Camera prototype is comprised of three Axis 207 W wireless webcams placed in various places throughout the home, which are accessed and controlled through the DigiSwitch. This particular camera model was chosen because the company provided a useful set of libraries that made integration with existing code straightforward. Additionally, these cameras supported a physical I/O connector that could be used to control the on and off status of the device. Using off-the-shelf parts from the local hardware store, a box was constructed with a physical button and an LED to display the camera's current (on/off) state. This box was wired directly into the camera's I/O port and placed on the nearest flat surface so that the older adult could simply walk up and hit the button when privacy was a concern. This physical button was provided as an additional means of controlling the state of the cameras, as this was also possible through the DigiSwitch interface (Fig. 3).

Into the Wild

As discussed above, going *into the wild* to conduct research has many benefits over traditional lab studies. One such benefit is *ecological validity*, which refers to the degree to which findings from a study has relevance outside of the study context (Brewer 2000). In traditional lab studies, ecological validity is often sacrificed for experimental control. For example, to understand the ability of an older adult to use the DigiSwitch for turning on and off devices, we invited participants into a laboratory environment where a certain level of *control* could be exerted by prescribing the tasks to be performed, limiting the outside help they receive from family or friends, and enforcing the time constraints under which tasks need to be

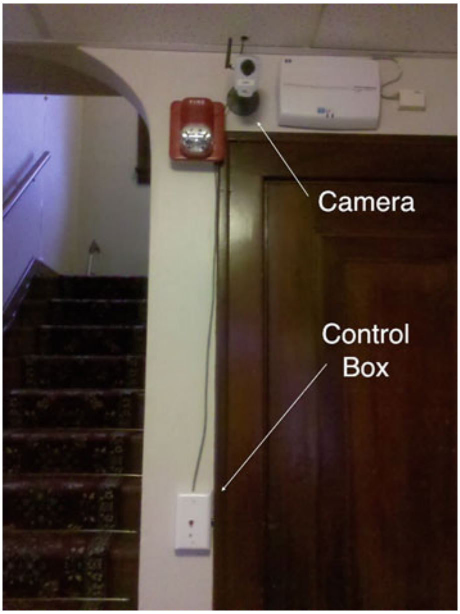

Fig. 3 Example of a camera with attached control box

completed. However, to understand the ability of an older adult to incorporate the technologies like the DigiSwitch into their daily routine, we sacrificed the control offered by the laboratory and instead installed these devices in the home of the older adult and observed their unscripted interactions over a period of time.

While such studies are generally higher in ecological validity, there are many issues that arise when conducting a study in the wild. The following section describes a plan that was developed for conducting the study described above, followed by a description of the issues which were anticipated during the deployment of the system, along with lessons learned regarding those which were not anticipated.

Developing a Plan

Before implementing the final customized versions of the prototype system for each deployment location, a protocol was required for how these deployments should be carried out. Even though all possible variables that would differ in the wild could not be predicted, every effort was made to perform the deployments as consistently as possible across participants. To aid in understanding what issues could arise outside the controlled lab environment, three participants were recruited who allowed pilot installations to be deployed within their homes. These participants consisted of a member of the development team, one of the project administrators, and a family member of one of the project administrators. These participants were selected based on their willingness to help identify issues and because of their varying range of familiarity with the technical details of the prototypes, thus providing different perspectives on the system and the deployment process.

During these pilot installations, a functional system was installed in each participant's home, and notes were made regarding the issues which could potentially hinder a clean and consistent deployment. This helped in at least two complementary ways. First, it helped in the development of a consistent installation plan, and, second, the pilot installations exposed system bugs and underdeveloped procedures which could be refined prior to the actual deployments. Thus, the pilot installations allowed for correction of such issues prior to the actual study.

Based on observations from the pilot studies, a rough document was compiled listing all essential tasks and equipment necessary for a successful deployment, so that each could be checked off and confirmed (e.g., user id set, correct ports camera software updated, DigiSwitch software installed, etc.). After the completion of the pilot studies, significant effort was put into planning a step-by-step scenario of how the deployments would be conducted. The final deployment protocol involved: (1) conducting a pre-deployment "scouting" visit to each participant's home, (2) making note of any potential problems specific to that location, (3) assembling and configuring a fully functioning system of prototypes following the checklist in the ETHOS lab, (4) addressing issues discovered during scouting, (5) running the new configuration for 24 h, (6) disassembling the functioning system for transport, (7) at deployment location, and (8) performing the installations.

Anticipated Issues

In addition to the development of a deployment protocol using pilot studies, past experiences were revisited to construct a list of issues and difficulties to address early in the development process. These are listed below, and an explanation is provided as to how each was addressed.

Connecting Devices Within the Home

It was assumed that devising a perfect way of connecting all the various prototypes together inside the homes of each participant would not be trivial. Even though the ETHOS lab had been made to resemble a small home, it was different from the typical home environment in that there were hardwired Ethernet connections in every room, and lab members had full governance over the arrangement of furniture and appliances as well as the freedom to drill a hole wherever necessary. It had to be assumed that participant homes would not be pre-wired with the level of connectivity offered in the ETHOS lab and that greater respect had to be paid to the existing decorum, hindering the rearrangement of furniture or doing any nailing or drilling.

The first solution considered to network the prototypes was to lay Ethernet cables around each home, being careful to secure cords along baseboards and under the carpet. However, during the pilot studies, the technical team found that this was unrealistic based on the layout of the homes. Such cabling would have required either laying cables across doorways (causing dangerous tripping hazards) or using very large amounts of cable to route around all possible hazards. Neither of these solutions would have been amicable to the participants of the study. Next, the possibility of using a type of wireless bridge – often used to make printers and game consoles wirelessly accessible – was considered. However, previous studies provided mixed results with the reliability of such devices due to their inability to maintain a persistent connection with the central wireless router. While many of the connection issues associated with these bridges can be fixed relatively easily (i.e., hitting a reset button located on the device), it was agreed that this practice could grow into a significant maintenance problem, and participants might not be willing to perform these sorts of resets themselves.

Ultimately, a device called a Powerline adapter was used to solve most connectivity problems. This device plugs into a standard power outlet and uses a protocol called HomePlug to convert the electric wiring within a home into a network hub. With these devices, it was possible to replicate the ETHOS lab setup more accurately since they essentially provided a dedicated Ethernet jack next to each prototype. These devices generally worked well, but there were a few instances where one bad module interfered with the communication throughout the home. Bad modules were discovered through trial and error, and once they were removed, the overall setup worked sufficiently well.

Acquiring Atypical Resources Through the University

Development of prototypes for the home environment often requires the use of materials not found in the typical university prototyping lab. An issue generally not discussed at length in UbiComp development literature is the problems that can arise when trying to acquire the unusual resources necessary for such deployments. The university purchasing department working with the ETHOS lab often had difficulty acquiring approval to purchase specifics items needed to build prototypes. For example, this deployment required things such as: no-slip carpet mats, woodworking tools, furniture (i.e., clocks), and pay-as-you-go services (e.g., 4 months of broadband Internet service for one of the participants). Waiting for the purchasing department to sort out these problems took several weeks in some cases, severely inhibiting adherence to the development schedule.

In many cases, the only option was to have members of the development team purchase necessary materials on their own with faith that the university would eventually reimburse everything. In the end, the university paid for most things, but every purchase required a significant amount of documentation and explanation. Dealing with these sorts of purchases requires having some lab member with the willingness to use his or her own credit and someone who can build a strong rapport with the purchasing department. By the end of the project, there was a specific set of people who became accustomed to dealing with the team’s unusual requests and who had developed their own protocol as to how these requests should be handled.

Customizing Prototypes for Idiosyncrasies of Individual Deployments

Completing the system on schedule required development to begin before any participants had been recruited. There was only speculation regarding the specifics of the deployment locations. Hence, several assumptions had to be made about the type and quantity of the various materials necessary for each prototype. This was particularly problematic with the construction of the Beacon Strip since the size and shape of this prototype depended on whatever path was taken between the bed and the bathroom.

This problem was alleviated by contacting the facility from which all participants were to be recruited and requesting the blueprints for each apartment style within the complex. While these blueprints did not tell/reveal everything about how items were arranged within the homes, worst-case scenarios for each layout were constructed (i.e., assuming the beds were small, and far away from the bathroom as possible, or that there would only be one power outlet in the worst possible place). These scenarios allowed slightly more accurate purchasing orders to be assembled and provided confidence that the estimates would be sufficient without overshooting by too much.

Doing Harm to Personal Property

Another issue that had to be resolved involved the physical installations necessary for deployment. Each home in which a system deployment was planned would have to be returned to the state in which it was before the study began. Accepting this principle required careful reconsideration in regard to the different installation options available. For instance, the initial plan was to mount the DigiSwitch on the wall, but the touch screen computers had become fairly heavy and cumbersome with the addition of the external enclosure. It became obvious that mounting the DigiSwitch on the wall would require drilling several holes and, thus, was no longer an option. The wall clock had also become heavy and cumbersome with the addition of all the necessary extra components and would thus require a sturdy bracket to be safely mounted. Lastly, each camera mount would require three holes to be drilled and in some cases would have to be mounted over wallpaper that could not be easily repaired. For reasons of liability, each of these installations would have to be overseen by a professional contractor, adding yet another layer of complexity to the deployment plans.

To avoid this complexity, the design of these prototypes was modified so that they could easily sit on a normal surface, rather than be hung on walls. An attractive wooden frame was custom-built for the touch screens, and desk clocks were purchased and augmented for sitting on tables. For the cameras, a clamp-like mounting bracket was purchased from the manufacturer. These changes in design added time to our development process, especially for custom design and construction of the wooden frames.

Dealing With Existing Home Infrastructure

While homes today are more likely to have several of the technologies that could be used to support a deployment such as the one described here (e.g., wireless routers, webcams, desktop computers, etc.), new issues that could arise when using similar, but not identical, hardware than what had been tested in the lab was a cause for concern. Potential problems could be avoided by not only providing prototypes for use in the home but also by installing a set of standardized component parts – routers and wireless access points – in each participant's home. This would help in avoiding most hardware and firmware incompatibilities, as well as any conflicting configuration issues that could have come from the existing home network.

This solution, however, created one new issue that had to be addressed in some of the deployments. Some households were annoyed that their family members and friends had to reconfigure wireless connections on their personal laptops when they visited and would have to change again after the deployments were removed. The difficulty was in that many older adults do not fully understand how their own home networks operate (Poole et al. 2008) and therefore have no way to gauge the relative level of inconvenience caused when the researchers were not around. To settle this issue, the research team offered to be "on call" for all technical issues during the study and for several weeks after the prototypes were removed. This was necessary to get approval for the use of new equipment, but, of course, this added to the amount of maintenance and support necessary for the project.

Prototype Robustness

While all ETHOS prototypes required careful consideration in terms of their construction, the most challenging of these was in the development of the Presence Clock. Integrating the required components with off-the-shelf clocks, while keeping the resulting prototype robust and professional looking, proved to be more difficult than was originally anticipated. Early versions of this prototype required an unmanageable amount of wiring and augmentation, which easily came undone whenever the prototype was moved or adjusted. Without the appropriate equipment, even spacing the holes for the LEDs correctly became a painfully arduous task. After constructing several – somewhat sloppy – versions of this prototype, a staff specialist was consulted who had greater electrical and mechanical engineering knowledge. The specialist was able to design a specially crafted circuit board that integrated the individual components being used into a self-contained module that could be more easily mounted inside the clock. While these boards were somewhat expensive, the resulting prototype was far superior to what had originally been assembled within the lab, and it was no longer necessary to worry about accidental damage. What was lost in monetary resources was easily made up for in the time saved on construction and maintenance.

Lessons Learned

In the previous section, a number of anticipated issues were described that had to be addressed during development and deployment of the ETHOS prototypes. It became obvious that there were several implicit assumptions made which also should have been addressed directly. These assumptions and issues are identified in the following sections, along with the lessons learned for future deployments.

Reliability of Network and Power

While it was apparent that the network connections within the participants' homes would not be as good as those in the lab, assumed that the level of service offered by local broadband providers would be consistent across all deployment locations. In reality, each home was found to have its own idiosyncratic connectivity issues, even among homes that used the same broadband provider and service plan. For example, in one case, a network technician from the commercial provider had to be brought to the deployment site, only to discover that the actual wiring within the home was faulty. Fixing this problem required several weeks and postponed the deployment schedule significantly.

Another mistake was assuming that the electricity in people's homes would be sufficiently reliable. While power outages are a daily occurrence in some areas of the world, except under the most extreme cases (e.g., massive heat waves and natural disasters), power outages are not often recognized as an engineering constraint in the Midwestern United States. Of course, power outages are nearly unheard of within a controlled lab environment, so it is not often a high priority to ensure prototypes can deal gracefully with such losses of power.

However, the ETHOS prototypes were unwittingly deployed during part of the summer in which thunderstorms are more common. These storms were particularly powerful during this year, causing "brownouts" that made the electricity in the homes unreliable. The result of these power outages was that a fair amount of data was lost since none of the prototypes had been designed to auto-restart and initialize. Not having anticipated this issue, the only solution was to send a technical team member to each participant's home whenever a power outage caused the prototypes to lose power. Since after the deployments had been installed, the solution was to write a separate program which pinged each installation to confirm that it was currently active and send an alert whenever a special trip was required to re-initialize any part of a deployment.

Managing Prototypes Through a Central Server

Of course, a common architecture to use when managing remote prototypes is the standard client/server model. However, the flakey connections and inconsistent power encountered at each of the deployment sites led to a series of other issues. The most significant issue was due to the use of this particular model, where all prototypes were communicating through a single remote server. Any occurrence that caused the network connections to become unstable resulted in prototype failure and participant frustration. More importantly in terms of the study, loss of connection meant loss of data, which caused a great deal of grief when it came time to analyze the results.

Difficulty of Onsite Visits

Reinitializing any systems affected by network disconnects turned out to be difficult simply because it involved an undesirable amount of scheduling between the researchers, prototype team, and participants. Assumed that there would be a some maintenance necessary to keep the prototypes functioning, and ways to access the deployed systems remotely were discussed, but this all relied on the system maintaining a usable network connection. Once this connection went down, the only option was to make a personal visit.

Suggestions for Future *In-The-Wild* Studies

As described above, there are a number of things to consider when planning for an *in-the-wild* study. The next section presents nine suggestions based on both issues that were anticipated going in to the study, as well as new lessons learned during the study. These lessons are intended to be useful for researchers considering conducting similar *in-the-wild* deployments.

Conduct Pilot Studies

While the technical team felt confident that they had done a good job considering many of the issues which could be faced when moving the system out of the lab and into participants' homes, discovered that no amount of speculation or planning can compare with a real trial run. While all three of the pilot studies were valuable, the one conducted with participants external to the research group provided the greatest amount of insight as to what was going to work and what was going to fail. Skipping this step could allow such unanticipated issues to wreak havoc once the study has begun.

Scout Locations Before Deployment

It is rare that any two deployment locations will ever be the same, thus it is critical to scout each location *before* making plans for an installation. While this advice is important for any "in-the-wild" deployment, it is particularly important within domestic spaces where people tend to configure their surroundings in a way that defines their own individual preferences. Because of this, it is important to scout all locations where a deployment will be situated so as to observe first-hand the specific minutia that could potentially cause problems during installation and over the course of the study.

Design Deployments Be Self-Contained

Any aspect of the system prototype, which was not selected, purchased, or built by the research team, has the potential to introduce inconsistencies into the study. This is true even down to the electricity being used in the location of deployment.

Of course there will always be resources necessary for the prototypes which cannot be realistically provided by the research team, but every effort should be made to avoid using resources provided by third parties, including the participants of a study. For example, several of the participants already had computers and wireless routers in their homes, but using these would mean adding several untested scenarios, and further complicate the deployments.

Do Not Build, When You Can Buy

While it may seem like a good idea to construct components for a system of prototypes in-house, it often only adds complexity to a project, even with a set of competent engineers readily at hand. Nearly any commercially available product or component is going to be more robust than what is constructed in the lab. Commercial products will have gone through a great deal of product testing, freeing the researchers from a heavy load of debugging and general maintenance. Monetary resources conserved in building versus buying can be minuscule when compared to the time and effort required in order to "do it yourself." For example, the AXIS cameras used in the ETHOS study represented one of the most expensive individual components purchased. However, over the course of development, the camera prototype was found to be the cheapest component within the entire system of prototypes. This is because the cameras did not require paying an additional student to develop the prototype, nothing special had to be constructed, and the resulting prototype required little or no extra maintenance.

Prototypes Must Be at a Very High Level of Fidelity

In the lab, it is rare that someone will vacuum over, spill water on, or just randomly unplug a prototype; it is rare that an infant or a playful pet will damage one's prototype. Prototypes can be very delicate because of the lack of these dangers within a controlled environment. This is why prototypes may be constructed in a loose-and-dirty fashion, using copious amounts of tape, hot glue, and fashioning electronic components together with nothing more than a breadboard. For real-world UbiComp deployments however, prototypes must be far more robust and hardy in order to withstand all the possible threats to their functionality. Additionally, these prototypes must be designed to require a minimum level of maintenance.

It should be noted however that high fidelity comes at a price. The more polished a prototype becomes, the more difficult it is to make changes. For example, the circuit board specially constructed for the clock made the prototype far more robust than the one constructed initially within the lab, but since it is designed for a specific set of components, there was no option to experiment with things discovered later in the process. For example, a new version of the Ethernet module used in the clock became available halfway through prototype construction. This module supported wireless, which would have removed the need for the Ethernet-over-power modules, but the pin layout was very different from the original component. Using this new component would have required a complete reimplementation of the circuit board. So, in essence, in creating the circuit board, we had become permanently tied to the original components.

Be Realistic

Even with the simplest prototypes, real-world UbiComp deployments can be complicated endeavors. Every new feature, or addition to a system of prototypes, can increase this complexity exponentially by adding increasing amounts of cost, development time, and maintenance. Therefore, it is important to evaluate every prototype-related decision in terms of its direct relevance to the study being conducted, trimming out all of the "wouldn't it be cool if..." suggestions no matter how enticing they may be. In the end, no feature or additional prototype should be added unless there are people willing to accept primary responsibility for the necessary design, implementation, and maintenance.

Assume That Nothing at the Deployment Location Will Be Reliable

Even with the current state of Broadband, home network connections should not be assumed to be completely reliable. Speed fluctuations and dropped connections can contaminate the results of a study if not adequately handled by prototype deployments. For instance, it is not advisable to configure a deployment so that it logs data exclusively to a remote database. Instead, replicate the data as much as possible.

Highly robust deployments will need to treat even the local sources of electricity with a bit of skepticism. One is smart to assume that it is not only possible, but likely, that at some point power will be dropped and devise a plan as to how prototypes will recover from these events. This issue is exacerbated within older domestic homes and in places known to have particularly stormy weather. In situations like this, it is also advisable to create automated systems that run remotely, constantly pinging the deployment site to ensure the system is up and running.

Be Prepared to Purchase Unusual Items and Then Request Reimbursement

Because acquiring items that are not typically purchased through the university is as often a requirement for studies with a deployment component, you and your team must be prepared to purchase unusual items yourself and then request reimbursement through traditional channels. In preparation to filing paperwork for reimbursement, it is helpful to extensively document the need for each item and the process for purchasing each item. Keep all receipts and any other paperwork associated with each purchase, and also write a concise explanation for why each item is necessary. It is also helpful to have one lab member who becomes familiar with purchasing procedures and understands how those purchasing procedures should be handled. Finally, it is helpful for the lab member who is in charge of purchasing to develop a rapport with the purchasing department so that person can act as the contact person between the research team and the purchasing department.

Be Ready for the Unexpected

Even if you have developed a completely self-contained prototype or system of prototypes, people's homes will always differ. Be prepared to spend time on individual fixes. With the ETHOS prototypes, the Ethernet-over-power modules seemed to function differently in each household, wireless was somewhat different in each household, and getting the carpet mats to stay in place required some rethinking in each home. Everyone had different ideas about where prototypes should be placed in their homes, etc. This requires research teams to be highly flexible and creative. Be ever ready to make a trip to the hardware store at a moment's notice to try and find something that will alleviate a new issue.

Conclusion

This chapter has described, in detail, an in-the-wild UbiComp deployment. Several issues were predicted upon starting the deployment, but as with all endeavors, new lessons were also learned, and a series of nine recommendations are given for those conducting similar research. Our hope is that the lessons presented in this chapter will aid future UbiComp researchers in conducting their own deployments and that others will continue to help grow and refine new lessons.

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Lab of Things: Simplifying and Scaling Deployments of Experimental Technology in Homes

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Abstract

Lab of Things (LoT) is a flexible platform that lowers the barrier for experimental research that uses connected devices in homes and other physical spaces. LoT enables (1) easy interconnection of devices and implementation of experimental technology, (2) easy deployment and monitoring of field studies and analysis of data from experiments, and (3) sharing of data, code, and participants among research groups. This chapter describes LoT and how it can be used by researchers to develop, deploy, and test their technologies.

Keywords

Smart home • User study • Field study • Deployment • Connected devices • Experimental research platform • IOT

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Introduction

Homes are incredibly important to our lives, health, and well-being. However, it can be challenging for researchers to understand what people do in their homes. Surveys suffer from self-reporting biases; home visits and interviews, while providing valuable qualitative data and context, typically last only a few hours. In many cases, researchers want to gather quantitative data over longer periods – days, weeks, months, or even years – to better understand patterns of behavior. Data gathered in homes is valuable both for learning about current behavior and studying how participants respond to an intervention. For example, at the Tiger Place retirement home, researchers use data sensed by a Microsoft Kinect to detect falls (Li et al. 2013). Similarly, to understand the value of speech dialog system at home, researchers deployed a speech recording prototype in kitchens that logged usage and motion and prompted participants for examples of speech commands (Brush et al. 2011).

In recent years, a range of inexpensive connected devices, such as lights, water sensors, security cameras, power meters, and thermostats, have become available. These devices provide a foundation for developing and deploying a range of experimental technologies in many domains including automation, security, energy management, and elder care.

Unfortunately, however, the mere availability of connected devices is not enough for successfully developing and deploying experimental home technologies. As we and other researchers have learned through field studies (e.g., Brush et al. 2011; Grinter et al. 2009; Hnat et al. 2011; Scott et al. 2011), many additional practical challenges remain. These include the amount of engineering effort required in developing technologies and the difficulty of scaling a deployment beyond a small number of homes.

Our goal in developing the Lab of Things (LoT) platform was to address these challenges and substantially lower the barrier for researchers to experiment with new technologies for the home environment. LoT provides a common framework to write applications that use connected devices and includes a set of cloud services that enable remote control of devices, monitoring of system health, and data collection. We released the LoT SDK in July 2013 and are working with a community of researchers to extend and improve the platform. The long-term vision is that research groups collaborate to create a test bed of homes around the world that are willing to participate in field studies.

In-Home Deployments

In-home deployments, also called field studies or in situ studies, allow researchers to collect data under real-world conditions as household members go about their daily lives. An in-home deployment typically involves a team of researchers visiting a set of households, installing devices and then collecting and analyzing data to answer a research hypothesis. In some cases, the devices installed are passively logging to help researchers understand current behavior; in other cases, the devices installed offer novel functionality that researchers want to evaluate. Researchers deploy technology into homes to conduct studies on a range of topics such as satisfaction with medication dispensing devices (Reeder et al. 2013), specific health concerns like sleep disruption (Kay et al. 2012) or physical decline (Li et al. 2013), improving social connectedness for older adults while maintaining privacy (Caine et al. 2011), and reducing home energy use (Scott et al. 2011).

In contrast to other evaluation methods such as surveys, interviews, and in-lab studies, all of which are important ways of gathering feedback, the unique benefits of in-home deployments are realism and length. By conducting an in-home deployment, researchers can gather data for days, weeks, months, or longer as participants live their normal lives. Participants that may have been initially enthusiastic about a technology may not actually use it in practice or use it unanticipated ways. For phenomena that occur relatively infrequently (e.g., weekly, daily, or a few times a day), such as meal preparation or sleeping, in-home deployments can collect enough data to understand behaviors, patterns, and trends.

However, getting the benefits of realism and length from an in-home deployment requires considerable effort. The researchers must figure out how to interact with the devices of interest. Further, any system deployed must be engineered to run robustly for the length of the study because if problems occur it can be difficult to debug and correct issues due to limited access to the house. System robustness requires development work that is not central to the research question but is necessary to ensure that the technology runs successfully. For example, for an in-home deployment on energy use, we developed a failure recovery mechanism to ensure a high "uptime" and methods to configure, remotely monitor, and remotely update the system (Scott et al. 2011). Other researchers report on similar effort needed for successful in-home deployments (Hnat et al. 2011). Requiring each research group to independently implement these necessary features raises the level of expertise needed to conduct in-home deployments and causes duplication of efforts that reduces the time each group can spend on their particular research topic and area of expertise.

The LoT vision is that an extensible platform for conducting in-home deployments, which research groups can extend as needed, will greatly lower the barrier to conducting studies. With a shared platform, each group would not need to engineer a system from scratch, thus reducing the development effort required. We identified the following requirements for an in-home deployment platform based on our own experiences as well as that of our colleagues.

Design Requirements for an In-Home Deployment Platform

1. **Support an extensible range of devices including custom ones:** Studies collecting multimodal sensor data require a diverse set of devices. Examples include IP cameras and occupancy sensors using Z-Wave or other non-IP networking technologies. Many of these devices may be off the shelf, but because of

disparate interfaces, interconnecting them is a challenge today. In some cases, off-the-shelf devices may not provide the data fidelity or control required in a study, and researchers may need to develop custom devices.

2. **Easy data collection and export for analysis:** Data generated in homes, as in any other setting, may be large and require appropriate means for collection, storage, analysis, and sharing. These functions need to be intrinsic to the deployed infrastructure. For in-home deployments, it is particularly important that, if desired, the data can be easily archived to cloud storage for reliability and to allow analysis to begin while a study is ongoing.
3. **Monitoring and updating:** Homes are inherently rapidly changing environments subject to power outages, network issues, accidental unplugging of devices, etc. These uncertain conditions make it critical to be able to remotely monitor and control the technology deployed. For example, researchers should be alerted if data collection stops and be able to check usage and, if necessary, make changes to the study design during an in-home deployment.
4. **Enable scale and diversity of deployment:** While conducting initial studies in a small number of homes is valuable to test technology, for many studies, researchers would like to deploy in a large number of homes. Practical considerations around installing and managing technology in the deployment sites often limit current studies to the geographic area where the research group is located so they can visit in person. This limits the potential diversity in participating homes and residents and, consequently, the generalizability of the findings.

In the next section, we describe Lab of Things, which was designed to satisfy the requirements above. General information on preparing for a successful in-home deployment can be found in references (Brush 2010; Hnat et al. 2011).

Lab of Things (LoT)

We built Lab of Things with the goal that any researcher conducting an in-home deployment should benefit from using the platform. The LoT SDK was released in July 2013 (Lab of Things Codeplex site 2013). We explain how researchers can use LoT with a simple running example in which Jane wants to study how often household members use the front doors of their homes. Jane's "simple study" will last 2 weeks, log the use of the doors, and be deployed in eight homes.

LoT Architecture

Figure 1 shows the high-level architecture of LoT. All elements shown in blue, including cloud services for logging data, monitoring the deployment, and remotely updating the software, are provided by the LoT platform. A Home Hub, a computer running Windows 7 or Windows 8, is deployed in each home. The hub runs the

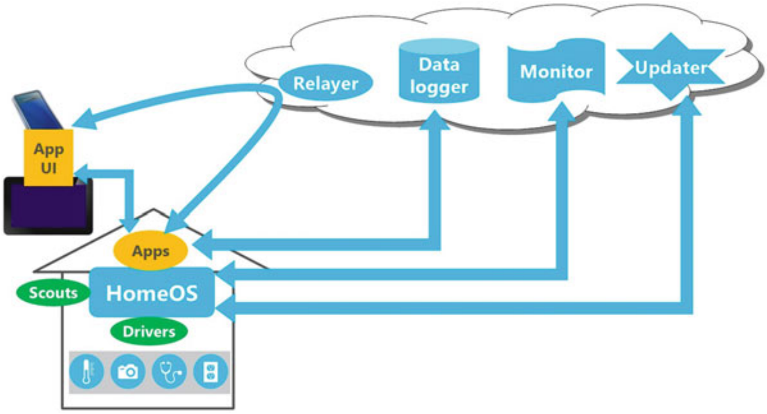

Fig. 1 Lab of Things architecture. The LoT SDK provides all elements in *blue*. Elements in *green* are required by each device and written and shared by members of the community. Elements in *yellow* are written by the researcher for their in-home deployment

HomeOS software (Dixon et al. 2012; HomeOS 2013) and one or more applications developed by the researchers for their specific study. HomeOS also provides standard user interfaces for configuring the hub, setting up devices, and enabling remote access from any web browser based on Windows Account authentication. For her study, Jane will need a computer to serve as the Home Hub for each house in the deployment.

Extensible Device Support (Design Requirement #1)

A key design requirement is that the platform works with many different devices and is extensible. The Home Hub discovers devices in the environment using a scout and communicates with devices through a LoT driver. These are indicated by the green elements in Fig. 1. One scout is typically needed for each type of device protocol (e.g., UPnP), and one driver is needed for each type of device. The current SDK includes several scouts and drivers. The platform is extensible; if a researcher needs to interact with a device for which the current SDK does not have a scout or driver, she can write the missing components. We hope that researchers then contribute these components to the shared code repository so others can benefit.

For her simple study, Jane can use off-the-shelf Z-Wave door-window sensors already supported by LoT. She needs to purchase enough for her needs. She also needs to purchase a Z-Wave USB communication dongle (e.g., Aeon Labs Z-Stick) for each hub to communicate with the sensors. If Jane had more complicated sensing needs, she may develop her own sensors. LoT includes a scout and driver examples for devices built using the Arduino platform. LoT also includes support for .NET Gadgeteer (2013), an open source device prototyping platform, to facilitate development of custom devices. This includes a .NET Gadgeteer scout, driver, and code for several example devices.

Data Collection and Analysis (Design Requirement #2)

Collecting study data typically requires an application unique to a particular study, for example, a novel camera interface or an application that sends a survey to participants after a particular set of events. The yellow elements in Fig. 1, applications and their user interface (UI), are developed by researchers based on their specific needs. The LoT SDK has several sample applications, including a sensor logger, camera viewer, and alerts application.

Applications consist of two parts: (i) a core service written in C# that implements the application logic and runs continuously in the background and (ii) a UI written in HTML5/Javascript. The UI can be accessed through a web browser on any device. The UI connects to the background service securely, and only authenticated and authorized clients are provided access. The platform handles secure access underneath the covers, and applications developers do not need to worry about it.

Although beyond the scope of this article, HomeOS is architected to decouple application logic from device specifics. For instance, an application can collect energy consumption data using various types of sensors while being agnostic to sensor-specific protocols (e.g., Z-Wave, ZigBee, or WiFi). This makes it easier to reuse and extend applications to take advantage of new sensors. See Dixon et al. (2012) for a full description of the architecture.

To ease data collection, the LoT SDK includes a Home Data Store (HDS), which provides seamless transfer of application data to the cloud (Gupta et al. 2014). HDS is robust to intermittent network connectivity, uses compression to deal with the scarce upload bandwidth that is commonplace in homes, and also supports encryption for privacy. Through HDS, researchers get reliable, low-latency access to their data, conducive for data analysis.

For logging-only studies such as Jane’s simple study, the sample sensor logger application, which streams data from associated devices to cloud storage using HDS, is likely sufficient.

Monitoring and Updating (Design Requirement #3)

To help researchers monitor in real time the status of their deployment, LoT includes a cloud monitoring service. Each Home Hub sends a heartbeat message to the monitoring service every minute with status information about what applications and drivers are running and memory and processor (CPU) consumption. Researchers can go to the management portal shown in Fig. 2 and see the list of hubs in their study and current state of those hubs. The researchers can also set up an email alert if a hub goes offline. The platform also automatically creates a log with console messages and sends that log to the cloud, which enables researchers to get a detailed and historical view of system execution. Researchers’ custom applications can add their own messages to this log file using an API call, making it simple to get status information.

For Jane’s study, she checks the management portal initially to make sure her eight homes are sending heartbeats after installation and enables email alerts so that she will know if any hub goes offline for more than 15 min.

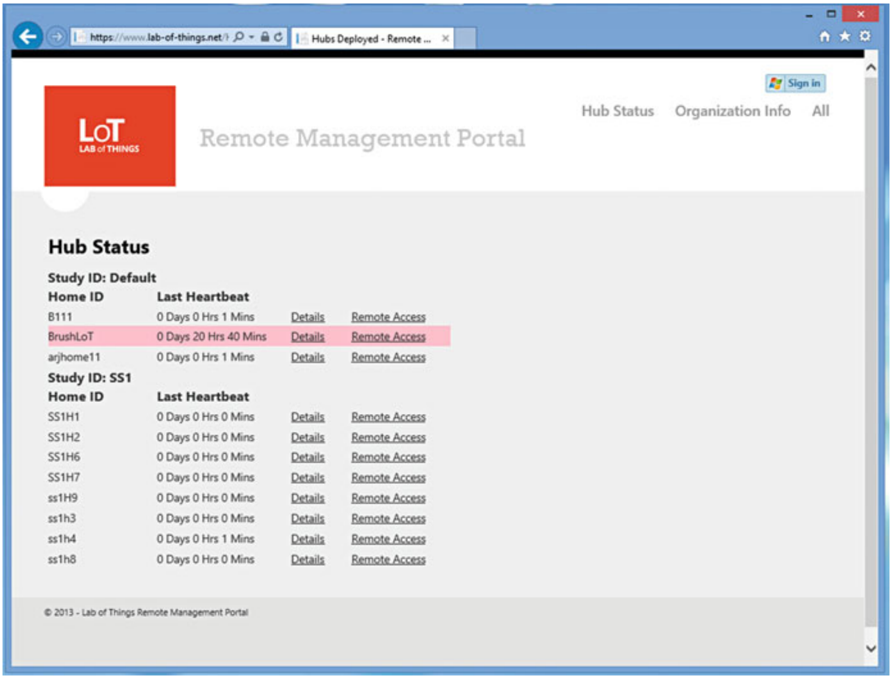

Fig. 2 Lab of Things remote management portal. Researchers can view the heartbeats sent from homes participating in their study and set up multiple studies. Homes that have been offline for more than 15 min are indicated in *red* (e.g., BrushLoT). Researchers can set up email alerts to be notified when a hub goes offline

While it is important to discover problems as soon as possible to avoid losing valuable data, if a problem that requires updating the study application is found, it can be difficult or nearly impossible to schedule time to go back to participants' homes to fix the problem. LoT's remote update functionality allows researchers to put a new version of their application into a cloud location and change the configuration of a hub to indicate that it should update to the latest version. Thus, changes can be pushed without physically visiting the home. If necessary, the HomeOS software can also be remotely updated.

Scale and Diversity of Deployments (Design Requirement #4)

To address challenges of conducting in-home deployments at scale among a diverse set of households, our vision is that research groups recruit and manage a set of homes, perhaps 10–20. Each such home will have a hub running the LoT platform. When the managing research group is not conducting a study, these households become available to participate in other groups' studies, assuming that the household residents are willing. By helping maintain a shared test bed of potential deployment sites, research groups gain the opportunity to recruit from participant households managed by other research groups. See reference (Brush et al. 2012) for additional details about the long-term vision for LoT.[1]

We have also taken a number of steps to ease the per-home deployment burden, which helps researchers scale and manage studies even when the study is limited to homes they have recruited themselves. In particular, for setting up the Home Hub and devices, the HomeOS software includes a simple interface, ideally enabling deployment to occur without the researcher visiting the home for some studies. In these deployments, the researcher would send a Home Hub and sensors to participants for them to install themselves or with telephone support. While not possible for all studies, for instance, those that require careful positioning of technology, in-person interviews or other data gathering activities, eliminating the home visit for technology installation significantly broadens the potential deployment sites.

For Jane's study, given the simplicity of the deployment, she decides to have a group interview with participants in her lab, gives them a walk-through of install process, and then sends each household a hub, box of sensors, and instruction sheet. From the heartbeats in the management portal, she can see as participants' install their home hubs and verify that things are working as expected by looking at the data sent to cloud storage. Instead of visiting every house, she can follow up with participants that have problems, scheduling phone sessions and then visiting if needed. Because Jane does not need to visit each house, she will be able to support many more houses in the next iteration of her study.

Using LoT: A Case Study

HomeOS and LoT have been used by several research groups to develop home technologies related to security, energy consumption, and health care. Given the focus of this book, we highlight a specific research effort that is using LoT to develop and test technology to help paralysis patients control their environment. This research is being conducted collaboratively by researchers at the University of Arkansas, the University of Maryland, and the University of San Francisco (Nelson et al. 2013a, b).

The researchers are developing novel assistive devices that include a glove with flex sensors and 3D accelerometer and a headband with dry textile electrodes (see Fig. 3). These two devices are used to detect specific hand and eye gestures, respectively. The gestures are then treated as navigational and control commands for a home automation system with devices such as lights, appliances, and thermostats.

To test this technology, without LoT, the researchers would have to write software to interact not only with their custom devices but also with the automation devices. They would also have to develop software to monitor their deployments and collect data from them. With LoT, they need to primarily write only drivers for their devices.

[1]Lab of Things was initially called HomeLab.

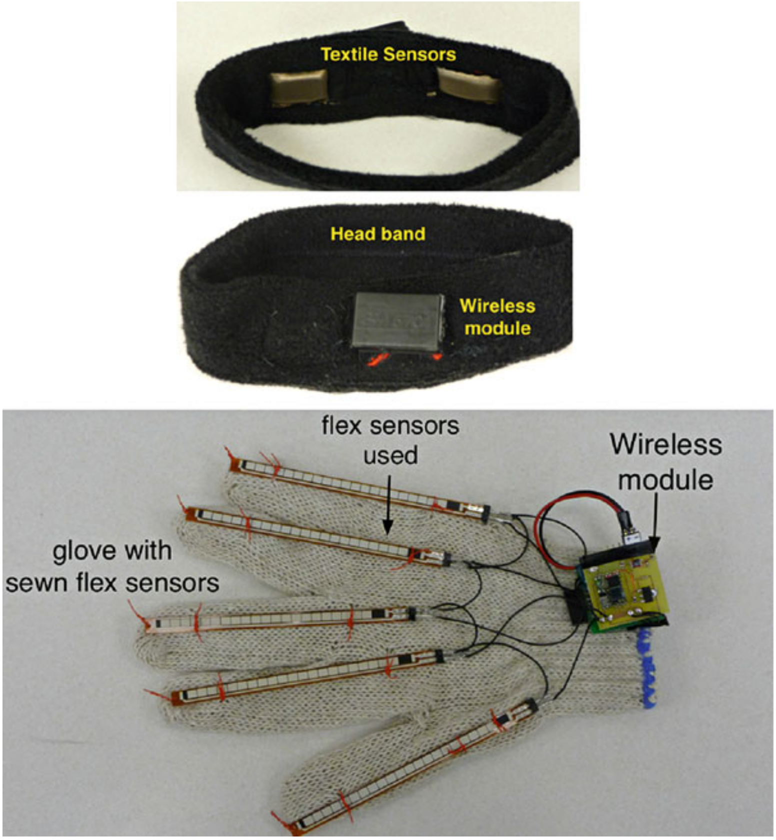

Fig. 3 Novel assistive headband and glove that help paralysis patients control their environments. The devices interact with a LoT Home Hub using a smartphone as a relay. The LoT Home Hub, consequently controls appliances (Nelson et al. 2013a, b have further details)

LoT provides them access to drivers for home automation devices and capabilities for monitoring and data collection. This lets the researchers focus their effort on the core of their technology, the assistive devices and gesture recognition software.

Concluding Remarks

Lab of Things is inspired by the notion that changing the pace of innovation requires a low barrier to experimentation, so that researchers and practitioners can iterate at a faster pace. While the seed investment in the LoT infrastructure came from Microsoft Research, its long-term future and eventual success lies in becoming a communal resource. We are seeing promising movement in that direction with several research groups using the infrastructure and contributing applications and drivers. As the platform matures, we now invite the broader research community to get involved.

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The Elderly Resources Centre

P. C. Sze and K. Y. Au-Yeung

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Abstract

Like other parts of the world, population ageing is one of the major concerns in Hong Kong. Housing solutions for the increasing needs of older people is a big challenge of our society. As there has not been adequate housing for older citizens on the local market, the Hong Kong Housing Society set up the Elderly Resources Centre (ERC) to promote Ageing in Place (AIP) in Hong Kong. Suitable living environment, healthy ageing and safety living are the three basic elements that we focus on to help the older people age in place. This chapter presents the approaches, which include education, advocacy and direct services through the usage of interactive technology, experiential learning and demonstrations in a fun and stimulating environment, to help older people achieve AIP in Hong Kong.

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Keywords
Ageing-in-place • Safe living • Age-friendly housing

Introduction

The Hong Kong Housing Society (HKHS) is an independent NGO established in 1948, aiming to serve the needs of the Hong Kong community in housing and related services. We strive to be a world-class housing solution provider and innovator with leadership in quality, value for money and management. We put customer, quality, talent and prudence as the core values that support our guiding principles.

The population of Hong Kong is rapidly ageing. It is estimated that over 30 % of the people will be over 65 years old in 2041 (Hong Kong Population 2012). With a current population of over 7.6 million in such a tiny place, Hong Kong will face a huge challenge in providing suitable housing for the older persons without compromised their functional levels.

Background

Although the provision of housing has never stopped, it is still far behind the growing demands of the market and needless to say the ageing population. Less than 9 % of the older adults in Hong Kong are living in purpose-built housing projects or old age homes (Hong Kong Population 2011). The majority of the older persons live in the community, either in self-owned private flats or in subsidized housing provided by the Housing Department or HKHS. However, as older adults get older, their previous living environment may no longer be suitable for the changing needs as a result of ageing and may lead to home accidents like falls. According to the study “Base rate of domestic accidents of community living older adults in Hong Kong” which was jointly conducted by the HKHS and Hong Kong Polytechnic University, there were around 20 % of older adult falls at least once each year (Fong et al. 2011). The causes of these falls were mostly related to environmental hazards such as uneven floor surfaces, slippery floor, steps or stair railings, etc. Apart from the development of more senior housing, extensive enhancement to the existing living environment of the elders seems necessary.

In view of the tremendous need in ageing in place, the Housing Society Elderly Resources Centre (ERC), which is the first of its kind in Hong Kong, was established by HKHS in 2005. It aims at promoting and advocating the concept of AIP to the public and providing information to help older adults or their care-givers to achieve AIP (Fig. 1).

Exhibit 1 summarizes our service delivery concept. We propose the following three elements to help them achieve AIP:

Fig. 1 Housing Society Elderly Resources Centre is the first of its kind in Hong Kong to promote Ageing in Place

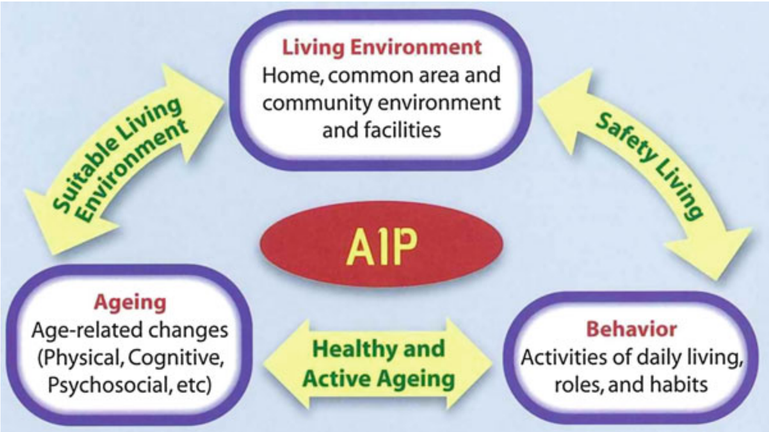

Fig. 2 Exhibit 1 Summary of ERC services delivery concept

1. A suitable Living Environment:
   To provide professional consultation in housing and related services by meeting the changing needs of the older persons throughout the ageing process
2. Healthy and Active Ageing:
   To educate the older people about age-related changes and help them engage their retirement life actively and optimistically
3. Safety Living:
   To help the older people become more aware of the potential environmental hazards and risky behaviors and prevent home accidents (Fig. 2)

ERC's Services

Education

Even though most of the older persons in Hong Kong favoured the idea of AIP, more than 70 % of the general public coming to the Centre possess limited knowledge to attain it (Sze and Au-Yeung 2003). One of the most important tasks is to promote and educate the public on how to achieve AIP and how it benefits the community-dwelling older people.

Exhibition on AIP

ERC provides free visiting tours to promote AIP to the public. We have three different exhibition zones, and each one is designed with regard to the three aforesaid elements of AIP. One of the most important roles of ERC is to help visitors realize the importance of AIP and assist them to achieve it:

(i) **The Healthy Ageing Zone**
We started with the Healthy Ageing Zone which helped visitors to become aware of the age-related functional changes and the importance of healthy ageing. We created a fun and relaxing environment to allow the older adults to complete the assessments and education panels in an interesting way. A series of computerized interactive assessment panels were developed and installed in this zone. A team of professionals including occupational therapists, social workers and biomedical engineers were responsible for the development of the functional assessments. Based on literature review, assessments in four areas including cognitive function, physical function, sensory function and basic health indices were selected. Advanced 3D kinematic software was adopted to develop the content and administer assessments. A smart card with a database system was applied to allow visitors to access the assessment panels and generate assessment reports at their own pace. Older people could easily follow the user-friendly interface as well as the verbal and visual instructions to complete the assessments. There is also interactive displayed information to educate visitors on how to enjoy a healthy lifestyle (Figs. 3–9).

(ii) **The Adaptive Housing Zone**
In the Adaptive Housing Zone, we aim at helping visitors to visualize how they can make their home more age friendly. We demonstrate latest age-friendly design in furniture, appliances, aids and gadgets in a mock-up flat.

In collaboration with other like-minded organizations, we joint hands to develop a smart home called the "i-home" to showcase the IT applications to assist the daily living of older persons. These include an environmental control system which allows older persons to control all the electrical appliances through a mobile device; the Tele-care system which allows care-givers to monitor remotely the safety of an older person living alone; and an e-health system which allows older persons to measure their blood pressure, blood pulse

Fig. 3 Computerized Cognitive Screening Station to assess cognitive function

and blood oxygen level conveniently, and the results will be uploaded to the "cloud" for monitoring by medical staff (Figs. 10–13).

(iii) **The Safety Living Zone**

In the Safety Living Zone, visitors enjoy the virtual reality games and experiential activities to avoid the common risky behaviors of the older persons. They can also learn safety tips such as choosing the right footwears, walking aids, etc (Figs. 14 and 15).

Education and Training Programs

ERC organizes education seminars and workshops for older persons, care-gviers, professionals and front line staff in the health, property management and social service sectors.

We collaborate with different service agencies for older people to organize training programs for care-givers who need to take care of their old-aged relatives and family members. Care-givers play an important role to facilitate older people to

Fig. 4 Physical Function Station to assess reaching abilities, such as forward reaching and literal reaching

Fig. 5 Sensory Station to assess hearing and visual ability

achieve AIP. In the training, we give the participants knowledge and skills in taking care of the older people through workshops, visitations and practical sessions.

For example, we organize “Intergeneration Program” for secondary and tertiary students. The aim of the program is to help them understand the needs of older persons through various kinds of experiential learning programs and foster respect for the elders. The program includes the following:

Fig. 6 Health Station collects basic health indices, such as blood pressure and blood oxygen

Fig. 7 Advanced 3D kinematic software and camera to detect elder's motion

1. Workshops and seminars in schools to educate students about the importance of AIP and the various skills in caring and communication with older persons as well as preliminary home environmental screening
2. Follow-up visit in ERC where they participate in experiential learning activities to understand the needs of older people and the features of an age-friendly housing environment for older persons
3. Field project in assessing the age-friendliness in the local communities regarding to the WHO Age-friendly City's guidelines
4. Conduct home visits to older persons (Fig. 16)

Fig. 8 Smart card with database system allows visitors' access to assessment panels and report

Fig. 9 Elderly Magazine with interactive display on healthy lifestyle

Through the participation of these activities, the younger generation can better understand the needs of the older people as most of them seldom live with the older generation nowadays in Hong Kong. This program also provides chances for the students to communicate with and learn from the older people and enhance reciprocity between the two generations.

Online Resources

Another important function of ERC is to provide information to the older persons and their family members on care and living. Hence, the Website for Elderly Services (WES, www.hkhselderly.com) has been launched since 2008. WES provides a wide

Fig. 10 Smart home demonstrates how IT applications assist daily living of the elders

Fig. 11 Environmental Control System allows the elders to control electrical appliances through mobile devices

range of information on housing, health, nutrition, leisure and recreational activities. Such information is useful for older persons to enjoy a healthy and meaningful life. Besides, a territory-wide elderly services database was linked within the website to facilitate users to search and get information of various community services. As at 2014, WES contains information of over 3,000 agencies providing elderly-related services including medical care, social, housing, home care services, etc (Fig. 17).

Fig. 12 Motion sensors facilitate care-givers to monitor the safety of those older people living alone

Fig. 13 E-health system is used to measure elders' blood pressure, blood pulse and blood oxygen level

In 2013, we launched an Age-Friendly Home Database which link to WES. It includes a wide range of age-friendly products such as aids and gadgets, furniture, housing appliances, equipment, etc. suitable for older persons who choose to age in place.

Fig. 14 Elders learn tips to avoid risky behaviors through experiential activities

Fig. 15 Display of suitable footwear for the elders

Fig. 16 Experiential learning of the intergeneration program allows the young generation to have more appreciations on elders' functional performances

Direct Services

Elderly Safe Living Scheme

Apart from the centre-based programme, we also provide outreaching services such as the Elderly Safe Living Scheme. Our occupational therapists visit the older people's households in the community and provide the following services:

- Conduct home environment assessment
- Recommend on home modifications based on the functional level of older persons. The report includes home modification suggestions and construction advices, recommended age-friendly furniture and/or assistive devices and outlets to purchase such equipment
- Provide recommendations to maintain the health status of the older person (e.g. physical exercise, cognitive exercise, usage of recommended equipment)
- Refer community services, e.g. meals-on-wheels where the older person lives (Fig. 18)

Advocacy

One of the most important roles of ERC is to advocate the concept of age-friendly home in the community so that it will become the ultimate choice for older persons when considering their living arrangement.

Fig. 17 WES provides a wide range of information on housing, health, nutrition, leisure and recreational activities

Collaborating Platform

In recent years, we worked closely with various government departments and R&D centres on application of IT in home environments of older persons. For example, we worked with the Innovation and Technology Commission (ITC), SAR Hong Kong, to set up the Smart Home at ERC to showcase how IT can help older people to achieve AIP. Interestingly, the Smart Home had been visited by nearly 14,000 people after 2 years of opening including policy makers, professionals, industry players, older persons and their family members as well as students. This showed that an R&D centre requires a platform to display future development or prototype to the public in order to get feedback from the users. ERC definitely plays an important role as the collaborating platform (Fig. 19).

Summary

Since the opening in 2005, over 2.6 million people had benefited from ERC through various online and offline channels. Over 95 % of visitors have become more aware of the importance of age-friendly housing after visiting ERC. We believe the model

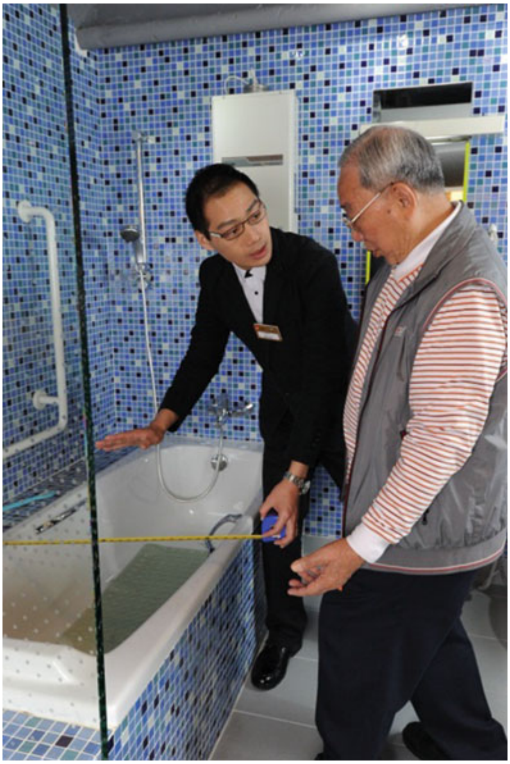

Fig. 18 Occupational Therapist of Elderly Safe Living Scheme provides outreach home assessment service for older home owners

Fig. 19 The remote-controlled electrical bed located at the Smart Home of ERC

of ERC can be replicated to other countries to advocate, educate and serve the older persons to attain ageing in place at the other corners of the world.

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TigerPlace

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Abstract

TigerPlace is presented as an example of senior housing which has incorporated smart home technology into senior apartments. The goal of TigerPlace was to develop a true aging in place housing site in which residents move into independent apartments and stay through the end of life. In-home sensing technology is used to augment care coordination to detect early signs of illness and functional decline to allow early interventions aimed at proactively keeping residents healthy. Over 55 apartments have been outfitted with in-home sensor networks since 2005 with an average longevity of 2.6 years. Sensors tested in TigerPlace apartments include motion sensors, bed sensors, stove temperature sensors, and gait/fall detection sensors. All sensors are environmentally mounted and designed to be as invisible as possible. Studies have investigated which sensors and sensor features are most important for detecting early illness signs. A prospective research study at TigerPlace using in-home sensing and automated health alerts

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showed significant differences in health outcomes between a control group receiving normal care and an intervention group with sensors and automated health alerts.

Keywords
Eldercare technology • In-home monitoring • Early illness detection • Health alerts

Introduction

TigerPlace opened as a senior housing facility in 2004 (Fig. 1). Located in Columbia, MO, this facility was designed to test a true aging in place (AIP) model. That is, residents would move into an independent living apartment and stay in the same apartment through the end of life, including through hospice care. This has been accomplished through a unique partnership between Americare, Inc., the private company that built and operates the housing facility, and the University of Missouri Sinclair School of Nursing (SSON) that manages the care component for residents. The aim of TigerPlace is to keep residents as functionally active as possible through proactive care coordination. If additional care services are needed for individuals, residents pay for these services only as long as they are needed. The services are brought to their apartments, thus allowing them to remain in the same home space.

The SSON operates a home health agency that manages the care of all TigerPlace residents. Services include several periodic health assessments, a wellness clinic, care coordination of residents including help with medication management, and other wellness activities such as exercise classes. TigerPlace residents can also bring their pets, typically small dogs and cats; veterinary services are available for residents' dogs and cats living with them.

The care coordination and other medical services have been augmented by smart home sensor technology that aims to proactively recognize residents' health changes early so that early interventions can be offered while health problems are still minor.

Fig. 1 The TigerPlace aging in place facility

The research studies conducted at TigerPlace have shown that health changes can be detected through in-home sensors before the residents themselves report a change which is often 2 weeks before health events such as emergency room visits and hospitalizations (Rantz et al. 2012). This chapter discusses TigerPlace as a housing structure and a living laboratory for testing care models and smart home technology to support aging in place. Examples are included of the sensors investigated and sensor data logged in the homes of aging seniors.

The TigerPlace Housing Structure

TigerPlace was opened over two phases. In its current structure, there are 54 independent apartments. Most are one- and two-bedroom apartments, ranging from 648 to 1,064 ft^2. A few studio apartments are also available at sizes of 445–540 ft^2. All apartments have a kitchen area with a stove, oven, microwave, and full-size refrigerator. There are also two common dining rooms. One dining area is informal and used for breakfast and lunch. The second dining area is more formal and used for the evening meal. Residents may cook their own meals but most use the common dining rooms for two to three meals each day. Each apartment has front door access through the inside hallways. In addition, each apartment has a screened-in porch with outside access directly from the apartment and a small garden area that can be personalized.

TigerPlace was built to nursing home standards and is licensed as intermediate care. However, the facility does not look like a medical institution. The structure has been designed to promote aging in place while looking as much as possible like a private home setting. Residents bring their own furniture when they move into a TigerPlace apartment and can bring their pets. Safety features are built into the design in a non-obtrusive way if possible, such as attractive hand railings in the hallways and lighting tubes that bring natural light into the hallways. Bathrooms are large with grab bars and accommodate residents with disabilities. Apartments have large walk-in closets with good storage and large windows and blinds to adjust natural lighting as well as good overhead lighting. With personalized furniture and accessories, the apartments look very much like the private home spaces they represent.

In addition to the common dining rooms, TigerPlace has other common spaces available for residents. There are two indoor exercise spaces, one with equipment, such as treadmills and exercise bikes, and one for classes, including tai chi and yoga. A courtyard provides a pleasant area to experience the outdoors. There is also a sidewalk that runs along the perimeter of the building and offers an outdoor walking path. A meeting room is available for visiting speakers or other activities. There is a small library managed by one of the residents and a large living area where residents can gather around the pool table, card table, and jigsaw puzzle table. TigerPlace also has a hair salon, a small movie theater where movies are played regularly, a veterinary clinic to support the care of residents' aging pets, and a sports bar with regular happy hours. Some TigerPlace residents are completely independent and drive their own cars. However, the staff provide transportation to residents that need it.

A Living Laboratory

From the beginning, TigerPlace was envisioned not only as a state-of-the-art senior housing facility but also as a site for conducting research studies to test clinical care models and new technologies that help residents age in place. Typically, around 64 residents reside in the 54 TigerPlace apartments, ranging in age from about 65 to 100. The average age is usually around 85. Both singles and couples are represented. Almost all of them have at least one chronic health condition, such as heart disease, arthritis, diabetes, hypertension, and some early stage dementia. Over half of the residents have multiple chronic health conditions. The residents represent a typical elderly population in the USA in terms of health status and thus provide a good opportunity for investigating new technology to support aging. In addition, all residents agree to the use of their health records for research studies, which provides access to health status and trends for a variety of research projects.

An infrastructure is in place to support research, including smart home projects. An electronic health record (EHR) is used to track health assessments, medications, falls, emergency room visits, hospitalizations, vital signs, and other significant health data (Rantz et al. 2010). Several types of health assessments are used, and assessments are given more frequently than in other senior housing, in order to closely track changing health conditions. To support technology projects in the home, TigerPlace apartments have a dedicated cabinet installed above the refrigerator that includes power and computer network ports to a dedicated research network. This has provided a space in which to install computer equipment in each apartment that is hidden and out of reach of the residents. Initial studies at TigerPlace positioned computers on the floor behind a couch or cabinet. It was assumed that this would be discretely hidden and out of the way. However, residents sometimes unplugged the computers, innocently thinking that they were not being used at the moment, so that another appliance could be plugged in. The dedicated cabinet over the refrigerator has stopped this unexpected interference so that computer equipment can run continuously 24 h a day.

Early on in the research, the team had planned to investigate the use of in-home monitoring using sensors to track health status and recognize early signs of illness and functional decline. Figure 2 represents a typical trajectory of functional ability as a senior ages. Rather than a gradual, linear decline, the trajectory typically follows a stairstep pattern. Functional ability plateaus until a significant health event occurs, which then results in a dramatic decline to the next level. The beginning of the decline represents a small window of opportunity for introducing interventions that may stop or lessen the decline. The goal of the research has been to use continuous monitoring with in-home sensors to recognize the very beginning of the decline or predict that a decline is about to occur, so that very early interventions can be offered. Thus, the intent of the in-home sensor-based monitoring is to proactively keep

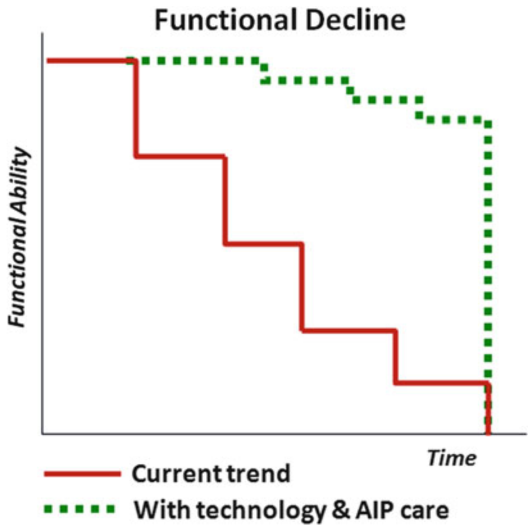


Fig. 2 Squaring the life curve with detection of early illness and functional decline

residents healthy and functionally active as possible, as represented by the green dotted line in Fig. 2 (Skubic et al. 2009). The structure of TigerPlace with elderly residents aging in place and access to health records has facilitated the study of correlating in-home sensor data with changing health status in order to investigate methods for recognizing very early health changes.

In-Home Sensor Technology

As an initial step toward introducing technology, a series of focus groups was conducted with the target senior population at TigerPlace and other senior housing. The results showed that seniors preferred non-wearable sensors that did not require them to actively do anything, such as charging batteries or remembering to wear something (Demiris et al. 2008). The research at TigerPlace has also shown the importance of the appearance of technology used in the home. Residents are very sensitive to how the technology is placed into their homes and have been insistent about keeping a pleasant homelike appearance. As a result, the approach taken at TigerPlace has been to make the smart home technology as invisible as possible. The goal has been to capture the activity patterns of seniors in their naturalistic state. It is desirable to have residents forget about the in-home sensors as much as possible and go about their normal activity. Interviews with research participants have shown that this typically happens within the first month after installation (Demiris et al. 2008).

In-home sensors were first installed in TigerPlace in October 2005 (Skubic et al. 2009). The initial set of sensors included passive infrared (PIR) X-10 motion sensors, a stove temperature sensor, a chair pad that recognizes on/off sitting, and a pneumatic bed sensor positioned on top of the mattress, underneath the linens, that reports low, normal, and high pulse rate; low, normal, and high respiration rate; and

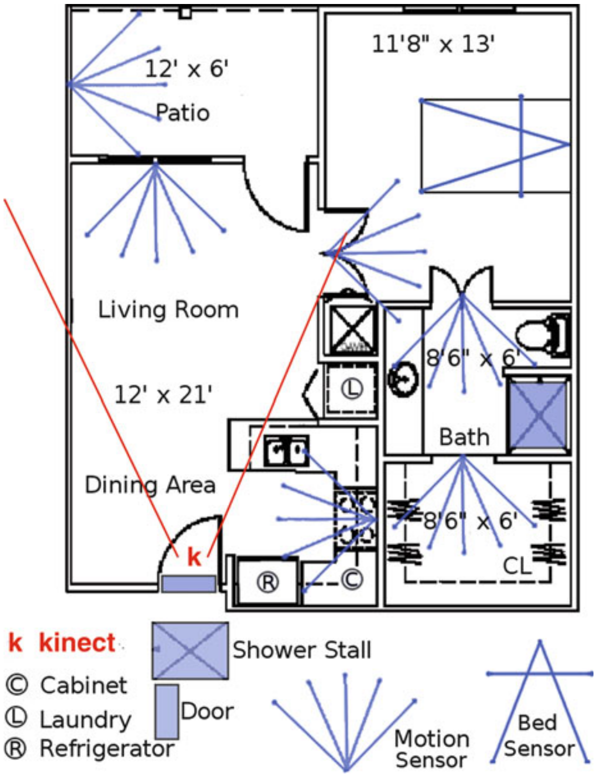


Fig. 3 A typical in-home sensor network in a one-bedroom apartment. The Kinect was added in 2011 to investigate in-home gait capture and fall detection

four levels of restlessness (Mack et al. 2009). Figure 3 shows a typical layout in a one-bedroom apartment. Motion sensors are installed in each room to detect general motion in the area. They are also installed in the refrigerator, in a kitchen cabinet, and on the ceiling over the shower to detect localized activity. A motion sensor is installed on the ceiling over the front door to detect front door activity; although a magnetic door sensor could be used in this case, TigerPlace residents sometimes leave the front door open slightly so the motion sensor proved to be a practical solution in detecting motion through the front door. Sensor data from this initial set of in-home sensors are transmitted wirelessly to a computer logger positioned in each apartment in the dedicated cabinet above the refrigerator. The computer logger then sends the data to the computer server, which stores the data in a database. All sensor data are transmitted and stored with an identifier number only, for security reasons. A web-based interface with visualizations is available for clinicians and researchers to aid in a better understanding and tracking of changes in the sensor data.

All in-home sensor installations are done as part of research projects with IRB approval. Residents sign informed consent forms to participate. There are no costs to the residents, as these are funded through research funding. The number of apartments with sensors has stabilized at 20–25 operational systems at any time.

As residents leave the study, due to death or, in some instances, moving out of TigerPlace, new residents are recruited to keep 20–25 systems operational. This has provided a manageable number in which to do continuing research projects. Over 55 sensor systems have been installed in TigerPlace apartments since 2005, with an average longevity of 2.6 years.

The motion sensors used in TigerPlace apartments generate an event every 7 s if continuous motion is detected in the detection cone (Wang 2011). The motion data can be used to capture activity in a localized region and used to determine whether this is appropriate for a specific time of day. For example, motion sensors placed in the refrigerator and kitchen cabinets capture activity associated with food preparation. Motion sensors placed on the bathroom wall, over the shower, and in the closet detect activity in personal hygiene and dressing, especially when activity is detected in the morning. Motion detected in the living areas in the middle of the night when residents would normally be in bed can indicate sleeping problems or potential cognitive problems. Unusual bathroom activity, especially at night, can indicate health problems. This case is illustrated in Fig. 4 in a bathroom activity map

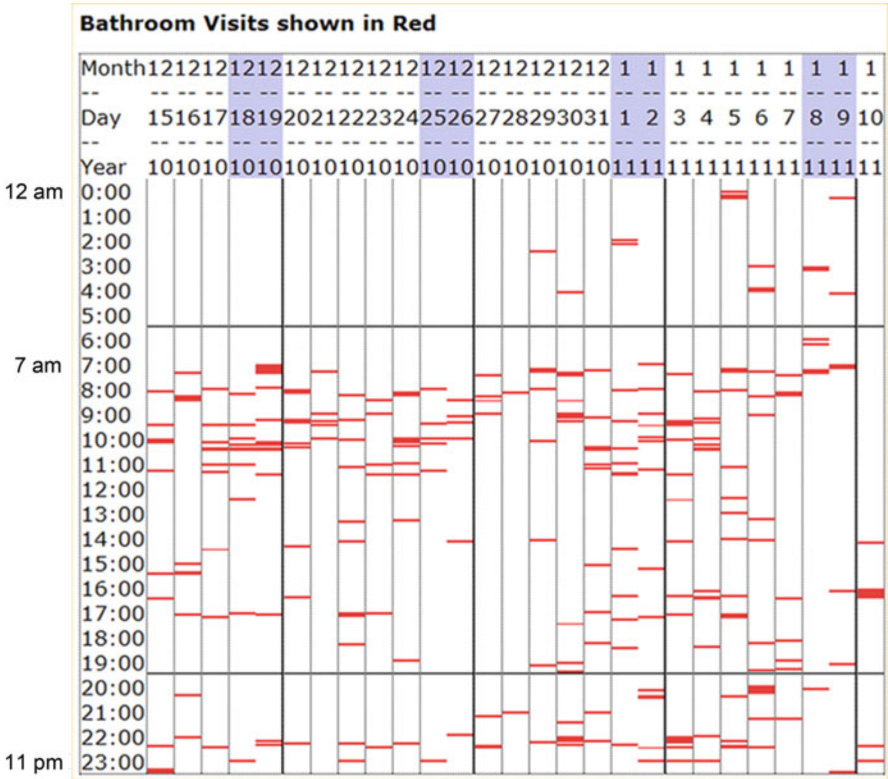


Fig. 4 Bathroom activity map showing a change in nighttime bathroom activity. A health alert was generated on January 1, 2011

visualization. Each column represents 1 day of activity, where the top starts at midnight. In Fig. 4, each red mark represents time in the bathroom; increased nighttime activity appears about midway through the mapped days. In this case, the TigerPlace resident was diagnosed with a urinary tract infection. The bathroom motion sensor detected the associated increased activity, as is especially noticeable at night.

The motion sensor data can also be used to detect patterns of overall activity by computing a motion density, that is, motion events per unit time. Figure 5 shows examples of motion sensor maps computed from a TigerPlace apartment (Wang et al. 2012). Again, each column represents 1 day of activity, where the top starts at midnight. The black regions correspond to time out of the apartment. The colored regions show the level of motion density in the apartment, ranging from low activity shown in white and gray to a higher level shown in yellow and green and the highest level shown in blue. Motion density is computed by adding up the motion events from all of the motion sensors in the apartment to create a composite pattern. As a visualization, the motion density map was intended to show the overall activity pattern such as sedentary vs. active. One can immediately see whether the resident was active at night or generally not active which usually corresponds to time in bed. Black regions at meal times typically indicate the resident was eating meals in the common dining room. Patterns with low activity and very limited time out of the apartment may correspond to periods of depression, such as the middle time period shown in Fig. 5 (Galambos et al. 2013). Visualizations such as those in Figs. 4 and 5 have been developed to help researchers and clinicians better understand the data and investigate correlations with health status. In addition, a similarity measure can be used to computationally compare the motion density pattern of one time period with that of another and automatically trigger an alert if the change is significant (Wang et al. 2012).

In later projects, additional sensors have been tested in TigerPlace. Figure 6 shows a hydraulic bed sensor design developed at the University of Missouri, which is positioned under the mattress (Heise et al. 2011). This sensor captures the superposition of the breathing cycle and the ballistocardiogram, which is the mechanical effect of the blood flowing through the body as the heart beats (Starr et al. 1939). A sample signal is also shown in Fig. 6. An embedded system has been developed to capture signals from four transducers positioned under the mattress and transmit them wirelessly to the computer logger in the home, which then sends de-identified signals to a computer server. Signal processing algorithms are used to separate the respiration signal from the ballistocardiogram, resulting in quantitative estimates of respiration rate and heart rate (Rosales et al. 2012). Bed restlessness appears in the signal as noise, typically with a much higher amplitude in the signal. Estimates of respiration rate, heart rate, and restlessness are reported for every 15 s period and stored in a database. A web-based visualization interface allows researchers and clinicians to view graphs of respiration and heart rates along with bed restlessness, providing options for daily and hourly averages with minimum and maximum values. The interface also supports a zoom-in feature for viewing the 15-s estimates if desired.

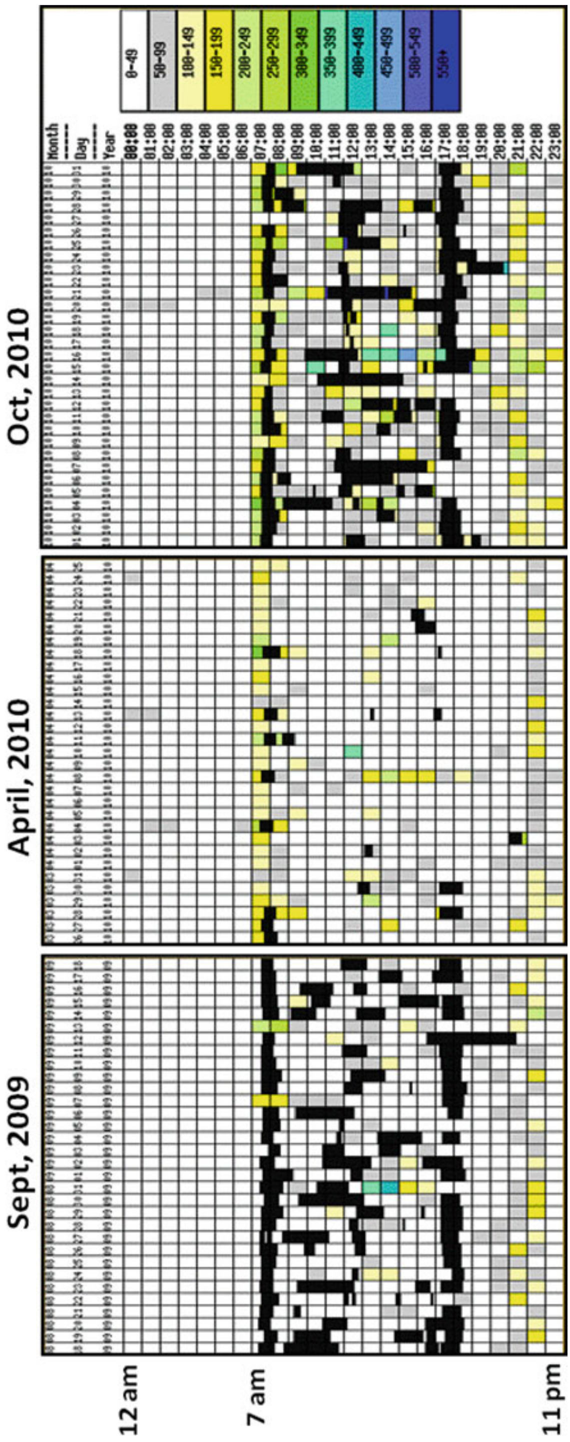


Fig. 5 Motion density maps for a TigerPlace resident showing a changing lifestyle due to decline and then improvement after an intervention

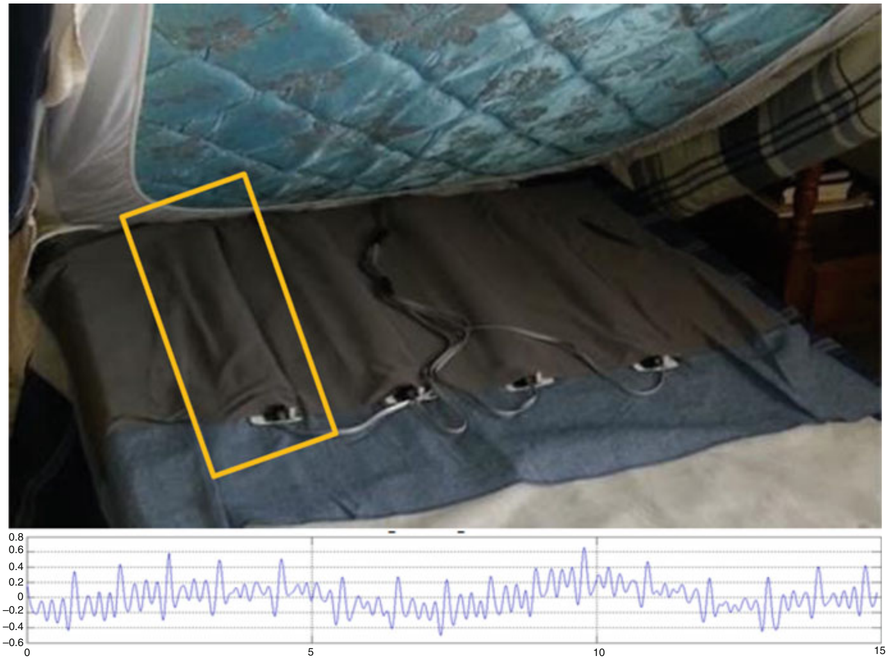


Fig. 6 The University of Missouri hydraulic bed sensor installed under the mattress with four transducers. The graph shows the combination of respiration and ballistocardiogram signals that are captured using this sensor

In 2011, three gait analysis/fall detection systems were installed in ten apartments for a period of 2 years. These include a Doppler radar (Liu et al. 2011; Yardibi et al. 2011), a Microsoft Kinect (Stone and Skubic 2011, 2013, 2014), and a two-webcam system that used silhouettes to build a three-dimensional model of the resident walking around the apartment (Anderson et al. 2009; Wang et al. 2013). Silhouettes were used to address privacy concerns. Research has shown that seniors are willing to accept silhouette imagery even when they reject regular cameras (Demiris et al. 2009). Although in-home gait and falls can be detected with each of the sensor modalities tested, the Microsoft Kinect proved to be the easiest and most cost effective system of the three. The Kinect is installed on a shelf close to the ceiling over the front door (Fig. 7). A wired connection is required between the Kinect and the computer logger located in the cabinet above the refrigerator; a small conduit discretely hides the cables, providing a clean look. The Kinect position was selected to be relatively close to the refrigerator cabinet and also to opportunistically capture purposeful walking paths as the residents move about the main living area of the apartment. Depth images from the Kinect are processed to extract moving residents as foreground objects. Algorithms track moving residents, select walks that are relatively straight and long enough and fast enough to be purposeful walks, and extract features used to estimate gait parameters such as walking speed, stride

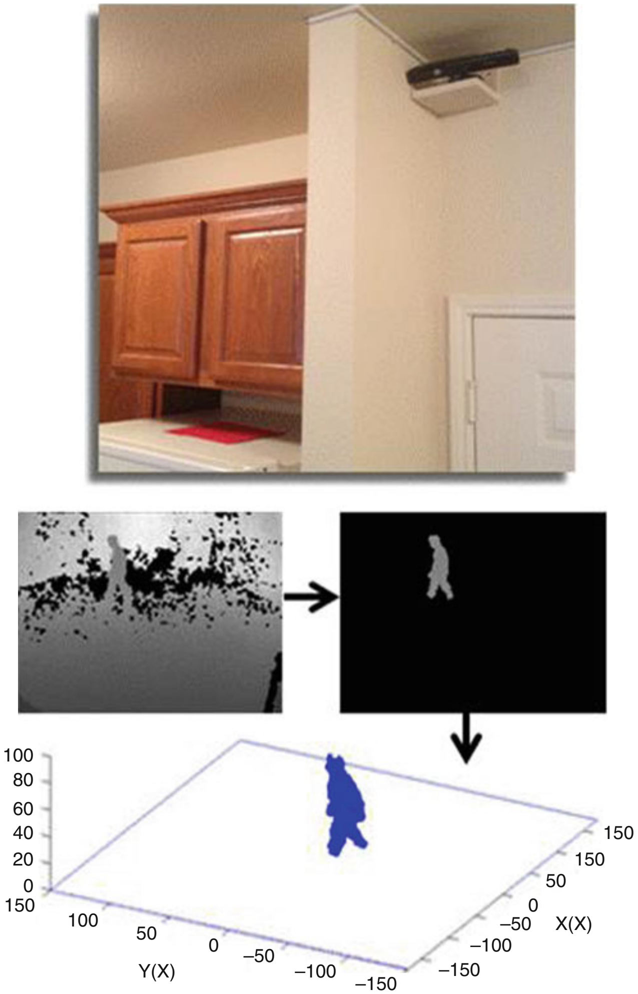


Fig. 7 A Kinect sensor installation with a 3D model constructed

time, and stride length (Stone and Skubic 2011). A model of a person's gait is learned and tracked over time to recognize trends in gait patterns (Stone and Skubic 2013).

A Model of Early Illness Detection for Health Alerts

The interdisciplinary research team at TigerPlace, along with the research infrastructure, has allowed the investigation of correlations between in-home sensor data and changing health status. Insights from the clinical research partners have provided a starting point on where to begin the investigation. Methods from pattern recognition and machine learning have provided validations on which sensors and which sensor features are most useful for detecting early changes of health and functional decline.

Initial studies of most meaningful features for early illness detection were done with the suite of motion sensors, pneumatic bed sensor, and stove temperature sensor. The stove, refrigerator, and kitchen cabinet sensors were not found to be meaningful for TigerPlace residents. Due to the common dining available, residents did not spend significant time in their own meal preparation. These sensors probably would be important for seniors living in private homes or other housing without common dining readily available.

An extensive feature selection analysis was done retrospectively using motion and pneumatic bed sensor data, to identify features most useful for early illness detection (Wang 2011). Features were generated on a per day basis or representing part of a day (e.g., night hours). Each day was labeled as a normal day or as an abnormal day in which a health alert would be warranted. Thirteen features were investigated from motion sensor data, including number of times out of the apartment, total time out of the apartment, number of visitor events, total time of visitors, motion densities during awake time, sleep time and total time, estimated relative energy expenditure, number of bathroom visits, total time in the bathroom, and number of sensor events in the living room, kitchen, and bedroom. Algorithms were developed and tested to estimate times of visitors and relative energy expenditure, based on motion density. Twelve features were investigated from the pneumatic bed sensor data, including four levels of restlessness; low, normal, and high pulse events; low, normal, and high respiration events; number of sleeping times; and total time spent sleeping.

The investigation showed that normal days tend to form clusters in the multidimensional feature space; abnormal days appear as outliers to the main cluster (Wang 2011). Detecting the abnormal, health alert days can then be viewed as detecting the outliers. In some cases of changing health, the "normal" cluster may drift or a new normal cluster may appear. This view of a normal cluster vs. abnormal outlier days provides a model that can be customized for each individual. That is, each resident's data can be used to learn a baseline unique to that resident. The investigation also showed that each resident had a different optimal set of features for early illness detection. However, for each resident dataset studied, the optimal set included bed sensor data. This study result showing the importance of capturing bed data and sleeping patterns has motivated the development of the new hydraulic bed sensor depicted in Fig. 6. Studies are ongoing to investigate this richer set of bed data for early illness detection.

Further investigation was conducted as a 1-year prospective study to investigate the use of in-home sensor data for early illness detection (Rantz et al. 2012). Based on the previous work, a system of automated health alerts was developed, as shown in Fig. 8. A baseline model of normal was established for each individual resident using a 2 week sliding window of data. A health alert algorithm was developed and implemented for testing. The health alert check was run once a day. Email alerts were then generated and sent to clinical researchers and staff at TigerPlace (see Fig. 9). Clinicians were asked to rate the clinical relevance of the health alerts on a scale of

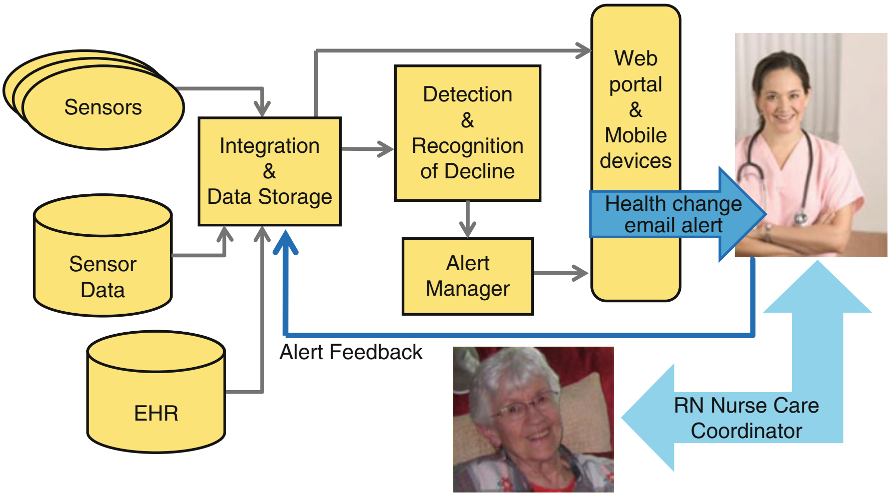
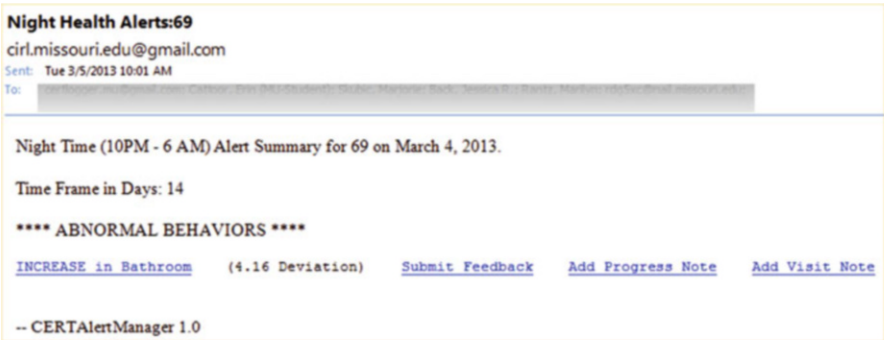


Fig. 8 The in-home sensor network and automated health alerts are used as a clinical decision support system for proactive care coordination


Night Health Alerts:69
cirl.missouri.edu@gmail.com
Sent: Tue 3/5/2013 10:01 AM
To:

Night Time (10PM - 6 AM) Alert Summary for 69 on March 4, 2013.

Time Frame in Days: 14

**** ABNORMAL BEHAVIORS ****

INCREASE in Bathroom (4.16 Deviation) Submit Feedback Add Progress Note Add Visit Note

-- CERTAlertManager 1.0

Fig. 9 An example of a health alert email with embedded links to the sensor data interface, the rating feedback interface, and the EHR interface

1–5, through an online feedback interface. These ratings were used to validate the health alert algorithm and further study the best features for early illness detection. Based on this prospective study, the six best sensor features were increases in bathroom activity at night and throughout the day, bed restlessness at night and throughout the day, and kitchen and living room activity at night (Skubic et al. 2012)

The prospective study also included an investigation of health outcomes between the control group receiving normal care and the intervention group with sensors and automated health alerts (about 20 in each group). Study results showed statistically significant differences in health outcomes between the two groups after only 6 months, in the form of walking gait and grip strength. Some of the health problems detected early using the in-home sensors include urinary tract infections, pneumonia and other upper respiratory infections, increasing congestive heart failure, post-hospitalization pain, delirium, and low blood sugar (Rantz et al. 2012).

Ongoing work at TigerPlace has continued to investigate the use of in-home sensors for capturing health status and detecting changes. As new, more sensitive sensors become available, these are being integrated into the health alert system. The results of clinical studies then drive the development of new sensing modalities, such as the hydraulic bed sensor and Kinect gait and fall systems discussed earlier. The studies show that continuous data from smart home sensors can capture new vital signs that are important in detecting very early signs of illness and functional decline, facilitating very early interventions that have significant impact in health outcomes for aging seniors.

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