Chapter 11
Smart Homes: Empowering the Patient Till the End

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11.1 Overview

The significant and continuous increase of the segment of the population globally 65 years of age or older (cf. Sect. 2.3 and Table 2.2) is calling for innovative solutions to supporting new models of aging. Technology can play an empowering role in allowing people to lead meaningful lives in the community while preserving quality of life and independence. With aging, people often try to cope with health related issues such as falls, sensory impairment, diminished mobility, isolation, diminished mobility, and in some cases the challenge of complex medication management. "Smart home" developments are being pursued worldwide in response to advancing technology, rising health care costs and the desire of older adults and individuals with disabilities to remain independent at the residence of their choice.

A "smart home" is a residential setting with embedded technological features that enable passive monitoring of the well-being and activities of their residents aiming to improve primarily overall quality of life, to detect or even prevent emergencies and ultimately increase independence for the involved residents. The technology is integrated into the infrastructure of the residence and, therefore, does not require training of or major operation by the resident, distinguishing thereby smart home applications from stand alone information technology (IT) systems that are operated by a user in a home setting (e.g., a videophone, a blood pressure cuff, a glucose meter etc.).

The number of research projects and commercial initiatives exploring the concept of smart homes has been growing worldwide. The Center for Future Health at the University of Rochester in the United States has developed a Smart Medical

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DOI 10.1007/978-3-319-19590-2_11

Home as a highly controlled environment including infrared sensors, biosensors, and video cameras [14]. The Aware Home at the Georgia Institute of Technology explores ubiquitous computing technologies that sense and identify potential crises, assist a senior adult's memory and track behavioral trends [13]. Researchers from five countries (the UK, Ireland, Finland, Lithuania and Norway) joined their efforts for the ENABLE project [3], which promotes the well-being of people with early dementia with several features such as a locator for lost objects, a temperature monitor and an automatic bedroom light. In Toulouse, France, the PROSAFE project is utilizing a set of infrared motion sensors to support automatic recognition of resident activity and possible falls [4].

The following Table 11.1 showcases some of the most cited smart home projects worldwide targeting specifically or broadly older adults . This list captures some of the diversity of technological approaches, geographic areas and overall design, and also includes some of the earlier pioneering efforts in this area, but is by no means a comprehensive list of smart home projects.

Table 11.1 World wide smart home projects

Project	Target audience	Technologies
Assisted Interactive Dwelling House [2] UK	Frail elderly and persons with disabilities	• Environmental control technologies (e.g., for windows, curtains, doors) • Sensor (e.g., bedside pressure pad, passive infra-red detectors, video door entry system) aiming to assess health, activity, and provide security monitoring and response
Aware Home [13] Georgia Institute of Technology, USA	Older adults and their families	• Health-related motion/activity monitoring technology (e.g., video cameras, "Smart Floor", pendant-based camera, ultrasonic sensors) for early detection and emergency response • Communication technology for enhancing social connection, including Digital Family Portrait which provides users and family members health, social, activity, and event information about each other, using icons framed in a dynamic, flat panel display • Memory aid technologies, including finding lost objects using radio frequency tags and Family Video Archive aimed at improving long-term memory
BESTA project [3], Norway	Persons with early dementia	• Environmental monitoring and control technologies (e.g., automatic lighting, stove monitors) • Activity monitoring (e.g., alert activated if user out of bed for over 30 min at night, door monitors to detect out-of-residence wandering)
comHOME [11], Sweden	Persons with cognitive disabilities	Video Mediated Communication technologies for everyday home activities

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Table 11.1 (continued)

Project	Target audience	Technologies
ENABLE Project [3], UK, Ireland, Finland, Lithuania, and Norway	Persons with early dementia	• Safety and assistive technologies for monitoring and controlling bath and wash basin water level, temperature and gas stove burners • Locating lost objects • Programming telephones with photos instead of numbers • Dispensing medications digitally
Gator Tech Smart House [9] Rehabilitation Engineering Research Center on Technology for Successful Aging at the University of Florida, USA	Older adults and persons with disabilities	• Environmental sensors for comfort and energy efficiency (e.g., smart thermostats), safety (e.g., smart stove, smart leak detector, smart bathroom that monitors water temperature), and security (e.g., home security monitors) • Activity/motion monitoring (e.g., smart bed that tracks sleep patterns; ultrasonic sensors and smart floor with pressure sensors that detect movement and location) • Fall detection system with emergency alert in development • Other smart devices and smart appliances (e.g., smart phone, smart mailbox, and development of smart microwave) • "Immersive" audio-video communication technology under development to be used for "social-distant dining" with relatives • Biometric technologies are under development for physiological monitoring (e.g., weight, temperature)
Gloucester Smart House [1], UK	Persons with dementia	• Sensor technologies that use voice messages to remind or alert residents, including sensors that monitor bath, stove, ambient temperature, and automatic lighting • Picture-phone and lost-item locator
Oatfield Estates [15] Oregon, USA	Older residents of an assisted living facility	• Sensor technologies for activities/movement (including locator badges or wristwatches) • Sensors for environment control (e.g., lighting, appliances) • Physiological monitoring (e.g., pulse, respiration, moisture level) • Other health-related monitoring technology (e.g., restlessness in bed) • Communication technology (including a portal that provides stakeholders, including family, web access to health and social information of residents)

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Table 11.1 (continued)

Project	Target audience	Technologies
PlaceLab [10] Part of House_n project of Massachusetts Institute of Technology, USA	General population	• Ubiquitous sensor technologies for activity and health monitoring, including wearable biometric technologies • Energy system monitoring and distribution (e.g., temperature, water, lighting, gas flow) • Development of technologies for learning, communication, commerce, entertainment, and work
PROSAFE [17] Toulouse, France	Persons with Alzheimer's	Infrared motion sensors to monitor activity and alert to possible falls
Smart Medical Home [14] Center for Future Health, University of Rochester, New York, USA	General population Strong focus on older adults through the Center's Aging Well Consortium	• Sensor technologies (including biosensors, infrared sensors, video cameras, microphones) for: • Physiological monitoring (e.g., blood pressure, pulse, respiration) • Motion/Activity monitoring (e.g., gait and behavior, sleep, and exercise patterns as compared to "normal" patterns for user) • Assistive technologies, such as: Personal Medical Advisor System, which includes a voice interaction system for medication compliance • Memory Assistance Aids, including object recognition system for frequently lost items such as keys
SmartBo and SmartLab [7] Swedish Handicap Institute, Sweden	Persons with visual, hearing, mobility, or cognitive disabilities	• Environmental control and safety technologies, such as for lighting, windows, doors, locks, water, electricity, and stove • Signaling devices, including a text enlargement program, speech synthesizer, and Braille display
Smartest Home of the Netherlands [18] Tilburg, The Netherlands	General population (Designed with input from older adults.)	Environmental technologies for safety, security, energy efficiency and comfort (e.g., automated security alarm; TV video of visitors at front door, activated by doorbell; automated lighting and heating)
Tiger Place [6] University of Missouri-Columbia, USA	Residents of assisted living facility	• Motion/activity sensors that monitor overall activity and location • Anonymized video sensor system for activity analysis. Pressure switch pads for activity monitoring and assistance such as automatic activation of lights • Bed sensor which monitors restlessness in bed and respiration and pulse parameters
Welfare Techno-House project [12], Japan	Older adults and persons with disabilities	• Sensors that monitor activity, environment • Development of biometric sensors that do not have to be attached to body (e.g., ECG measurement via electrodes attached to bath tub wall or to the foot and head of bed; and excretion or voiding measurement via load sensor on floor adjacent to toilet bowl • "secured lifelines" for natural disasters

11.2 Smart Home Functionalities

When examining the broad spectrum of technologies and the purpose they serve, smart home functionalities serve the following purposes:

- Physiological monitoring: Collection and processing of data pertaining to physiological measurements such as vital signs of pulse, respiration, temperature, bladder and bowel output, etc.
- Functional monitoring: Collection and processing of data pertaining to functional measurements such as general activity level, motion, gait, meal intake, and other activities-of-daily-living.
- Safety monitoring: Collection and processing of data pertaining to measurements that detect environmental hazards such as fire or gas leak. Safety assistance includes functions such as automatic turning on off bathroom lights when getting out of bed, facilitating safety by reducing trips and falls. Location technologies aimed at safety also fit into this type.
- Security monitoring and assistance: Measurements that detect human threats such as intruders. Assistance includes responses to identified threats.
- Social interaction monitoring and assistance: Collection and processing of data pertaining to social interactions such as phone calls, visitors, and participation in activities. Social interaction assistance includes technologies that facilitate social interaction, such as video-based components that support video-mediated communication with friends and loved ones, virtual participation in group activities etc.
- Cognitive and sensory assistance: Provision of automated or self-initiated reminders and other cognitive aids such as medication reminder and management tools, lost key locators, etc., for users with identified memory deficits. Cognitive assistance applications also include task instruction technologies, such as verbal instructions in using an appliance. Sensory assistance includes technologies that aid users with sensory deficits such as for sight, hearing, and touch.

While formal smart home initiatives targeting older adults date back to the late nineties, this is a relatively new and still emerging concept and research domain which calls for further examination of older adults' acceptance, ethical and practical considerations and the solidification of scientific evidence of the effectiveness of such systems.

11.3 Acceptance

The diffusion of smart homes and their adoption by the population ultimately depend on user acceptance of the concept. Introducing technologies in the residential infrastructure that support the ongoing passive monitoring of all inhabitants and visitors calls for the consideration of numerous factors. We believe that the concept of obtrusiveness, defined as "a summary evaluation by the user based on characteristics or effects associated with the technology that are perceived as undesirable and physically and/or psychologically prominent" [8], needs to be systematically examined in the context of smart homes. Obtrusiveness covers several underlying constructs and is meant as a summary evaluation, namely the cumulate effect of a number of characteristics or attributes that may be important or prominent to a user [8]. Obtrusiveness is also a subjective assessment (i.e., what one person perceives as obtrusive may not be perceived the same way by another). The user in this context is not only the patient or the older adult but also all other residents in the home. Given that perceived obtrusiveness is a subjective assessment, it is important to take the needs and expectations of the specific stakeholders in consideration. There is evidence that people will weigh their perceived need for such health care technology against potential privacy considerations [5].

11.4 Ethical Considerations

The research agenda for smart homes must include ethical considerations for their design and implementation. Implications, including those for social relationships and interaction, over-reliance, and privacy, must be fully considered. Moran [16] was one of the first to pose crucial questions about the social impact of smart technologies. She stated that

> The introduction of advanced technology into the home has the potential to change qualitative and quantitative aspects of relationships between household members, as well as the role and function of the home and its relationship with the wider environment.

As we design smart home features we are called to examine the possibility of such technologies removing choice and control from users as they learn to rely on automation. One may even hypothesize that smart homes would result in a reduction of social interaction, or may provide tools that substitute for personal forms of care and communication [20]. As we consider ways to implement smart home systems, we need to address the warning by Wylde and Valins [21] that we may be indeed creating "societies of high tech hermits".

An additional consideration is the extent to which smart homes may lessen the sense of personal responsibility on the part of residents or their formal or informal caregivers. Family caregivers, for example, may become less vigilant in monitoring health changes in their loved one and the residents themselves may become less vigilant in health self-monitoring and/or self-management as they rely on an automated process. This in turn introduces the question about the appropriate eligibility criteria or characteristics that make a smart home intervention appropriate for a population. Stip and Rialle point out [19] that the issues of individual freedom, personal autonomy, informed consent, and confidentiality have to be examined in the context of the target population. They provide an example of applications for residents with schizophrenia, a condition that causes distortion of reality in the form of delusions of persecution and psychosensorial phenomena, and highlight the likelihood that surveillance technologies may exacerbate such symptoms. Similarly, smart home systems may be of benefit to people with dementia as they facilitate monitoring and detection of emergencies; at the same time, it is hard to assess what the resident's true wishes may have been in terms of being monitored, if they themselves cannot provide consent for such an intervention and their participation is determined by a loved one who acts on their behalf. Such challenges raise the question how smart homes may affect or alter the relationship between a patient/resident and their family or other members of their social network.

Smart home systems create a large amount of new datasets. While data mining and advanced algorithms processing these data may result in the identification of abnormalities or trends that require immediate attention, questions are being raised who and how often should be monitoring such data sets. Health care providers are already struggling with limited time and may not easily integrate these new streams of data into their workflow. The challenge becomes in applying sophisticated data mining and pattern recognition tools to create meaningful information that can be used in a timely manner by health care providers, rather than overwhelming data that will be burdensome for clinicians to take into consideration and will raise questions of accountability and liability.

11.5 The Evidence for Smart Homes

Scientific literature is lacking evidence of the effects of smart homes on health outcomes, including earlier disease, illness, and injury detection and intervention. There is a lack of research studies addressing the effect of a smart home on acute episodes requiring emergency care or a possible delay or prevention of nursing home placement. Ultimately, such questions will necessitate large randomized and controlled studies, possible only with more widespread penetration of smart homes. Conducting such large experimental research studies, however, may prove to be challenging given the cost of implementing or retrofitting large number of residences and furthermore, observing other homes as a control group for long periods of time. Many argue that randomized clinical trials may not even be feasible in this domain. In order, however, for health systems to consider smart homes as tools that can play a role in the health care and well-being of older adults, and to introduce mechanisms for reimbursement of such systems or services, further evidence is needed. In order to assess the cost-effectiveness of smart homes, we need to have evidence of potential health care or quality of life related benefits. Currently, the evidence base consists of small pilot and feasibility studies and some larger studies that have followed cohorts of residents over a longer period of time. As initiatives continue to emerge, the body of scientific literature for smart homes will also continue to increase, and one would hope that the quality of scientific evidence would also improve (cf. Chap. 15).

11.6 Future Trends

The advancement of personal health records that allows the collection of management of health related information by the patients themselves can play a great role in the future of smart homes. The large amount of data generated by continuous passive monitoring can be processed to identify trends and patterns (for example, of overall mobility or sleep quality). Such information can be integrated into personal health records, allowing for a more comprehensive assessment and documentation of one's health and furthermore informing potential lifestyle changes that may be needed for disease prevention and management. The behavioral sensing component that is enabled by smart home technology can be integrated into personal records to provide a comprehensive view of one's status; such aggregate information can then be shared with health care providers and informal caregivers to facilitate shared decision making. One such example would be for decisions pertaining to transitions of care; often older adults themselves and their families have to make decisions about transitioning to a different setting with a higher level of institutionalized care, based on subjective or incomplete information. Health care providers in this case may only have episodic fragmented snapshots of one's overall wellness without information on the actual health related trajectory. A personal health record that integrates smart home data could in such a case become a meaningful tool to facilitate decision making and improve communication between the stakeholders.

Smart homes in the future and as a direct result of the rapid technological advances will strengthen their three attributes of *invisibility, ubiquity and adaptivity*. As technologies integrate into the architecture, furnishings, appliances and clothing, they become effectively invisible to residents and visitors. Moreover, they are located in multiple rooms, making them ubiquitous in the home and some support monitoring and data collection outside the home as well. Smart home systems often include artificial intelligence (AI) features, allowing them to learn and adapt to the particular patterns of residents.

The field of smart homes demonstrates the potential of information technology to support aging. As technological advances enable more sophisticated and tailored home-based solutions, we face the challenge to ensure that the design and implementation of informatics applications for older adults are not determined simply by technological advances but by the actual needs of older adults and their families.

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