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Inclusive Society: Health and Wellbeing in the Community, and Care at Home

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Preface

Owing to the rapid growth in the aging population and the so-called silver tsunami, a proactive healthcare strategy is being put in place across the world. This approach emphasizes active aging, wellness management, and a continuous monitoring of chronic diseases, hand–hand with the treatment of diseases and debilitating conditions of frail elderly. The approach also promotes awareness of elders' needs in the community, an attitude of inclusion among the population at large, and a care-provisioning infrastructure that meets the needs of elders living alone in their own homes, as well as those living in group facilities. *Inclusiveness* ensures a conscious awareness of elders as respected citizens in the community, and not those relegated to reside on the fringe. The need for the future is a shift in our attitude toward a position of inclusion among the population at large, a shift in the policy makers toward a care-provisioning infrastructure that meets the needs of elders, and a shift in each of our attitudes as we individually approach the inevitable goal of aging with dignity. Today, increasingly, many elders who are living by themselves are not truly alone. They are being watched by a number of new technologies custom designed to enable them to live independently and avoid expensive trips to the emergency room or nursing homes.

This is facilitated by smart environments and technical advancements in health sensing and monitoring technologies that operate on cost points that are unprecedented. A smart home allows residents to perform tasks efficiently, while at the same time being automatically monitored for early warning in health changes. In the near future the elderly and people with disabilities will avail of smart assistive technology to assist in carrying out daily activities, socializing, enjoying entertainment and leisure activities while still maintaining good health and wellbeing. Health Telematics makes the most of networks and telecommunications to provide, within the home environment, health services, expertise, and information and hence radically transform the way health-related services are conceived and delivered. We believe that in the future, aging and disabled people will use smart assistive technology to perform daily living activities, socialize, and enjoy entertainment and leisure activities.

ICOST is considered as a premier venue for the presentation and discussion of research in the design, development, deployment, and evaluation of smart environments, assistive technologies and health telematic systems. The theme for this year's ICOST conference was "Inclusive Society: Health and Wellbeing in Aging-Friendly Community, – eHealth, Telemedicine, Chronic Disease Management and Care at Home." This theme focused on the 'inclusiveness' of solutions and technologies to enable the support of aging-friendly communities through health and wellbeing management.

We are happy to note that this year, ICOST2013 received submissions not only from the traditional focus area of smart home technologies and architectures, but also from those dealing with engagement of end-users and caregivers. The review process was quite selective; 22 papers were selected for oral presentation, out of 53 submissions. The papers were organized into various sessions focusing on healthcare issues of the elderly, wellness and aging at home, privacy and security, algorithmic aspects, human–computer interface issues and architecture and protocols for services. Anchoring the 2013 ICOST was a set of five keynote and invited speeches from world-renowned researchers. A special competition entitled Hacknovate was organized by the Khoo Teck Puat Hospital in conjunction with A*STAR. The second day of the conference hosted a special Healthcare and Lifestyle session organized by A*STAR, where the emphasis was primarily on healthcare issues spanning across engineering and medical communities – addressing acute care as well as stepped down care.

We would like to thank all the people who were involved in the making of this conference, in particular the members of the Steering Committee for their valuable guidance, assistance and support; members of the Program Committee for their in-depth and timely reviews of the papers; members of the Organizing Committee for their hard work and prompt handling of innumerable issues that cropped up; and finally the keynote speakers and presenters of invited talks, the authors, and the attendees for their contributions and participation in the conference.

June 2013

Jit Biswas
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Organization

We would like to acknowledge the support of the CNRS Image and Pervasive Access Laboratory (IPAL), the Institute for Infocomm Technology, Neural and Bioengineering Technology Department (NBT) for supporting the conference through participation of its members, the A*STAR Science and Engineering Research Council (SERC) for the Health and Lifestyle special session of the conference, the Ministry of Health Holdings of the Infocomm Development Authority (IDA) of Singapore, for their support, and last but not the least, Khoo Teck Puat Hospital (KTPH), Singapore, for their participation in the organization of the Hacknovate event prior to the conference and for their continued support of ICOST conferences over the years.

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The Nature and Use of Surveillance Technologies in Residential Care

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Abstract. To support an aging population there has been a move towards developing surveillance technologies that observe the movements, behaviours and health status of older people. These technologies are meant to support health and independence within the context of limited resources. Although there have been studies about the development of new devices and systems, there has been less research examining the impact of surveillance technologies that monitor those residing and working in care facilities. This paper reports the findings from a qualitative study of a residential care facility that instituted video surveillance. The findings revealed how surveillance was used as a care management tool – to provide access to real-time data, to preserve the safety of older people and to monitor the working practices of formal carers. However, there may also be some unintended consequences of the implementation of video surveillance in residential care.

Keywords: Surveillance, observation, monitoring, privacy, residential care.

1 Introduction

The recent growth of technologies to monitor the movements and actions of individuals has created what has been termed the 'surveillance society' (Lyon, 2001), reflecting the expanding presence of surveillance technology and its intrusion into many aspects of daily life (Marx, 1998). In the care of older people, there is a long history of surveillance in institutional settings, where the layout and design of the facilities allow easy observation of residents and patients. More recently, technologies such as video surveillance tagging have begun to emerge to monitor people in both institutional and private settings (Sixsmith, 2013). Such technologies have been developed to improve safety, support health and well-being, manage high risk behaviours (e.g. falls) or as an alternative to restraints (Moffatt, 2008). However, ethical concerns have been raised about how surveillance technologies may diminish privacy, and compromise autonomy (Minuk, 2006). This paper explores the ways surveillance technologies have evolved and emerged in the field of elder care in

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recent years and the potential implications for monitoring those residing and working in long-term care. The motivation for this paper is stimulated by the need to better understand the potential impacts of introducing surveillance technologies in care settings where remote monitoring is becoming increasingly pervasive. To this end, the paper draws on data from a case study of a care facility collecting video surveillance to monitor the activities and behaviours of those working and residing in the setting. We explore some of the intended and unintended ways in which the video data is used by the care facility and discuss some of the implications for those living and working within residential care.

2 Surveillance Technologies in Residential Care

Whilst residential care is considered by some to be a risk free environment, studies have shown that there are a number of adverse events and safety deficiencies that put residents at risk of life threatening injury (Wagner and Rust, 2008). This has stimulated discussion in how to ensure that residential care facilities are safe and supportive environments to support older people. One approach has been the development of technologies to assist in monitoring older people within the facility. These interventions have been rapidly maturing and include video surveillance, integrated sensor systems, ambient monitoring and physiological sensors to monitor activity within the domestic and residential care environment (Bharucha et al, 2006).

The benefits of electronic surveillance to monitor nursing home residents have been justified through its ability to yield real-time, continuous and naturalistic data of everyday life within the care environment. This has included passive monitoring through basic alarm systems and security devices (Blackburn, 1988) and body worn sensors including tagging devices worn by the older person (Miskelly et al, 2005). This paper focuses specifically on the remote monitoring of older people through the use of passive video surveillance technology. Broader surveillance technology has been applied to generate observable evidence of individual behaviour within the nursing home environment (Wigg, 2010). The use of continuous video recording has also been applied to analyse the movement patterns of residents and to detect elopements amongst those with dementia (Chen et al, 2008). Robinovitch et al (2013) utilized fall incident videos captured in the communal areas of care facilities to better identify the biomechanical factors associated with fall incidents. Another study has indicated there is a link between the introduction of surveillance and the reduction of harmful incidents including falls (Lauriks et al, 2008). In this way, surveillance technology allows the opportunity for residential monitoring and to detect patterns in behaviour which suggest the need for intervention.

There has been ongoing debate about the ethical use of electronic monitoring within nursing facilities to monitor movements in communal spaces and in bedrooms (Cottle, 2004). There is the suggestion that residential care facilities have an obligation to support the interests of the resident and that this requires making regular intrusions into the private spaces of older people through the care that they deliver i.e. residential care as a quasi-private space (Adelman, 2002). Ongoing monitoring is seen as an extension of this care responsibility and to protect older people from harm, whilst maintaining high standards of care. The debate about the use of surveillance in long-term care includes a wide variety of stakeholders including institutional representatives, the care giver, the local resident and visitors.

To better understand the intended and unintended consequences of video surveillance in residential care, a participant observation study was conducted in a residential care facility in British Columbia, Canada that had implemented video surveillance technology.

3 Methods

This paper presents part of the findings of a larger ethnographic research which was conducted within the care facility over the course of 12 months between August 2011 and August 2012. The care facility had installed a network of 216 cameras to undertake continuous monitoring of the communal areas in 2007 to preserve resident safety. No cameras were located in bedrooms or bathrooms. All cameras were networked to recorders, which stored video at a resolution of 640x480 pixels and frame rate between 4 to 15 frames per second. The care facility collect, store, own and have access to the video data collected. The research was part of a project to understand the environmental factors in the causes and prevention of falls in LTC and the results presented here focus on the specific role of the technological interventions. During the study, the lead author was in the care facility for approximately two days per week engaged in case study research. Part of this research explored the ways that video surveillance was being used and integrated in the ongoing care process in the facility.

Observations were documented with fieldnotes collected contemporaneously and through reflective notes written-up immediately following each day at the care facility. The observations were supplemented by discussions with staff at the care facility to probe areas of interest further. To improve memory recall these discussions were recorded and written-up immediately after they took place. Specific quotations recreated in the results sections are excerpts from these fieldnotes. Over the 12 months, the researcher compiled a total of 30 pages of typewritten observational data collected within the care facility. The data was analysed to identify key themes relating to the specific intended and unintended consequences of using video surveillance.

4 Results

The analysis revealed four main ways in which the video technology was creatively utilized within the care facility to monitor the residents: reflective, real time, reflexive and retrospective monitoring. Reflective monitoring is defined as the use of surveillance data to improve understandings of an incident, for example a fall incident involving a resident. Real time monitoring refers to the use of 'live' data to provide a snapshot of what is happening in the care facility at a particular time. Reflexive monitoring is defined at the use of surveillance data as a tool to improve workplace practice. Finally, retrospective monitoring refers to the care facility ‘looking back’ at historical data to provide evidence to support a version of events.

4.1 Reflective Monitoring

The video surveillance data was used in a reflective way by senior management at the care facility to develop a better understanding of resident behaviour preceding a fall event. A significant advantage of video surveillance was its power to yield detailed information on the activities of the residents. The visual provided a more nuanced understanding of what the resident was doing immediately before the fall which would otherwise unlikely be available. In this sense, privacy intrusion through surveillance was rationalized in terms of providing a better understanding of resident behaviours:

> *“It is about understanding residents, their behaviour and the way that they interact with each other. Why has an older person suddenly got up from his chair and started moving around when that is not normal behaviour.” (Care co-ordinator, Unit 3)*

In a reflective capacity, the video was not only used for the monitoring of residents, but also for establishing the actions of formal caregivers in the event of a fall. In reviewing a video of the fall incident there was often the presupposition of individual blame to a care aide or nurse, reinforcing the hierarchical power relationships that exist between the observer and observed:

> *“It gives us more details about why a fall has happened. The fall incidents reports are very limited in that they do not contain all the information. For example, a carer is not going to write that they were talking to another carer about what their holiday was like and that this prevented them seeing the fall so the video allows us to see what is going on.” (Director of the care facility)*

Much of this reflective use of video was reactive and involved a care co-ordinator entering the operations room post-fall to replay the incident and identify contributory factors. Yet video monitoring also provided the opportunity to ascertain what was happening in different areas of the residential facility in real time.

4.2 Real Time Monitoring

Real time monitoring of activities within the care facility was undertaken by care co-ordinators through an iPad (connected to the video server) which provided a snapshot of the care unit at particular times of day. The availability of multiple angles of the unit from different viewpoints enabled the care co-ordinator to ‘keep an eye’ on activities without being physically present:

> *"I observe the videos real time on my iPAD. [Demonstrates the iPAD and moves between multiple video angles of the care unit]. I use this so I can keep an eye on what is going on when I am not. I will not look at this religiously but I will go in for half an hour at random. See what is going on and if things appear normal." (Care co-ordinator, Unit 1)*

Other care co-ordinators felt that real time surveillance provided them a truer perspective to what they could gain if they were physically observing within the unit. This form of 'covert' observation was based on the observed not being aware they are being 'looked upon'. Here, the surveillance data has the potential to compromise the privacy of those delivering care who may feel they have the right to work without 'undue' intrusion:

> *"I will also use it just before I go into the facility. So, I will turn the iPAD on for 5 minutes to see what is going on, then open the doors and see how the carers respond because as soon as you go in they will automatically change what they are doing. Suddenly it is all best practice but they don't know that I have just seen what's going on." (Care co-ordinator, Unit 2)*

Real time video monitoring was also used as a method for safeguarding the well-being of residents by allowing care co-ordinators to visually identify hazards within the immediate environment that might compromise safety. This form of monitoring allowed care co-ordinators to identify those visible environmental factors that could be a factor in fall incidents without having to undertake an assessment in person. For example, inadequate lighting, spillages, trip hazards. In this example, ongoing monitoring was justified in terms of preserving the welfare of the resident:

> *"If a fall is caused by something in the environment, could we have intervened earlier? For example, an older person nearly falls whilst navigating their way round some object that has been left out. Then half an hour later someone falls. What could we have done to stop that? So I look at the live data to see if there is anything immediately apparent that we can address earlier in that process." (Manager of the care facility)*

Used in this way, ongoing and continuous monitoring of the residential care facility allows vulnerabilities to be identified earlier and safeguards put in place before an incident happens. This is a potential improvement on existing approaches to fall incidents, which tend to adopt a reactive approach, putting safeguards in place after the incident happens. In this sense, preserving the well-being of the residents was prioritized over any privacy intrusion potentially brought about through surveillance.

4.3 Reflexive Monitoring

Reflexive monitoring was a form of video observation undertaken by the care facility with the intention of improving existing workplace practices. Video affords the potential to review what happened at the time of a fall incident. As a large proportion of falls in residential care are not witnessed, this provides new insight into falls and a tool for intervention:

> *"I honestly believe that the majority of falls are preventable in some way. Whether that is making sure that somebody is not sat in the chair all day, going up and talking to somebody and keeping them stimulated, making sure that they are toileted and given their medication, making sure that they are not dehydrated." (Director of the care facility)*

The residential care facility also used the videos of falls reflexively as a tool for staff education and improving practice. This was achieved in two ways. Firstly, to make recommendations to care aides about the ways in which their delivery of care could be improved by speaking to them one-to-one. This sometimes involved showing the carer the video as evidence to demonstrate the falls and discuss ways in which the fall could have been prevented. On the one hand, this has the potential to improve care practices. On the other it may compromise levels of 'trust' if the carer feels they are being 'watched over':

> *"I will have a direct word with the carer if I think it can be prevented in that way and say you know this happened or that happened and make sure it does not happen again." (Care co-ordinator, Unit 1)*

Secondly, the residential care facility used video-captured falls in regular fall review meetings as an instrument to improve practice. This involved the video as a form of knowledge translation, followed by group discussion to talk about how the fall could have been prevented. This group discussion resulted in fall prevention recommendations at the individual and organisational level:

> *"I have regular fall review meetings with the wider group. For example, if the fall is a result of a spillage I will get them together collectively and say listen, this is something we need to respond to... At the last meeting, the carers said that we need a piece of new equipment to help dry the surfaces quicker so we have ordered that." (Care co-ordinator, Unit 3)*

The video data was also utilized by administration staff to amend and change existing fall incident reports. Videos were used to corroborate the evidence of the care aide or nurse either (i) to amend an existing incidence report to improve its accuracy or (ii) to generate an incident report if that fall has not been captured:

> *"I also use the videos of falls to amend the fall incidence reports to improve accuracy. Sometimes we just don't know what has gone on so we go into the video and then amend the report. Occasionally we think that something might have happened so we go in and then find that we have a fall on our hands." (IT/administration officer)*

In this example, video surveillance afforded the opportunity to improve existing instruments of monitoring and assessment through verifying existing fall accounts or identifying falls that have not been witnessed.

4.4 Retrospective Monitoring

The care facility also used the video data as a form of retrospective monitoring, to defend themselves against outside allegations of negligence. In one case, a dispute occurred regarding the condition of a resident who was transferred to another care facility. The dispute centred over the condition of the resident prior to transfer and his health status upon arriving at the facility. The care facility reconstructed the movements and behaviours of the resident in the days leading up to the transfer which demonstrated that he was fit and well. The video was used in dialogue with authorities to resolve the dispute.

In another case, a resident experienced a heart attack at the care facility and there followed accusations from the hospital that standard emergency protocols had not been followed by nurses at the care facility. The care facility reconstructed the episode and compiled video evidence, which was passed onto the investigating body. In this case, it was deemed that proper procedures had been followed:

> *"In this case the video helped us to ensure that we were not negligent and that the procedures had been followed. If they had not [been followed], then we would have had a word with the carer and told them what procedures to follow." (Manager of the care facility)*

Another form of retrospective observation was using the video surveillance to monitor the activities of care workers. There were examples of the video being used to discipline care workers who arrived at work late, took extended breaks or engaged in inappropriate work activities (for example, using their mobile telephone).

5 Conclusion

Video surveillance within residential care has the potential to generate detailed observational data on the movements and behaviours of various actors within the care facility. This paper has highlighted the various ways in which video monitoring emerged as a key component of the care regime in one residential care facility. The analysis indicates that video surveillance provides potential benefits – to develop in-depth understandings of events such as falls, to improve safety culture and care practices, as objective evidence for improving existing instruments or as evidence during investigations. This suggests that electronic monitoring and video surveillance has a place in the residential care environment, given the responsibility that these institutions have for safeguarding the health and well-being of the residents and their employees.

These benefits need to be balanced with the limitations of relying upon video surveillance as the only source of data. Video provides only a narrow frame of reference for determining exactly what happened at the time of any one incident. Residential care is a complex healthcare setting, where incidents are symptomatic of broader systemic failures as opposed to individual errors (Nowak and Hubbard, 2009). Surveillance that is used to challenge the working practices of formal carers creates 'trial by video' encouraging person-centred blame for for the behaviours and actions of carers, when in fact there are broader environmental, situational or organisational factors that need to be considered (Schnellet et al, 2004) - for example, allocating blame for failing to operate equipment effectively when the individual concerned may not have been provided adequate training.

More fundamentally, the way the video technology emerged as an important part of the care process highlights how the outcomes of introducing new technologies are often difficult to predict and it is the unanticipated outcomes of new technology that are often most significant (Rogers, 1995). The introduction of any technology is socially transformative in nature and should be seen as part of the social landscape, rather than as a separate set of devices or tools for a specific task. Technology cannot be introduced into a social context without changing the nature of the social environment. Methodologically, it is unfeasible to suggest that video surveillance can be introduced as a tool for observation without fundamentally changing the nature of the thing being observed.

Lastly, it is recognized that the research presented in this paper has a number of limitations. First, the paper presents insights into the use of surveillance data in a long-term care facility through observations conducted in a period of time after the surveillance technology had been installed. This prevents a more longitudinal comparative analysis with working practices before the presence of the technology. Second, the methodology was restricted to observations conducted in the care facility. To explore the attitudes and perceptions of those residing and working in long-term care in response to the technology a more in-depth qualitative approach is required, for example, through nterviews with carers and residents.

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Sensors on My Bed: The Ups and Downs of In-Home Monitoring

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Abstract. Australia's increasing aged population is associated with rises in health expenditure and residential care costs, creating a public health challenge. This challenge can be met with in-home monitoring systems that allow older people to live at home longer. There is, however, a dearth of knowledge on how Australians feel about being monitored. Here we describe an ongoing study conducted with elderly residents as part of a smart home pilot. We aim to identify perceptions of the sensor-based in-home monitoring system throughout the pilot, from conception to completion. In this paper, we provide our preliminary findings of initial reactions to the technology and contributions made by prospective residents at pre-pilot workshops. We found participants favoured system flexibility and enhanced family communication and that undesirable aspects could be circumvented or solved by our researchers. Much of the participant feedback was incorporated into the design of the pilot and the associated technologies.

Keywords: Smart Home, Assistive technologies, Home monitoring, End user engagement, Quality of life, Social inclusion.

1 Introduction

A post-war fertility boom, advances in healthcare and increased life expectancy have seen Australia's ageing population grow significantly over the last decade, with a greater percentage of people over 65 than ever before [1]. Female longevity is apparent with a ratio of 2:1 females:males in the 85–99 group and 3:1 in the 100+ group [1]. Associated with this 'silver tsunami' is an increase in health and residential care costs. Health expenditure rose from 7.5% of GDP in 1998 to account for over 9% of GDP in 2010, the majority of which was funded by the government [2]. At up to $50,000 per bed per annum [3], the cost of residential aged care services is also high, and is similarly subsidized by the government. As the number of aged Australians is predicted to continue to increase [4], there is a strong imperative to develop innovative assistive technologies to support and extend elderly home stay and therefore reduce costs associated with health and aged care.

Several countries have now introduced assistive technologies and smart homes to facilitate safe independent living [5]. The types of services and technologies differ

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depending on the aim of the project, and the needs of the elderly. Most of the technologies within the home are for use by the resident, however, some are designed for use by social workers and carers, particularly in homes designed for elderly people with dementia [6]. In general, most smart homes contain a combination of sensors and monitoring systems and an avenue for social engagement. An advance in wearable technologies has seen the introduction of actigraphs [7], sensorised clothing [8], and even air bags to prevent fall injuries [9]. Sensor-based in-home monitoring systems have the capacity to provide a safe environment for the residents, and the analysis of data derived from these devices has proven to be valuable in detecting changes in activity or routine that underpin health decline [7,10]. However, cultural and behavioural differences are likely to influence acceptability and uptake of both invasive and non-invasive monitoring devices.

In order to gauge the level of acceptance and determine the full range of benefits ensuing from the provision of assistive technologies to elders living independently, a qualitative component has been incorporated into studies conducted in the United States and Ireland [11,12,13]. In general, these qualitative studies have revealed that positive elements of home monitoring include an increase in peace of mind, safety and medical compliance; while negative aspects include technical glitches, privacy concerns, and the limitations imposed by a daily diary and wearable technologies. Wearable technologies were reported to have a further negative affect arising from a perceived increase in frailty and loss of personal autonomy [13]. Currently there is a dearth of knowledge of how Australian elders feel about being monitored.

In Australia, the Smarter Safer Homes project is being piloted in a group of elderly residents of an independent living facility. The primary aims of the project are to improve Quality of Life for the residents through social inclusion and to develop a decision support platform for care providers. This in turn will improve Family Quality of Life through increased contact and reliable health knowledge. As the Smarter Safer Homes project is the first of its kind in Australia, it is important to record the initial impressions of residents and their families. This will allow tailoring of services meet the residents' needs, and redesigning of elements perceived to be unacceptable.

Here we describe an ongoing qualitative study to identify perspectives of, and gauge reactions to, the sensor-based in-home monitoring system. Our study traces the pilot from conception and pre-pilot workshops, through implementation, activation and cessation. In this paper, we provide initial perceptions of prospective residents at pre-pilot workshops that were both positive (specifically, system flexibility and enhanced communication), and negative (flashing lights, cords and unfamiliarity with technology). Participant feedback was incorporated into the design of the pilot and the technologies to ensure that systems and services meet their needs and requirements.

2 Methods

The objective of the initial workshops was to gain an understanding from residents of an existing independent living facility of the requirements, desires and challenges to acceptance of this new sensorised, supported independent living technology being developed. To achieve this objective we met with interested parties in a regional town in New South Wales, Australia, to discuss technologies, services and the practicalities of becoming involved in the nine month pilot trial.

2.1 Participants

The pilot study is being conducted in accordance with Human Research Ethics approval (12/17), while the initial workshops received low risk approval under LR14/2012. Pilot participants (N=20) are residents of independent living units in a regional town in New South Wales, Australia. They are aged over 70 years, have access to fast broadband internet, are willing to use an iPad and have no home care arrangements in place. They must remain in the town for the duration of the study and have significant others who are located in another Australian location. Pre-existing conditions with compromised cognition are exclusion criteria. Pre-pilot workshop participants (N=11) are residents who have expressed interest in the pilot study and hence meet the inclusion criteria above (n=9) or family members (n=2). Pre-pilot workshop participation does not guarantee pilot placement.

2.2 Sensor-Based In-Home Monitoring System

The Smarter Safer Homes platform relies on broadband connectivity and is a combination of sensors, monitors, iPad and software. The platform will aggregate sensor information at environmental, cognitive, behavioural and physiological levels that can be accessed by relevant parties nominated by researchers and participants. An iPad will be provided to each resident to access the data and to facilitate video conferencing. The pilot participant's homes are fitted with a range of in-home sensors, including a GPS tracker fitted to a key ring to monitor external excursions (Table 1). None of these devices require participant training, maintenance or interaction. A suite of medical devices is also provided to residents on a needs basis together with training and instructions (Table 1).

Table 1. Examples of sensor type, placement and data gathered

Sensor type	Data gathered	Place of installation
Motion sensor	Motion within 5m	Ceiling in all rooms
Accelerometer	Bed movement	Under bed
Plug meters	Current draw of appliances and devices	Wall power outlets
Acoustic sensor	Fall detection; Presence of visitors	All rooms; Lounge
Temp/humidity	Temperature and Humidity readings	Kitchen Bathroom Living
Pressure sensor	Use of sofa/couch	Under sofa cushion
Reed switch	Open/close events	Doors, pill box
Security camera	Live video stream	Front door
GPS tracker	Outdoor trajectories	Key ring
BP and heart rate	Systolic/diastolic and heart rate	Medical station
Weight scale	Body weight, BMI, fat	Medical station
Blood glucometer	Blood glucose	Medical station
Sonomat*	Sleep quality, heart and lung data	On mattress

* Invented by Colin Sullivan, University of Sydney, Australia.

2.3 Procedure

Two workshops were held in the lounge room of a demonstration smart home prior to both implementation of sensors in the residents' homes and pilot commencement. Four residents attended the first workshop (3 females). Two of these residents (both female) returned for a second workshop along with five other residents (4 females) and two family members (both female). All female residents lived alone, while the two male residents lived in dual occupancy. An overview of the system along with selected demonstrations formed part of the pre-pilot workshops, followed by open discussion of the technologies and iPad applications. Workshops were recorded and transcriptions underwent content analysis to explore arising themes.

3 Results

Here we provide preliminary results from the pre-pilot workshops with prospective residents of the Smarter Safer Homes pilot study. The aim of these workshops was to demonstrate and discuss the smart home technology. We had a particular interest in determining unacceptable aspects of the technology and how these could be modified.

In general the demonstrations were received favourably by the participants who were curious about aspects of the technology and interested to know more. As they started to picture themselves using the technology, they began to question what the technology would do for them and what the implications of using it were (Table 2).

Most of the questions related to how the participants would use the technology and what information they would be provided by the sensors. Some of the residents queried, but did not seem concerned by, additional costs of internet provision or electricity usage. Similarly, participants were interested to know if the pilot was successful could it be applied to independent living units in other Australian regions, or to more dependent forms of aged living such as residential care or nursing homes.

3.1 Modifications Arising from End User Input

In most cases there was consensus over the acceptability of sensors. Pressure sensors, plug meters and reed switches were met with unconcern; however, participants did find some technologies unappealing. The units have illuminated devices, such as smoke alarms and emergency call buttons. Residents felt these provided enough light at night and were not keen on sensors with flickering lights. The accelerometers on the bed were the only sensors perceived to be a real invasion of privacy. While all participants felt alerts would be valuable, there were various views on the usefulness of specific alerts. One was keen for a 'running tap alert' to be activated in the bathroom, while another did not want this in the kitchen. Altruism emerged where participants accepted the technology on the proviso that their baseline data would benefit others, for example if we gathered data on typical running tap events, weight gain or sleep quality in their age bracket to use as a measure of forgetfulness, unhealthy weight gain, or dementia [14] respectively. Concerns raised by the residents and the solutions that resulted in design modifications are provided in Table 3.

Table 2. Indicators of participant curiosity of smart home technology

Topic	Question
Camera	So I can see and hear who's at the door? That's a good idea.
Cost	Will that raise our power bill or what extra will that cost in a home?
Detecting falls	[can it tell] if you had a fall? Would it go 15m outside? Who is monitoring it?
	If you knock over the ironing board do you ring and tell them?
GPS	So you mean that little machine would tell me how far I walked?
In-home monitoring	How widespread do you think you will go with this? Will it be in most homes of the aged? Is that what you're aiming at?
iPad	Would this thing be in a holder that you could pull it out and put it back in again? So it's got to go near somewhere which has a power point?
	What else can you do with one? Can you send emails? Read the news?
Medical portal	One of those things was a glucose level, that has a test. Who would use that?
	So for all those six health items, you've got indicators and graphs?
Pilot	When is this likely to start now? And where do we sign up?
	And when do you come around finding out where we want things, what we want measured and that? You put in all our information - we put it in?
	Do I need the internet on before you people start? Are you paying for that?
Video calling	What has my son got to have to receive my messages?
Weekly diary	And does that weekly diary then get read by you?

Table 3. Examples of end user concerns and modifications to pilot design

Context	Participant's concerns	Proposed solutions
Sensors	'More little flashing lights in our house?'	Cover lights on sensors
	'I'm too aware of them, yes.'	Unobtrusive placement
	'Do these gadgets need maintenance?'	Conduct maintenance
Automatic alert generation and receipt	'If something happened in the middle of the day, they would never know anyway.'	Tailor contact for alert type (Family, carer, GP)
	'I don't want an alert that the kitchen tap is running, I fill my watering can there.' 'An alert on the bathroom tap would be good'	Allow alerts to be tailored to residents needs
Technology	'My son gave me an iPad, I can't work it.'	Provide training
Recharging	'So it's got to go near a power point?''	Finding a suitable spot
Extension cords	'You trip over them. You get tangled '	Cords to run along walls

Most of the conversations around aspects of the pilot they did not want were based on practicality. Participants did not see the point in having motion or acoustic sensors if they did not alert you to an event, and they did not want alerts for events that they did not perceive to be relevant to them ('I don't leave taps running'; 'I only take two pills'; 'I know how I've been sleeping'). Participants felt they did not need to be provided with irrelevant information which was 'meaningless' to them, such as data relevant to components of the project that aimed to assess for example, declines in cognitive or physical health. The participants were happy for this data to be collected, but did not feel it should be provided to the resident or their families.

3.2 Wish List Modifications

Participants were imaginative about the potential applications the technology could provide that would enhance their lives. Particularly if the technologies could warn someone that they were about to fall out of bed; or find objects they had misplaced.

3.3 Interacting with Technology

Much of the second workshop was devoted to demonstration of the iPad and its applications with a view to designing the interface in line with the resident's needs and preferences (Table 4). Participants were quite forthright and fairly unanimous in their preferences for the visual appearance of the iPad user interface. In summary, they expressed a preference for large font, blue or grey background, black print, sans serif font and buttons over blocks. These preferences were subsequently incorporated into the iPad user interface design. In terms of functionality, there was less agreement, and in general it was decided that information provision would need to be tailored for the individual. There were some functions on which there was consensus, such as a preference for audio over visual alerts; ability to change alert settings; ability to nominate which family members receive what data; and that family are advised that the participant is fine, but are not bombarded with medical and sensor data.

Table 4. Examples of participant contributions for the user interface of the iPad application

Feature	Specifics	Consensus and Additional Comments
Font	Size	Medium to large
	Type/ Colour	Sans serif/ Black
Layout		Selections in list on left hand side
Background		Blue or light grey
Tabs		Buttons over boxes
Alerts	Audio vs visual	Preference was for audio alerts
		Liked a list of devices left on
Family	Information sent	Basic info only, flexibility with nominations

Only one resident had family members present at the workshop, most were unable to join in as they either work during the day, or live out of town. None-the-less there was discussion on how residents and families would interact with the system. Participants felt families would be able to talk to them more often through the iPad and wanted to know what equipment families would need to have to do so.

Participants felt that information provision needed to be tailored for each family. For this reason, the configuration built into the iPad allows for individual family members to be added with three levels of information provision (none, basic, full) with the resident able to adjust these settings. Finally, participants did not feel alerts should go to families for three main reasons: not all family members had computers; most family members were busy during the day; and it would be too late by the time they got there or made contact. Hence alerts were configured to be sent to the resident or, in the case of extreme medical alerts, their care provider.

4 Discussion

An important aim of the workshops was to gain insight from the residents into how the technology and services could be tailored to their requirements. In fact, the participants provided a wealth of data that could be used by several of our researchers to inform and augment the pilot. Modifications were made to the design and placement of the sensors to reduce visibility; alert and information settings were configured to be tailored individually; and the iPad interface was designed on the basis of participant feedback.

Favourable comments were received around the flexibility of the system to be tailored to individuals, usefulness of alerts generated in response to taps or stoves left on, security afforded by a front door camera, potential for increased or easier family communication, enhanced peace of mind and the notion that others could benefit from the study. Several areas of discussion generated negative comments from the participants. Almost all concerned issues that were easily solvable, preventable, or pertained to existing devices or abilities, and thus not directed at the introduced technology. Participants were against equipment that had lights, extension cords or required maintenance and felt they would require training to use the iPad and medical devices. Apart from this, most of the undesirable aspects of the pilot were based on perceived usefulness of the data. If they could not see how the data could be used, they did not see the point in collecting it. This was keenly felt where the technology for data collection was considered an invasion of privacy, such as accelerometers on the bed or weight scales. Once it was explained that their information could provide baseline data on which to measure less healthy participants, they were much more accepting of the technology.

The wish list modifications were imaginative and intuitive but not unrealistic. It may well be possible to generate an alert based on bed accelerometer data that would warn someone about falling out of bed. The Gloucester Smart House [6] has a wall mounted locater device for frequently lost items. While not a part of this pilot it is conceivable that these devices could form part of a future Australian smart home.

All the discussion on families related to information provision – what they would like their families to know; and what the families would like to receive. In general it was considered that the families needed to know that the residents were fine, but not their personal or medical information such as daily patterns, weight, and so on.

More females than males attended the workshops, consistent with residential numbers at the independent living units and with female longevity noted in [1]. To ensure maximum participation, workshops need to be planned well in advance. Residents had a range of routine activities, like the weekly mah-jong tournament, that took precedence over ad hoc events. Small workshops worked well, as each resident had an opportunity to vocalise questions, qualms and opinions. It was favourable for the researchers too, as it allowed elements of the system to be thoroughly discussed and various perspectives gathered. In the first workshop, participants were distinguishable by voice, but this useful capacity was lost in the second, slightly larger, workshop.

The face to face nature of the workshops was extremely valuable in that the workshop facilitators could provide clarification and answers, both immediately, and after consultation with the research team. This communication was considered to ease the concern of the participants, make them feel they are being heard, and allow a smoother transition to in-home monitoring. Furthermore, the questions participants raised can now be addressed in a workshop for all residents prior to the pilot commencement. The participants spoke of an unfamiliarity with, and a reluctance to take up, new technology which will need to be addressed with training workshops in order to assuage concerns and ensure resident and family involvement.

The perspectives of prospective residents that we have recorded can now be used by researchers looking to develop technology based support systems that have been informed, in part, by the recipients. Understanding end user perspectives and communicating these to the wider community will help foster uptake of in-home monitoring services while providing peace of mind for families and carers. The inclusion of a qualitative component to smart home research will ensure that the delicate balance between service provision and preservation of dignity is maintained for these valuable community members.

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Corridor Sensor Arrays for Dementia Group Home

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Abstract. This paper describes a trial detection system to monitor the behavior of patients walking along the corridor of a group home for dementia patients. Generally, we do not install video cameras, in order to protect the privacy of the residents. We have developed a simple linear array sensor to detect the behavior of a person walking along the corridor. We have deployed these linear array sensors at a group home where 27 patients are living together. This paper provides an explanation on the sensors and the entire information system.

Keywords: behavior, dementia patients, linear array sensor, group home.

1 Introduction

Dementia is a typical problem of the aging society. The dementia population in Japan is expected to reach 2.92 million in 2020, as shown in Fig. 1.

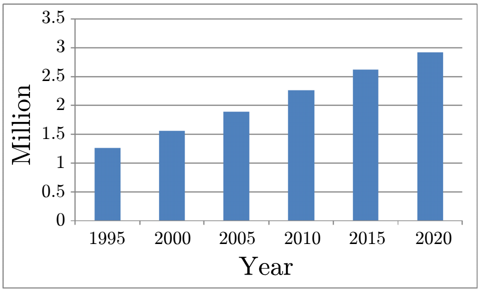

Fig. 1. Population of Dementia in Japan[1]

A group home is one of the solutions for the care of these people and their environment. This disease is considered as indolent. There are many group homes launched in Japan for this purpose. However, labor at these facilities is not an easy task. Particularly, night-time shift is very difficult for the caregivers, because

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there are only a few of them to take care of all the patients and the patients'-symptoms worsen at midnight. The serious problems related to the dementia patients are as follows: (1) the patients try to get out of the group home; (2) they get into the wrong room when they return from the rest-room; and (3) they stay at the corridor for a long-time. When a caregiver is taking care of a patient, he/she cannot recognize these problems and can cause serious accidents.

Few caregiver's assistance systems have been discussed for group homes, although health monitoring system in home environments has been considered for caring elders in many works [2]–[4]. One solution to overcome these problems is to install video cameras in the corridor. For example, M. A. Hossain and D. T. Ahmed [4] have proposed caregiver's assistance system based on several sensors such as cameras, motion sensors, appliance modules and so on for smart home environment. However, video cameras always cause privacy violation problems for the residents, and moreover, image processing is required for detecting the abnormal behaviors of the patients. While Fujinami *el at.* [5] have considered a walking data logging system with RFID Slippers at group homes, a wearable sensor may be felt as a disturbance for elderly residents. Therefore, we have developed a very simple linear array sensor to be installed at the ceiling of the corridor. Specially, our proposed system focuses on alerting to caregivers rather than distinguishing an individual, because it is important for caregivers to know whether someone wanders around during the nighttime.

Further, Section 2 describes the linear array sensors and hardware structure. Section 3 explains the basic information processing. Section 4 describes the deployment method. Section 5 presents the conclusion and future works.

2 Hardware System

For the detection of human motions, we propose a novel motion detection system, which is installed at the ceiling of the corridor, as shown in Fig 2. In this section, we describe the components of the proposed motion detection system.

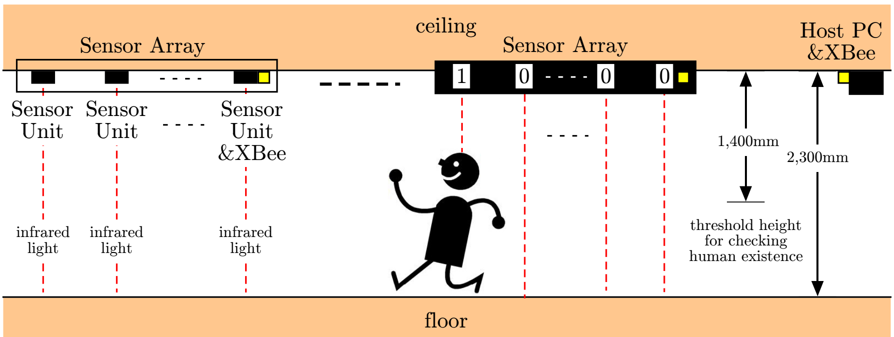

Fig. 2. Proposed Motion Detection System

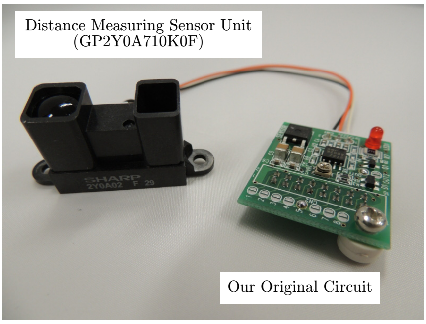

Fig. 3. Proposed Sensor Unit with Distance Measuring Sensor Unit (GP2Y0A710K0F)

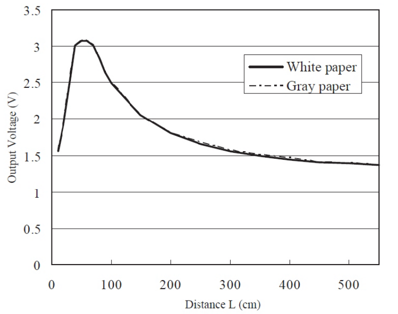

Fig. 4. Distance Measuring Characteristics[6]

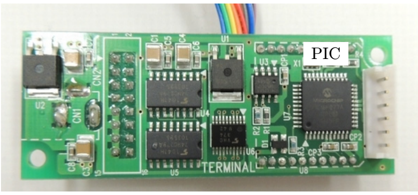

Fig. 5. PIC microcontroller (PIC16F877A)

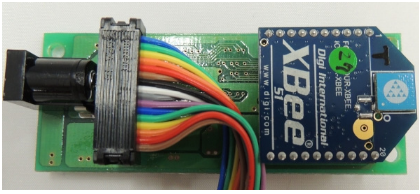

Fig. 6. XBee S1 DigiMesh 2.4 as a Zigbee module

2.1 Sensor Unit

For detecting the movements of human beings, we use a distance measuring sensor unit (GP2Y0A710K0F) produced by SHARP Corporation, as shown in Fig. 3. GP2Y0A710K0F of an integrated system of a position sensitive detector (PSD), an infrared emitting diode (IRED), and a signal processing circuit. It can measure distances in the range from 1,000 to 5,500 mm, and we use 1,400 mm as the threshold for detecting whether there is a human being under the sensor unit from a ceiling height of 2,300 mm. Although GP2Y0A710K0F outputs the analog voltage depending on the distance, as shown in Fig. 4, our sensor unit outputs the digital data 0 or 1, denoting the state of the distance measuring sensor unit depending on the determined threshold, that is, no-reaction or active state, respectively.

2.2 Sensor Array

Our proposed sensor array contains eight sensor units (at most), a PIC microcontroller (PIC16F877A) produced by Microchip Technology Inc., and XBee S1 DigiMesh 2.4 as a Zigbee module produced by Digi International Inc., as shown in Figs. 5 and 6. These sensor units are directly connected to the PIC16F877A via cables. The PIC microcontroller generates an 8-bit digital date from the information on the state of the eight sensor units. Therefore, our proposed sensor array can transmit the 8-bit digital date with the Zigbee ID to a host computer through the Zigbee module. Each Zigbee module is connected by DigiMesh, which is a proprietary peer-to-peer networking topology, in order to ensure robust networking connections.

2.3 Motion Detection System

Each sensor array stores the 8-bit digital date into a local buffer memory of the PIC at each sampling time. If the host computer demands from the sensor arrays the stored data, the sensor arrays switch to another buffer memory in order to protect the stored data and immediately transmit the stored data with the Zigbee ID. In the proposed system, we define the following commands for obtaining the data from the sensor arrays.

"S1/" Initialization and deciding the sampling time of the sensor arrays. "1" means 1sec as the sampling time. Normally, this command is used once when the system starts.

"F" Changing the buffer memory of PIC.

"Rxxxxxxxx/" Reading the preserved data of PIC with Zigbee ID xxxxxxxx. This command has to be used after the command "F". The sending data format from the sensor arrays to PC is "Zigbee ID xxxxxxxx"(the bottom 8 bits only), "/", "the preserved data" and "/<CR>", e.g., 4068AF1A/0,0,1,2, 1,0,···,0,32,/<CR>

The host is provided with the information on the relationship between the Zigbee ID and the location of sensor arrays beforehand, and therefore, it can determine the active sensor unit(s) in the entire set of sensor units.

3 Information Processing

The information from the sensor arrays is a bitwise 1/0 signal. When someone walk under the sensor, the signal turns 1, whereas it is 0 when there is nobody under the sensor. We can combine all the bitwise data into several-byte data. Generally, each sensor array consists of eight sensors and it transmits a 1-byte signal to the host computer. The host computer combines these data into several-byte data.

For a simple explanation, let us assume that the combined data is 3 byte, 24 bits. We obtain 24-bit 1/0 data at a sampling time. Let $V(t)$ denote the 24-bit data at time t. $V(t_0)$ is the following form at time t_0, when only the second sensor detects a person.

$$V(t_0) = [0, 1, 0, 0, \cdots, 0, 0] \in R^{24} \tag{1}$$

Let τ be a sampling period, thus we get the series of data at the sampling times.

$$V(t_0 + k\tau) \quad k = 1, 2, \cdots \tag{2}$$

Let us consider $m \times 24$ matrix W, where m is an integer of enough large. At first, we store $V(t_0)$ in the first row of the matrix; set $i = 1$ and $W(i) = V(t_0)$.

Loop Point

If one of the following conditions is satisfied, then we add the new data to the next row of the matrix W.

IF	$V(t_0 + k\tau) \neq V(t_0)$	OR	$k\tau > \delta$
Then	set $i = i + 1, W(i) = V(t_0 + k\tau), t_0 = t_0 + k\tau$ and $k = 1$		
Else	$k = k + 1$		

Back to **Loop Point**.

The following is an example of the matrix W with a timestamp at the heading.

02:53:02	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:53:11	0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:53:17	0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:53:24	0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:53:29	0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:53:33	0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:53:39	0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:53:47	0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:54:10	0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:54:16	0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:54:22	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:57:15	0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:57:23	0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:57:33	0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:57:45	0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:57:55	0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
02:58:03	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

The sensor location physically corresponds to the door locations of each room as follows. Where (r1) stands for the door of the room 1 and so on, (rr) stands for the door of the rest room.

(r1)				(r2)				(rr)			(r3)			
s01	s02	s03	s04	s05	s06	s07	s08	s09	s10	s11	s12	s13	s14	s15
s16	s17	s18	s19	s20	s21	s22	s23	s24						
(r4)				(r5)				(r6)						

By using the above physical mapping, we can interpret the matrix W to the following time-line statements.

02:53:02	The resident of living in the room1 gets out from the room.
02:54:10	The person is standing beneath the sensor 8 for 23 seconds or more.
02:54:22	The person is getting into the rest room.
02:57:15	The person is getting out of the rest room.
02:58:03	The person is getting into the room 2.

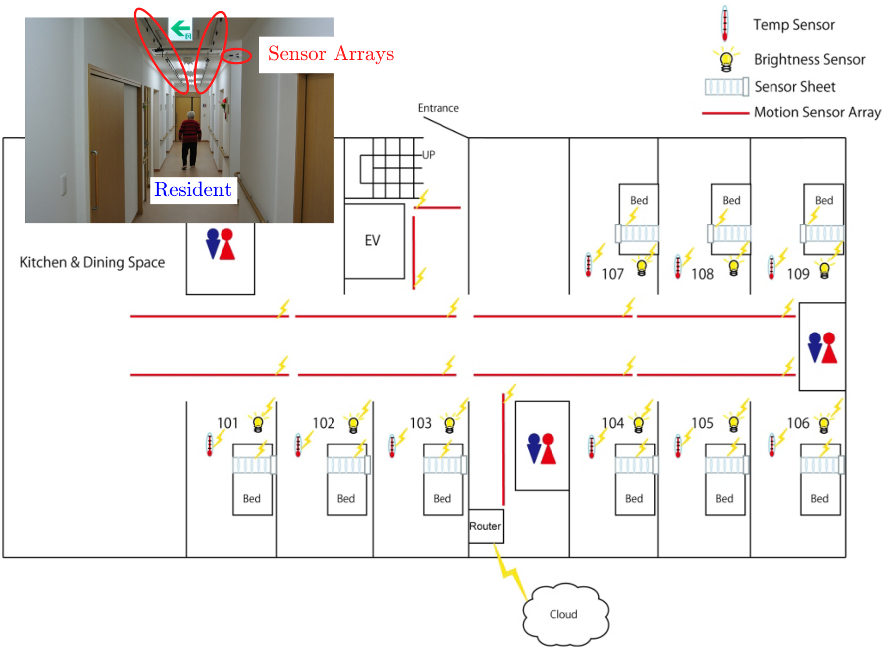

Fig. 7. Layout of Motion Sensor Arrays

When there are motion sensors installed the rooms, we can verify the behavior a person while "getting into the room" and "getting out of the room." The above statements can be automatically generated. From these statements, we know that the person has incorrectly entered room 2. The caregiver has to let the person out of room 2 and steer him/her into room 1. At 02:54:10, the person is standing under sensor 8 for a while. This period is only 23 s: however, when this period is longer than several minutes, the caregiver has to remind what the person has been doing. The interpretations are automatically generated, and the necessary warning can be sent to the caregivers on the basis of the appropriate criteria. The size of matrix W is not very large, and we can save the matrix W as a diary of the corridor movements.

4 Deployment

In this section, we describe the deployment method of the detection system in a real group home. In close collaboration with an elderly group home, we have designed a detection system to fit into the group home at a very early stage of designing its building, as shown in Fig. 7. The motion sensors are carefully designed and installed to correctly detect the behavior of each of the residents at the corridor, as described in the previous sections. The sensor arrays are installed on both sides of the ceiling of the corridor. As we have noticed that most of the

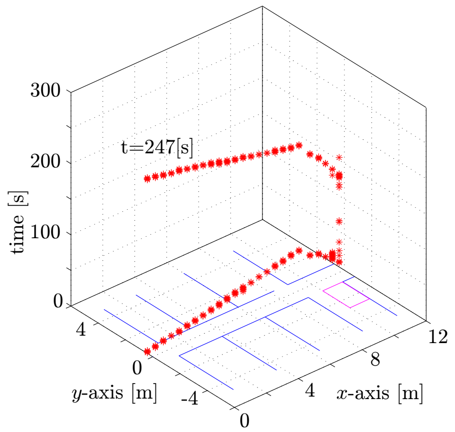

Fig. 8. Experiment Results in Time Sequence

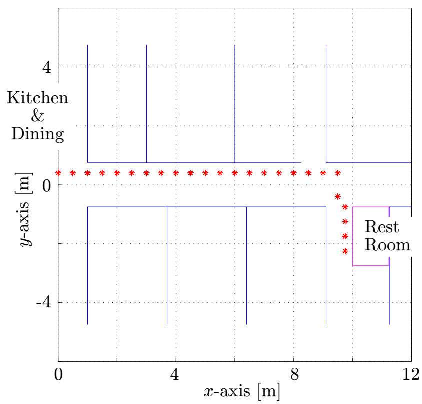

Fig. 9. Experiment Results on xy-plane

elderly residents tend to walk along the sidewall, by observing their behavior, we have placed the sensor arrays at a distance of 350 mm from the sidewall, which is one-fourth of the width of the corridor.

Here, we show trial experiment results by using the proposed motion sensor array. The considered behavior is that a resident goes to the restroom between room 103 and room 104 from the dining, has a wash, and comes back to the dining for about four minutes. Figs. 8 and 9 depict the active sensor unit, that is the digital data 1, as the red asterisk "*" in the time sequence and on xy-plane, respectively. The magenta square means the restroom. Although the behavior of the person walking is not represented exactly in Figs. 8 and 9, we can estimate the rough behavior of the person walking.

5 Conclusions and Future Works

This paper has considered the motion detection system to monitor the behavior of patients walking along the corridor of a group home for dementia patients as a caregiver's assistance system. The proposed sensor arrays have been installed in the real group home. From the experiment results, we confirmed that our proposed system can estimate the rough behavior of the person walking. Based on the proposed system, we have to consider the following abnormal behaviors in order to develop a useful caregiver's assistance system in our future works.

With these motion sensor arrays, we will attempt to monitor the abnormal behaviors of the dementia patients for early detection of their health problems as well as for understanding their behaviors particularly during the nighttime. The following are the typical abnormal behaviors of the dementia patients:

a) Wandering
Dementia patients tend to wander around more often at nighttime than during daytime, which can increase the risk of injury.
b) Frequent visit to the restroom
A high frequency of visits to the restroom is, sometimes, considered a warning sign of the disease.
c) Trouble returning to the correct room
It is often the result of worsening of the symptoms of the dementia patients, and letting him/her alone at the corridor can result in wandering, as described above.

Taking into account the abovementioned abnormal behaviors, we have placed the motion sensor array in front of the restroom, elevator, kitchen, and entrance to detect all the abnormal behaviors.

Detecting these abnormal behaviors helps not only to prevent a disease or an injury but also to reduce the burden of the caretakers. In addition, we have installed several different types of sensors in each room to enhance the reliability of the detection system and gather a wider range of information, such as the room environment, as well as the vital data when the patient is asleep. We will combine the motion detection system and the several sensors in order to estimate the behavior of the residents more precisely. All the information gathered from each sensor, via the main router installed on each floor, is transmitted to a cloud server. Further, the care manager and the caretakers can monitor the current status as well as the historical data through the website specifically designed for them.

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PhonAge: Adapted SmartPhone for Aging Population

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Abstract. SmartPhones can play a significant role in maintaining decent a Quality of Life for elderly people. There are numerous solutions available on SmartPhones that can assist the elderly in their activities of daily living, however these solutions are sometimes not welcomed in elderly community due to usability and accessibility factors. In this paper, we present PhonAge, an accessible & adaptable solution for SmartPhones that can host diverse useful services to elderly people. The first stage user evaluation results shows the usability of our solution.

Keywords: Elderly, Mobile Phone, SmartPhones, Human Machine Interaction, Accessibility, User Centered Design.

1 Introduction

Mobile technology can play a significant role in maintaining decent Quality of Life (QoL) for elderly people. It can promote active aging, active socialization, and independent living, while ensuring safety. The aging process is associated with progressive degradation of sensory, physical and/or cognitive abilities [5,8]. Elderly people want to keep their independence, remain active and maintain social relations while advancing in age. In a recent study, we sought to understand the technological need (including mobile technology) of elderly in modern society and to study the impact of technology use to promote active aging inside and outside the home [3]. The results of the study show that there is a real need for mobile assistive technologies that are adapted to elderly skills and needs, while providing them useful assistive services.

Recently, Smartphones have gained attention among elderly people [17] and many of them are starting to use them for various purposes (e.g. as a reminder). Numerous services are available on SmartPhones that can assist elderly (e.g. navigation, interactive diary, activity reminder, speed dial, SOS service), however these solutions are not much welcomed in elderly community, either, because of elderly resistance or rejection of technology, complex & tedious perception of technology, accessibility issues, and so forth. [3,20].

At present, the mobile industry is targeting young and a tech-savvy population [6,7] and does not always take into account the special needs and expectations of the elderly population when designing services or phone devices. The main

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difficulties in adapting Smartphones for elderly people are limited or lack of personalization, complexity of interface or a navigation menu, quantity of information arranged on screens, number of functions, language, etc. [9,20]. Consequently, mobile technology becomes more and more complex, and elderly people are confronted with devices and services that are not adapted to their needs.

In our experience while designing mHealthcare & social services on Smartphones for elderly people, we found that accessibility of phones is the major obstacle towards acceptance, usability and continuity of use. To address such issues, we designed and evaluated PhonAge, an accessible & adaptable solution for SmartPhones that is customized to the elderly profile and can host diverse services to assist them in their activity of daily living (ADL).

The rest of the paper is organized as follows, section 2 presents literature review focused on mobile phone based solutions to assist elderly people, section 3 describes PhonAge, section 4 shows the results of first phase evaluation and finally we conclude our work and discuss future work in section 5.

2 Related Work

A recent proliferation in mobile technology has given an opportunity to better deliver services to elderly people in their ADL. However, to the best of our knowledge very little work has been done to address the needs and difficulties of the elderly population while interacting with mobile phones. The proposed solutions are mainly available on either special devices or customized solutions on SmartPhones.

Special device solutions (such as Doro PhoneEasy[1], Mobi-click[2], Easy 5+[3], offer basic functionality of making calls and sending & receiving messages using accessible simple interfaces. Most of these devices also offer the functionally of speed/touch dial where some pre-assigned contacts numbers are stored that would help elderly (mainly those with cognitive disability) to call (e.g. family, caregivers, SOS services). These solutions have up to some extend address the cognitive and physical limitations of elderly, however these systems are not scalable and does not support implementation of mHealthcare services to assist elderly in their ADLs.

On the other hand, SmartPhone based solutions have been proposed to assist elderly in their ADLs (e.g. Fujitsu phone [14], silver line[4], Phonotto[5], Big Launcher [6], etc). The mobile User Interface (mUI) provided by these solutions are designed keeping in mind the elderly profile. The general idea of these mUI is to provide the most relevant information on the main screen while encapsulating the information and phone features. In contrast to special devices, cognitive, visual and

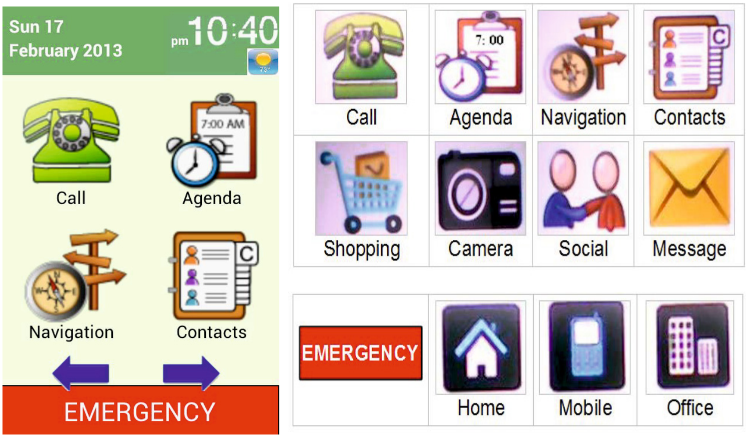
[1] www.doro.com/
[2] www.mobi-click.com/
[3] www.bctech.fr/telephonie/easy5.html
[4] www.igg.me/at/silverline
[5] www.phonotto.com/
[6] www.biglauncher.com/

physical limitation of elderly are addressed. For instance, Big launcher offers features for people with visual impairment to provide maximum readability and ease of use. It also provides the customization option where users can choose the color of their choice, size of the text and other features. Similarly, Fujitsu's RakuRaku offers an interface especially designed keeping elderly and their skill in mind. The hardware of the phone is able to distinguish between accidental touches and purposeful taps that make it intelligent in its group of solutions.

The solutions presented above (based on special devices and smart phones) have some pros and cons. Several studies have been conducted to evaluate the factors that contribute to affect the use of mobile phone among elderly [12,19,2,13,10,11]. Looking at these studies, we concluded that special device phones are not the optimum solution in case of elderly due to disability/frailness tags associated with them and limited functionality to provide assistive services. On the other hand, considering the touch screen feature in SmartPhones, there is a need to improve mUI so that it can satisfy & please elderly in their use, while providing a line of useful services related to the elderly population [4]. To the best of our knowledge, research in mUI design for elderly people has not been extensively explored and there are limited interface design guidelines available while designing for elderly (interested readers are refer to [7]). In the next section, we present our effort to address the issues presented above.

3 PhonAge: Adapted SmartPhone to Assist Elderly

PhonAge is an attempt to design an accessible phone to promote the use of smartphones among elderly people and to better assist them in their ADLs. As stated above, a key factor of usage success of mobile phones among elderly people is accessability of the mobile user interface (mUI). We designed and evaluated PhonAge, an accessible & adaptable android based solution for SmartPhones that can host diverse useful services to elderly people. PhonAge's interface is specially designed to meet the needs of elderly, according to their profile, taking into account cognitive degree (e.g. memory, attention, initiation, planning, time and spatial, and orientation impairments). PhonAge interface/screen is divided in three sections, namely **(1)** a spatiotemporal assistance section (Top section) (to continuously provide elderly people with spatiotemporal contextual information (date, time and weather)), **(2)** the main Activity and service area section (to provide accessible phone feature and services to assist elderly) and **(3)** an emergency section (to ensure safety of elderly people while moving (inside and outside)). PhonAge also provides a configuration of options that allow elderly people/caregiver/family to adapt phones according to elderly needs. For example, it enables them to change the text and icon size, choose among the icons from gallery, change the order of icons, etc. PhonAge's main screen and icons are shown in figure 1a. In the following section, we describe the design principles of PhonAge and its features.



(a) Main Screen (b) PhoneAge Icons

Fig. 1. PhonAge User Interface and Icons

3.1 Spatiotemporal Assistance Section (Top Section)

Temporal information is central to elderly people as our environments are organized on the basis of time and events are ordered by time of occurrence and duration [3]. Numerous eye-tracking studies have shown that the area where users look most is the top of the screens (e.g. [16,18]). Thus, we position spatiotemporal contextual information (time, date and weather) at the top section of the screen to allow users to access this information easily and quickly. Since Spatiotemporal information is central to elderly people, unlike traditional solutions we choose to display spatiotemporal values thought-out in all the navigation screen of system, so that elderly people will have access to this information every time they navigate in menus. The font size of spatiotemporal values are set according to the sensory needs of elderly (e.g. bigger font size for visual impaired). The configuration option of PhonAge allows users to choose the style of dates they like or are accustomed to i.e. dmy - European style, mdy - American style, ymd - Asian style, also to enable and disable weather information from the top screen.

3.2 Main Activity Section (Center Section)

The center section of PhonAge displays the main functions i.e. Call, Agenda, navigation shopping, etc. The functions are arranged in a grid of two rows and two columns. The number and position of icons are designed to facilitate visibility and learning, and not to exceed memory span (which in our case is 4 which is less than 7$\pm$2 that the work memory can process at a time t [15]. In the first row, we placed two features of mobile devices that are mostly used by elderly people (i.e. Call and Agenda). These function icons are locked and cannot be moved. In the second row, users can choose among a list of function icons (e.g. contact, navigation, shopping) by flipping (right/left) or by using the navigation arrows.

The design of navigation arrow buttons is to facilitate the use of those who are not accustomed to Smartphone or scrolling features on touch screen phones. For consistency purpose and ease of use, similar arrows are placed in other screens where users need to navigate through screens.

PhonAge icons are specifically designed so that they give the look, feel and meaning to its user with labels available in their choice of language (to address cognitive abilities). These icons are available in four sizes so that a user can select the size of icon they feel comfortable with respecting screen density and spacing between the icons. The icons also provided the sense of feedback by audio, haptic and visual confirmation.

3.3 Emergency Section (Bottom Section)

Safety is one of the reason that keeps elderly people from being socially active outside of their homes (e.g. streets, malls and parks). In several situations, elderly people have a fear on being tagged as frail, attacked or abused, lost (wandering problem), or in a medical emergency situation (e.g. Fall). To address such situations, we choose to include a context-aware emergency service (based on the context-aware framework presented in [1]) enabled with an emergency button . The emergency button is placed on the bottom of the screen to make it accessible nearby the thumb in regular holding position of the phone. The button is available on all screens of PhonAge so that elderly people can access it any time in any operation. It is colored red to represent emergency (although the color can be changed according to user preferences through configuration function). Unlike emergency or SOS services in existing mobile phone based systems, the PhonAge's emergency service is context-aware and is triggered based on the predefined emergency protocol. PhonAge emergency service is triggered by pressing the emergency button once respecting the threshold of time t (in default setting t=3 sec, and can be changed in configuration function). In addition, in case of emergency services (e.g. Fall detection) automatic emergency response is invoked using environment context (e.g. those gathered with phone or wearable sensors). Here no interaction or confirmation is required from user.

4 Evaluation

To evaluate the usability and accessibility factor of PhonAge, we conducted first stage evaluation with elderly people. The goal of the evaluation was to explore usage and expectations of elderly people while using PhoneAge, and how elderly people understand and interact with PhonAge. Following, we present the method, and summary of results of the evaluation study.

Method. To evaluate the mUI of PhonAge, we compiled a semi-structured interview supported by a questionnaire of about 45-60 minutes composed of 18 questions divided in two parts. The interview is designed to be conducted in person (by examiner) and the feedback and remarks to be recorded by the examiner. Following we describe each of part of questionnaire:

Part. 1. Gathering User Information:
In this part, we ask questions related to participants profile, such as age, education level, living environment (independent or nursing home), etc. Participants are also informed about the purpose and procedure to evaluate PhonAge. The participants were asked to rate each item using a 5-point Likert scale.

Part. 2. Accessibility and Usability Test:
In this part, we ask questions about understandability, usage, utility and satisfaction of the PhonAge interface.

- **Icon Understandability Test:** (similar to that used by [3]) was run to evaluate the meaning which PhonAge icons give. Firstly, participants were asked to give the meaning of the 12 icons proposed in PhonAge (i.e. *According to you, what is the signification of these icons* ?). Secondly, we presented the icons with their respective labels (see figure 1b) and asked the following question: "*According to you which information do you consult if you touch the next icons*". The order of the icons is modified to avoid inferring with any meaning about next placed icons.
- **Use Test Method:** was used to evaluate the usability of PhonAge including usage difficulties encountered by elderly people while using PhonAge mUI. The evaluation was designed to assess difficulties in use, utility of the navigation arrows provided (to switch between screens), and utility of functions (e.g. emergency, organization of icons/functionality on main screen). Participants were asked to navigate through phone functions and perform four defined tasks i.e. call, search contact address & email and locate the camera function. Moreover, participants were asked to evaluate the PhonAge interface in terms of utility, facility of use and their preferences (i.e. interface structure, color of the wallpaper, services usefulness). We ask questions like (*According to you, it is easy to* ?; *According to you, it is useful for outside activities to*? *According to you, the background is*?.

4.1 Results and Discussion

The results presented in this paper are those conducted with twenty elderly persons aged 60 to 84 (Mean=70 years, standard deviation=8,2, 13 females and 7 males) who participated in this study. The results of evaluation were compiled according to the tests conducted. Following, we present the results:

4.2 Icons Understandability Test

Evaluation of the icon understandability showed, that common icons (e.g. phone, SOS) were easily understandable (meaning, purpose) by all participants, even without a label. However, none was able to understand the following two icons: "shopping" for shopping list and "home phone number" on contact screen. Figure 2 illustrates the results of the understandability of PhonAge icons. Labeling the icons helped participants to understand the icons (e.g. navigation, social).

In certain cases, participants could not recognize the icons even when labeled e.g. 20 participants inferred that the shopping icon is for on-line shopping and not a shopping list; similarly only one participant inferred that time shown on the agenda icon (7:00) referred to an appointment at 7:00 AM. These results confirm the compliance of 9 icons to the associated functions. They also provided us with valuable feedback to modify the icons of shopping list, home and office phone. e.g. Taking into account our observation that elderly people pay attention to details/indications of icons, adding a sheet to the "shopping" icon improved the understandability of the icon.

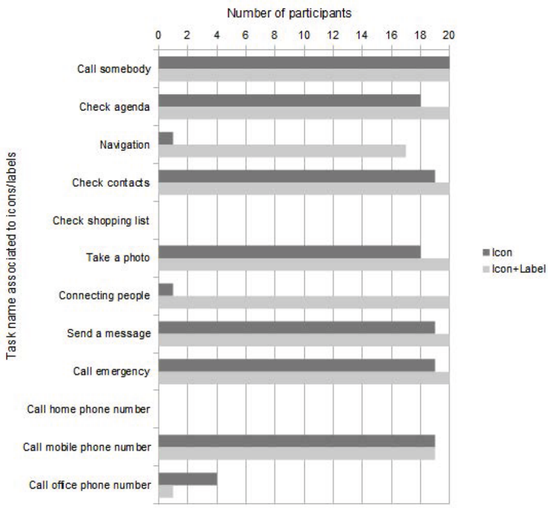


Fig. 2. Results of Icons Understandability Test

4.3 Use Test

Evaluation of PhonAge usage shows that the majority of participants (17/20) were able to easily execute the four proposed tasks. Only 3 people found these tasks difficult due to a visual impairment condition and their first time operating a mobile phone. During the first interaction with PhonAge, 17 participants used only the navigation arrows of the mUI to navigate through screen and icons selection. Only three used the touch scrolling, as they were already accustomed to it. After a demonstration time of the option (learning phase), 17/20 participants preferred to keep both in the mUI (i.e. navigation arrows and touch scrolling). After this learning phase, participants found touch scrolling very intuitive as most of them said "we flip pages like in magazine, moving finger/hand form right to left". sixteen participants faced a difficulty to return to home screen (while navigation between screens). In the current version of PhonAge, returning to home screen is done always using the back button provided by the device. Since these participants were all novice Smartphone users, they were not aware of the presence of the button. One of the novice participants and the three who were already accustomed to touch screen devices had no problem returning to the home screen. After a learning phase of this option, the 20 participants were accustom to the use.

The overall evaluation results shows that participants appreciated the clear color (e.g. green, yellow, blue) of the wallpaper and they appreciated the readability (16/20), visibility (20/20), pleasant aspects (18/20) and contrast (20/20) of the interface. Eighteen participants preferred the portrait display contrary to landscape display as they found it more classic *like a book*. The position of the icons and information on the main screen are also very much appreciated, for instance, all participants (20/20) liked the access to the spatiotemporal values and emergency button on all screens. Seventeen participants reported that weather information is not necessary to accessible on all screens all time. Six participants also pointed, that one way to appropriate PhonAge is to personalize the label of the icons by adding the work "my" as *my contacts, my agenda, my shopping list* rather than *contacts, agenda, shopping*.

5 Conclusion

SmartPhones can play a significant role in maintaining decent Quality of Life for elderly people. However, a key factor in usage success of SmartPhones among elderly people is accessibility of the phone interface. In this paper,we presented PhonAge our solution for an accessible & adaptable SmartPhone that is customized to the elderly profile. Phonage offers personalization options for elderly/caregiver and family members. The evaluation results confirmed that PhonAge design complies to the expectations and perceptions of elderly people. Moveover, the feedback received by the evaluation helped to improve and modify the icons so that the elderly can have a better understanding of the functions they use. In future, we are working to develop services in the context of Age Friendly cities that would assist elderly to remain independent and maintain social interaction. The results of the studies and application are available on our Website site[7]. We encourage the research community to use PhonAge, and welcome an opportunity to work together. Our goal is to build a social prosthesis that promotes successful aging by use of PhonAge as a host that enables successful deployment of useful assistive services.

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Extracting Intra- and Inter-activity Association Patterns from Daily Routines of Elders

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Abstract. One of the most challenging issues faced by many elders is the over-decreasing independence mainly caused by impaired physical, cognitive, and/or sensory abilities. Activity recognition can be used to help elders live longer in their own homes independently, by providing assurance of safety, instructing performance of activity and assessing cognitive status. In this work, we propose to discover both intra- and inter-activity association patterns from daily routines of elderly people. Specifically, a data mining method is proposed to extract the most frequent sequential sequences of steps inside each individual activity (i.e., intra-activity pattern) and activities (i.e., inter-activity pattern) of a set of daily activities. These patterns can then be used to model human daily activities for activity recognition purpose, or to directly instruct/prompt elders with impaired memory when they perform daily routines. The experimental results conducted on two individuals' datasets of daily activities show that our proposed approach is workable to discover these association patterns.

Keywords: Elderly people, activity recognition, sequential pattern, association extraction.

1 Introduction

Autonomy or independence is identified as one of the most challenging issues for the elderly in their daily living. This is because, with age, many elderly people experience a variety of impairments on physical, sensory, and cognitive aspects at some extent. While the traditional manual caregiving should not be replaced, intelligent assistive technologies that can supplement traditional caregiving have the potential to improve the quality of life for both elders and their caregivers, through providing assurance of safety while the elderly carrying out daily activities, helping elders compensate for impairments to assist in the performance of daily activities, as well as assessing their cognitive status [1].

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Due to its identified importance, activity recognition has become a focal research area in assistive living over the past few decades. A vast amount of work has been reported in literature, ranging from recognizing simple actions such as sitting and walking [2, 3], recognizing activities of daily living [4, 5], to discovering patterns of activities [6, 7].

As human behavior is quite complicated, and human activities especially the ADLs (Activities of Daily Living) are usually performed in an indefinite manner in terms of their occurrence, duration and sequential relationship for a specific person in different periods, making it challenging to recognize ADLs using the probabilistic or statistical methods. Recent years have witnessed an increasing interest in finding patterns from recordings of human daily activities by applying data mining techniques. The spatio-temporal associations between different activities are frequently concerned to extract particular patterns that are used to directly recognize activities or indirectly support modeling activities.

Our objective, in this work, is a comprehensive model of individuals' activities that summarizes association patterns of procedural steps inside those long-term activities, and the ones between different activities. An association pattern is in fact the spatio-temporal constrain relation between components (i.e., steps or activities). With such a model consisting of associations on different levels of activities, elders with memory deficit mainly caused by dementia can be timely prompted with the upcoming steps or following activities when they perform daily routines independently. Based on which, activity recognition can be enabled to enhance independence or autonomy. To achieve this objective, we apply a data mining approach called *Apriori* [8] to extract frequent sequential patterns from sequences of spatio-temporal signatures (i.e., steps) inside each individual activity for intra-activity association patterns, and from sequences of individuals' routines consisting of activities for inter-activity association patterns. By aggregating these extracted intra- and inter-activity association patterns, a model that summarizes individual's daily routine can be obtained. To the best of our knowledge, this is the first work to investigate discovering both intra- and inter-activity patterns of elders' daily activities simultaneously.

The rest of this paper is structured as follows. Section 2 reviews related work. In Section 3, we present our proposed approach in detail. Experimental results conducted on two real individual datasets will be demonstrated in Section 4. Section 5 concludes this work and discusses the future research directions.

2 Related Work

This section reviews related work in the activity recognition field focusing on pattern-based approaches.

Rashidi et al. [9] investigated pattern-based approach for discovering and tracking activities in smart environment, their approach detects patterns in event sequences and chooses an interesting pattern from a group of similar patterns to represent an activity. Then a HMM-based model is used to predict activities. Chikhaoui et al. [6] proposed a model based on frequent pattern mining for activity recognition, by first extracting

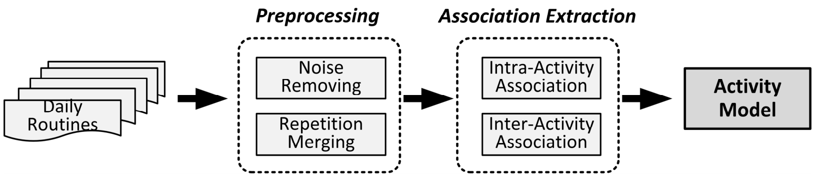

Fig. 1. Overview of the proposed method

frequent patterns from sequences and then applying a mapping function between the extracted patterns and those generated from activity models. In their recent work [10], an unsupervised model has been proposed to study relationship between activities and the sequential patterns extracted from the sequences. Activity discovery is formulated as optimization problem in which sequences are modeled as probability distributions over activities, as well as activities are, in turn, modeled as probability distributions over sequential patterns. The optimization problem is solved by maximization of the likelihood of activity data. Lymberopoulos et al. [7] presented an automated method for extracting the spatiotemporal activity model using wireless sensor network that is modeled as a source of spatiotemporal symbols. With the stream of symbols, authors formulated the problem of human activity modeling as a spatiotemporal pattern-matching problem and solved it using an exhaustive search algorithm.

Currently, topic model based approaches have also been used to recognize human activity. For instance, Huynh et al. [11] proposed a method to recognize daily routines by combining activity patterns, the authors utilized a supervised learning approach to generate and recognize a vocabulary of activities. The vocabulary is used by the topic models to learn and discover activity patterns, which are then used to recognize daily routines. A novel and different method for recognizing human ADLs is the emerging patterns based approach proposed by Gu et al. [12], in that activity models are built by mining a set of emerging patterns from the sequential activity traces using sliding windows, and these models can be used to recognize both sequential, interleaved and concurrent activities.

Differently, in this work, we explore to discover not only association patterns from sequences consisting of daily activities but also association patterns from procedural steps of those long-term activities. To the best our knowledge, this is the first work in assistive living research for elders.

3 Methodology

Fig. 1 shows the overall procedure of our proposed method. The original recordings of activities are first preprocessed to remove noisy data and then to merge repetitive sensor activations. The extraction procedure is used to extract low-level association of steps (i.e., intra-activity) and high-level association (i.e., inter-activity), by mining the frequent steps and activities, respectively. We will finally achieve a complex graph-like model that can perfectly summarize an elder's daily living.

3.1 Activity Data Preprocessing

From the hierarchical point of view, an individual's routine can be decomposed into a set of different activities, with each activity including varied quantity of sub-activities or activity steps (as depicted in Fig. 2). For a given period of time (e.g., one month or more), all the collected routines will constitute a dataset that is used to extract activity model. In our selected datasets, the activity steps directly connect to sensors that have been deployed in physical locations (e.g., motion detector in porch) or equipped on devices or instruments (e.g., faucets and cookers). Due to the randomness in human behavior, environmental noise and imperfect deployment of sensors, there will be two categories of sensing data in original recordings of activities which are required to be preprocessed before extracting hidden activity patterns.

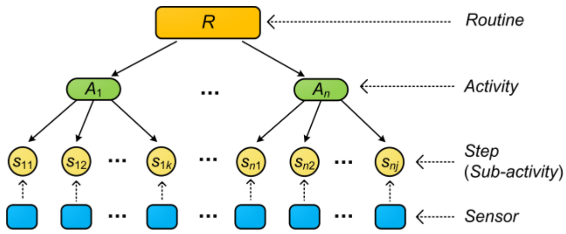

Fig. 2. A hierarchical organization of human activities

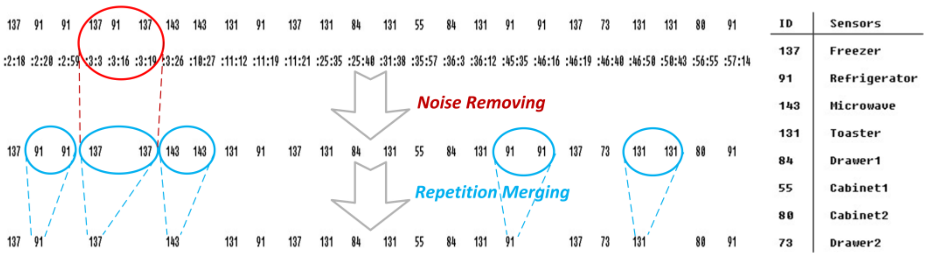

Fig. 3. An illustration of data preprocessing for '*Preparing Dinner*' activity

- Noisy data: referring to those sensor activations (or steps) which are clamped by two same neighbours and the duration to their right neighbors is less than the given threshold (5s in our experiments). For instance, as illustrated in Fig. 3, the *Sensor* #91 is activated after #137 and followed by #137 again, and the time difference between #91 (i.e., 19:3:16) and #137 (i.e., 19:3:19 for the last) is 3*s*. So, the activation of <#91, 19:3:16> should be identified as noisy data. In fact, it is only an invalid activation mainly caused by randomness of human behavior.
- Repetitive data: denoting those sensor activation like <#91, 19:2:20> or <#91, 19:2:29> in the original sequence of activities, and the sensor activation like <#137,19:3:3> or <#137, 19:3:19> in the noise-removed sequence as depicted in Fig. 3 with blue circles. In real life this kinds of activations may be the real steps of activities, but they are often disadvantageous to extract sequential patterns of activities if left unprocessed.

The data preprocessing is designed to first remove all noisy data in raw recordings of every activity, and then emerge all repetitive activations of sensors. After the above operations, we achieve a new sequence for each activity consisting of noise-removed and non-repetitive steps. For instance, the most bottom row in Fig. 3 represents the sequence which has been preprocessed. In this preprocessed sequence, all the noisy and repetitive activations have been removed.

Algorithm 1: Mining Frequent Sequential Pattern

Input: D — A dataset
f_{th} — Threshold constant of f_s
Output: F — A set for recording extracted frequent sequences
Procedure

```
F_1 ← Find all frequent sequences of size 1 according to f_th;
for i = 2 to n    // n = size(F_1)
    F_i ← Generate all sequences of size i from F_{i-1}
    W ← Find all frequent sequences of size i by mining D
    F_i ← W    // Update F_i with frequent sequences
    i ← i + 1
    F ← F ∪ F_i
end for
```

Fig. 4. The algorithm for extracting all frequent association patterns for dataset *D*

3.2 Extracting Intra- and Inter-activity Association Pattern

Given a dataset $D = \{A_1,A_2...,A_n\}$ including n different activities, where $A_i = <s_{i1},s_{i2},\ldots s_{ik}>$ is the i-th activity consisting of k steps and $s_{ij} = (\text{ID}_j,t_j)$ refers to the j-th step of the i-th activity, this section explores to discover association pattern between steps within an individual activity (e.g., A_i) and association pattern between activities inside given routine (i.e., D) by mining frequent sequential pattern on A_i and D, respectively.

A frequent sequential pattern is a sequence, all elements contained in this sequence are required to appear sequentially with a required frequency condition. Therefore, if $s = <a,b,c,d>$ is identified as a frequent sequential pattern, that: 1) individual element a, b, c, and d is frequent; 2) the dual $<a,b>$, $<b,c>$, and $<c,d>$ is frequent; and 3) the triple $<a,b,c>$ and $<b,c,d>$ is frequent. However, the remaining sub-sequences such as $<a,c>$ and $<a,c,d>$, whether they are frequent sequential patterns or not is completely decided by the selected dataset. The frequency of a sequence s is calculated according to Equation 1.

$$f_s = |D_s| \, / \, |D|. \tag{1}$$

where D_s is the set consisting of sequences that contain s, and D is the complete set.

Due to the fact that a frequent sequential pattern must contain one or more frequent sequential sub-patterns, we can therefore discover longest frequent sequential patterns in a given dataset via augmenting all frequent sequential sub-patterns according to the proposed mining algorithm as described in Algorithm 1. Particularly, when extract the association patterns of an individual activity (e.g., A_i) we initialize D using instances of this activity in Algorithm 1; when extract the association pattern of all activities we initialize D using all activity instances of R. A sequence F_i of length i is generated by adding elements in F_1 into F_{i-1} one at a time (line 3 in Algorithm 1).

4 Experimental Validation

This section validates the proposed method on two open datasets of activities [13].

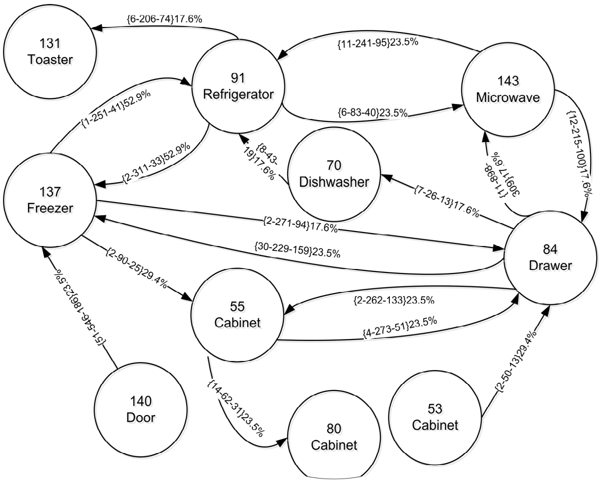

Fig. 5. Extracted association pattern of steps for Person 1's *Preparing Lunch* activity

4.1 Experimental Setup

Our selected datasets consist of a group of daily activities (more than 8 activities for each of the datasets) acquired from two elderly persons for a duration of 2-week. For sensing activity data, more than 75 data collection boards equipped with reed switch sensors were installed in two single-person apartments, the sensors were installed in everyday objects like refrigerators, drawers, containers, etc. to record opening-closing events as the subjects performed everyday activities.

4.2 Experimental Results

Fig. 5 shows the extracted association pattern of sub-activities (i.e., steps) for *Person 1*'s *Preparing Lunch* activity, in that the steps and the directions between these steps associated with this activity are illustrated. Specifically, the ID and sensor name in each circle represents the step of activity, and the direction from one step to another is described as {*min*-*max*-*avg*} X%, where *min*, *max* and *avg* denotes the minimal, the maximal, and the average duration between two steps, respectively, while X% is the transformation probability (i.e., frequency as defined in Equation 1) extracted from historical dataset. In addition to the association patterns of size 2, we also explore to extract longer ones associated with every activity. Table 1 summarizes the extracted association patterns with length more than 2 for *Doing laundry* activity of *Person* 1.

Table 1. All the longer patterns for Person 1's *Doing laundry* activity

Patterns of steps	Frequency (%)
(141) Door → (142) Washing Machine → (90) Laundry Dryer	15.70
(141) Door → (90) Laundry Dryer → (142) Washing Machine	21.00
(90) Laundry Dryer → (141) Door → (142) Washing Machine	31.50

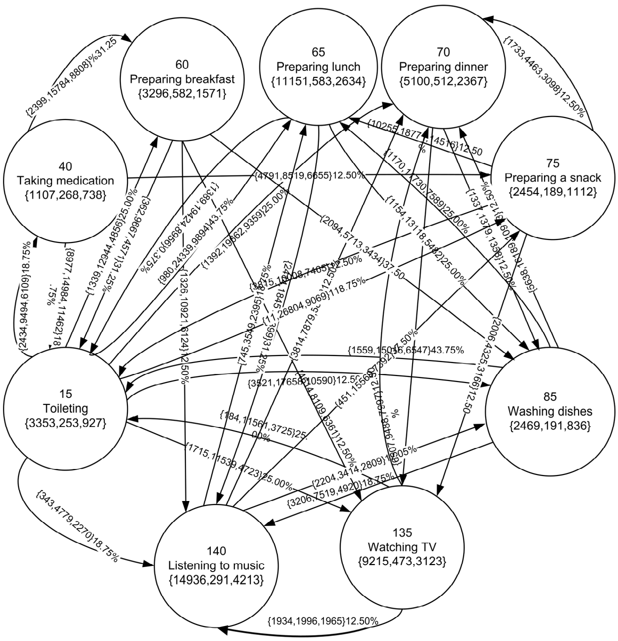

Fig. 6. Extracted association pattern of all activities for Person 2

Fig. 6 depicts the association patterns of all activities for Person 2. In this complex graph-like model, each activity is represented with activity ID, activity name, and its duration as form of {*max*, *avg*, *min*}. The transformation between any two activities is also indicated with duration information from one to another, as well as the frequency mined from individual's historical dataset.

Table 2. The extracted patterns with length of 2 from all activities of Person 2

Patterns of activities	Frequency (%)
Toileting→Preparing lunch→Listening to music→Washing dishes	12.50
Taking medication→Preparing breakfast→Toileting→Preparing lunch	12.50
Preparing breakfast→Toileting→Preparing lunch→Listening to music	12.50

Table 2 summarizes all the extracted patterns with length of 4. Limited to the small size of datasets (only two weeks), the extracted patterns have relatively low frequency, which are expected to be improved if there are more routines contained in individuals' historical datasets.

For a specific elder, we can obtain a comprehensive activity model by aggregating the extracted intra-activity association patterns as demonstrated in Fig. 5 and the inter-activity association patterns as shown in Fig. 6. Based on which, timely reminder can be enabled for those elders with impaired memory when they perform daily activities by prompting them with the upcoming steps or following activities.

5 Conclusion and Future Work

In this paper, we have proposed an approach that is able to extract intra- and inter-activity association patterns from individuals' historical datasets of daily activities by mining the frequent sequential sequences of steps and activities. The preprocessing of activity data and the approach for extracting association patterns has been presented. In the future, we plan to extend this work as follows: First, we collect large-scale data of activities based on an ongoing application system in our lab to verify and improve the proposed approach. Second, we develop real applications based on these extracted patterns to instruct elders with impaired memory for carrying out daily activities, and further refine this approach according to feedback from elderly users.

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A Wavelet Feature Based Mechanomyography Classification System for a Wearable Rehabilitation System for the Elderly

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Abstract. This paper proposes a pattern recognition based system for identification of the forearm movements using Mechanomyography(MMG) for the rehabilitation of the elderly. The system is used to assist in the relearning and rehabilitation of the movements of the wrist and the hand. Surface MMG signals acquired from the *flexor carpi ulnaris*, *brachioradialis supinator* and *abductor pollicis longus*. The MMG is processed and wavelet based features are extracted which are classified into eight different forearm movements using a multilayer perceptron (MLP) classifier. A classification efficiency of 90.2 % is achieved using the MLP classifier. The MMG system is designed to measure data using accelerometers built into the assistive device and, hence, doesn't require any active involvement of the elderly.

1 Introduction

With advancing age, the agility of the brain to process information that are critical for going about doing daily chores slows down, and as a result, persons affected lose their dexterity, reflexes and speed in performing simple day-to-day tasks. Rehabilitation is an essential component in the recovery and restoration of motor functions for the elderly. Motor practice consisting of simple, repetitive motions leads to a form of use-dependent plasticity that results in the brain rewiring its neurons and a re-organization of the motor pathways in the spinal cord and the motor cortex [1].

A robotic assistive system that guides the elderly in rehabilitation would not only be useful in performing repetitive exercises during rehabilitation but the elderly could also use it at their homes for their day-to-day activities. Such a system would require a control signal to actuate the motors and sensors to detect the initiation of the hand movement.

Though Electromyography (EMG) is usually used to monitor the muscle activity, there is valuable information in the mechanical index of the muscle dynamics. Skeletal muscles on contraction, emit low frequency vibrations that can be measured on the surface of the skin. These vibrations are generated as a resultant of the total lateral movement of the muscle at the start of a contraction, subsequent resonant frequency oscillations and physical changes in the active muscle fibers [2], [3], [4]. The EMG is a direct function of the neural activation and, thus, is affected greatly by ageing and injury. MMG being a function of the mechanical

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vibrations is less likely to be affected by ageing and injury and, hence, can play an active role in designing a pattern recognition system for rehabilitation of the elderly [5] with input of comparative data from a younger age group of healthy individuals.

MMG can have applications in control of upper limb prosthesis or body-machine interfaces if unique patterns can be identified for different movements [6],[7],[8]. A human assisting manipulator for amputees, using accelerometer sensors to measure MMG, was proposed in [9]. A probabilistic neural network was used for separation and estimating the information on force and motion from the measured MMG signals with high efficiency. A MMG based pattern recognition approach was proposed in [10] for classification of, hand open, hand close, wrist flexion and wrist extension, while using a single accelerometer for measuring the MMG at the *flexor carpi ulnaris* muscle. The authors used Principal Component Analysis (PCA) for reducing the dimension of the features and a Quadratic Discriminant classifier was used with an average accuracy of 79.66 %.

A description of MMG patterns is a critical step towards a better understanding of the mechanical activity of muscles during movement control. This paper focusses on isolating different patterns from the recorded MMG signals of the forearm muscle groups during hand and wrist movements using accelerometers, and classifying them for use in pattern recognition based assistive actuator systems. The advantage of using an accelerometer to measure the MMG is that, if placed properly, it can also measure the joint angle or orientation of the hand and, thus, eliminates the need to assign multiple sensors to do the same function.The MMG system is designed to measure data using accelerometers built into the assistive device and, hence, doesn't require any active involvement of the patient. Wavelet transform features [11] are extracted and a Multilayer Perceptron Classifier (MLP) is used to differentiate eight different forearm motions [12]. The block diagram of the whole system is shown in Fig. 1.

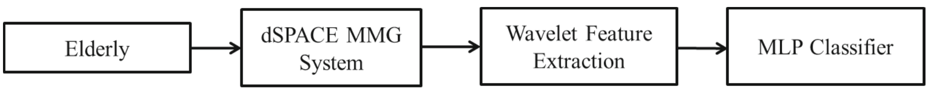

Fig. 1. Outline of the MMG Pattern Recognition System

The response time of the system is less than 300 ms so that the user does not perceive a delay between the intent of the action and its execution by the glove [13],[14]. Section 2 describes the MMG measurement and processing protocols. Section 3 outlines feature extraction and classification of the MMG signal. Section 4 lists out the experimental results and the final section outlines the conclusions and future work.

2 Measurement Protocol

Data was acquired from six able-bodied individuals, aged 23 ± 3 years. All subjects were healthy and reported no physical or mental disorders. Each subject had access to the full range of forearm motions and no previous history of musculoskeletal illness.

All subjects were instructed not to perform fatiguing upper limb exercise one day prior to the sessions. A custom dSPACE Graphical User Interface with a manual trigger was used to start data acquisition and visually cue participants to perform various classes of muscle activity corresponding to the following eight hand motions: hand open, hand close, wrist flexion, wrist extension, wrist pronation, wrist supination, wrist ulnar deviation and wrist radial deviation. The raw MMG signals at the three muscle sites *flexor carpi ulnaris*, *brachioradialis supinator*, and *abductor pollicis longus* for all of the hand motions in the study are shown in Fig. 2.

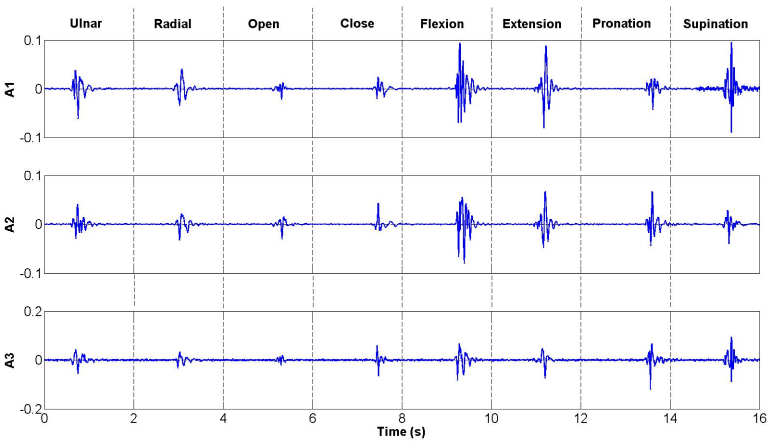

Fig. 2. The MMG signal at the three muscle sites for all the hand motions in this study

Subjects performed ten repetitions of each of the motions. Each motion was comprised of the full range of motion from the resting position to the final position, followed by 2 seconds of the hand being held in the final position. The measured and filtered surface MMG signals were stored and analysed on a PC using MATLAB software. Each channel of the MMG data was processed and analysed separately. The DC offset was removed by filtering the mean value in the MMG data while the 2nd order Butterworth high pass and low pass filters, with cut-off frequencies of 5 Hz and 100 Hz respectively, were applied to filter out the noise and motion artifacts including changes in forearm joint angles. The data sets were equally divided into a test set and a training set.

It can be observed from Fig. 2 that, each accelerometer channel has signal component present from different hand motions. This feature is exploited in designing the classifier system with lesser number of electrodes, as feature identification here is focussed on extracting unique features that isolate each of the different hand movements from the same three sites.

3 Feature Extraction and Classification

Different sets of features are extracted using wavelet transform for the analysis window of 500 ms with a moving window of 250 ms. A wavelet transform characterizes the signals locally in time domain in the analysis window and is useful for approximating non-stationary signals like MMG.

The level of wavelet decomposition (J) is chosen as 4, while the wavelet used is a Daubechies family wavelet '*db4*'. The detailed sub-space or the high frequency sub-patterns at each level of decomposition are represented by *D1, D2, D3, D4, D5* while A5 is the low frequency sub-pattern or the approximate subspace, and is the final level of decomposition.

The following features were defined for each of the detailed and approximation wavelets.

- Root Mean Square Value: Root mean square value of each wavelet in the time segment is defined as

$$W_{jk}^{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2} \quad (1)$$

  where x_i is the i_{th} sample of the j_{th} wavelet in the k_{th} time segment, containing N number of samples.
- Mean Absolute Value: The mean absolute value of the wavelet in the time segment is defined as

$$W_{jk}^{MAV} = \frac{1}{N}\sum_{i=1}^{N} |x_i| \quad (2)$$

- Shannon Entropy: The Shannon entropy of each wavelet in the time segment k is

$$W_{jk}^{H} = -\sum_{i=1}^{n} P(x_i) log_i(P(x_i)) \quad (3)$$

- Mean Frequency: The mean frequency component present in each wavelet is

$$W_{jk}^{MNF} = \frac{\sum x_i^2 f_i}{\sum x_i^2} \quad (4)$$

– Waveform Length: A feature which provides information on the wavelet amplitude, frequency and duration. It is the cumulative length of each wavelet over each analysis window.

$$W_{jk}^{WL_0} = \sum_{i=1}^{N} (x_i - x_{i-1}) \tag{5}$$

These features, extracted from the MMG signal constitute the feature set of five features per wavelet per channel. Thus, the total number of time-frequency features extracted for each hand motion is seventy-five for the three channels of MMG data and five wavelet coefficients.

The MMG is not consistent for different individuals for similar hand motions. Moreover, training an individual to use the glove would improve their motor skills resulting in variations in subsequent MMG recordings of the same muscle group. A classifier that is able to adapt to these variations in features for different individuals as well as accommodate each individual's MMG change over the course of time is required. A multilayer perceptron classifier(MLP) having two layers is used for pattern classification from the input vector. Every input layer neuron is connected to every hidden layer neuron and every hidden layer neuron is connected to every output layer neurons. A sigmoid function is chosen as the activation function for the hidden layer and a linear function is selected for the output layer.

The network is trained using the training MMG data set and then evaluated using the test set. The learning rate of the backpropagation algorithm is kept small to ensure long term adaptability to change in features.

4 Experimental Results

A set of wavelet features for the A4 wavelet of the MMG signal at the *flexor carpi ulnaris* is shown in Fig.3. The Shannon wavelet entropies in Fig. 3 of all the wavelet sub-patterns not only provide a boundary envelope for the signal movements but also varies according to the variations in each of them. The waveform length, RMS value, and the MAV along with the Shannon wavelet entropy can be used to distinguish not only the dynamic and the isometric components of the signal but also the different wrist movements.

The confusion matrix of the wavelet features for classification of the eight hand motions is given in Table 1 and the error in classification for the MLP classifier is given in Table 2.

– OBSERVATIONS
  - It can be inferred from Table 2 that the overall classification rate for the MLP classifier for using wavelet transform features is 90.2 %.
  - The wrist pronation is the most poorly classified motion with an efficiency of 81.7% as seen from Tables 1 and 2.
  - The next poorly classified motion is the wrist extension motion that has a classification rate of 91.7% as seen from Tables 1 and 2.

It can be concluded from the above observations that the wavelet feature based classifier can faithfully classify different hand motions using the MLP classifier.

Table 1. Confusion Matrix for the the MLP Classifier

Classified Motion	Actual Motion							
	I	II	III	IV	V	VI	VII	VIII
Wrist Flexion (I)	35	0	0	0	1	0	1	0
Wrist Extension (II)	0	33	0	0	0	0	0	2
Hand Close (III)	1	0	39	1	4	0	1	0
Hand Open (IV)	0	0	1	49	0	0	0	0
Wrist Pronation (V)	0	0	0	0	31	0	0	0
Wrist Supination (VI)	0	0	0	0	0	38	0	0
Wrist Ulnar Deviation (VII)	0	1	0	0	2	0	33	0
Wrist Radial Deviation (VIII)	0	2	0	0	0	0	1	33

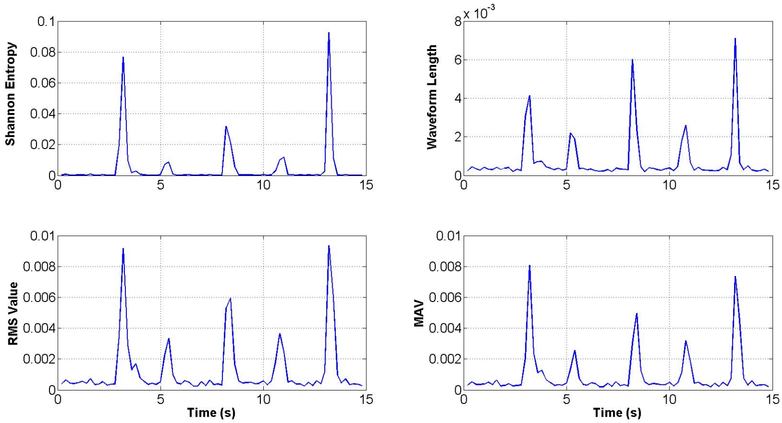

Fig. 3. Wavelet feature set for A4 wavelet MMG Signal at the *flexor carpi ulnaris* for hand open and close

Table 2. Error in Classification for the MLP classifier

Motion	**Error**
Wrist Flexion	0.027
Wrist Extension	0.083
Hand Close	0.025
Hand Open	0.020
Wrist Pronation	0.183
Wrist Supination	0.000
Wrist Ulnar Deviation	0.083
Wrist Radial Deviation	0.083
Total Error	0.098

5 Conclusion and Future Works

In this paper, a pattern classification based system is implemented for the classification of the forearm movements using MMG for the rehabilitation of the elderly. Three accelerometers are used for measuring the MMG from major forearm muscle sites. Features are extracted using wavelet transform and a MLP classifier is used to classify eight different forearm movements with a classification efficiency of 90.2 %. The classification rates for wrist pronation is the poorest at 81.7% while wrist ulnar deviation, wrist extension and wrist radial deviation have acceptable error of approximately 8.3 %. and is acceptable for a pattern recognition based MMG classification system. The overall high classification rate is due to the MLP classifying the wrist supination, hand open and wrist extension motions with better accuracies.

A moving window of 250 ms ensures that the processing time required by the algorithm for feature extraction and classification is well within the threshold of 300 ms for the user to perceive a delay in the initiation of the action while the measurement protocols ensure that the biosignals were broadly representative of that measured from the elderly.

Currently, only MMG sensors are used for classifying the different movements. A fusion of the EMG and MMG sensor data along with the angular data will be implemented in the future to not only eliminate the need to have a higher number of sensors but to also improve upon the classification of different hand movements and the torque prediction of different joints.

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Activity Recognition and Activity Level Estimation for Context-Based Prompting System of Mild Cognitive Impairment Patients

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Abstract. The number of elderly people, who are unable to live independently and need assistance due to cognitive impairment, will rise rapidly in the aging society. To assist the independent living of these individuals and decrease the caregiver burden have become an important public health concern in the future. Mild Cognitive Impairment (MCI) is an intermediate state between normal cognitive function and dementia. The symptoms of MCI include difficulty remembering recent events or recently acquired information, depression and anxiety. MCI also increases the fall risk and affects patients' social function and behavior. Sufficient physical activities can improve health of brain and reduce the risk of MCI. Since the context-aware computing technologies for assisting living have gained great popularity. We proposed a context-based activity prompting system to improve quality of life for MCI patients. The proposed system utilizes a smart phone as a sensor device to transmit sensing data to cloud server for activity recognition and activity level estimation, and uses context-based technique to provide activity prompting message to MCI patients. The activity prompting service supplies the activities self-management for MCI patients and helps them living independently. The system also provides real time fall detection mechanism to shorten the rescue time when accident happened. The experimental results have demonstrated that the proposed system achieves high accuracy on activity recognition and activity level estimation.

Keywords: activity recognition, activity level estimation, prompting system, mild cognitive impairment.

1 Introduction

Recently, the proportion of the elderly population relative to total people has increased in Taiwan. The number of elderly people, who are unable to live independently and need assistance due to cognitive impairment, will rise rapidly. To assist the independent living of these individuals and decrease the caregiver burden have become an important public health concern in an aging society. The assistive

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technologies that can support health care have the potential to improve the quality of life for both elderly adults and caregivers. Mild cognitive impairment (MCI) is an intermediate state between normal cognitive function and dementia. The prevalence of MCI in elderly people is between 10% and 22% and has higher rate to become dementia[1]. The symptoms of MCI include difficulty remembering recent events, lower processing speed and lack of insight into environmental dangers. Cognitive impairment also increases the fall risk and affects patients' social function and behavior, increasing medical cost and the burden of caregivers[2].

Sufficient physical activities can improve body health as well as brain health. Physical activities, especially exercise training, can increase physical function, cognitive function and reduce the incidence of MCI[3]. Regular exercise such as walking has multifarious health benefits in older adults and helps them maintain quality of life. However, physical inactivity rises with age. The proportion of physical inactivity adults above 60 years old is the highest in worldwide[4]. These may raise the odds of having MCI and deteriorate the quality of life of MCI patients. Obviously, it is becoming more important to increase physical activities of MCI patients.

Since the context-aware computing technologies for assisting living have gained great popularity, we proposed a context-based activity prompting system to improve quality of life for MCI patients. The proposed system utilizes a smart phone as a sensor and transmits sensing data to cloud server for activity recognition and activity level estimate, and uses context awareness technique to provide activity prompting services for MCI patients. The activity prompting service supplies the activities self-management for MCI patients to achieve sufficient physical activities and helps them living independently. The system also provides real-time fall detection function so as to shorten the rescue time when accident happened. In order to achieve these goals, activity and activity level are the basic information for the context-based prompting system. In this paper, we design an activity recognition mechanism and an activity-level estimation method by using smart phone as a sensor device. The experimental results have demonstrated that the proposed methods have high accurate and reliability for activity recognition and activity level estimation. Moreover, we integrate these methods to context-based prompting system for assisting independent living of MCI patients.

2 Related Work

Activity recognition technology using body mounted sensors automatically recognize different activities into real-time and continuous record. In health-related applications, activity recognition can be used to increase physical activity, improve the treatment and differential diagnosis of neurological and degenerative disorders and detect fall event as early as possible to shorten the rescue time[5]. Most approaches of activity recognition can be divided into multi-stage process. Firstly, the continuous signal of body-mounted sensor is divided into a number of small time segments by using time window selected technique. The fixed time window selected technique has been employed by most studies due to its simplicity. The small time segment, also called window, can extract one or more features to characterize the signal segment. The features are used to be the inputs of an activity classification algorithm. Then the classified result is associated an activity within each window. From our perspective, we find there are some activity recognition results does not accurate because smart phone is not a professional motion sensor. Therefore, we use an inference engine to refine activity classification results that improves the accuracy of activity recognition and activity level estimation.

Physical activity is defined as "bodily movement that is produced by the contraction of skeletal muscle and that substantially increases energy expenditure"[6]. Medical research measures physical activity as energy expenditure using metabolic equivalent of task (MET) as unit to quantify activity level. One MET is defined as 1 kcal/kg/hour. MET classification was not developed to determine precise energy cost of physical activity, but rather as an index of physical activity evaluation[6]. In recent researches, there are three type methodologies to estimate activity level[7]. The first is energy expenditure, using biochemical method to quantify energy cost of physical activity. This approach uses calorimetry or double labeled water to provide most accurate estimation. High cost is the limitation of this method. The second is questionnaires. This method has the advantage of being inexpensive and easy to apply in large scales. However, questionnaires are subjective and limit to subject recall. The last is motion sensor. It is inexpensive, objective, and suit for individual record. It is widely used and has great attention in recent years. The limitations of this method are technical problem (e.g. battery life) and friendly user surface.

3 Materials and Method

3.1 System Architecture

The hardware of the system is composed by a smart phone and a remote cloud server. The smart phone (HTC Desire A8181) has a tri-axial accelerometer as a motion sensor which is provided with a range of ±2 g and average sampling rate of 22 Hz. The operating system of smart phone is Android 2.2.2. Smart phone is wearied in the right front waist by using a mobile phone set, as shown in Fig. 1. Once the motion signals have been sensing, the smart phone will transmit raw data to remote cloud server through Internet. Then, the remote cloud server will start to recognize activity and estimate activity level.

The proposed mechanism includes five main steps which are signal preprocess, time window selection, feature extraction, classifier and inference. Activity recognition and activity level estimation use the same signal preprocess, time window size, and features extraction methods but difference in classification algorithm and inference rules. The raw data is acceleration value which contains gravity and body movement acceleration. In the signal preprocess, a low pass filter is used to separate gravity signal and body movement signal[8]. Then the proposed mechanism uses a window technique (time window size is 1 second) to separate both gravity and body movement signal segments. The gravity signal segments extract 2 features: orientation

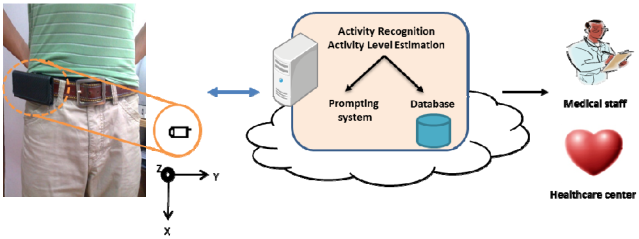

Fig. 1. System architecture

of x-axis and standard deviation. The body movement signal segments extract 10 features: signal magnitude vector (SVM), signal magnitude area (SMA)[8], maximum value of y- and z- axis, and the first three magnitude values and frequencies of fast Fourier transformation (FFT). These features are used to be the inputs of classification algorithm to classify an activity and an activity level.

3.2 Activity Recognition

The proposed activity categories and corresponding activity levels are defined in Table 1. In these pre-defined activities, slow motion activity means a person is not static but move slowly or not sitting quietly. Body transition means the transition between sitting to standing, lying to sitting and in versa. The activity recognition classifier is a threshold-based algorithm which is designed base on experimental observation and related works. The classification process schematic diagram is shown as Fig. 2. After finish activity classification process, the associated features and classification result of each window can be used to inference the activity of next window by setting inference rules to get more accurate classification result. For example, if a person from standing to lying very quickly and the y-axis acceleration value is large, it can be recognized as fall. To fulfill the requirement of real-time system, inference engine is triggered when the results of near window are abnormal.

Table 1. Activity category and corresponding activity level

No.	Activity	Activity Level
1	Lying	Sedentary
2	Sitting	Sedentary
3	Standing	Sedentary
4	Slow motion activity	Light
5	Walking (2 – 4 km/h)	Light
6	Walking fast (5 – 8 km/h)	Moderate: 5 – 6 km/h Vigorous: 7 – 8 km/h
7	Running (6 – 9 km/h)	Vigorous: 6 – 8 km/h Very vigorous: 9+ km/h
8	Body transition	Light
9	Fall	Not defined

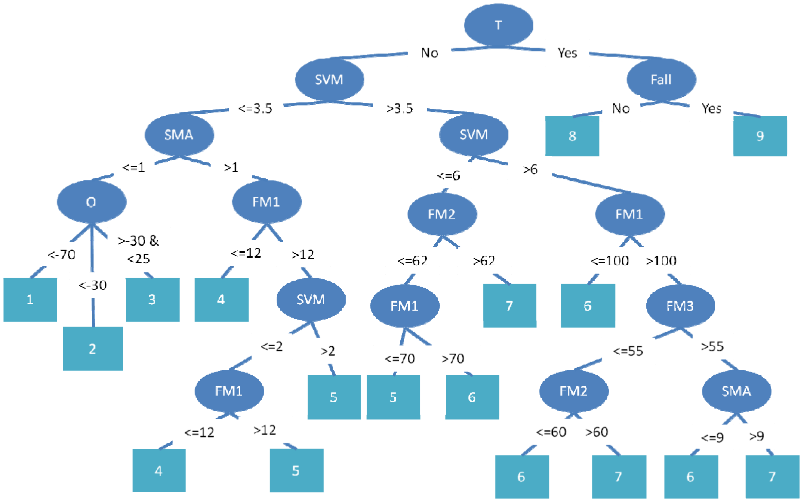

Fig. 2. A threshold-based activity recognition algorithm. T is standard deviation, SVM is signal magnitude vector; SMA is signal magnitude area; O is orientation of x-axis; FM1, FM2, and FM3 is the first to third magnitude value of FFT; 1-9 is the No. of activity category in Table 1.

3.3 Activity Level Estimation

The classification of activity level intensity is based on compendium of physical activity. Lying, sitting, and standing are sedentary level activity. Slow motion activity is near static but move slowly; therefore it is defined as light level activity. Body transition usually transits not quickly, especially in elders. Body transition is defined as light level activity. Fall is a special activity pattern and does not be defined any activity level. The activity level estimation classifier is a threshold-based algorithm and schematic diagram is shown as Fig. 3. After completing the classification process, the results can also be refined by inference rules. Because activity level is hard to inference from previous results, it should depend on the ultimate results of activity recognition. If activity reclassify is occurred, activity level will be reclassified.

3.4 Prompting System Diagram

Since MCI patients is hard to remember recent events or recently acquired information. They may not know what exercise and activity level they have done before. They may lack of exercise and deteriorate cognitive function. Consequently, a reminder system can remind them to finish the rest of exercise and fulfill the goal of exercise plane. Activity and activity level are the input of a prompting system which offers the information what user has done before. A schedule or exercise plane is another input of prompting system. Compared these two input, the prompting system can decide which related message need to inform the user, helping them to complete the preset goal.

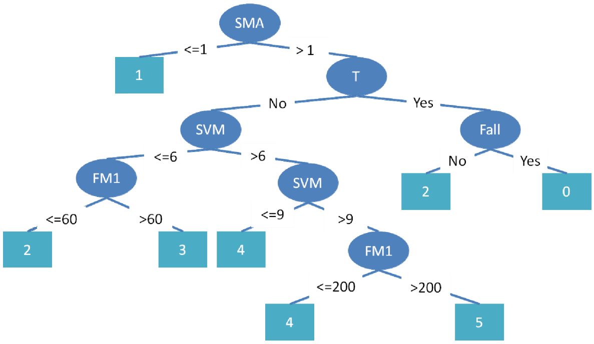

Fig. 3. A threshold-based activity level estimation algorithm. T is standard deviation, SVM is signal magnitude vector; SMA is signal magnitude area; FM1is the first magnitude value of FFT; 1-5 is activity level intensity, 1for sedentary and 5 is very vigorous, 0 for not defined.

3.5 Experiment Procedure

A set of experiments were designed to test the accuracy of the activity and activity level classification. The laboratory-based tests were performed with 3 health subjects (age: 23±1, height: 176.3±1.6, BMI: 22.75±2.2), with each performing a set of 15 different tasks as describe in Table 2. The task of walking, fast-walking and running was performed in the running machine with different velocity.

Table 2. Experiment tasks

Task	Description	Duration(s)
Sit-to-stand	From initially seated position to stand up and remains standing.	10
Stand-to-sit	From initially standing position to sit down and remains seated.	10
Stand-to-sit-to-lying	From initially standing to sit down on bed slowly and then lying.	10
Lying-to-sit-to-stand	From initially lying to seated on bed slowly, then stand up and remain standing.	10
Stand-to-fall	Standing for a while then fall onto bed	10
Stand-to-fall with knee first contact	From initially standing position then falling forward onto bed with knee first contact to bed.	10
Sit-to-fall backward	Initially standing then falling backward onto bed when sitting down.	10
Sit-to-stand and walking	From initially seated to stand up, then walks with normal speed for 15 m, then sit down to chair.	15
Walking-to-fall	Walks for 15 m and then fall onto bed.	20
Running-to fall	Runs for 15 m and then fall onto bed.	20
Walking-to-fast-walking	Walking to fast-walking on running machine from 1 km/h to 8 km/h, each velocity remains 50 seconds.	400
Running	Running on running machine from 6 km/h to 9 km/h, each velocity remains 50 seconds.	200

4 Results and Discussion

The results of activity recognition and activity level estimation are shown in Table 3. The experimental results show that the proposed mechanism provides high accuracy of activity recognition and activity level estimation. Basically, the accuracy of activity recognition is higher than activity level estimation. From the observation of the running task, the wearing clothes and shoes, and exercise habits may affect the activity level estimation obviously. Moreover, the differential acceleration signal can be found between subjects when the velocity of running machine is higher. The selected window size can influence classification accuracy. The features from divided signal segment may "just" lower or higher than the threshold of the classification algorithm. It may affect the accuracy of the activity recognition and activity-level estimation results. By setting logic inference rules to refine these error can decrease misclassification probability.

Table 3. The results of activity recognition and activity level

Task	Total(s)	Incorrect(s) of activity recognition	Accuracy(%) of activity recognition	Incorrect(s) of activity level estimation	Accuracy(%) of activity level estimation
Sit-to-stand	30	1	96.7	0	100
Stand-to-sit	30	1	96.7	0	100
Stand-to-sit-to-lying	30	4	86.7	2	93.3
Lying-to-sit-to-stand	30	2	93.3	1	96.7
Stand-to-fall	30	2	93.3	1	96.7
Stand-to-fall with knee first contact	30	0	100	0	100
Sit-to-fall back	30	0	100	2	93.3
Sit-to-stand and walking	45	5	88.9	0	100
Walking-to-fall	60	3	95	3	90
Running-to fall	60	0	100	1	96.7
Walking-to-fast-walking	1200	109	90.9	156	87
Running	600	12	98	173	71.2

5 Conclusion

In this paper, an activity recognition and activity level estimation method for context-based prompting system of MCI patients was developed. The proposed system uses an embedded tri-axial accelerometer in smart phone as motion sensor worn in the right front waist and transmits sensing data to cloud server through Internet for activity recognition and activity level estimation. The classification results can be refined by setting a logic inference rule. Our preliminary experiment results have demonstrated that the proposed mechanism achieves high accuracy of activity recognition and activity-level estimation and provides the feasibility of system implementation. We will deploy the proposed system in real world and the results will be reported in future occasions.

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Behavior Recognition for Elderly People in Large-Scale Deployment

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Abstract. Behavior recognition through ambient assisted living solutions for elderly people represents an ambitious challenge for actimetry. Numerous and versatile solutions have been deployed. However, a commercial adoption is still pending, due to scalability and acceptability constraints. Most research in Ambient Assisted Living (AAL) appears to have a heavy design, where precise features are first selected, and hardware architecture is designed accordingly. Although it may provide interesting results, such approach leads to a lack of scalability. This is why we experimented a lighter approach for a real deployment. The complexity is shifted from hardware to software, and we aim to make meaningful information emerge from simple and generic sensor data, in order to recognize abnormal and dangerous situations. In this paper, we will describe how to retrieve consistent information, so that residents' behaviors may be observed. This work might serve as a proof of concept that a light and generic approach fits in large scale deployments, with acceptable cost and scalability.

Keywords: Ambient Assisted Living, Human Abnormal Activity Detection, Sensor Deployment, Actimetry, Context Awareness.

1 Introduction

As population is getting older, concerns are raised about eldercare [9]. For various reasons, many families are not able to support their elders, and nursing houses are not the first choice for most of them. A reasonable solution for elders and their family is to let them be independent, at their own home. However, residents suffering from mild dementia are subjects to dangerous situations. Even though these residents may be supported by caregivers, they remain vulnerable during their absence. In this context, Ambient Assisted Living (AAL) systems are used to provide useful healthcare services for elderly people with continued

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supervision. An interesting feature would be to detect abnormal behaviors, such as falling or running away, in order to notify caregivers. Many prototypes of smart spaces have been realized, however, only few of them involve long-term deployments in real conditions [8].

AAL requires context awareness, handled by deducing situational information from a datastream of sensor events [6]. It also requires the introduction of a formal unit for measurement of the amount of activity, as it can be defined through actimetry [5]. In most deployments, the system is expected to detect precise situations, such as "open the fridge", "watch TV", etc. [10,2]. For this level of actimetry, specific sensors are required on numerals objects, and algorithms observe the emerging patterns in those sensor data to deduce activities. Such approach may be relevant for specific applications, e.g. medical treatments [1] or ergonomic studies.

However, the goal of our research is to detect high-level abnormal behaviors, like falling or running away, as well as sleep disorders or changes in life rhythm. The major constraint lies less in the coarseness of data than in the adaptability of deployment in several houses. Therefore, a complete and adaptive coverage on residents' house is difficult to be performed with a fine-grained and complex hardware deployment. Therefore we have chosen to perform behavior detection from a low-cost and scalable deployment, which is our key differentiator from the state of the art.

2 A Design for Large-Scale Deployment

A large-scale deployment requires simple and generic sensors to be installed, rather than sensors attached to specific objects. The purpose being to make as many information as possible emerge from the deployment of simple sensors. It may appear like a blind approach, because sensors are deployed before developing reasoning algorithms. However, features such as "fall detection" are set as requirements first to guide a selection of sensors. This paradigm is interesting for industrial deployments, as it requires neither upstream calibration nor prior knowledge of the environment.

In order to work on AAL, we need real deployments, that provide real data and feedbacks. These deployments take place through the Quality of Life project, focusing on elderly people with mild dementia, who live independently, but receive daily help from a caregiver. Currently, our platform has been deployed in three houses, generating two months of data, and target up to five hundred houses within five years. Each house contains motion sensors in each room. As an input for algorithms, sensor will send "1" when it detects a movement, or "0" after it did not detect any movement for one minute. In each house, we detect an average of 800 events per day. We aim to develop algorithms to detect risks in residents' behaviors, but it is also interesting to perform life logging in order to detect residents' shifts of habits as an important clinical information.

To ensure the relevance of the detected risks, the data analyzed will then be sent to a call center, and monitored by a human supervisor. In case a dangerous behavior is detected by the system, the supervisor will receive an alert. He will then call the resident to check on his safety. In case the resident does not pick up the phone, the supervisor considers the alert relevant and notifies a caregiver or the family. As our project is dealing with the health of people, it would be irresponsible to leave the control solely to a computer system. This is why a human supervisor has to be placed at the end of the line, to keep under control the errors in the reasoning. However, the data processing is still necessary in order to improve the accuracy of the supervisor.

3 Statistical Analysis of Actimetry

3.1 Input Data

The system receives several unrelated data as input, and provides consistent information as output. The selection and calibration of inputs have a major influence on algorithms. Therefore, before running the algorithms themselves, we need to pay a particular attention on input data.

Reducing the deployment costs is a challenge, we have experimented a deployment with low-cost motion sensors, however, when looking at the data, these appeared to have failures, and data is not totally consistent. Noise in data comes from sensor failures, but also from unpredictable events, such as motion sensors triggered by a pet. Hence, the ground truth is not entirely reliable, and we have to deal with the uncertainty in the data. Some solutions involve changes in the hardware design, e.g. sensor collaboration [7], but in order to keep our hardware architecture simple, we have chosen to deal with uncertainty from the software side, and are currently experimenting Dempster-Shafer algorithm [3].

3.2 Data Treatment

In deployment, we receive a sequence of signals, each of them notifies an event in a room at a specific time. Signals are defined as a triple $< time; location; signal >$. In Fig. 1, we receive data from sensors in Location 1 and Location 2, over 900 seconds. This format is useful for data transmission, but too raw to be processed.

$$\begin{array}{l} \\ \text{Location} \\ \text{Signal} \end{array} \begin{array}{cccccccccccccccc} t_0 & t_{15} & t_{40} & t_{45} & t_{60} & t_{120} & t_{130} & t_{190} & t_{510} & t_{540} & t_{720} & t_{720} & t_{780} & t_{840} & t_{860} & t_{900} \end{array} \atop \begin{pmatrix} 1 & 2 & 1 & 2 & 2 & 1 & 2 & 1 & 2 & 2 & 1 & 2 & 2 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \end{pmatrix}$$

Fig. 1. Initial data stream

First, we split this sequence by location so that each location gets a vector with sequence of pairs $< time; signal >$ (Fig. 2).

$$\text{L1: } \overset{\begin{array}{cccccccc} t_0 & t_{40} & t_{120} & t_{190} & t_{720} & t_{840} & t_{860} & t_{900} \end{array}}{\begin{pmatrix} 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \end{pmatrix}} \quad \text{L2: } \overset{\begin{array}{cccccccc} t_{15} & t_{45} & t_{60} & t_{130} & t_{510} & t_{540} & t_{720} & t_{780} \end{array}}{\begin{pmatrix} 0 & 1 & 1 & 1 & 0 & 0 & 1 & 0 \end{pmatrix}}$$

Fig. 2. Data vectors by location

The second step consists in making events as a $i \times j$ matrix, where i is the location, and j the time. $M[x, y]$ shows the status $\{1, 0\}$ at time y, in location x.

We retrieve every event time from each room, and sort the union of them. When a location l contains an event e at time t, then $M[l, t] = e$. We obtain a partially filled matrix, so we need to extrapolate signals (Fig. 3). For each line of this matrix (each location), we apply the Last Observation Carried Forward (LOCF) algorithm [11], to fill the blank with last observation.

	t_0	t_{15}	t_{40}	t_{45}	t_{60}	t_{120}	t_{130}	t_{190}	t_{510}	t_{540}	t_{720}	t_{780}	t_{840}	t_{860}	t_{900}
Location1	*1*	1	*1*	1	1	*0*	0	*1*	1	1	*0*	0	*1*	*0*	*0*
Location2	?	*0*	0	*1*	*1*	1	*1*	1	*0*	*0*	*1*	*0*	0	0	0

Fig. 3. Binary situational vector of the house

The next treatment is the most meaningful. Indeed, when a data value is 0, the resident may either be absent, or be present but immobile. So, rather than binary signals, we would like to have Absent/Immobile/Movement signals (A/I/M). To infer such information, with reliable and reasonably complex algorithms, we apply several rules to each element of the matrix. First, when sensor sends "1", it means we have a Movement. Then, when it sends "0", if the resident is in another room, we consider he is Absent from the current room. However, if sensor sends "0" and the resident is not currently seen in another room, we search where he has last moved: if he was previously in the current room, we consider he is still there and Immobile; otherwise, we consider he is Absent from the current room.

	t_0	t_{15}	t_{40}	t_{45}	t_{60}	t_{120}	t_{130}	t_{190}	t_{510}	t_{540}	t_{720}	t_{780}	t_{840}	t_{860}	t_{900}
Location1	*M*	*M*	*M*	*M*	*M*	*A*	*A*	*M*	*M*	*M*	*A*	*A*	*M*	*I*	*I*
Location2	?	*A*	*A*	*M*	*M*	*M*	*M*	*M*	*A*	*A*	*M*	*I*	*A*	*A*	*A*

Fig. 4. Situational vector of the house, handling Presence and Absence

Finally, we want to detect when the resident is not alone as this situation should be handled differently. Indeed, although multiuser is harder to handle than single user in terms of context understanding, this is not an issue since we can consider that the resident is in company of a caregiver or family who is taking care of him. Hence, the system has no need to process the alerts anymore. Detecting multiuser is quite easy as we simply need to check whether more than one location shows a presence (Immobile or Movement). However, when the resident is moving from Location A to Location B, there is always a delay when Location A has not yet sent 0, and location B already sent 1. Multiuser will be triggered only if it is still detected after this delay. From our sequence, with a delay defined as 60 seconds, we observe two occurrences of multiuser (Fig. 5).

	t_0	t_{15}	t_{40}	t_{45}	t_{60}	t_{120}	t_{130}	t_{190}	t_{510}	t_{540}	t_{720}	t_{780}	t_{840}	t_{860}	t_{900}
MultiUser	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0

Fig. 5. Situational vector of the house, with multiuser detection

As the statistical analysis of data performs best on data with regular time granularity, we may also want to get a matrix of the situation at regular time intervals. To perform this transformation, we will again use the LOCF algorithm. First, we need to define the time vector, with a regular interval, for example 60 seconds. We then place all existing data of the original matrix into the new matrix at the closest time sequence. In case several events would go to one element, for instance t_{840} and t_{860}, we need to reduce them to the most significant, so we decided to keep the maximum, considering $M > I > A >?$. However, such case implies a loss of data, thus we must therefore be careful of not using an interval too loose compared to some densities of events. Finally, because we are facing a partially filled matrix, we apply the LOCF algorithm to fill the blanks. We regularized our sequence with an interval of 60 seconds and present the result in Fig. 6.

	t_0	t_{60}	t_{120}	t_{180}	t_{240}	t_{300}	t_{360}	t_{420}	t_{480}	t_{540}	t_{600}	t_{660}	t_{720}	t_{780}	t_{840}	t_{900}
Location1	M	M	A	M	M	M	M	M	M	M	M	M	A	A	M	I
Location2	M	M	M	M	M	M	M	M	A	A	A	A	M	I	A	A
MultiUser	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0

Fig. 6. Situational vector of the house at regular intervals of 60 seconds

3.3 Statistical Methods

From previous treatments, we performed a clean vectorization of data, we can now use these vectors to perform a statistical analysis. The first application of statistics for risk detection is to observe variation from routine. When the resident's behavior is too different from his daily routine, we may suspect an alert.

To perform such analysis, we observe the routine on a period of two weeks. Over this period, we perform the processing previously described, and then we calculate the average amount of activity for each 20 seconds times of the day. We consequently obtain an average routine day from 00:00:00 to 23:59:40.

Finally, we analyze one specific day and compute the difference in each room between the expected behavior and the actual behavior of the resident. We also compute the total difference as an indication on how close the resident is from his routine.

4 Results

4.1 Abnormality Detection

From our deployment under the Quality of Life project, we gathered two months of data for three families. Each resident generated an average of 800 events per

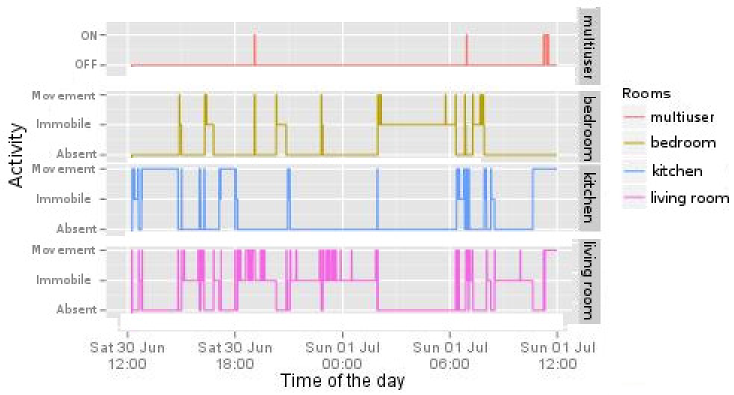

Fig. 7. Graph generated with data analysis algorithms

day. We then applied previously described algorithms, using these data as input. The resulting Fig. 7 contains several meaningful informations, and we may for example observe the night of the resident, between 0:00 and 6:00. We also observe that he spends most of his day in the living room, although he has lunch around 13:00 and probably a dinner at 17:00. When looking at it a human can infer basic life activities and notify major issues.

The following graph in Fig. 8 shows the variation in the resident's behavior within a day, compared to his daily routine.

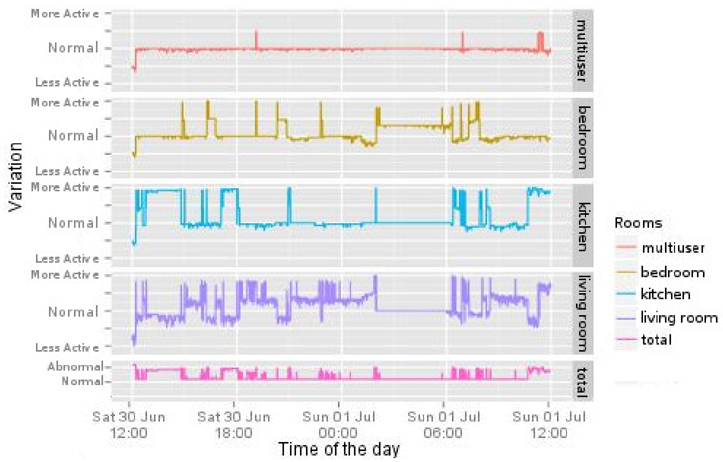

Fig. 8. Statistical analysis of the variation of one specific day over normal routine

If for one room the line is around "Normal", it means than the resident is having a normal behavior, according to his routine. However, a line below "Normal" means that the resident is less active than he usually is at this time, and a line above "Normal" means that he is more active than expected. The graph named "Total" represents the average distance between the resident's behavior and his daily routine in the whole house.

From this graph, we observe that the resident has a regular sleeping rhythm since his night is considered normal. However, his meals generate an abnormal behavior in the kitchen, implying this is not part of his daily routine. More generally, almost every behaviors from the resident are considered as abnormal, as they do not fit the routine.

4.2 Discussions and Perspectives

Our conclusion facing this graph is that a special attention must be payed when we determine a routine. Indeed, an inaccurate routine leads to a bad classification between normal and abnormal behavior. Routine-based statistical analysis first appears to be error-intolerant, but we may highlight the importance of the time granularity in the accuracy of the result. A granularity of 20 minutes would probably provide more error-tolerant results than this granularity of 20 seconds. In that case, processing would need to be adapted, looking for the average of movement on each interval, instead of the maximum level of movement withing each interval as it is currently. Our current results based on a fine-grained time granularity may be useful as an alert filtering, to highlight potential risk. When the resident's behavior fits with calculated routine, we may reasonably consider there is no alert.

Moreover, Hidden Markov Model (HMM) appears as a promising method to make pattern emerge from data [4]. HMM are error-tolerant, and provide results in terms of probability, so that the supervisor would have reliable indicators for detecting alerts.

So far, most observation has been performed on large periods of time, to perform life logging. It would then be interesting to observe shorter periods of time, in order to detect more precise and critical behaviors and events, such as falls.

5 Conclusion

The Quality of Life project demonstrates the validity of a light approach for the deployment of AAL solutions. So far, we detect the presence of resident and multiuser situations from the data provided by motion sensors, so that a human supervisor is able to manually detect activities.

Stating that one is able to detect activities from simple sensor data is a proof of concept. It lets us suppose the existence of patterns in human movements, correlated with daily activities, and visible through actimetry. Such statement is positive for the potential technology transfer of AAL solutions into mainstream eldercare, since simple and low-cost hardware appears to be reliable enough for large-scale deployment. By transferring complexity from hardware to software processing, we provide a scalable and reusable design for AAL solutions. From this statement, we now need to provide automated risk detection, through behavior recognition algorithms.

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Towards a Context Aware Modeling of Trust and Access Control Based on the User Behavior and Capabilities

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Abstract. During the last decade, several context based security models has been proposed to take into account the user behavior aspect. However the studied context is mainly related to device and spatio-temporal features, which may led to a weak and inappropriate contextual modeling. By using the huge and various contextual data issued from the sensors deployed in smart environments, our objective is to provide a security framework suitable for dependant people. This paper shows our approach to model both trust and access control based on the deduced user behavior and capabilities.

Keywords: Smart environment, trust evaluation, authentication, access control, device usability, user behavior, user capability, context awareness.

1 Context, Motivations and Challenges

1.1 Security in Smart Environments

Pervasive systems contribute significantly to the deployment of personalized services in smart environments. When considering dependant users within their living spaces, security requirements still remain an open issue.

While pervasive environments raise new security challenges, they also bring new opportunities owing to ubiquitous technologies and ambient intelligence which provide valuable contextual information about the user and his environment.

Authentication and access control are the main security services which are required to check the identity of users and to grant access to the resources they need.

Context-aware based security is an emerging approach to deal with the new security problems introduced by the high dynamicity and heterogeneity of mobile devices that characterize pervasive and highly dynamic computing environments.

We believe that this can be really achieved owing to context awareness which allow us to benefit from sensing and mobile technologies to derive more accurate contextual data about the user profile and his environment.

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1.2 User Authentication Devices

Usually the adoption of authentication devices relies on three factors [1]: effectiveness, cost and user acceptance. An underlying constraint of most existing authentication techniques is that they require the user to actively do something in order to be authenticated. When these devices are used by physical or mental impaired people, we have to consider two important additional factors:

• Usability: the ease with which people can interact with any device/technology.

• Non Intrusiveness: use in a discrete and transparent manner without any inconvenience for the user.

The various impacts of several different disabilities on the security and usability of many existing authentication means have been demonstrated in [2]. In some situations the authentication device can be considered as intrusive, and it is therefore desirable to have methods that may be applied transparently, without the need to interrupt with legitimate user activities. By using the anatomy of human head and the dynamics of human voice, the Head Authentication Technique (HAT) proposed in [3] is a non intrusive biometric technique to provide a continuous and transparent authentication.

Despite the huge previous research work, the problem of achieving adequate and effective user authentication still remains an ongoing challenge. Among the range of authentication techniques (based on secret knowledge, token or biometrics), no single method can be considered as applicable to all contexts and for all. Furthermore, the authentication process is mainly based on the provision of some credentials (PIN codes, passwords and even biometric templates) which can be forged or replayed and by the way is exposed to potential spoofing attacks.

Recently, a new approach has been emerged by using the behavioral features of users. A feasibility of having such authentication was studied by Al-Khazzar [4] who proposed an approach based on psychological mechanisms through a 3D graphical maze. A user authentication on mobile devices based on User's behavior and spatio-temporal context was adopted by Rocha [5]. A user behavioral model based on activities, environmental contexts, and user profile is proposed by Lima [6]. The continuous authentication system using behavioral analysis of users, proposed by Brosso [7] is built using the evidences of behavior to establish trust levels for a continuous authentication of the user during the application software.

2 Our Context Aware Framework

A pervasive environment is characterized by a richness of contexts in which users, devices and agents are mobile. The availability of contextual data provided by sensors can be used to extract behavior patterns of the mobile entities (users, devices, agents). Context awareness can bring a valuable help to understand the relation between users, devices and environments. Owing to the big range and variety of sensors deployed, the pervasive space can provide a very rich and valuable information set which can be used to derive the "dynamic profile" of users (social relationship and user behavior).

By combining the dynamic profile with the user capabilities, our research strategy is motivated by the following challenging tasks:

1°) to identify users discreetly and transparently,
2°) to provide an adaptable service of users based on their capabilities and behavior to ensure more personalization and suitable security.

The objective of our approach is the design and implementation of a context aware framework illustrated in Figure 1.

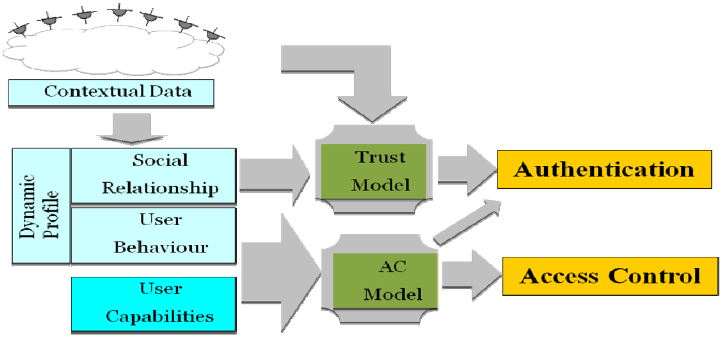

Fig. 1. Our Context Aware framework

The contextual data collected from sensors are used to derive user behavior patterns which will contribute to set up an implicit authentication process without using any intrusive device (Figure 2).

By the way, the user behavior can be combined with the user capabilities to build a dynamic trust and access control models.

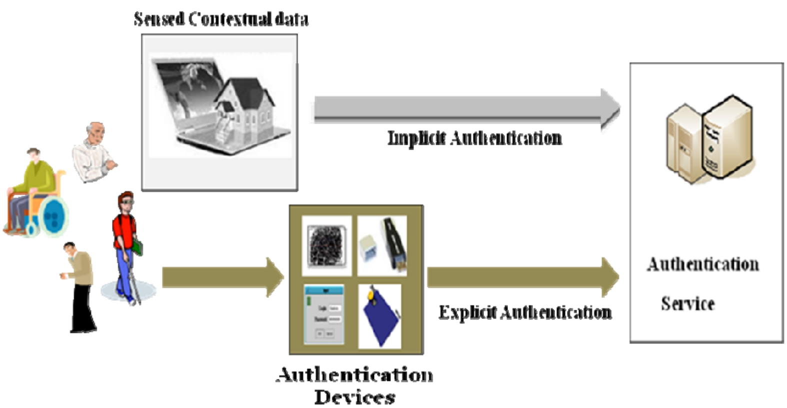

Fig. 2. A transparent authentication process

2.1 Contextual Trust

The contextual data open new opportunities for the establishment of trust relations between communicating entities. Trust models based on user abilities, user behavior, user preferences and contextual factors must be explored to improve trust models.

The recent literature brings some interesting ideas going towards the new vision of trust modeling and its contribution to built new context aware security frameworks. To handle the dynamic and variable nature relationships in pervasive environments, some new properties of trust were considered in [8]. Boukerche et al. proposed a novel trust evaluation prototype in which the updating process of trust value relies on the cooperation level of nodes. Honest behavior will be rewarded while malicious behavior will be penalized [9]. According to Tanveer Zia et al, the recent trust models migrate from a single dimension to multi-dimension trust calculation models by merging the history, the experience and the context of related entities [10]. The given review of trust models show that some basic elements of context such as time and context similarity are considered. However none of the existing works gives a common and unified consideration on all factors that influence the trust.

We have proposed a context-aware trust model based on user behavior by taking into consideration both the user profiles and context attributes [11]. We introduced a protection against the malicious threats affecting the trust evaluation process. We also improved the accuracy of trust metrics based on the right human behavior in situations that require trust.

2.2 Contextual Access Control

For pervasive systems, the access control is handled by the development of context aware based access control models which rely on context data to assign the permission to the users (roles) in the right situation which makes the model dynamic according to the change of context over the time. Extended Role Based Access Control (RBAC) models [12] are based on context awareness. Their aim is to improve RBAC by assigning the right access more dynamically. The access is based on the validity of the context by adding to RBAC a single contextual data which is spatial, temporal or environmental [13, 14, 15]. According to our literature review the current access control policies don't take into account the user impairments nor the behavior of users.

We have proposed a context-aware access control model based on user behavior and capabilities [16]. The model is based on ontology learning, enriching and evolution which support continuous learning of behavior and capability patterns.

3 Trust Modeling

The main features of our proposed trust model [11] are given below:

- It combines many of the good features presented in other models, like trust recommendations and the idea of trust distribution, and trust per service concept;

- It was essentially made for mobile devices with limited resources, which means it requires less overhead and uses less bandwidth;
- It combines the concept of trust evaluation and risk assessment,
- It ensures preserving the privacy of the users and devices, without disclosing personal information about users, like time of usage and location;
- It introduces the new concept of Judgment;
- It deploys a new scheme to detect any abnormal behavior of the nodes,
- It can provide different levels of trust based on requested services.

3.1 Trustworthiness

The calculation of a trustworthiness value includes the direct trust and the indirect trust. Direct trust is what is commonly called "Risk Assessment". It is used for dealing with newcomers which the entity has not yet any past records of trust evaluation. In case where trust is service-dependent, we added a multiplicative factor to the number of negative actions. This factor is called the Security Action Coefficient (***SAC***). This coefficient refers to the security level of a service.

Direct trust is obtained using:

$$DT = \frac{\Sigma PA_i}{\Sigma PA_i + SAC \times \Sigma NA_i} .$$

$\boldsymbol{PA_i}$ is the number of positive actions done by the given node and noticed by node $\boldsymbol{i}$. $\boldsymbol{NA_i}$ refers to the number of negative actions.

The indirect trust is given by: $IT = \frac{\Sigma Tw_i \times J_i}{n}$.

$\boldsymbol{Tw_i}$ and $\boldsymbol{J_i}$ are the trustworthiness and judgment values of the node $\boldsymbol{i}$.

The net trustworthiness is a combination of direct and indirect trust values:

$$Tw = \alpha_{DT} \times DT + \alpha_{IT} \times IT .$$

where $\boldsymbol{\alpha_{IT}}$ is the indirect trust coefficient given by:

$$\alpha_{IT} = \frac{TS_{self}}{TS_{self} + \Sigma \frac{TS_i}{n_{recomm}}} \times \frac{\Sigma J_i}{n_{tot}} .$$

and $\boldsymbol{\alpha_{DT}}$ the direct trust coefficient is given by: $\alpha_{DT} = 1 - \alpha_{IT}$.

$\boldsymbol{TS_{self}}$ refers to the timestamp of the trust value of the node itself, while $\boldsymbol{TS_i}$ denotes the timestamp of the trust value of the node $\boldsymbol{i}$.

$\boldsymbol{n_{tot}}$ is the total number of nodes in the network, whereas $\boldsymbol{n_{recomm}}$ is the number of nodes that responded with recommendations.

3.2 Judgement

Judgment is one of the new features introduced that aims to imitate the human behavior in a technical approach. The judgment ability is represented by the overall experience of dealing with the node in question. That experience includes both the total number of control messages exchanged and the total number of actions whether positive or negative. The two judgment values related to the number of actions (***J_A***) and messages (***J_M***) exchanged are given below:

$$J_A = \frac{\Sigma A_i}{Maximum\ \ A} \qquad\qquad J_M = \frac{\Sigma\ messages_i}{Maximum\ \ messages}$$

At last, the overall judgment value is:

$$J = J_A \times J_M$$

4 User Behavior and Capability Based Control Access

We have proposed a new User Behavior and Capability based Access Control Model [16]. The proposed model has the following components: Users (*U*), Services(*S*), Devices (*D*), Environment (*Env*) and permission (*P*). Each entity is described with a set of attributes:

Entity = {att_1, att_2, …., att_n}.

Policy: <(U, S, D, Env), P>

where *P={permit, deny, obligation or recommendation}.*

Authorization decision is assigned according to the combination of all the entities.

We provide and construct an intelligent security policy specification following the main four steps:

1°)Behavior tracking: to collect the data about the person, the environment and the activities.

2°)Profile capability identification: According to the collected data, we define some discriminate factors to distinguish between the different behavior patterns. The next task consists to authenticate the users then to analyze the contextual data for attributing to each user included in behavior classes the right decision.

3°)Access control policy modeling and reasoning: It consists to represent data on standard format by using ontologies to ensure the interoperability, the sharing and the reuse of security policy. The current captured data and the inference rules are stored in the database to deduce a new knowledge and to check the consistency of the ontology.

4°) Evolving: A learning process is a continuous monitoring data provided over the time from different sources in order to update the behavior classes.

The design of our proposed access control model is an ontology-learning and evolving security policy for predicting the future actions of dependent people. This is reached by reasoning about historical data, contextual data and user behavior according to the access rules that are used in the inference engine to provide the right service according to the user's needs.

Our ontology model was built using three case studies: deaf person, blind person, Alzheimer person. We have shown the efficiency of an adaptive access control and the role of tracking the behavior, profile capability in such adaptive access control system. The access control is ensured according to the assignment of the users to behavior and capability groups then we check the valid time, location, device, service and environment to assign the "permit" or "deny" decision.

5 Conclusion

The proposed trust model has been implemented using Java language and Eclipse IDE platform. A server in our architecture is the device that provides the service to other nodes. It can be a computer, an RFID reader, or even a sensor. Our model will be tested on Android mobile phones using Android SDK tools in Java. A real evaluation will takes place in a residence dedicated to physically impaired people.

The proposed access control model is based on the semantic web technologies (OWL language, SWRL for rule specification and SPARQL to query the ontology). The ongoing work is aiming to deeply explore the behavior clustering and classification tools and to improve our sensing data base. We are planning to deploy our model in Tele-monitoring health care platform to provide automatic assistance for dependent and frail people living alone.

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PriGen: A Generic Framework to Preserve Privacy of Healthcare Data in the Cloud

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Abstract. With the rise of Healthcare IT infrastructures, the need of healthcare data sharing and integration has become extremely important. Cloud computing paradigm is one of the most popular healthcare IT infrastructures for facilitating electronic health record sharing and integration. Many predict that managing healthcare applications with clouds will make revolutionary change in the way we do healthcare today. Enabling the access to ubiquitous healthcare not only will help us improve healthcare as our data will always be accessible from anywhere at any time, but also it helps cutting down the costs drastically. However, since healthcare data contains lots of sensitive private information, how to protect data privacy within the untrusted cloud is facing a huge challenge. Thus, a mechanism to protect the privacy of healthcare data is needed when these data are stored and processed within the cloud to provide various medical services. To address this issue, in this paper, we present a generic framework named *PriGen* that preserves the privacy of sensitive healthcare data in the cloud. PriGen allows the users to preserve privacy while accessing cloud based healthcare service without the help of a trusted third party. With making use of homomorphic encryption function on sensitive private information; our proposed framework maintains confidentiality of private information sent by the cloud users to untrusted cloud based healthcare service providers. In this paper, we also present a brief discussion of different components of PriGen framework.

Keywords: Healthcare data, Cloud computing, Privacy, Homomorphic Encryption, Framework.

1 Introduction

In recent years, the cloud computing technology has seen a revolutionary expansion, acceptance and support both by industry and governments. Computing infrastructure are now offered as a service, instead of being offered as a product. And this is possible due to the rise and acceptance of cloud computing technology. Instead of running on machines owned or controlled by the users or client these services are now run in the cloud. Now a day, platforms, storage, computational power, as well as software is designed, managed and delivered as cloud based services.

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Cloud computing is also one of the popular IT infrastructures in healthcare sector for facilitating electronic medical record sharing [1]. Cloud can provide an exchange platform that all hospitals and clinics can use, and can serve as an electronic medical record storage center. This can simplify the complex electronic medical record exchange procedure between different systems, and save the equipment setup expenses for smaller hospitals. In addition, through the use of cloud platform, patients only need one interface to find their complete medical history, instead of having to check through different hospitals and risk finding only partial medical history. Another benefit of using cloud computing in healthcare is that it allows users to have access to different types of healthcare services via internet. While cloud technology significantly changed how medical and healthcare services are offered, there is a major privacy violation issue that has been in the focus for quite some times. Cloud technology has been criticized in terms of the potential for cloud service providers to gain access over personal data. With detailed person specific data contained in healthcare data, sensitive information about individuals may be easily revealed by analyzing the shared data. An example in [2] shows that linking medication records with voter lists can uniquely identify a person's name and his/her medical information.

As a result of these privacy violation concerns, privacy protection laws are passed in many counties. Many approaches have been proposed over the years to ensure users privacy and help medical institutions or participants to comply with those privacy protection regulations. These approaches cover quite a lot of research areas. Privacy protection during data publishing phase is very famous area and these kinds of approaches try to protect patient privacy by transforming the healthcare data before they are shared. Privacy preserving data publishing models such as Kanonymity, l-diversity [4] and privacy preserving data mining models and methods like privacy preserving decision tree, privacy preserving associate rule mining [5] have been developed as a result of these research work. Allowing authorized access to sensitive private information is another famous research. Many access control models have been developed to increase the flexibility of private data management [3, 6, and 7]. Privacy preserving data storage in cloud platform has attracted quite a lot of attention in recent years. Approaches for privacy aware data storage and auditing in cloud environment are proposed to protect private data [8, 9]. However, there is still need of research in the area of privacy preserving health care data sharing framework that has practical view for real life application. One technique to ensure user privacy while using cloud computing in healthcare is to encrypt all the data that needs to be stored and processed in the cloud. But encrypting all data in the cloud very computation intensive and will reduce the data's availability at the same time. To overcome the problems mentioned above, in this paper, we propose a framework named *PriGen* that preserves privacy of users while their healthcare related data are stored and processed in the untrusted cloud without the help of any trusted third party. Our major contributions in this paper are as follows:

- We present the architecture of a *Privacy Preserving Framework, PriGen that* protects privacy of healthcare data in the cloud without a trusted third party. By making use of homomorphic encryption function, PriGen is able to maintain confidentiality of sensitive private information sent by the cloud users.

- We discuss the significance and challenges of designing a practical privacy preserving framework for healthcare data in the cloud platform.
- We present the details of three major components of PriGen: Data Partitioning Manager, Encryption Manager and Decryption Manager.

The rest of the paper is organized as follows. In section 2, we discuss the relevant related works. In section 3, we discuss the significance of privacy preservation of healthcare data in the cloud. In section 4, we discuss the architecture of PriGen Framework. This section also contains the details of other components of PriGen. Finally, we conclude the paper with some future research directions in section 5.

2 Related Works

With the rapid development of healthcare IT area, all kinds of healthcare application will utilize the cloud storage technologies to store and process massive data. However, it will bring out huge challenge for the traditional privacy protection model and technologies [10]. How to protect the information in the cloud is attracting lots of researchers [11, 26]. Although, the traditional data encryption algorithm can be applied to cloud services platform, most of the encryption algorithm cannot support the calculation of the encrypted data. Research on data privacy in cloud computing is still in its early stages. Good research findings on this topic are presented in [12] which discuss the risks imposed by the adoption of cloud computing and which emphasizes on the need to develop a sound digital identity infrastructure to tackle privacy and security concerns in cloud platforms [13]. [14, 15] present a comprehensive set of guidelines on designing privacy aware cloud based services. [14] summarizes the privacy patterns in recommended common practices. Note that our proposed framework, in this paper, also maintains the common privacy practices including the most important one which is “protecting sensitive customer information in the cloud”. We believe that the customer should be able to safely send any kind of sensitive data to the cloud and to secure it by providing user-configurable privacy enforcement mechanisms. It should be noted here that Homomorphic encryption [16] techniques for allowing specific algebraic operations on encrypted data are still theoretical and lack any pragmatic implementation. A practical fully homomorphic cryptosystem is still an open research topic [17].

3 Significance of Privacy Preservation in the Cloud

Cloud computing is a technology based on Internet which allows the user to have access of storage and applications from remote servers by web browsers or other terminals. It is widely recognized that cloud computing is an important foundation to provide quality healthcare services whether it is for maintaining health records, monitoring of patients, managing diseases and or collaboration with peers and analysis of data. Healthcare data usually contains a lot of private information and sharing that data directly without any sort of intelligent encryption may jeopardize patient's privacy. But encrypting all the data in the cloud is not very feasible. Moreover, when healthcare services are provided over the cloud the healthcare related information travels through the entire cloud which is a great target for attackers. The attackers may examine, corrupt and even infer significant private information which violates users' privacy rights. Privacy is a fundamental human right and personal sensitive information is key factor of privacy [18]. Privacy sensitive information includes personally identifiable information (any information that could be used to identify or locate an individual e.g. name, address or information that can be correlated with other information to identify an individual e.g. credit card number, postal code, etc). It also includes sensitive information related to religion or race, health, sex, union membership or other information that is considered private. This information also includes any type medical condition or medical diagnosis information. When these types of information are stored and processed in the cloud, with detailed person specific data contained in healthcare data, sensitive information about individuals may be easily revealed by analyzing the shared data. Research shows that patients could be easily identified by using identifiers or specific combined information (such as age, address, sex) from each other in a certain health care dataset [2]. Therefore, to provide better privacy facilities to cloud platform users, we need to ensure that sensitive private information is not revealed to any third party even to the cloud itself. Our objective, in this paper, is to achieve anonymous privacy while sensitive healthcare information are stored and processed within the cloud to provide various services to the users. We propose a generic framework, PriGen that preserves privacy of users while using and processing their healthcare data in the cloud to access various medical services.

4 Overview of PriGen Framework

In this section, we present the overview of PriGen framework and its different components. Figure 1 shows the high level architecture of PriGen framework.

4.1 System Model of PriGen Framework

The system model assumed in this framework is a typical cloud computing model with two major players: *a cloud provider which manages a cloud infrastructure of storage and computing services* and *a cloud service user that employs the cloud storage and computing resource facilities to remotely store and process data*. The Internet is the main communication technique for exchanging information between the cloud service user and the cloud. There is no trusted third party in our framework.

4.2 Data Partitioning Manager in PriGen

The Data Partitioning Manager of PriGen framework plays a major role in preserving privacy of healthcare related data. The main task of this module is to identify Privacy Sensitive Data and General Data from a stream of data provided by the Data Provider.

Before uploading the data to be stored and processed in the cloud, the Massive Data provided by the Data Provider is classified, based on privacy sensitivity, into two categories. The data provider can also play a role in classifying the data by marking the privacy sensitivity of the data with an attribute (Private and Non-Private). This attribute marking is considered while classifying the massive data into following two categories:

1. General Data: This type of data is not sensitive and hence the cloud service provider is fully trusted to store it without any form of encryption. If network security is needed, the client can send the data over a secure SSL session.

2. Privacy Sensitive Data: These types of data contain sensitive private information of users that allows a specific person to be uniquely identified within a group. Privacy Sensitive Data needs to be encrypted by a specific provider key. In this case the provider (certification Authority) is trusted to encrypt the data using her own secret key. This attribute is crucial for compliance with regulatory policies. To send this data to the cloud, the customer is required to encrypt it over a secure SSL session to achieve network data confidentiality and integrity. The cloud provider is obligated by the contractual policy to extract the SSL secured data and store it encrypted.

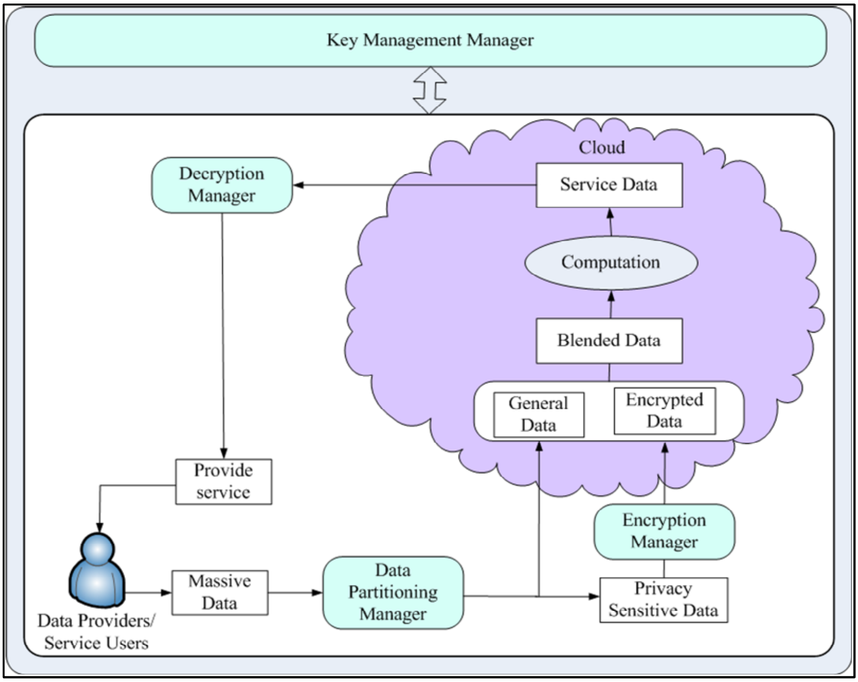

Fig. 1. Architecture of PriGen framework

Data Classification or Partitioning Technique: Privacy Sensitive Data are defined as data that could be used to identify one from a group both in HIPPA [3, 19-21]. This is a very common definition that is also used by many countries of the world.

However, it's not practical to use such a simple definition in application as it's difficult to judge if the data could be used to identify one from a group. In order to comply with HIPPA, an *Identifier List* can be created that can be used to identify one from a group. Since the initial list may not cover all the possible identifier, a system administrator may add additional identifiers to keep the list updated. In order to partition the data specific privacy policies mentioned in HIPPA also play a major role. The *Semantic Rule* database provides access to any privacy policy mentioned by the law or even by the user to provide a certain level of privacy while processing data in the cloud. The Identifier List along with the Semantic Rule database can be used as a keyword table and policy table respectively, to separate Privacy Sensitive Data and General Data from a stream of Massive Data. The Privacy Sensitive Data can be protected by Encryption Manager Module before storing into the cloud. And the General Data can be stored in the cloud directly. Our data partitioning technique can be logically described as shown in figure 2.

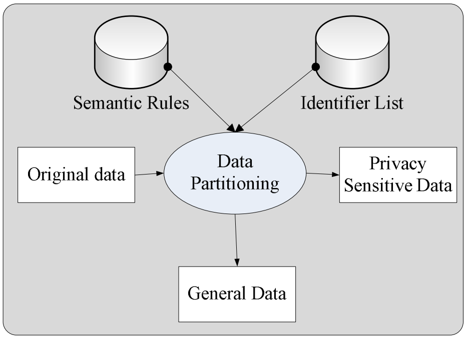

Fig. 2. Logical diagram of data partitioning technique

4.3 Encryption Manager and Decryption Manager in PriGen

Homomorphic encryption is a famous encryption technique which is very suitable for the cloud environment. The other encryption techniques cannot be used in the cloud environment since the data stored in the cloud cannot do necessary computation after being encrypted using the traditional encryption methods. The first implementation of Homomorphism encryption was proposed in 2009 by IBM. The Paillier cryptosystem is a probabilistic asymmetric cryptographic technique for public key cryptography. The additive homomorphic encryption property of the Paillier cryptosystem means that multiplication of encrypted values corresponds to addition of the decrypted ones.

<u>*Definition (Homomorphic Encryption).*</u> *For two algebraic systems* $(A, \circ)$ *and* $(B, \bullet)$ *of the same type in the sense that both* $\circ$ *and* $\bullet$ *are binary operations and a mapping function* $f: A \rightarrow B$ *is called homomorphism if for any* $a1, a2 \in A$*, the following is true:*

$$G(a1 \circ a2) = g(a1) \bullet g(a2)$$

If such a function g exits, then it is customary to call $(B, \bullet)$ *a homomorphic image [5] of* $(A, \circ)$*, although we must note that* $g(A) \subseteq B$. ■

In the Encryption Manager and Decryption Manager of the PriGen framework, the property of homomorphism is used, which means that operations on plain text can be performed by operating on the corresponding cipher text. Based on the requirement of the service, the additive or multiplication property of the homomorphic function can be used. For example, the ElGamal [23] and the RSA cryptosystems [24] support multiplicative homomorphic encryption. Moreover, there are recent results on "somewhat" homomorphic cryptosystems [25], i.e., cryptosystems which support a limited number of homomorphic operations including both additive and multiplicative operations. The main goal of Encryption Manager, in PriGen Framework, is to encrypt the Privacy Sensitive Data before uploading it to the cloud using Homomorphic Encryption. Inside the cloud, computation is performed on the encrypted data and the result is aggregated without violating the privacy of the users. The result is computed in encrypted form. These encrypted results known as *Service Data* is passed to the Decryption Manager which uses the concept of homomorphism to decrypt the results back to the data required by the user. Figure 3 shows the logical diagram of Encryption Manger and Decryption Manager components of PriGen.

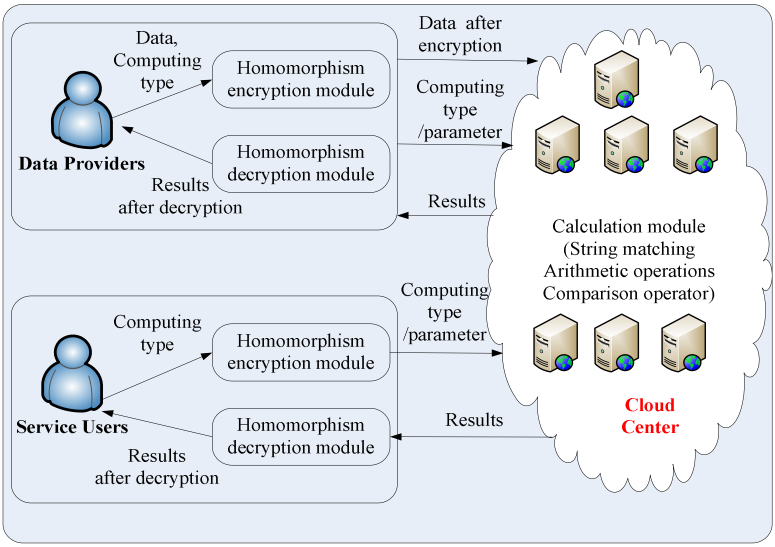

Fig. 3. Logical diagram of encryption and decryption technique in PriGen

5 Conclusion and Future Work

In this paper, we presented the design of a privacy preserving framework, PriGen, to protect healthcare data privacy in the cloud. The main goal of this paper is to present the architectural and logical design of the PriGen framework. We are still working to enhance the logical design of the framework. One future work that we are currently working on is to investigate an efficient technique to divide the original data into privacy sensitive data and general data seamlessly. How to extract the privacy sensitive data from a data file or database is a big challenge here. Some other future works will include investigation of variety of design choices including those that rely on the presence of a trusted third-party, investigation of key management and distribution mechanisms, development of different components of PriGen to systematically support the privacy preservation process and provide detailed analysis and evaluation of the framework implementation. Another future research direction can be to deploy the framework in real cloud based healthcare applications.

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Dynamicity in Social Trends towards Trajectory Based Location Recommendation

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Abstract. The pervasiveness of location acquisition technologies has significantly elevated the demands of experience sharing recommendation systems. These systems are highly affected by social dynamicity and trends which are not exploited in existing studies. In this paper, we have proposed a GPS trajectory focused approach that endorses interesting locations. Tree based hierarchical clusters of visited locations are utilized to incorporate the timely changing social trends and personalized preferences of the users. Experimental studies are conducted on real world dataset for verification and validity of the proposed technique.

Keywords: Trend Analysis, GPS trajectories, Location recommendation.

1 Introduction

In recent years, everywhere in the world, the trend of using locations attainment technologies such as GPS, GSM, and Wi-Fi have grown up rapidly in different domains. Especially the GPS based path finder devices in transport systems has been proved a competent way to extract the traces of moving objects. These traces are being used to exploit the human behavior and social dynamicity [1]. Recently, a huge number of social networks and websites have also enabled people to establish Geo-related web communities, and share their daily life experiences. Experiences related to movements such as visiting locations, movement paths etc. help an individual to learn about an unknown area in a short period with minimal efforts. Meanwhile, such information also helps mobile guides and recommendation systems [2-3].

However, deducing the interest of a user and the recommendation of an appropriate location is quite complex phenomenon. Since it depends on a number of factors e.g. location history of users and their corresponding experiences, ease of attainment and social importance of the location. Another important measure, which is being ignored by existing techniques, is the effect of dynamically changing social trends on evolution of user's interest. A recent study [6] show that change in social trends has impacted the renovation of interests of people, enormously. Since peoples' experiences and social dynamicity lead the world towards easy and better solutions. Therefore people want to transform their routine activities by overwhelming these trends. For example, consider the case of a diabetic patient who used to visit a

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physician at clinic X, for his weekly checkup but he recently started visiting clinic Y because of the possible bad experience and displeasure he got. Thus, his current location history shows the preference of clinic Y, however historic patterns express the betterment of clinic X. Considering the above scenario existing techniques recommend clinic X to the user due to its higher frequency. However, clinic Y should be recommended due to the change in preference of the user based on his experience of historic adoptions.

In this paper, we aim to mine top-k interesting locations by using GPS trajectories of multiple users. Assimilation of correlation between the user and location, and timely changing trends are included to reflect state-of-the-art interest of people. In step 1, the visited location histories of the users are identified by using GPS traces and in second step it is divided into N time intervals to incorporate the effect of changing interest. In step 3, for each time interval a hierarchical clustering based tree is constructed. The clustering in accomplished based on the nature of the visit (performed activity) and region of location. In step 4, evaluation of each location is done based on both of the peripheral and personalized stimuli. Peripheral stimuli include social importance and experience of the visitors of the location. However, personalized stimuli incorporate the user's personalized preferences e.g. time and cost of reaching that location. Finally, skyline computation technique, LSA is applied to fetch the most preferred interesting location according to both stimuli.

The summary of main contributions of the paper includes the introduction of a novel location recommendation measure based on dynamically changing social trends, evaluation of both peripheral and personalized stimuli of the location and experimental assessment of the proposed technique on real data sets. The rest of the paper is organized as follows. Section 2 describes related work. The preliminaries are discussed in section 3. Computations of location rank score and working of Skyline location recommendation are shown in section 4 and 5 respectively. Section 6 exploits the results of experiments and conclusion is given in section 7.

2 Related Work

Recommendation systems [2-3] use the public experiences to provide help in exploring the community. They effectively identify the content of interest from a potentially overwhelming set of choices. Collaborative filtering and nearest neighborhood approaches [9] are exploited to find the use of similar activities between users, and rank the options based on their correlation. Further, Pearson correlation and cosine similarity [10] are also widely used correlation measures. Another category of run-time mobile guide and recommendation systems [3] [11] estimates the individual preferences based on location history and target the recommendations. Moon et al, in [11] proposed the map-based personalized recommendation system. In this study, preferences of user are modeled by Bayesian network and history data is exploited to fetch most potential recommendation. However, in our proposed approach a novel measure of dynamically changing trends of the interest of domain users is presented to find their correlation. Second, we combine both the real world social impact of places and user's personalized measure to reflect their importance towards categorization of available choices.

3 Preliminaries

Definition 1: Imperative Location (L_I): An imperative location L_I is a group of trajectory points at a geographic region where a user stayed over a certain interval of time i.e. $L_I = \{p'_m, p'_{m+1}, p'_{m+2} \ldots p'_k\}$. The extraction of a stay point depends on three scale parameters, a time threshold T_{min}, a minimum and maximum distance threshold D_{min}, D_{max} and speed of a moving object s_{min}. These thresholds ensure the importance of location based on time, distance and speed [3]. So, a location will be considered imperative only if all of these three thresholds are satisfied i.e. $T_S \geq T_{min}$, $D_{max} \leq D_S \geq D_{min}$ and $s \leq s_{min}$; Where, T_S is the total time spent at a particular place, D_S is the distance area of a location and s is the speed of a moving object. Haversine formula [8] is used to find the distance and speed between two GPS points. Identification of imperative location is triggered on sequence of fulfillment of s_{min}, D_{min}, D_{max} and T_{min} respectively.

Definition 2: Location History (H_{Loc}): A location history is a set of visited imperative locations of a particular user i.e., $H_{Loc} = \{(L_{I_1}, t'_1), (L_{I_1}, t'_2), \ldots, (L_{I_1}, t'_n))\}$. It is further sub-divided into N number of timestamps T, based on t'_i where a threshold time T_t, represents time stamp T_i, where $t_j \leq T_t \leq t_k$.

Definition 3: Tree Based Hierarchical Clustering *(TBHC)*: A hierarchical clustering based tree is constructed for location history of each time stamp T_i. Clustering of imperative locations is accomplished on the basis of nature and region of imperative locations. However, nodes of *TBHC* are the nature based clusters of imperative locations called Activity Cluster and region based clustering is consummate with in activity clusters.

Definition 4: Activity Cluster ($C_{i'j'}$): Activity cluster is the set of imperative locations of same activity category at level *i* of *TBHC*. Each child of $C_{i'j'}$ contributes the lower granularity level of activity of locations as compared to its parent i.e. $C_{i'} = \{C_{i'1}, C_{i'2} \ldots C_{i'm}\}$, Where $C_{i'j'}$ is a set of imperative locations of same nature, at more granular level than $C_{(i'-1)j'}$. For example consider a node of *TBHC*, an activity cluster $C_{11} \in$ *Clinics in Seoul (city)*. Children of this C_{11} will be sub-divided based on nature of clinics, e.g. Clinic for diabetic C_{21} and cancer patients C_{22}, will be clustered as two separate children of C_{11}, respectively (Shown in figure 1).

Definition 5: Location Cluster ($C_{i'j'k'}$): Location Cluster divides the activity cluster based on regions of imperative locations. Thus $C_{i'j'k'}$ is the set of imperative locations of same category in a particular region. i.e., $C_{i'j'k'} = \{C_{i'j'1}, C_{i'j'2} \ldots C_{i'j'l}\}$. In figure 1, two blue color sub clusters of C_{21} are showing the diabetes clinic in southern and northern part of Seoul respectively.

Problem Statement: Recommend the top-k interesting locations to the user for potential visits based on dynamically changing peripheral (external factors) and personalized (user's personalized) stimuli.

4 Computation of Location Rank Score *(S_{LR})*

Each L_I is evaluated to find a score called S_{LR}. Recommendations of locations are based on these scores. The detail computation of S_{LR} is given below.

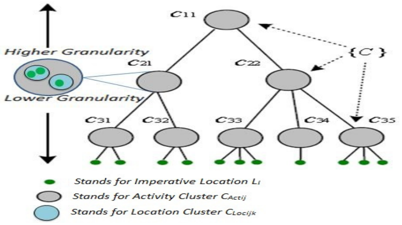

Fig. 1. Tree based Hierarchical Clustering

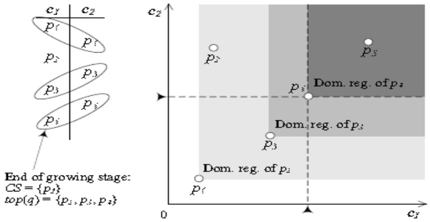

Fig. 2. LSA: Top k skyline facilities[9]

Since H_{Loc} of various people are uneven and incomparable thus the stay points pertaining to different individuals are not identical. *TBHC* is proposed to model the location history of multiple users. In this technique [4] is modified to incorporate the two level clustering at each step of the tree and to express the relationship of both nature and region cluster nodes at different granularities. *TBHC* is a hierarchical tree of *Activity clusters*, shown in gray color in the Figure 1. Each node of the tree represents the category of set of similar L_I of activities, (shown in green color). These nodes are further drilled into children based on category division of imperative locations (Definition 3, 4, 5). To identify the significance of a location at a particular area, each of the *Activity Cluster* nodes is further clustered on the basis of region of corresponding L_I. Here point to be noted is that while moving from parents to children granularity of both of location and activity cluster changes i.e. granularity of nature of activity clusters, and region of location clusters of imperative locations increases at each step of *TBHC*. To fetch the interesting locations for a particular user, activity and location clusters of all the time stamps of all the users (friends) are examined and stimuli are calculate based on peripheral stimuli and personalized stimuli. Computation of both of the measures is given below in detail.

4.1 Peripheral Stimuli *(S_p)* Computation

The interest of a location is highly influenced by the measure of its importance in society. S_P incorporates the effect of external factors of society on an L_I. These external factors include significance of visiting location, and visitors' experiences. S_p is calculated by a monotonic function, given by following equation.

$$s_p = \alpha(v_{fL_I}) + \beta(u_s) \tag{1}$$

Where;

s_p = Influence scored of external factors (peripheral stimuli)

v_{fL_I} = Number of visit of L_I at *i-th* level of TBHC

u_s =Visitor experience of L_I

α, β = personalized coefficients to assign the weightage of visiting frequency and user experience respectively.

Usually popular places are visited more frequently thus we consider visiting frequency as directly proportional to the S_P. Here an important point is that numbers of visit in latest timestamp are assigned higher score as compared to previous one, to consider the dynamically changing social trend. It is given by following equation.

$$v_f = \sum_{T=1}^{N} \frac{T}{N} \left(\frac{v_{fUL_I} C_{i'j'k'}}{\sum_{j=1}^{m} \sum_{k=1}^{l} v_{fU} C_{i'jk}} \right) \tag{2}$$

Where;

$v_{fUL_I} C_{i'j'k'}$ = Number of visit of location L_I by all users at location clusters $C_{i'j'k'}$

$\sum_{j=1}^{m} \sum_{k=1}^{l} v_{fU} C_{i'jk}$ = Number of visits of all users at all the locations clusters of all the activity clusters at level *i*

T, N = Time stamp and total number of time stamps of *TBHC* , respectively

The visitor's experience is also considered as an important parameter to evaluate a location. The overall historic experience of a visitor towards locations in a particular region and also to corresponding category is evaluated for each of time stamp T_i. After assigning the higher weight to timestamp of recently visited imperative locations, an overall rank score of a visitor u_s is computed. The two factors involved in computation of u_s are given below in the equation 3. First part of equation (fractions in first parenthesis) shows the importance of location for a visitor *u'*, among his visited location history and second (fractions in second and last parenthesis) is for assessment of the importance of visitor *u'* among all the visitors *U*. It is given by equation 3.

$$u_s = \sum_{T=1}^{N} \frac{T}{N} \left\{ \left(\frac{v_{fu'L_I} C_{i'j'k'}}{v_{fu'} C_{i'j'k'}} + \frac{v_{fu'} C_{i'j'k'}}{\sum_{k=1}^{l} v_{fu'} C_{i'j'k}} + \frac{\sum_{k=1}^{l} v_{fu'} C_{i'j'k}}{\sum_{j=1}^{m} \sum_{k=1}^{l} v_{fu'} C_{i'jk}} \right) + \left(\frac{\sum_{j=1}^{m} \sum_{k=1}^{l} v_{fu'} C_{i'jk}}{\sum_{j=1}^{m} \sum_{k=1}^{l} v_{fU} C_{i'jk}} \right) \right\} \tag{3}$$

4.2 Personalized Stimuli (S_{prn}) Computation

User's personalized preferences toward any location also hold significant importance towards selection of it as a potential recommended position [8] [13]. Since usually visitor incorporates their own likings and interest, while planning to visit some location such as distance, cost and time of reaching at location. Thus in this section we incorporate these preferences of user (who request/query for location recommendation) called Personalized Stimuli S_{prn}. S_{prn} is the set of user's personalized preferences and their assigned preference weights i.e. S_{prn} ={(p_1,w_1), (p_2,w_2),… (p_m,w_m)},where p_i is the individual preference of user *u'* and w_i is its corresponding weight, for selection of interesting location L_{In}. All of these preferences S_{prn} and monotonic function score of peripheral stimuli S_p is send to Skyline location recommender for ultimate evaluation.

5 Skyline Location Recommendation

Each imperative location is evaluated, based on multi-cost parameters i.e. S_p and S_{prn}. Thus to assign corresponding importance to each of parameter we used skyline computation technique (*LSA*) [5]. *LSA* finds the entity that is best, based on all the concerned measures. Thus the purpose of using it is to pin the location that is most preferred among all the evaluated parameters. A general concept and working of *LSA* is shown in figure 2.

Score of peripheral stimuli is considered as a single parameter because it covers the evaluation of the social impact of location. While S_{prn} is the set of personalized presences and each of it is deliberated as separate individual parameter i.e. $S_{prn} = \{(p_1, w_1), (p_2, w_2), (p_3, w_3)\}$, where the p_1 is cost, p_2 is time and p_3 is distance parameter of a user u'. After evaluation on the basis of their corresponding weights, and provision of S_p for each imperative location, *LSA* compute the *top-k* interesting locations that are best based on each of these four parameters i.e. cost, time, distance and peripheral stimuli S_p.

6 Results

For the experimental evaluation, we used the dataset of Geo life trajectory [4] [7] to evaluate our proposed approach. It contains 17,621 trajectories with corresponding transportation mode. We visualize this dataset in a sense that transportation modes of trajectories are considered as imperative locations and use of transportation mode is deliberated as a visit of imperative location. Transport modes are considered as nature of imperative location. Thus *Activity Clusters* include the users, having same transport mode, and number of using of same transport portrays the frequency of visiting an imperative location in a *Category Cluster*. For *Location Cluster*, we divide the dataset into 11 groups based on region of observed trajectory. Further data set is divided into 6 equal time intervals of 6 months each, to incorporate the dynamicity and changing of social trend. Each time interval represents the time stamp T_i of TBHC. Thus, here we are recommending the *top-k* transportation modes by incorporating the changing social trends to depict the location recommendation.

TBHC is built for each T_i of all the 11 groups. We include the results of group 1 due to maximum availability of data for all intervals, except interval 6 which is ignored in the results. Fig.3 represents the normalized weight of using transport modes by all the users for corresponding time stamp T_i. The trend of using transportation mode is shown in the Fig. 4. The absolute stimuli shows the total frequency base result but trend analysis stimuli demonstrates the peripheral stimuli based on changing trends, given by equation 1(α, β are assigned equal weight, '1' to ignore dominance on each other). It can be observed that result of trend analysis stimuli is different than absolute one. In absolute measure *top-3* transportation modes are taxi, bike and bus respectively. However, result of trend analysis shows bus, taxi and bike as *top-3* interesting transportation mode respectively.

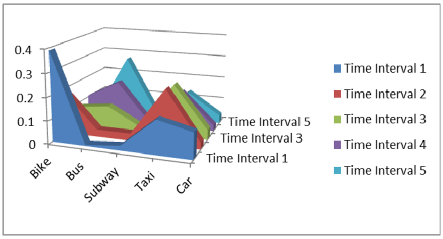

Fig. 3. The trend of using transportation modes over different time intervals

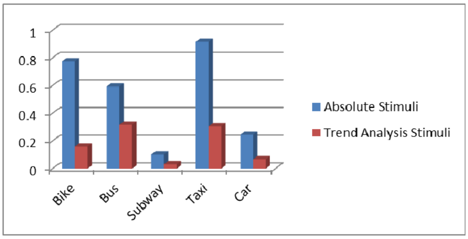

Fig. 4. Changing trend of Transportation modes

To calculate the peripheral stimuli we assumed three preference parameters, exercise, time and cost of using transport. Preference weight to each of these parameters (p_i) is assigned randomly e.g., (exercise, 0.3), (time, 0.5) and (cost, 0.2). Further each of transportation modes is evaluated based on these parameters and weights are assigned intuitively. Evaluation of transportation and preference score for each of p_i is shown in Table 1. Further, *LSA* is applied on it and pinning of transportation modes as skyline facility is shown by different colors. The representation of each color to corresponding transport mode is shown in the last two columns. The transportation mode that is pinned firstly by all the parameters (columns) is considered as most potential mode for recommendation e.g. Bus in the table 1. Similarly all the transportation modes are evaluated and are shown in last column of table 1, in descending order of their priority.

Table 1. Top-K interesting modes by LSA, based on both S_p and S_{prn}

Exercise Stimuli	Time stimuli	Cost stimuli	Peripheral stimuli		
1.8	0.5	0.4	0.317		=Bus
0.9	1.0	0.6	0.305		=Car
0.9	1.5	0.6	0.158		=Bike
0.6	1.5	1.4	0.068		=Taxi
0.3	4.0	1.8	0.032		=Subway

7 Conclusion

Social trends that change dynamically put a significant effect on renovation of people interests. In this paper, we explored this phenomenon as a vital measure for real life experience sharing based recommendation systems. The proposed approach incorporates both peripheral and personalized stimuli with changing social trends to categorize the interesting places for possible recommendations. Experimental evaluation on dataset of real life trajectories of users is performed to verify and validate the method. Results show that interest of people change over the interval of time and combining both peripheral and personalized stimuli on the basis of these changing interests, substantially affect the selection criteria of recommendation approaches. Author considers treatment sharing social networks such as patientlikeme, location based social networks and experience based recommender systems such as emerging shopping malls and best physician clinics for a particular disease, as potential applications of the proposed approach.

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A SmartTV Platform for Wellbeing, Care and Social Support for Elderly at Home

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Abstract. This paper presents Care@Home, a smartTV platform integrating assistive living services for elderly in their homes. The SmartTV is acting as a user-centered 'hub' providing communication that connects the elderly to their formal care network, family, friends, communities, and provides services including household help, healthcare, exercise programmes and entertainment. The paper highlights Care@Home as a low-cost, personalized and open platform that is flexible and easy-to-use. We describe the human-centered design and first results from user studies.

Keywords: Active aging, gerontechnology, wellbeing, care, social support.

1 Introduction

The increase in global population over the age of 60 is a highly foreseeable long-term trend [23]. While the number of elderly rises, fertility rates have been falling from 5 children per woman in 1950 to roughly 2.5 in 2012. This leads to an imbalance in working to retired population. These demographic changes present new challenges to society including (1) pressure on public budgets and fiscal system, (2) strains on pension and social security systems, (3) adjustments of workplaces to an aging labor force, (4) higher rates of non-communicable diseases and disabilities that restrict lifestyles, which lead to: (a) the need for increased number of healthcare professionals and (b) higher demand for healthcare services and long-term (institutionalized) care and, last, (5) potential conflict between generations over the distribution of resources. [5,9,23] The demographics changes also bring new opportunities due to a steady increase in life expectancy across the world leading to increased longevity. With years of experience, older people become indispensable resources of knowledge for their family and communities [5]. The concept of "active aging" is promoted by the World Health Organization (2002) and is defined as the process of optimizing opportunities for health, participation and security in order to enhance quality of life as people age. Within this context, the European Union has taken initiatives to (1) help elderly play an active role in society and (2) encourage healthy aging and independent living [9].

In line with these initiatives, the goal of our work is to improve the quality of life of elderly and their carers by supporting them to stay independent longer in their own

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homes. In this paper we present a smartTV platform acting as a user-centered 'hub' to provide communication and services aimed to increase the elderlies' wellbeing, healthcare and social support at home. As an open platform that is implemented on consumer-driven products, it presents a cost effective and easy-to-use solution. In this paper we focus on the human-centered design process and the modular architecture of the system and present first results.

2 Challenges and Opportunities for Designing for the Elderly

2.1 Defining Old

The UN accepts the age of 60 years as a definition of 'elderly' or older person, while the EU categorizes 65+ years to refer to the older population. However, there is no general agreement on the age at which a person becomes old and more important when people consider themselves old. Brant et al [6] found that almost nobody among the group of people between 55 to 75 years old appreciated being stigmatized as 'elderly' or 'senior citizen'. Rather they tend to refer to 'the others' or even to their own parents.

Research found that older adults are a less homogenous group than younger generations [14]. Individual differences exist in the severity of mental [1, 21] and physical [2, 7, 16, 20] debilitation and we cannot predict exactly which components will be affected first or how quickly. These effects of ageing and their diversity in end-users need to be handled by technology for the elderly. In our project we, therefore, develop personalized services and interfaces that are adaptive to the end-users.

2.2 Economic and Social Changes

Retirement marks a major step in people's lives. Risk of poverty or social exclusion depends highly on the pension systems applied in the countries [3]. High medical costs, family models and low personal savings can cause the inadequate income for the elderly [11]. Because of their lower income and lower opportunity cost of time, retirees spend more time doing household productive activities, personal care (e.g. eating and sleeping), watching TV, and sports than employed individuals [13]. They also become a source of support for others, e.g. childcare and volunteering, while 70% of the population age 15+ thought that people aged 55 and over played a major role in the local community and in politics [9].

Care for dependent elderly is often provided on an informal basis, by spouses, relatives or friends [9]. Only about half of the dependent elderly are attended by professional caregivers. However, changes in family structures, higher labor force participation, and increased geographical mobility may reduce the provision of informal care in the coming years. As people age, the loss of a social network is especially noticed due to work colleagues being encountered less often, friends bring more remote or dead, or family visits becoming less frequent. Moreover, in addition to physical disability the loss of a spouse or the loss of social network reinforces the feeling of loneliness [17]. The need of support and care facilities for the old within the community become prominent.

2.3 Elderlies' Attitude Toward Technology

The lack of technological experience has been identified as a reason for low adjustment to the advent of new technologies by elderly [8]. Complying with this, Morrell [14] pointed out that older adults born after World War II, who have often been using ICT at work, might have greater ability than the current elderly.

Self-image, self-perception of health, and awareness about own vulnerability and changes to the aging process can also be factors that influence the acceptance of technology, which causes the elderly not to be able to perceive a direct benefit [21]. Other important factors are value-related consideration, such as privacy and trust [18]. Most elderly people initially show anxiety using a new technology. When having gained experience in using the technology, elderly people show a less negative attitude. The promotion of technological solutions through trusted sources could enforce inclusion.

Problems with usability and perceived ease of use are higher with older than younger users and lead to dissatisfaction quickly [15]. Often technologies are designed without consideration of the cognitive and physical challenges older users may have. Various research attempts to deliver basic sets of design guidelines for technological development for elderly, e.g. Arch [4].

3 Care@Home: A Low-Cost User-Centered Solution

The Care@Home project aspires to design and develop ICT-based solutions that: (1) encourage healthy aging and independent living for elderly people with degrees or types of impairment and technological literacy, without the prohibitive costs of retrofitting existing dwellings; (2) improve social inclusion of the elderly; (3) allow carers to remotely monitor real time emergencies and lifestyle changes over time in order to manage the risks associated with independent living; and (4) allow family members to remain active with their roles in society while at the same time be able to continuously remotely monitor, communicate and support their elder relatives.

Interactive multimedia on an internet-connected SmartTV platform that integrates personal services for elderly and connects to formal/informal care network and communities, has been chosen to enable higher quality of life, wellness, and social care provision to the homes of the elderly at low cost. As a familiar interface, TV provides media that encourages elderly users to use the services toward attaining a 'self serve' society. Reports showed that the elderly dedicated a great part of their time to watching TV [13], three times more than did younger adults [12]. A study in Portugal involving seniors 65+ found that iTV and social media have great potentials to improve elderly participation and sociability [19].

3.1 Architecture

To achieve the aforementioned goals, Care@Home provides an innovative and open infrastructure that includes:

- *Services*, delivered to the elderly users, e.g. facilitating communication and scheduling capabilities, activity coordination, physical activity, community involvement, and wellness monitoring. The open platform creates possibilities for continuous deployment of new services without installation of new infrastructure.
- *Services Portal*, offering the users to access the available services and providing a platform for the service providers to deploy and advertise services.
- *Sensors and Sensor Network*, facilitating broad acceptance of monitoring procedures and novel sensing systems.
- *Device Portal*, offering a safe and robust access to devices (e.g. personal and home sensors) for the elderly users and allowing the carers to remotely update and configure the devices.
- *Communication Devices*, providing access to services and seamless switching of communication platforms using consumer products such as SmartTVs, PC, tablets, etc.

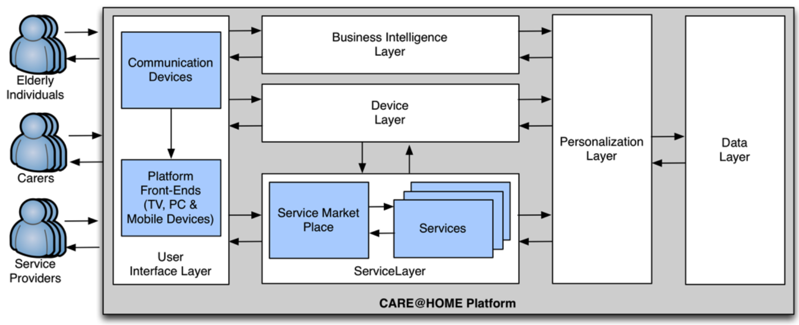


Fig. 1. Care@Home Conceptual Architecture

The modular architecture of Care@Home allows ad-hoc deployment of services and devices. Fig. 1 shows the layers of components with discrete functionalities described in the following.

The *Data Layer* is responsible for handling all the data exchange and storage that takes place within the Care@Home platform. This includes both internal- (i.e. data exchange within the platform) and external communication (e.g. web services). This latter allows the Care@Home services to access any external services on the web.

The *Personalization* Layer is responsible for handling user interaction that is tailored to the needs, views and current contexts of the users. This layer includes components of (a) knowledge representation that models the user's functional capabilities, behavioral pattern, and wellness factors; (b) context awareness acquisition that collects and compiles information about the user, his/her task and the user's environment from various sources including dynamic user profiles, user interaction logs, real-time sensor input, and historical information stored in the system; and (c) adaptive procedures that perform reasoning toward dynamic, context-dependent output adaptations.

The *Business Intelligence Layer* is responsible for implementing and delivering the necessary mechanisms for service providers to publish and advertise services. The input from the Personalization Layer is incorporated to deliver personalized offers based on the user's profile and preferences.

The *Device Layer* is responsible for handling the information exchange with sensory devices that will be utilized for acquiring contextual information about the user, his/her task and the situation of his/her environment. This layer includes components for (a) aggregating information from various devices, (b) configuring these devices, and (c) monitoring their performance.

The *Service Layer* is responsible for handling the operation, communication, information exchange and the overall management of services offered through the Care@Home platform. The *Service Market Place* component within this layer handles the registration and authorization of users on the available services.

The *User Interface Layer* has the *Platform Front Ends* component that responsible for handling the display of the information to the users through different devices, including a SmartTV, a PC/laptop and a mobile device. The *Communication Devices* component handles the user interaction with the platform. Currently, this component includes modules for the remote control and the tablet-based input device. Both are targeted for the TV Front End.

3.2 Research and Development Methodology

The research and development of Care@Home follows a human-centered approach. Methods focus on understanding all stakeholders and organizational and societal structures. In order to ensure human-centeredness at all stages of the incremental design process (see Fig. 2) we build on principles and employ methods from Value

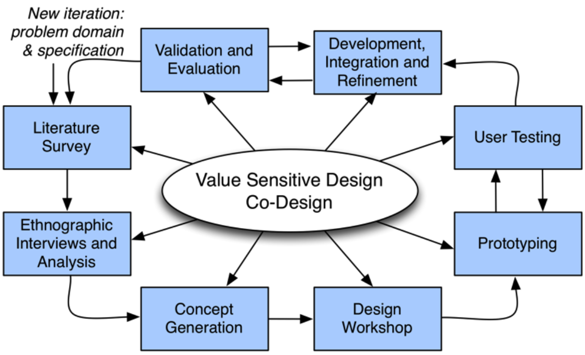


Fig. 2. Care@Home research and development

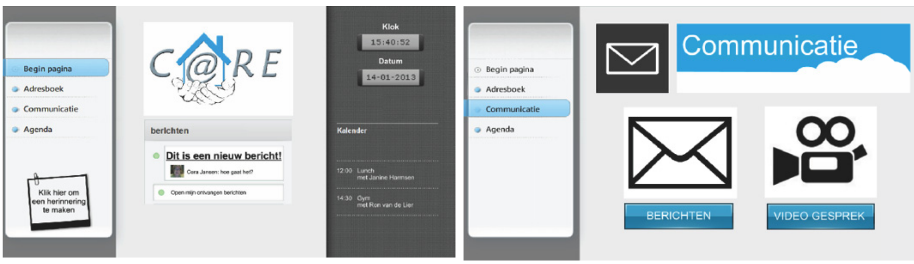
Sensitive Design and Co-Design. Value Sensitive Design is “a theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive manner throughout the design process” [10]. We apply the VSD approach to identify both direct and indirect stakeholders, which expands user-centeredness to considering all people affected by a technology. This distinction helps to understand the perspectives of the elderly, carers, and service providers as well as all other affected by the development of ICT-services for the elderly. Harms and benefits are identified for each group, and satisfying value trade offs are aimed for.

Co-design [22], is an approach to involve stakeholders. It uses joint creativity of designers, end-user untrained in design, and other stakeholders in the domain who are working together in design processes. We use Co-Design to involve stakeholders in *concept generation* activities to collect views, ideas and wishes, and formulate them into design concepts of services available in the platform.

In the *design workshop* we develop the concepts into concrete visual designs with defined functionalities together with the stakeholders. We develop *prototypes* based on the developed designs. *User testing* assesses the usability of the prototypes. In this activity, we involve the same participants of the previous activities plus a new set of participants to compare the results for users who were involved in the design process and users who are new to the system. The prototype is *integrated* into the Care@Home platform and *evaluated* in field tests. The findings of each iteration are used to *refine* the previous.

3.3 Results of User Studies

We have identified elderly individuals, formal and informal carers, and service providers as our direct stakeholders, while the municipality, designers, technology providers, home care organizations, institutions (medical and educational) and real estate companies are our indirect stakeholders. Focusing on the elderly users for now, the ongoing development has resulted in a prototype of the Care@Home portal for SmartTVs (see Fig. 3). The current version offers messaging, video calling, scheduling and activity coordination. The infrastructure of the Care@Home platform allows synchronization of multiple messaging and agenda accounts, and sharing the to-do list with specific Care@Home users, i.e. his/her carers. The carers are able to check the to-do list and offer him/her to assist his/her task on a specific date. A new planned task is added automatically on the user’s agenda.



(a) (b)

Fig. 3. The interface of (a) the main page of the Care@Home portal on SmartTVs and (b) the main page of the Messaging service

In these activities we found that all participants were enthusiastic about video calling and agreed that notifications, agenda reminders and the to-do list should be placed on a prominent place. Smart functions were perceived as overwhelming. However, if they became familiar with the system, they would like to try such functions. Thus, we decided on designing subtler visuals and user interaction of the automation aspects of the offered services. We also developed a simple menu by limiting to two options on each page (see Fig. 3(b)). The User Testing of the prototype involved 14 participants aged 75-85 years, which included eight participants from the previous activities. Previous participants appreciated that their collected ideas were used on the developed prototype. Several suggestions were prompted (e.g. a reminder of overlapping agendas), but generally it was easy to use.

We also found issues related to technology acceptance. Almost all our study participants made references to the usefulness of the envisioned system for older people but not themselves. Moreover, some participants thought that the current ways, e.g. paper scheduling and calling people, were more suitable instead of making them possible on the TV. Others thought that they did not have the infrastructure (e.g. lacking an informal care network) to make the technology possible. We found that our methods involving end-users in the development process were well suited to reduce gaps between the perspective of the researcher and of the elderly.

4 Conclusion

Our work contributes to current research on technology for the elderly in these ways: Care@Home provides an (1) *open platform allowing new service development, (2) context-based services and adaptive interaction, and (3) integration in existing consumer products.* The R&D of Care@Home follows a human-centered design approach focused on understanding all stakeholders and their values in context. Value Sensitive Design and Co-Design principles are applied to tackle usability, user experience, and ethical issues systematically through early user involvement and iterative integration of research, development, and evaluation. We believe that through this approach we can increase the acceptance of the developed platform and its services, which would lead to a sustainable care system, social inclusion, higher quality of life, and reduced healthcare cost in the long term.

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Evaluation of the Pet Robot CuDDler Using Godspeed Questionnaire

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Abstract. This work is to report the development of an interactive pet companion, CuDDler, with the capability to recognize verbal and non-verbal communication acts that are tied to the emotional state of a person. CuDDler, is a cuddly and affectionate interactive robotic pet companion and around the clock companionship to the elderly. This will positively impact their emotional wellbeing and their quality-of-life, ultimately leading to improved overall health and reduced healthcare cost. A study using Godspeed questionnaire [16] was carried out on general public in an exhibition technology road-show. The experiment indicated high ratings of the Godspeed attribute in “likeability” and “perceived safety”.

Keywords: Robotics, elderly, companionship, emotions and human-robot interaction.

1 Introduction

According to the statistics from the United Nations Population Division, the elderly currently stand at 1.6% (110 Million) of the world population. By the year of 2050, this figure will increase to 4% (400 Million) [1]. Number of elderly staying in nursing home will increase and this may lead to more seniors suffer from loneliness and depression. Research and development in technologies to support for the aged population is widely explored. These include fall monitoring system [2], tele-healthcare systems [3] and medicine compliance devices [4]. In terms of service robots for elderly there are Care-o-Bot [5] and Pearl [6]. In addition to that there are also companion robots that primarily function to enhance the health and psychological well-being of an elderly. Example of such companion robot includes Paro [7], Pleo [8] and Aibo [9]. As such pet-like robot provides assistance to their human-counterpart through social, rather than physical interaction, they are also widely known as Socially Assistive Robotics (SAR) [10]. Pet therapy using domestic animals such as dogs and cats are proven to be capable of promoting positive effect on elderly in nursing home settings [11][12][13]. However as some institutes have certain pet

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restrictions and elderly are allergic to animals, healthcare institutes deter the entry of domestic pets. To further accelerate the research in using pet robotics for elderly, a pet robot, CuDDler, integrated with verbal and non-verbal emotion act recognition engine is proposed. The integration of such component is based on the hypothesis that in addition to simple touch, reaction towards verbal emotion acts (e.g. crying, laughing, shouting and talking) and non-verbal emotion acts (e.g. squeeze, stroking, petting and hitting) is important that may lead to a richer human-robot interaction. Though much debate has been discussed on the use of robots to provide care to humans [14][15], it is hoped through such effort, a more empathetic robotic platform capable of expressing appropriate empathy actions will bring much happiness and improve their quality of life.

In this paper, we investigated the general public acceptance, attitude and response to CuDDler. Findings from this experiment would be used to further improve the capabilities and design of CuDDler. This paper is organized as follows: Section 2 describes the hardware and software design of the robot, CuDDler. In section 3, we presented the experiment carried out in the two day technology exhibition. Section 4 we presented and discussed the experiment result. We concluded in section 5 with a summary and future works.

2 Robotic Platform

CuDDler version 1.0 was based on the form of a polar bear (figure 1). The internal structure of the CuDDler was designed based on the original shape of the polar bear stuffed toy. All the structure used in CuDDler was fabricated in-house using a 3D printer. Minimum readjustment was made on the neck and arm section of the stuffed polar bear for moving the necessary parts of the robot. The neck was capable of performing 3 degree-of-freedom (DOF) movements. Meanwhile eye lid comes with 1 DOF and each arm is with 1 (DOF). The motors used here were purchased from SolarBotics (model GM13a and GM20).

Fig. 1. Actual appearance (left) and internal structure (right) of CuDDler version 1.0

Figure 2 below shows the placement of sensors and motors inside CuDDler version 1.0. Three surface microphones to capture non-verbal emotion acts (e.g. hitting, squeezing, stroking and patting) were embedded in different section of CuDDler: head, stomach and back. Another microphone was placed in the nose area to capture audio signals to recognize verbal emotion acts (e.g. laughing, crying, shouting and talking).

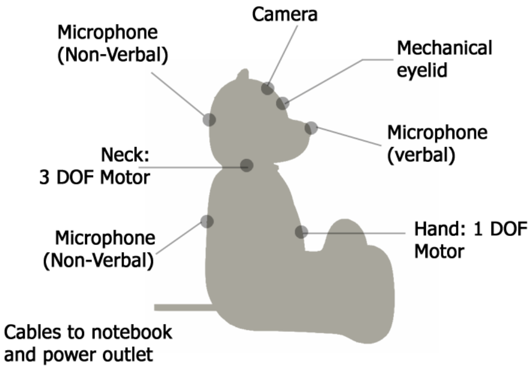

Fig. 2. Sensors and motors in CuDDler version 1.0

The hardware configuration of the prototype robotic platform was divided into two: Arduino™ Mega 2560 ADK board and external notebook running on Windows™ XP operating system. The Arduino™ board controls components controls the motor meanwhile the Windows™ XP operating system executes emotional act recognition and logics of the robotic platform. The cables connected between the robot and the PC includes microphone, USB and power cables for various motors. Table 1 lists the possible emotion acts to be detected and the actions performed.

Table 1. Possible interaction and motion feedback performed by CuDDler version 1.0

Emotional Acts Detected	Emotion Types	Actions Performed
Patting and stroking the back, head, stomach	Happy	Purr, head and front limb moving up and down
Squeezing the back, head & stomach	Angry, Sad	Cover its eyes and shriek in pain
Hitting the back, head & stomach	Angry	Shake head and produce angry sound
Laughing	Happy	Purr, head and front limb moving up and down
Crying	Sad	Shake head and produce angry sound

3 Experiment

3.1 Participants and Study Setup

The participants involved in this study comprised of conference delegates from the Institute for Infocomm Research (I^2R) TechFest 2012 technology exhibition as well as visitors from the general public. A total of 59 participants (39 males and 20 females) participated in this study. All the participants were able to converse and read English and their age ranged from 15 to 40. None of the participants had previously interacted with CuDDler before. No rewards were given to the participants in this study.

The robot (CuDDler) was placed on the exhibition booth counter to allow any visitors to interact with it. Two cameras were placed on top and side of the exhibition booth. The video recordings recorded by these cameras would be observed offline and manually for Human-Robot Interaction studies. Video presentation was also shown in the booth using a 21 inch monitor. The video included a brief introduction of CuDDler technology and capability. The booth also consisted of a poster that summarized the capability of CuDDler.

Participants who approached CuDDler were greeted by the facilitator and given a short briefing about its capabilities using the poster, robot and video. Afterwards, the participants were given a minimum of 2 minutes to interact with CuDDler. Participants were free to touch any part of CuDDler and a response would be generated. Participants were allowed to ask the facilitator question(s) while interacting with CuDDler. Upon completing the interaction with the CuDDler the participants were invited to fill up one page questionnaire based on Godspeed questionnaire [16]. Godspeed questionnaire measures five factors, including perceived anthropomorphism, perceived animacy, likeability, perceived intelligence, and perceived safety. Each factor was assessed by 5-point Likert-scale items which will be shown in the result section.

4 Experiment Results

Table 2 shows the average rating of the Godspeed questionnaire based on the input of 59 subjects in the experiment.

To evaluate the internal consistency reliability, Nunnally [17] recommended a minimum value 0.7 of Cronbach's Alpha. The overall alpha values of the Godspeed attributes for the CuDDler were 0.89, hence sufficient internal consistency reliability was achieved.

Table 2. Overall average score of each Godspeed attribution on CuDDler version 1.0 (Overall Cronbach's Alpha = 0.89)

Godspeed Attribution	Attributes	Mean (*M*)	Standard Deviation (*SD*)
Anthropomorphism (*M*=3.15; *SD*=0.83; Cronbach's Alpha = 0.79)	Fake/Natural	3.36	0.78
	Machinelike/humanlike	3.12	0.83
	Unconscious/Conscious	3.34	0.80
	Artificial/Lifelike	3.10	0.86
	Moving rigidly/Moving elegantly	2.85	0.83
Animacy (*M*=3.29, *SD*=0.79; Cronbach's Alpha = 0.81)	Dead/Alive	3.36	0.74
	Stagnant/Lively	3.29	0.79
	Mechanical/Organic	2.95	0.88
	Artificial/Lifelike	3.12	0.74
	Inert/Interactive	3.51	0.73
	Apathetic/Responsive	3.54	0.73
Likeability (*M*=4.06, *SD*=0.69; Cronbach's Alpha = 0.89)	Dislike/Like	4.14	0.73
	Unfriendly/Friendly	4.10	0.64
	Unkind/Kind	3.93	0.67
	Unpleasant/Pleasant	4.08	0.70
	Awful/Nice	4.02	0.73
Perceived Intelligence (*M*=3.32, *SD*=0.69; Cronbach's Alpha = 0.80)	Incompetent/Competent	3.39	0.74
	Ignorant/Knowledgeable	3.20	0.64
	Irresponsible/Responsible	3.29	0.67
	Unintelligent/Intelligent	3.24	0.73
	Foolish/Sensible	3.49	0.65
Perceived Safety (*M*=3.96, *SD*=0.74; Cronbach's Alpha = 0.52)	Anxious/Relaxed	4.20	0.64
	Agitated/Calm	4.12	0.70
	Quiet/Surprised (Reversed)	3.56	0.75

4.1 Discussions

The following section would discuss in detail the Godspeed attributes gathered in the experiment as discussed in section 3. Based on the results in table 2, the attribution of the anthropomorphism was rated with an average score of 3.15 (SD=0.83) out of the full score of five. According to Bartneck [16], "Anthropomorphism refers to the attribution of a human form, human characteristics, or human behaviour to non-human things such as robots, computers, and animals". Anthropomorphism was not rated high by the subjects and this might largely due to CuDDler's limited motion. Observation of the characteristics "Moving Rigidly/Moving Elegantly" was rated the lowest (*M* = 2.85, *SD*=0.83) in the anthropomorphism group. To address the limitation of hardware/technologies of not being sophisticated enough to conjure any animal accurately, one possible solution was to employ an unfamiliar animal [18]. Through an unfamiliar animal, in this case a polar bear for CuDDler, the expectations would be lower hence it would be easily accepted by the general public. This could be observed through the anthropomorphism attributes of "Fake/Natural" (*M*=3.36, *SD*=0.78) and "Unconscious/Conscious" (*M*=3.34, *SD*=0.80).

Animacy refers to the lifelikeness of a stimulus [16]. In terms of animacy, CuDDler achieved an average score of 3.29 (*SD*=0.79). Possible reason for such average score might be due to the limitation of the motor and number of possible motion. At this stage, CuDDler was capable of performing 3 sets of motions with only limited degree-of-freedom (DOF): Neck = 3-DOF; Eyelid = 1 DOF; Arms = 1 DOF each. The external CuDDler was uneven as no hard casing was fabricated. Hence when users touched CuDDler, it was different from touching a real animal or a stuffed toy. These hypotheses could be proven as CuDDler was rated more mechanical as oppose to organic. Further investigation regarding this would be performed with an improved version of CuDDler with more appropriate motion and proper casing to improve the touch sensation/experience.

Likeability is related to the first impressions made by a person that lead to more positive evaluations to the same person [16] [19]. Among all the Godspeed attributes, Likeability attribute was rated the highest with an average score of 4.06 (*SD*=0.69). Reason for such an observation could probably be correlated to the research findings for animal-assisted therapy (AAT). AAT has been found to raise children's self-esteem and make it easier for them to express themselves [20]. When AAT was employed in elderly nursing home setting, it encouraged expressions of emotions, social behavior, verbal interaction and cognitive stimulation [21]. It was possible for CuDDler to induce such effects to subjects that inherently increased the likeability ratings. However it was not clear the factor(s) leading to such high-rating. Further studies are necessary to identify the exact factor that may increase the likeability of a robot.

As most interactive robots comes with various reasoning or recognition capabilities, perceived intelligence can be monitored through the stimulus competence of performing task(s) [16] [22]. As the current version of CuDDler was only programmed to perform recognition of a few emotional acts and react with limited sets of feedback motion, perceived intelligence received an average scoring of 3.32 (*SD*=0.69). Perceived intelligence might hold certain importance even for a simple pet robot. To address the novelty effect and prolonging the interest of user towards the robotic platform, certain "surprise" and "unpredictability" elements would be necessary [23].

Perceived safety describes the user's perception of the level of danger when interacting with a robot, and the user's level of comfort during the interaction [16]. Average score of perceived safety for CuDDler was 3.96 (*SD*=0.74). The Cronbach's Alpha for Perceived Safety was lower than 0.7 points to ensure consistency reliability as suggested by Nunnally [17]. This was due to the attribute “quiet/surprised”, which according to the online feedback of Godspeed questionnaire, the question might be more suitable to be inverted as in “Surprised/Quiet”. It was also possible that subjects took the attribute “surprised” in a positive manner and hence rated it that way. Regardless of the misinterpretation of the attribute, perceived safety still received a high average score that indicated the comforting level of CuDDler was high as well.

5 Conclusions and Future Work

This paper described the overview of the CuDDler, an interactive pet companion with emotional act recognition engine. Experiment using Godspeed data was presented. Weaknesses of the CuDDler such as animacy due to limitations of the motor and set of possible motion were identified. Another possible improvements required by CuDDler was perceived intelligence. There were plans to incorporate emotion state of the CuDDler that would affect its feedback and mood. By integrating such emotional state into the CuDDler system architecture, more feedback could be generated that would prolonged the interest of the human subject towards the robotic platform. Other methods also included capabilities to respond to speech commands and also to self-learn and adapt to its users’ preference of interaction.

The work presented here laid the foundation for the improved version of CuDDler to be used in an elderly nursing home environment for real-life pilot-study. To measure the efficacy of the CuDDler for the elderly, metrics such as Menorah Park Engagement Scale, Apparent Affect Rating Scale, Cohen-Mansfield Agitation Inventory and salivary biomarkers will be employed. It is also hypothesized through recognition of emotional acts, a richer human-robot interaction can be observed. Various human-robot interaction studies will be performed in the future to prove such hypothesis.

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A User Study for an Attention-Directed Robot for Telepresence

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Abstract. The motivation of this paper is to study the potential use of an attention-directed robot, embodied as a pan-tilt tablet display, for telepresence applications with the elderly. With an audio-visual attention control system, the robot automatically directs attention to a speaker by fusion of visual and auditory features. We conducted a user study involving experiential interaction with the robot, which oriented its display in the direction of the user's voice, and also tracked the user's face once it is in view of the robot's camera. A questionnaire was given to gather the opinions of the participants regarding the usability of the robot for the elderly, and their responses indicate a positive attitude, acceptance, and trust towards the attention-directed robot. By comparing the responses of subjects with different levels of video-conferencing experience, we found that subjects who video-conference more frequently tend to be more accepting of the robot. Furthermore, they indicated an acceptable price of the robot as less than the price of a tablet, and most of them expressed the desire to buy the robot in the near future.

1 Introduction

By the year of 2050, the number of elderly 60 years or older will make up 22% (2 billion) of the world population, according to the statistics from the United Nations Population Division. With this rapid increase of the elderly population comes social problems associated with loneliness and depression. Recently, a new investigation based on home studies finds that social robots can reduce loneliness and improve psychological wellbeing among the elderly [6]. Colin Angle, CEO of iRobot, advocated for assistive and telepresence robots to help the elderly live independently (keynote talk at the 2010 Connected Health Symposium). Motivated by the need for telepresence robots that are acceptable to the elderly, especially those living alone and/or having mobility problems, we developed an attention-directed robot for social telepresence in this work. It is envisaged that the robot can help elderly people connect with their family and friends, thus reducing their loneliness and improving their psychological well-being.

With the growing popularity of Internet call systems such as FaceTime and Skype, telepresence is widely used today. The fixed screen and camera is a major limitation in some existing telepresence robots. When one person moves, the display and camera do not follow the movement and this can easily deteriorate

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the engagement in the telepresence experience between the two parties, especially when a person unintentionally leaves the camera view in the process of a conversation. In this work we describe our portable, integrated robot. The tablet display moves together with the camera to face a speaker, much like one turns his/her head to face another person during a conversation. Our developed robot can be directly used in diverse environments for telepresence to overcome this limitation. While in comparison with existing portable telepresence robot such as Galileo by Motrr [1] which can only be manually controller by users, our robot can automatically realize the audio-visual attention control.

In this paper, we study the potential use of our telepresence robot in the video-conferencing with the elderly. Different from the approach in [2,4,5,8], wherein elderly people are chosen as users, in this user study, we select subjects in the age group of 30-40 years old. While many elderly people are less technically savvy when it comes to technology and robotics, and may thus be less inclined to accept them, younger members of the family, who are more accepting towards robots, can play an important role in encouraging them to overcome anxiety or inertia with regard to high-tech solutions. In order to study the subjects' acceptance of the telepresence robot for elderly, we design a questionnaire examining the subjects' acceptance of the attention-directed robot, anxiety regarding the usage of the robot, and the market potential of the robot, and the relative usefulness of robot for social telepresence with elderly people compared with alternative applications such as business meetings.

2 User Study

The aim of the user study is to observe the use of an attention-directed robot for elderly and the acceptance of robotic technology by users' positive attitude. Currently, the majority of elderly have not much knowledge about robots and come to know about robots from their children and grandchildren. Thus we selected the people whose age ranged from thirty to forty years as the subjects. These subjects' parents were retired older adults above 55 years of age. We would like to study what aspects of the proposed robot caused the users' positive attitude and whether such a robot would ensure actual use for elderly in future.

The robot consists of a pan-tilt actuation unit, auditory and visual sensors, and a tablet display. The display and visual sensor are mounted on the pan-tilt unit, and the auditory sensors are mounted on the base, as shown in Figure 1. The tablet display moves together with the camera to face a speaker, much like one turns his/her head to face another person during a conversation.

The robot is capable of orienting its display in the direction of the user's voice, and also tracking the user's face once it is in view of the robot's camera. Speech source localization is based on the algorithm in [3], wherein a Voice Activity Detector (VAD) is used to discriminate human voice from irrelevant sounds, and then, a combination of Time Delay of Arrival and Steered Beamformer methods is employed to infer the direction of the speech source. Face tracking is based on the algorithm of [7], using a modified implementation of the OpenCV Haar-Based Cascade Classifier.

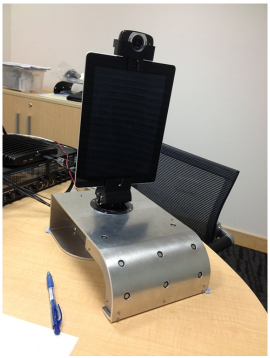

Fig. 1. The prototype of the telepresence robot

A total of 15 persons, comprising 10 males and 5 females, were invited to participate in the experiment. The participants were researchers and graduate students with engineering background, and elderly parents above 55 years old. We set up the robot in a quiet conference room. Each participant had a one-on-one session with a facilitator, who explained the functions of the robot and helped the participants become familiar with how to use it. During the conversation with the facilitator, the participant observed the robot directing attention to the person who was speaking. The participant was also instructed to move around to observe the robot's face tracking performance. After that, the participant was interviewed by the facilitator according to a questionnaire consisting of the following questions:

Q1. How often do you use video-conferencing technology?
1) *Never* 2) *Rarely* 3) *Sometimes* 4) *Often*

Q2. Do you think the robot is useful for elderly people?
1 —— 2 —— 3 —— 4 —— 5 —— 6 —— 7 —— 8 —— 9
strongly negative *negative* *neutral* *positive* *strongly positive*

Q3. Do you think elderly people are able to quickly learn how to use the robot?
1 —— 2 —— 3 —— 4 —— 5 —— 6 —— 7 —— 8 —— 9
strongly negative *negative* *neutral* *positive* *strongly positive*

Q4. Would you like to use the robot for video-conferencing with your elderly family members?
1 —— 2 —— 3 —— 4 —— 5 —— 6 —— 7 —— 8 —— 9
strongly negative *negative* *neutral* *positive* *strongly positive*

Q5. Do you feel that it is convenient to use the robot for video-conferencing with your elderly family members?

1 —— 2 —— 3 —— 4 —— 5 —— 6 —— 7 —— 8 —— 9

strongly negative *negative* *neutral* *positive* *strongly positive*

Q6. Do you feel uncomfortable when using the robot?

1 —— 2 —— 3 —— 4 —— 5 —— 6 —— 7 —— 8 —— 9

strongly negative *negative* *neutral* *positive* *strongly positive*

Q7. Would you be afraid of your elderly family members making mistakes or breaking something on the robot?

1 —— 2 —— 3 —— 4 —— 5 —— 6 —— 7 —— 8 —— 9

strongly negative *negative* *neutral* *positive* *strongly positive*

Q8. What is an acceptable price for the robot?

1) $< \$250$ 2) $250-500 3) $500-750 4) $750-1000 5) $> \$1000$

Q9. If you could have this robot, how soon from now would you want it?

1) *Immediately* 2) *A few months* 3) *One year* 4) *A few years*

Q10. Please rank your preference for the following applications of the robot (1: most preferred, 5: least preferred).

1) *Monitor baby* 2) *Talking with elderly* 3) *Receptionist*
4) *Security and surveillance* 5) *Business meeting*

With Q1, our intention is to study if there is a difference in perceived acceptance of the robot as a result of prior experience with video-conferencing. Questions Q2-Q5 are to evaluate the subjects' acceptance of the attention-directed robot for social telepresence with elderly. Safety and reliability are the important concerns when users decided on accepting a robot in the home. Some users may worry that the robot damage items in the home. In Q6 and Q7, our aim is to observe if the subjects experience anxiety when using the robot. Questions Q8 and Q9 are meant to provide a rough indication of the market potential, with Q8 asking about an acceptable price for a commercialized version of the robot, and Q9 the urgency of the need to use the robot. Finally, Q10 seeks to find out about the relative preference of the robot for applications other than social communications with elderly people.

3 Results and Discussion

This section summarizes the findings by analysis the subjects' responses to the above questionnaire.

3.1 Usefulness of Robot for Social Telepresence with Elderly (Q2-Q5)

The mean responses to Q2-Q5, which measure the subjects' perception of the usefulness of the robot for social telepresence with elderly, are shown in Figure 2 (top graph). All mean scores are more than 7, implying that the majority of the participants found the attention-directed robot useful for social telepresence with elderly people. For Q2, a total of 13 subjects believed that the robot is useful for the elderly, and only 2 subjects gave the neutral "5" score on the Likert scale, which is the lowest score for this question. Similarly, for Q3, only 2 subjects gave low scores (≤ 5), and the remaining subjects felt that the elderly could quickly learn to use the robot. For Q4 and Q5, there were 13 subjects who affirmed their willingness to use the robot and also felt that the robot would be convenient to use for video-conferencing with the elderly, while only 2 subjects felt neutral about these points.

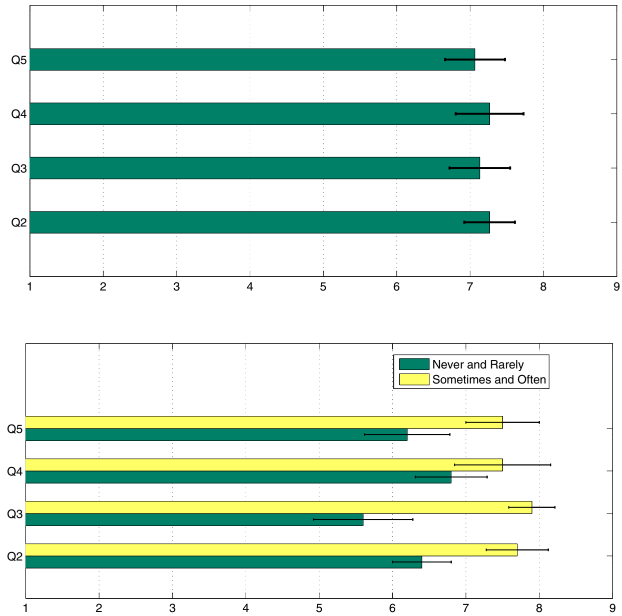

Fig. 2. Top: Mean responses to Q2-Q5. Each box represents the mean value of the response and each bar means the standard error of the mean value. Bottom: Comparison of responses to Q2-Q5 between 2 groups with different amount of prior video-conferencing experience.

Next, we group the subjects into 2 populations according to their prior experience with video-conferencing, and compare the responses to Q2-Q5 between the two groups in Figure 2 (bottom graph). For Q2, the comparison suggests that subjects with more video-conferencing experience felt that the robot was more useful for elderly people. Because elderly people are generally less savvy with new technologies, it is important to take into account the ease with which they can learn how to use the robot. The response to Q3 showed that subjects with more video-conferencing experience tend to agree more with the statement that the elderly can quickly learn to use the robot. For Q4, subjects who video-conference frequently felt more willing to use the robot for video-conferencing with elderly family members, compared with subjects who never or rarely use video-conferencing before. For Q5, the feeling that it is convenient to use the robot for video-conferencing also increases for subjects who had more video-conferencing experience. These comparison results imply subjects who use video-conferencing frequently tend to perceive the robot as more useful as a social telepresence tool for the elderly.

3.2 Comfort Level When Using Robot (Q6 and Q7)

Questions Q6 and Q7 were used to measure the subjects' comfort level when using the robot, including their perception of the robot's safety and reliability around elderly people. The aggregate responses to Q6 and Q7 are summarized in the top chart of Figure 3, where we see that the subjects, on average, disagreed quite strongly (mean score of 2) with the statement that using the robot made themselves feel uncomfortable (Q6). For Q7, the mean score is close to 4, indicating a stronger concern on the safety and reliability of the robot around their elderly family members.

We also evaluate if there is a difference in response between subjects with different levels of experience in video-conferencing. The comparison presented in the bottom chart of Figure 3 provide indication that subjects who used video-conferencing more frequently felt more comfortable about using the robot themselves and letting their elderly family members use the robot.

3.3 Market Potential of Robot (Q8 and Q9)

We asked the subjects about the acceptable price of the robot (Q8), and most of them selected the range $250-500. When subjects were interviewed to elicit their feedback after completing the tasks in the experiment, we also had a chance to discuss some possible reasons for their choice. An interesting finding is that a lot of subjects asked if the tablet (mounted in our robot for demonstration) was part of the robot. After they know that the robot excludes the tablet, most of them selected the range $250-500. Some of subjects commented that the cost of the robot should not be more than the cost of tablet. There were also a few subjects who estimated the price by adding up the individual estimated prices for the major components of the robot, including the motors, webcam and microphones, and finally arrived at the range of $250-500.

Besides the price, we also wanted to find out about how urgent and compelling is the need for the robot (Q9). The response showed that 2 subjects wanted the robot immediately, 8 after a few months, and 5 after a year. None chose the

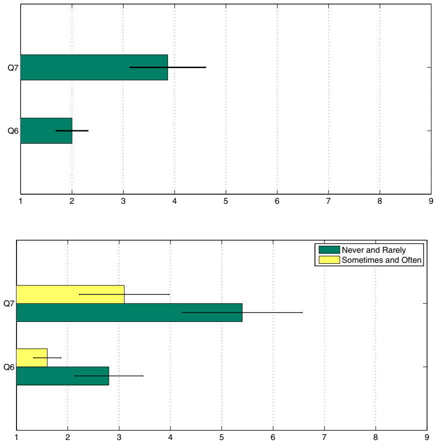

Fig. 3. Top: Mean responses to Q6 and Q7. Bottom: Comparison of responses to Q6-Q7 between 2 groups with different amount of prior video-conferencing experience.

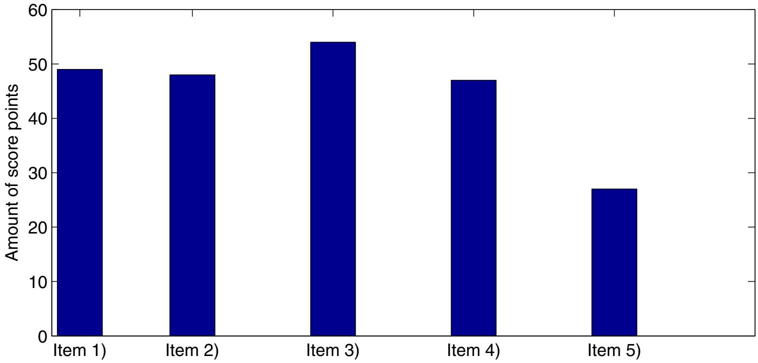

Fig. 4. Ranking scores for different application scenarios according to Q10

option “after a few years”. Thus, most of the subjects felt willing to purchase the robot within the near future. These results suggest that there may be marketing potential for the robot.

3.4 Preferred Application Scenario for Robot (Q10)

We obtained feedback about the subjects' preferred application scenario for the attention-directed robot through Q10. In this question, we provided 5 possible applications, and the facilitator gave a detailed explanation for each application. Subjects are required to rank these applications from 1 to 5, where 1 denotes the most preferred and 5 the least preferred. For each application, we accumulated the rank points given by the subjects. Figure 4 shows a comparison of the total scores accumulated by the various applications. Since the lowest score represents the highest rank, we found that the "business meeting" scenario is the most preferred application, while "receptionist" is the least preferred. However, it is noted that other than the clear winner, the other application scenarios have similar scores. This means opinions are uniformly divided about applications other than "business meeting". While "talking with elderly" is not the most preferred application for the attention-directed robot, it is comparable with the other applications, and certainly not the least preferred.

4 Conclusion

In this paper, a preliminary user study of an attention-directed telepresence robot has been presented. The main objective of the study is to find out the perceived usefulness of the robot for social telepresence with elderly people, along with the level of comfort when using the robot. Based on responses to a questionnaire, we found that most subjects are positive and comfortable about using the robot. We also found that subjects who use video-conferencing frequently tend to be more positive and accepting of the robot than subjects who rarely use video-conferencing. Furthermore, most of the subjects indicated that the cost of the robot should not be more than the cost of a smart tablet (estimated at $500), and most of them expressed the desire to buy the robot within a few months from now. When 5 application scenarios for the attention-directed robot are compared and ranked in order of preference, the "business meeting" scenario is the most preferred, while "talking with elderly" obtained similar scores with the remaining 3 scenarios, namely "receptionist", "security and surveillance", and "monitor baby".

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Supporting Technology for Wheelchair Users
Intuitive Interface and Step Climbing Assistance

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Abstract. This paper introduces the two types of supporting technology for wheelchair users. One is the intuitive interface for electric wheelchair user. The other is step climbing mechanism for manual wheelchair users. In order to realize intuitive interface, we adopt to use human body motion interface. From the experiment, it turned out that proposed interface has a potential for providing intuitive operation. For manual wheelchair users, we propose the assistive caster unit for step climbing. This Caster unit has two functions, one is the assistive plate and the other is lock function. The assistive plate makes easy step climbing. The lock function enables to climb a step form oblique approach. For the experiment, the proposed caster unit could reduce user's driving force, namely it could assist manual wheelchair users.

Keywords: Human Body Motion Interface, Intuitive, Step climbing, Caster.

1 Introduction

This paper introduces two supporting technologies for wheelchair users. One is the intuitive interface for electric wheelchair. The other is the caster unit to assist a step climbing for manual wheelchair users.

There are two types of wheelchair which are electric and manual drive, and they are typical assistive apparatus. The wheelchair has not only complement functions of mobility but also means of assisting the human activities and social participation of user. For example, In order to save user's physical power as much as possible, the wheelchair takes charge of all mobile functions. Then preserved user's physical power can be allotted to the user's activity such as work, leisure and sport after locomotion, then user can receive the vitality and enjoyment. The locomotion is no more than means for obtaining enjoyment.

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The locomotive assistance by wheelchair, which does not spend user's physical energy, can contribute to enhance the quality of life and enjoyment.

Thus the wheelchair is the assistive apparatus for not only complementing user's mobile functions but also enhancing user's quality life by promoting user's activity and participation. The components of the human life which is shown by ICF (International Classification of Functioning, Disability and Health)[1] also suggest that concept.

For this concept, it is important to focus the design which does not require waste power or energy of user. The key points are the intuitive interface in case of electric wheelchair, and mechanical system to reduce user's driving power in case of manual wheelchair. Therefore this paper considers following issues. Here, this paper targets the users who can move their arms and keep their upper body posture arbitrarily.

(I) What is the intuitive interface design for electric wheelchair?
(II) What is mechanism to reduce user's driving power?

Regarding (I), the interface, which uses natural body motion caused by voluntary motion, is proposed in section 2. For (II), we indicate the caster which can reduce the driving power and can be replaced from conventional wheelchair caster without any modifications at mainframe of wheelchair in section 3.

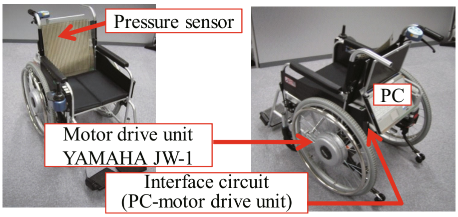

Fig. 1. The overview of the prototype

2 Human Body Motion Interface

In order to utilize the electric wheelchair as an assistive apparatus, its interface should offer the intuitive control. Non-intuitive interface gives stress to the user[2]. If the locomotion, which is essentially means, becomes the purpose, and then the motivation of user for a certain activity is decreased. The conventional electric wheelchair interface is the stick controller. For using the stick controller, user needs to estimate the motion of wheelchair and combine some wrist motions. Therefore stick controller is not always intuitive, because it requires logical combination of estimation and motion. Furthermore, it requires complex wrist movement that becomes difficult with age[3] and may result in inadequate control leading to accidents.

Therefore it is useful to consider an interface that uses a body part other than the wrist without need for complex movement. In order to realize this intuitive interface, we focus on the natural body motion which comes from voluntary motion[4]. It is considered that this natural motion is linked to intention of actions. Therefore, we think that the intuitive interface is realized by using natural body motion. We call this interface as Human Body Motion Interface(HBMI), and adopt it for controlling an electric wheelchair[5](Fig. 1).

2.1 Control of the Electric Wheelchair

We made a prototype by using human body motion interface. In this section, the outline of the system and control scheme is presented.

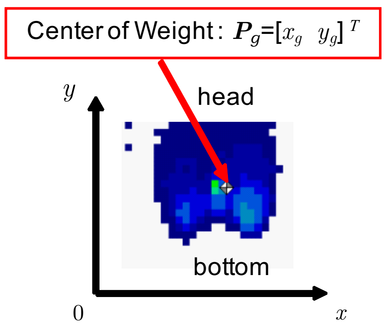

Fig. 2. The coordinate of the center of weight of pressure on the backrest

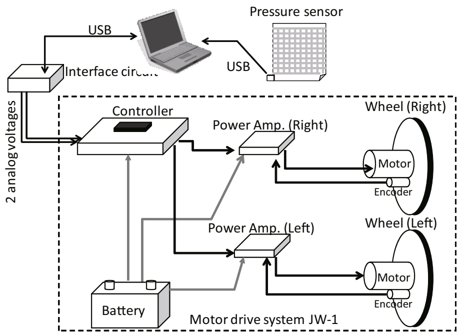

Fig. 3. Proposed system configuration

System Configuration. The center of weight on the pressure distribution on the backrest(Fig .2) is used for control input to the interface. The system configuration is shown in Fig. 3. The main elements of this system are motor drive unit, pressure sensor and PC. BPMS (Tekscan Inc.) is adopted as a pressure sensor, YAMAHA JW-1 is used as motor drive unit. The control unit of JW-1 receives two instruction voltages which are back-forward and left-right direction from PC, and allots adequate voltage to left and right wheel motor. PC has both roles which are main controller and collecting data from pressure sensor. PC gives the drive voltage to each wheel based on the pressure information. Fig. 1 is the overview of the electric wheelchair controlled by HBMI.

Control Scheme. Proposed system uses the center of weight (Fig. 2) as a change of pressure distribution caused by body motion. Since the interface of JW-1 is two voltages, the position of center of weight is converted into two voltages. Then body motion is connected with the motion of wheelchair. The following procedure is control scheme.

1. The initial position of the center of weight $\boldsymbol{P}_{g0}$ is recorded when the operation starts.
2. The instruction voltage is calculated by following equation.

$$\boldsymbol{V} = \boldsymbol{A}(\boldsymbol{P}_{g0} - \boldsymbol{P}_g) \tag{1}$$

   Here,
   $\boldsymbol{P}_g$: Position of the center of weight
   $\boldsymbol{P}_{g0}$: Initial Position of the center of weight
   $\boldsymbol{A}$: Transfer matrix from position to voltage
   $\boldsymbol{V}$: Instruction analog voltage

3. The instruction voltage is sent to the motor drive unit through the interface circuit.

The wheelchair is controlled by above-mentioned method. Fig. 4 shows the test run result. The subject could drive the wheelchair on the figure 8 course layout. As the test run result shows, user can control the wheelchair.

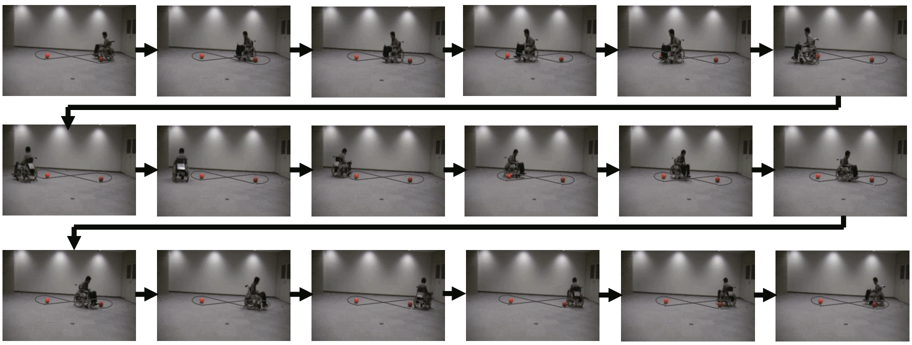

Fig. 4. The test run, on figure 8 course layout

2.2 Evaluation

Experiment was conducted by using 10 subjects to evaluate feeling of operation by utilizing SD method. For 10 subjects, this experiment was the first time to ride a proposed system. Subjects run on the indoor floor, which size is 4m X 4m, in 5 minutes. At this time, there is no restriction for the trajectory, namely, the subjects can run freely in 5 minutes. After that, subjects filled in the questionnaires, and feeling of HBMI was evaluated by SD method. Fig. 5 indicates the answer of each subject. For this figure, Subject A, E, D have the impression of "intuitive and easy operation" rather than the impression "the intention matches the motion" because their questionnaire results are plotted in fourth quadrant. Subject B has the impression of "the intention matches the motion" rather than "intuitive and easy operation" because his answer is plotted in second quadrant. The impression of the subject C, F, G, I and J is

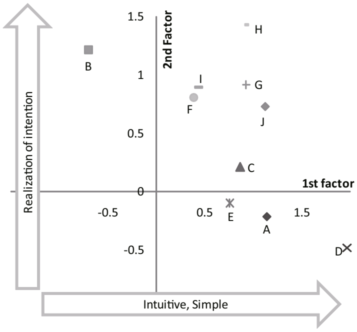

Fig. 5. Factor score

both "the intention matches the motion" and "intuitive and easy operation" because their answer are plotted in first quadrant. Therefore it turned out that HBMI realizes intuitive operation and conformity with the intention although there are differences of impression among the subjects. Thus it was confirmed that HBMI has a potential to provide intuitive operation, and it is the one of the answer for the issue (I) mentioned in section 1.

3 Assistive Caster Unit

One of the main physical loads for manual wheelchair user is driving wheels. User has to drive main wheels by arms whenever he/she wants to move. In particular, in case of uneven road such as stair or gap, user is required to generate more driving forces compared to flat road. Reducing the driving forces in such case contributes to relieve users of their physical burden. That may bring to increase the quality of life of wheelchair users. Therefore, this section introduces the caster unit(Fig. 6 and 7) for assisting the step climbing.

This caster unit also provides easy step-climbing including oblique approach, thus required driving torque for step climbing is reduced comparing with the conventional caster. For this feature, the two functions have been proposed. One is the assistive plate to enlarge the caster radius imaginarily. The other is a lock function on a caster rotation around yaw axis, which enables easy step climbing with oblique approach. Moreover, this unit is easily replaced with the conventional wheelchair caster.

3.1 Key Functions

The problems in case of step-climbing are following two points.

Problem 1) The climb-able step height is limited by the radius of wheel
Problem 2) The driving force is divided in case of oblique step climbing, because the yaw axis of caster rotates when the caster faces the step.

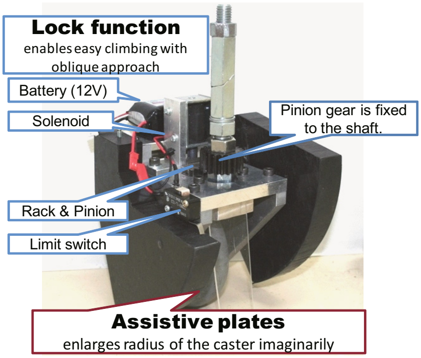

Fig. 6. Proposed Caster unit

Fig. 7. Wheelchair with caster unit

Problem 1) is that: The space between wheelchair frame and footrest where the wheelchair caster is attached is limited, and the caster is designed so as to be installed in this small space. Therefore the caster diameter should be small compared with it of main wheel. Generally, the climb-able step height is less than 1/3 of its diameter for conventional wheel. Thus in case of climbing a 30-40 mm step, users need much power, and have to change the center of weight of his/her body.

Problem 2) is that: In case of oblique step climbing (Fig.8(a)), the yaw axis rotates due to the caster dynamics(Fig.8(b)). For this yaw axis rotation, driving force which is generated by the user is divided into two directions: "moving direction (parallel direction to the step)" and "right direction to the step". The only the force of "right direction" is effective for step climbing. The force "moving direction" is not used, namely the user's force is exhausted. Therefore it is difficult to climb a step or much power is required(Fig.8(b)).

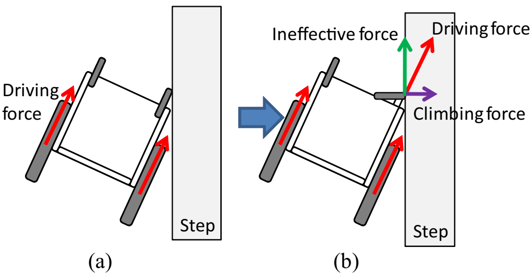

Fig. 8. Driving force in case of oblique approach to a step

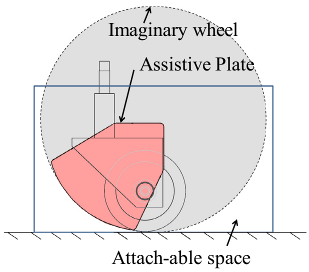

Fig. 9. Assistive plate makes imaginary big caster in the confined space

In order to solve these problems, we propose following two functions

1. Enlarge the radius of caster wheel as possible in the confined space shown in Fig. 9.
2. Lock-function to fix the yaw axis rotation of the caster in case of oblique step climbing.

Assistive Plates. The radius of assistive plate is 123mm. The assistive plates rotates as same as general wheel when the plates touch the step. The assistive plate is not a complete circle, but a sector. The arc part of the assistive plate touches the edge of the step. And it rotates as the same manner of genera wheel rotation. The assistive plates have to be equipped with righting moment force at its rotational center, in order to return the plate in the initial position. For this moment, the torsion spring is attached to the rotational center of the assistive plate.

Lock Function. The role of lock function is to fix the yaw axis rotation of the caster in case of oblique step climbing. The lock function is composed by the solenoid, rack and pinion gear, and limit switch. Fig. 10 is a lock function mechanism. When the assistive plates touch a step, the limit switch is turned on. And then the solenoid is enabled and the rack gear is lifted up, because the rack gear is connected to the output shaft of the solenoid. Then the rack and pinion gear are engaged, and the caster yaw rotation is locked.

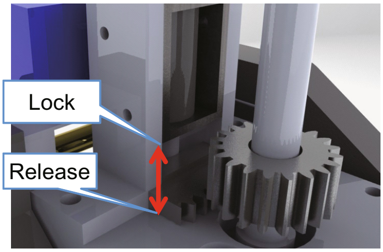

Fig. 10. Lock function mechanism

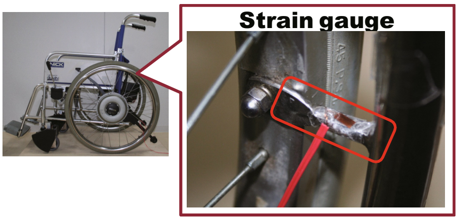

Fig. 11. The attached strain gauge

Table 1. Strain at the root of handrim

Step Height [mm]	Disable Lock Func. Strain[10^{-6}]	Enable Lock Func. Strain[10−6]
10	51.5	42.5
20	78	37.5
30	X	38.5
40	X	68

3.2 Evaluation

In order to verify the efficiency of proposed caster units, we measured the strain at the attached point of hand rim to the main wheel by using strain gauges (Fig. 11).

The one of the results is shown in Table 1. In this table, gXh indicates that wheelchair could not climb a step. It turned out that driving force is reduced by using lock function and assistive plate.

4 Conclusion

This paper introduced the two types of supporting technology for wheelchair users. One was the intuitive interface for electric wheelchair user. The other was step climbing mechanism for manual wheelchair users.

The wheelchair is the assistive apparatus for not only complementing user's mobile functions but also enhancing user's quality life by promoting user's activity and participation. For this concept, it is important to focus the design which does not require waste power or energy of user. The key points were the intuitive interface in case of electric wheelchair, and mechanical system to reduce user's driving power in case of manual wheelchair. Therefore this paper considered following issues.

(I) What is the intuitive interface design for electric wheelchair?
(II) What is mechanism to reduce user's driving power?

Regarding (I), the interface which uses natural body motion caused by voluntary motion was proposed. From the experiment proposed interface has a potential for providing intuitive operation. For (II), we indicated the caster which can reduce the driving power and can be replaced from conventional wheelchair caster without any modifications at mainframe. This Caster unit has two functions, one is the assistive plates and the other is lock function. The assistive plate makes easy step climbing. The lock function enables to climb a step form oblique approach. For the experiment, the proposed caster unit could reduce the driving force.

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Hybrid Reasoning Framework for CARA Pervasive Healthcare

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Abstract. Pervasive computing has emerged as a viable solution capable of providing technology-driven assistive living for elderly. The pervasive healthcare system, *CARA*(Context Aware Real-time Assistant), is designed to provide personalized healthcare services for elderly in a timely and appropriate manner by adapting the healthcare technology to fit in with normal activities of the elderly and working practices of the caregivers. The work in this paper introduces a personalized, flexible and extensible hybrid reasoning framework for *CARA* system in a smart home environment which provides context-aware sensor data fusion as well as anomaly detection mechanisms that supports Activity of Daily Living(ADL) analysis and alert generation. We study how the incorporation of rule-based and case-based reasoning enables *CARA* to become more robust and to adapt to a changing environment by continuously retraining with new cases. Case study for evaluation of this hybrid reasoning framework is carried out under simulated but realistic smart home scenarios. The results indicate the feasibility of the framework for effective at-home monitoring.

Keywords: Pervasive Healthcare, CARA, Cased Based Reasoning (CBR), Fuzzy Rule Based Reasoning (FRBR), Activity of Daily Living(ADL), Anomaly Detection, Home Automation, Smart Home.

1 Introduction

With an increasingly ageing population profile, the provision of healthcare is undergoing a fundamental shift towards the exploitation of pervasive computing technologies to support independent living and avoid expensive hospital-based care [1]. Pervasive and context-aware applications [2] have been widely recognized as promising solutions for providing ADL analysis for the elderly, in particular those suffering from chronic disease, as well as for reducing long-term healthcare costs and improving quality of care [3].

The original CARA healthcare architecture has been shown to enable improved healthcare through the intelligent use of wireless remote monitoring of patient vital signs, supplemented by rich contextual information [4,5]. Important aspects of this application include: inter-visibility between patient and caregiver;

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real-time interactive medical consultation; and replay, review and annotation of the remote consultation by the medical professional. A rule-based reasoning engine is implemented in the CARA system by using fuzzy logic [6]. It allows a user to configure the fuzzy membership functions which represent the context model, and applies user designed fuzzy rules to make inferences about the context. The annotation of significant parts of the fuzzy-based reasoning provides the basis for the artificial intelligence of the CARA system. However, this system requires certain medical knowledge to structure fuzzy rules to perform the reasoning. It is limited by being domain specific and not so adaptable to a changing environment.

In this paper we present a novel approach that combines context awareness, case-based reasoning, and general domain knowledge in a healthcare reasoning framework. In combining these concepts the architecture of this system has the capability to handle uncertain knowledge and use context in order to analyse the situation and lead to an improved independent quality of life. The limitations of a single reasoning method are overcome by adapting the domain knowledge as rules in the process of reusing cases. Moreover, we introduce the idea of query-sensitive similarity measures in the case retrieval step which dynamically adjusts weights of contexts based on the output of the fuzzy-based rule engine.The context aware hybrid reasoning framework we proposed is flexible and extendible which can be applied to various domains. Especially in the medical field, the knowledge of experts does not only consist of rules, but of a mixture of explicit knowledge and experience. Therefore most medical knowledge based systems should contain two types of knowledge: objective knowledge, which can be found in textbooks, and subjective knowledge, which is limited in space and time and individual. Both sorts of knowledge can clearly be separated: objective knowledge can be represented in the form of rules, while subjective knowledge is contained in cases. The limitations of subjective knowledge can partly be solved by incrementally updating the cases [7]. The objective of this paper is to present a scalable and flexible infrastructure for the delivery, management and deployment of context-aware pervasive healthcare services to the elderly living independently.

2 Hybrid Reasoning Framework

2.1 Overall Design

A pervasive healthcare system is an ambient intelligence system that is able to (i) reason about gathered data providing a context-aware interpretation of their meaning, (ii) support understanding and decision and (iii) provide corresponding healthcare services. To achieve that in the CARA system, we adopted a context-aware hybrid reasoning framework by means of case-based reasoning and fuzzy rule-based analogy. The high-level interactions in the hybrid reasoning engine are presented in Figure 1. Raw data coming from sensors is processed and integrated with context knowledge by the context data fusion services, producing contexts for building case queries and fuzzy sets. After that, the case-based reasoning component starts running a standard CBR cycle(Retrieve, Reuse, Revise and

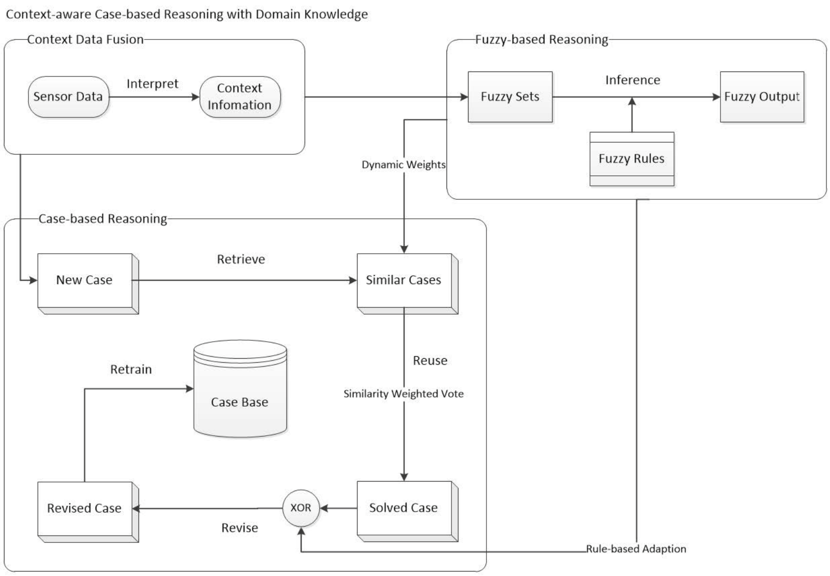


Fig. 1. The Structure of Context-aware Hybrid Reasoning Framework

Retain) to perform anomaly detection and home automation. Meanwhile, the fuzzy rule-based analogical component loads fuzzy rules from the inference rule database to generate higher level contexts(e.g. medical condition, and accident event) and further to identify current situation of the user (normal, abnormal or emergency). The result of the fuzzy output can be used to dynamically adjust weights of features or groups for case retrieval, and can also affect the adaptation of the retrieved solution to the new case. The case is revised according to the combination of retrieved similar cases and fuzzy outputs. Finally, if the detected situation is abnormal or an emergency, a notification or alarm is automatically sent to the remote monitoring server and an emergency service call can be triggered. The collected raw data and revised case are stored for enhancing the case base and subsequent additional analysis.

2.2 Context-Aware Query Sensitive

Case-based reasoning is recommended to build intelligent systems that are challenged to reduce the knowledge acquisition task, avoid repeating mistakes made in the past, reason in domains that have not been fully understood or modelled, learn over time, reason with incomplete or imprecise data and concepts, provide a means of explanation, and reflect human reasoning. However, the common k-nn (k nearest neighbour) algorithm for case retrieving has limitation as pointed out in [8], finding nearest neighbours in a high-dimensional space raises the following issues:

1. Lack of contrast: Two high-dimensional objects are unlikely to be very similar in all the dimensions.
2. Statistical sensitivity: The data is rarely uniformly distributed, and for a pair of objects there may be only relatively few coordinates that are statistically significant for comparing those objects.

To address these problems, we propose to construct, together with context awareness, a query sensitive mechanism for similarity or distance measure. The term *Query Sensitive* means that the distance measure changes depending on the current query object. In particular, the weights used for the features similarity measure automatically adjust to each query. Specifically, we apply fuzzy rules to the input query and use the crisp value of fuzzy output to dynamically adjust weights, which we expect to be significantly more accurate than the simple k-nn method associated with case retrieving. The query sensitive similarity measure function employed by our reasoning framework is shown in Equation 1.

$$Sim_g(Q,P) = \frac{\sum_{k=1}^{n} W_k Sim_l(Q_k, P_k)}{\sum_{k=1}^{n} W_k} \tag{1}$$

In this formula, Sim_g(Globe Similarity) of Q(Query) and P(Past Case) is calculated based on Sim_l(Local Similarity) of Q_k(Feature k of Query) and P_k(Feature k of Past Case) and the dynamic weight of the feature W_k. If k is the feature of a query, we use the term *weighted* to denote any function mapping W_k(weight of k) to the binary set 0,1. We can readily define the function using fuzzy logic. Given a query Q, and a block of fuzzy rules F_{rule}, we can define a weighted function $W_{Q,F_{rule}} \rightarrow \{0,1\}$as follows:

$$W_{Q,F_{rule}}(k) = \begin{cases} f(k) & if\ \forall k, k \in F_{rule} \\ 0 & otherwise \end{cases} \tag{2}$$

Where $f(k)$ is the degree of fuzzy membership function of feature k. For instance, we define the fuzzy membership function of Systolic Blood Pressure containing fuzzy sets {*very low, slightly low, normal, slightly high, very high*}, among them, *very high* is a left linear fuzzy set in the range of 140 to 200. If the Systolic Blood Pressure of a new case is 167mmHg, once the fuzzy rule "if (Activity is Sleeping or Activity is Resting or Activity is Watching TV or Activity is Toileting) and (Systolic Blood Pressure is High or Dynamic Blood Pressure is High) then Situation is Abnormal" is evaluated and triggered, the weight of Systolic Blood Pressure used for the similar case retrieval is set to 0.45 which is the fuzzy degree of *very high* fuzzy set of Systolic Blood Pressure. As the result, the final weight for each feature of the query is dynamically adjusted by the fuzzy outputs.

2.3 Similarity Weighted Vote

Similar cases are retrieved after the K Nearest Neighbour(K-NN) function is applied to similarity measurement. Normally, the possible solution for the given query can be predicted from the most similar case. In our case, for anomaly detection, the results of retrieved cases are supposed to be classified into *Normal, Abnormal, Emergency* categories. To determine the possible situation of the subject, a similarity weighted voting mechanism is considered to be used in the voting decision during prediction. Basically, every nearest neighbour has a different influence on the prediction according to its distance to the query. The principle of similarity weighted voting method is to use the similarity value of each retrieved case as the weight to vote for the most reasonable solution. It is achieved in following steps:

1. Classify K-NN retrieving result into different groups.
2. Calculate total similarity of all retrieved cases.
3. Get the sum of similarity of each group.
4. Use the group similarity to vote for prediction.
5. Calculate confidence value of the predicted result.

To distinguish the predicted result from past cases, we apply a threshold to the confidence value of the predicted solution which is used as a controller to balance the detection rate and false alarm rate of the rule engine. Let us remark that the threshold ε can be freely set by the user. If user chooses $\varepsilon = 0$, the rule engine takes into account all possible problems in P(Past Case), and the determination of the solution of a unique Q(Query) associated with given P lies in this case on the voting result. Otherwise, the threshold ε can be considered as a level of decidability: if there exists no P such that $Conf(Q, P) \geqslant \varepsilon$, then there is no already solved problem sufficiently similar to Q and no solution can be proposed. In this case we introduce the fuzzy adaptation model to deal with the uncertainty. The core competence of our reasoning framework is that domain knowledge, which is represented by fuzzy rules and fuzzy sets, is applied to both case retrieving and case adaptation.

2.4 Fuzzy Adaptation Model

We have developed an adaptation technique for case-based reasoning derived from fuzzy logic based analogical reasoning and modelling. Fuzzy logic imparts to case-based reasoning the perceptiveness and case discriminating ability of domain knowledge. Problems and solutions are, in many cases, described by means of linguistic terms or approximate values derived from expert knowledge. A convenient knowledge representation is thus fuzzy set based. The reason why we choose fuzzy logic is because it provides a simple way to arrive at a definite conclusion based upon ambiguous, imprecise, noisy, or missing input information. The steps to constructing the fuzzy adaptation model assisting CBR are:

1. Configure the fuzzy reasoning model.
2. Traverse the case base to find k-nn similar cases.
3. Make a prediction based on weighted median of similarity.
4. Apply the fuzzy adaptation if the confidence of the prediction is low.
5. Use the fuzzy output to revise the solution of the present case.

Step 1 is performed only once to configure the fuzzy membership function and register fuzzy rules. Step 2-4 are performed every time a CBR cycle starts. Note the fuzzy reasoning mechanism is applied if and only if the CBR method couldn't find a similar solution for the present query, the result of fuzzy output then uses as possible solution from the domain knowledge point of view to make up for the lack of experience. The principle of building a fuzzy framework is to design appropriate member functions which are also referred to as fuzzy sets. The fuzzy relations among these fuzzy sets indicate some of the rules in our reasoning engine. An example of anomaly detection rules are given in Table 1. Such rules can be specified by medical experts or a particular healthcare giver. They can also be modified by patient under supervision in case of individualization.

Table 1. Sample rules for anomaly detection in smart home environment

Medical Associated Rules
if Activity is not Exercising and HeartRate is VeryHigh then Situation is Abnormal
if SystolicBloodPressure is VeryHigh and DynamicBloodPressure is VeryHigh then Situation is Abnormal
Event Associated Rules
if Activity is Sleeping and (TV is ON or Cooker is ON or Lights is ON) then Situation is Abnormal
if Location is Outdoor and Time is Late Night then Situation is Abnormal

3 System Evaluation

It is difficult to evaluate the CARA system in its entirety without extensive field deployment and analysis. Issues including medical, ethical and practical make field experiments infeasible at present.

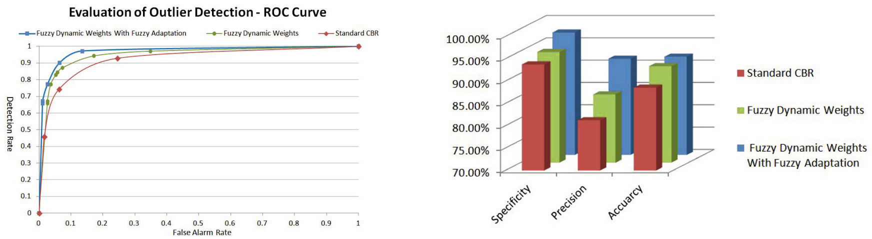
However, we have conducted realistic simulation experiments in our lab to test the correctness of the proposed context-aware hybrid reasoning framework in a pervasive healthcare environment and report the results in this section. In our testing scenario, we deploy the CARA system composed of Remote Healthcare Sever, Wearable Sensors and Client Applications in our lab. For this test stage, real-time vital signs of the patient are collected from wearable BioHarness sensors [9] while environmental sensing is simulated by an android application which we developed to reflect the change of the ambient environment. Biomedical parameters currently taken into account in the model are: heart rate frequency, pulse oxygen level, systolic and diastolic blood pressure, body temperature, and respiration rate while ambient contexts involves time, space and duration associated with a subject's activity, environmental sensing e.g. temperature, light, noise and humidity, device interactions e.g usage of TV, cooker, phone, and status of heater, window and lights.

Use case testing is underway with a trial in our lab. It is carried out to evaluate performance and acceptance of the implemented features. Since the test-bed for smart home environment is still under construction, we have to simulate the behaviour of a person living in a realistic home environment based on the daily routine of an elderly person, which provides us with *Activity Contexts*. We also simulate light, room temperature, sound and humidity changes during the test stage which gives us *Ambient Contexts*. *Physiology Contexts* and *Personal Contexts* are collected from the BAN and loaded from server database respectively.

All the contexts are used to build up the input query for CBR, they are also mapped into fuzzy sets and enforced by applying consistency rules which refers to the domain knowledge. The system then produces the final decision which indicates the current situation of the subject. To simplify the evaluation process for anomaly detection, here we only consider a two-class prediction problem (Normal or Abnormal), in which the outcomes are labelled either as positive or negative. The case base used for testing contains 262 cases, among them, 192 are normal cases and 70 are abnormal cases. We evaluated the proposed approach against the common CBR approach and evolving CBR approach using dynamic weights in case retrieval. Given the high variability among these trials, we are able to evaluate the accuracy of situation prediction over a wide range. The results are shown in Table 2. As we discussed in the previous section, we adjust the threshold for the confidence value to get a trade-off between Detection Rate and False Alarm Rate. We use receiver operating characteristic(ROC) in signal detection theory [10] to evaluate our reasoning framework. By calculating true positive rate and false positive rate, we are able to draw a ROC curve as shown in Figure 2 (a). Each prediction result or instance of a confusion matrix represents one point in the ROC space. The best possible prediction method would yield a point in the upper left corner at coordinate (0,1). So any point closer to that would be considered as a better approach. It is shown that the proposed approach is the best prediction method for anomaly detection. The best performance of each approach is compared and presented in Figure 2 (b),

Table 2. Results of Various CBR Approaches

Threshold	True Positive	False Positive	True Negative	False Negative	Accuracy
Common CBR					
0.9	65	47	145	5	80.15%
0.8	52	12	180	18	88.55%
0.7	32	3	189	38	84.35%
Improved CBR with Fuzzy Dynamic Weights					
0.9	68	67	125	2	73.66%
0.8	66	33	159	4	85.88%
0.7	54	7	185	16	91.22%
Proposed CBR with Fuzzy Dynamic Weights and Fuzzy Rules Adaptation					
0.9	68	26	166	2	89.31%
0.8	63	12	176	7	92.64%
0.7	54	5	187	16	91.98%



(a) ROC Space of Three Different Approaches for Anomaly Detection

(b) Best Performance of Three Different Approaches

Fig. 2. Use-case testing results

where the proposed approach gives 97.4% Specificity, 91.5% Precision and 92.6% Accuracy at Confidence Threshold value of 0.7 while the normal CBR approach only gives 93.7% Specificity, 81.2% Precision and 88.5% Accuracy at Confidence Threshold value of 0.8.

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Elderly Safety: A Smartphone Based Real Time Approach

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Abstract. As the number of elderly people living worldwide and average life expectancy increases, older adults' safety assurance has become increasingly important. There are many works on safety issues of the elderly focusing on human activity classification. Most of them use external sensor devices and/or completely or partially user input based classification and prediction systems. In this paper, we have developed an algorithmic model, monitored and documented elderly people`s daily activities by using the gyroscope and accelerometer of a smartphone and with the use of those data and model, we calculated how much activity is required or overdone for a subject in order to maintain a healthy lifestyle. More importantly, we built a real time system that could not only judge what basic activity the subject is currently doing, but also protect the subject from possible injury that might happen to the subject if abnormal data is received.

Keywords: Pervasive Systems, elder-care, physical and health safety, smart space.

1 Introduction

According to statistics, in 2012 there were approximately 6.2 billion mobile subscribers in the world, which is roughly 87 percent of the Earth's population [1]. Since the technology for smart phone sensors is growing rapidly, most smartphones now have internal sensors such as light, sound, gyroscope, proximity, accelerometer, orientation and GPS (Global Positioning System).

In recent years, the spending on healthcare in the United States has almost exceeded 2 trillion dollars [2]. People have a variety of health issues, such as a sedentary life style, heart disease, high cholesterol, diabetes and so on. Also people have automobile accidents every day that are caused by negligence. This is very common for older people. About 39,000 adults aged 65 and older die each year in the United States from injuries; worldwide this annual toll is about 946,000 persons. The top three causes of injury related death in this age group in the United State are falls, injuries related to motor vehicle crashes, and suicide [3].

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Based on these issues, this paper is aimed at improving the health and safety of the elderly in daily activities. We separate safety issue into two parts; the first is health safety which could be harmed by unhealthy habits and longtime improper activity. Another is physical safety that could quickly be compromised when critical behaviors occur. Therefore, we first built a framework that could be used to easily monitor, get and record sensor data from smartphones. Both accelerometer and gyroscope data are recorded in the SD card. We used a list to keep real time data for both the gyroscope and accelerometer for a short period time. Then we built an algorithmic model to differentiate basic activities such as walking, resting, running, and driving using the sensor data. Based on the collected sensor data and the algorithmic model, we can differentiate basic activities, record the time of each activity for health calculation purposes and conclude how much exercise is needed for the subject to at least maintain current their health status. Also, it reminds the subject what problems might arise if the situation is not changed. Furthermore, our algorithm can also estimate sudden fluctuations in sensor data which might indicate a sudden change of activity. We detect running, turning sharply, moving backwards, and sudden changes in activities. Once one of these is detected, the application warns the subject that there might be potential danger. The goal is to prevent dangerous behavior and anticipate it before it happens. We get weather data and combine that data with our algorithm to make a more accurate judgment on the danger estimation.

2 Related Works

There are many research papers focusing on human activity classification. Most of them use external sensor devices like external tri-axial accelerometer [4] or any other external sensor devices worn by the subject [13]. Some of them use smart phones to collect activity data [5]. One of them [14] use database to store data collected from a MEMS based monitoring system. And then use a fuzzy rule based approach to define each activity. The activity monitoring system is also based on an external device. Although, most of research studies on human activity classification who use smart phones in any phase of their research [8], [9], [10], [11], [12] are good at classification on the algorithmic level, it is difficult to implement on a cell phone as a real time monitoring system because their algorithm requires a large amount of activity data. There is no current work that directly relates real time elderly safety with various human activities, particularly physical safety completely based handheld device.

3 Our Approach

3.1 Framework

In order to efficiently retrieve data from sensors, we created a library that could provide basic sensor operation on Android. In this library, it could list detailed information about the sensor, such as power, frequency, manufacture, and so on. It can also show all this sensor information and real time data on the UI. It can record sensor data and write it onto the phone's SD card. Each recorded file is named by the current system time. The format of the data file is set as 'time X value Y value Z value', While the format of the filename is set as 'month-date, year hour-minutes-seconds'.

All data stored in the file will be recorded with an indicator of the current system time plus the X, Y, Z value of the sensors. Each time the application starts up or restart there will be a new file created in case of filename duplicate or data overwriting. If the application is running all the time without stopping or closing, the data would still be record to one file until any output interruption occurred.

There are four methods in this library each responsible for listing sensors, showing sensor information, showing sensor values and recording sensor data. Any other classes in other projects could easily do these four operations by simply importing the library and call methods.

3.2 Data Recording

After we created the framework that allowed us to easily retrieve data from sensors and record data on the SD card, we added the library to our project. Then we call methods from the library in order to collect sensor data from the accelerometer and gyroscope. We set the delay frequency as normal, which means the time interval between two recordings is 200 milliseconds. Then we keep a record of the system current time that corresponds to each recording. Finally, we write all this information – system time, and value of X, Y, Z of gyroscope and accelerometer on the SD card. The files stored on the SD card are primarily used for static analysis, which requires a relatively large amount of recording.

On the other hand, in order to keep track of short time changes for dynamical analysis, we make several array lists to store information as system time, gyroscope data and accelerometer data. The length of these lists is set to 25 because within that each list would record 5 seconds of continuous data, and we assume the subject could complete at least one cycle of activity. For example, no matter whether the subject is walking or running, we assume that in 5 seconds he or she already finish a set of actions (step left foot – step right foot – step left foot).

3.3 Algorithmic Model

In activity classification, our system has five categories: resting; walking; fast walking; running; and fast running, fast driving. In order to build the algorithm, we used a smartphone (HTC g11) to record both accelerometer data and gyroscope data as training data. In our system, we set the delay frequency of the sensor listener as normal, which means that the sensor takes a recording approximately every 0.2 second (based on testing results of our model phone). Then we take 25 data as a cycle to perform feature extraction, which means only the average value from every 5 seconds will be used to calculated activity classification. In order to eliminate negative number influence, we integrate the sum of the three axis' absolutely value. Here are the steps of algorithm:

- Step1. Create five lists e, t with length of 25;
- Step2. Add the system's current time into list t; add the sum of absolute X, Y, and Z value to list e; t1 XYZ t0(we call the result of this integration energy to describe how much activity the subject has done in a period of time), t1 stands for current recording time
- Step3. Calculate energy with the formula: energy=e(i)*(t(i+1)-t(i));

With the help of the sensor energy, we can calculate how violent of an activity the subject is performing irregardless of direction and orientation. Also, we can judge whether the change from one activity to another is smooth enough to ensure potential safety by comparing the average energy in a short time segment with the real time energy.

In order to do feature extraction, we calculate the average value of sensor data fluctuations of the time segment chosen before. Within this time segment, there are maximal and minimal values for each activity cycle. We try to find the limits of the highest maximal value and the lowest minimal value as a range for activity fluctuation. We define any data beyond those limits to indicate either an activity change or abnormal fluctuation which would refer to a potential danger.

With the help of data mining software tool (WEKA [6]), we build the algorithm that classify human activities into five steps:

- Step 1. Calculate energy (the algorithm we mentioned before);
- Step 2. Calculate the average energy value in order to compare with limits.
- Step 3. Check if GPS is available. If not, skip driving classification. If yes, retrieve speed data.
- Step 4. If the speed data is close to zero, then classify that activity to rest. If not, classify it as driving.
- Step 5. Compare the average energy with multiple limits. Judge which limits the average value is within. And then classify activity to corresponding category.

4 Danger Estimation

4.1 Physical Danger Estimation

Physical safety is different from mental issues and health problems, it is a special kind danger that could happen very quickly and cause physical damage to the subject. For example, running fast on a rainy day may cause slipping. Slipping can happen at any time if subject keeps running and may cause physical injury when he or she falls down. In our system, we defined five types of 'physical danger: suddenly speeding up, turning too fast, losing balance, driving too quickly and moving backwards.

Suddenly Speeding Up. This is determined when there is a surge of accelerometer energy during walking or resting. We assume that there should be a warm-up process for whatever activities the subject is performing. For example, when a subject wants to run, he or she should go from resting to walking, then to jogging, and finally to running. A sudden change from a low speed activity to a high speed activity is not allowed in our system, such as from resting or walking to fast running. This is also true for changing from a high speed activity to a low speed activity. Although the surge in the data might happen due to other intensive activity, we include them all in this type. Therefore, sudden activity changes, such as violent movement when in a low energy activity are taken as this particular danger type. The safe limits are first determined at the same time as activity classification and then calculated real time.

Turning Too Fast. This is similar to speeding up fast. The difference is that for this physical danger type we use the gyroscope to identify sharp increases in energy. Because we assume that no matter how the subject puts his or her phone into his or her pants pockets, the Z axis is always vertical. And when he or she is turning, the X value of gyroscope would change tremendously. For example, if a subject is turning in a circle then the accelerometer energy would show very little difference between that activity and rest. But the gyroscope could better identify that activity. So we use the gyroscope to determine if a subject is turning violently, which we assume would detrimental to elderly people`s muscle and tissue health. The algorithm is similar to speeding up quickly; the difference is that we use gyroscope data instead of accelerometer data.

Losing Balance. This type of threat might be caused by falling or jumping down. Even when a subject is static, the sensors still have data that indicates balance. Once the energy is far less than the gravity value or getting close to zero, it indicates that the subject is falling. In our system, we use this threat type to estimate falling down and to warn elderly people

Driving Too Quickly. Driving is similar to the rest of the categories as it uses data from both the gyroscope and the accelerometer. When the subject is driving the data from the gyroscope and accelerometer look similar to the rest except with a little fluctuation when speeding up and speeding down. Therefore, we use GPS or a network as an additional quantifier to determine the subject's speed. If these additional quantifiers are present then the activity is in driving type. If not, we classify it as rest. Then we monitor the speed and record the time, as either driving for too long or driving too fast can be dangerous. We also calculate safe limits for driving activity. These limits would be narrower and more restrictive since any little sensor data change indicates a much more violent change.

Moving Backwards. This is the most difficult type among these five. Because smartphones may be kept in different orientations, and the integration of absolute accelerometer data or gyroscope data is done it can be very hard to tell whether the subject is moving forwards or backwards. We used feature extraction within a time segment, and this time kept the sign in front of sensor data. If there is a number of opposite sign to the average value (calculated during the time segment), and if the absolute value of that number is larger than the absolute value of any number of the same sign, we conclude that there is backwards movement or at least there is a trend of backwards movement. Here is the algorithm we used to estimate backwards movement:

- Step 1. Use lists x, y, z to store accelerometer data X, Y, Z;
- Step 2. Use lists maxx, maxy, maxz, minx, miny, minz to store the maximal and minimal value of x, y, z;
- Step 3. By comparing (maxx-minx), (maxy-miny), (maxz-minz), identify along which axis the activity has highest fluctuation;
- Step 4. After finding the highest fluctuation axis, calculate the sum value and the absolute sum value;
- Step 5. Compare the last value of the highest fluctuation list with the calculation result. If the absolute value of the last value is larger than the average of the absolute sum and the sign of it is opposite to the sign of sum, the moving backwards condition is satisfied.

Integration. After we use activity classification to classify each type of threat to elderly safety, we call those algorithms of different threat types to judge whether the threat condition is satisfied and which threat condition is satisfied. If the threat condition is satisfied, the phone will warn the subject with sound and vibration as a reminder that he or she should watch what is going on.

Additional Features. We added the weather condition to our physical safety condition to ensure more accuracy with it. The thought is that most activities take place outdoors, which would be influenced a lot by weather condition. Our system first find the longitude and latitude of the phone at its current location, and then retrieve weather data from Google weather report. Based on temperature, wind speed, and weather condition, we can add the weather factors into threat factors.

4.2 Health Danger Estimation

For health safety, we are aiming at evaluating the subject's health condition from daily activities and forward approximations that determine whether the subject is or is not within a safe activity range to maintain health. In order to reach this goal, we use the MET value as a numerical way to measure activity[7].

Every time we collect activity data from the smartphone, we first classify activities. Then we transfer those classified activities into a MET value by a specific MET-Relation table (from health science research). The table shows 600 kinds of activities and their related MET values. For our system, we only choose running, waking and resting. We record daily running and walking activities and transfer them into MET values, then we calculate how many MET values the subject has acquired for one week. After that, we compare the MET value with a MET-Disease table to draw conclusions about whether the subject participated in enough activity or not.

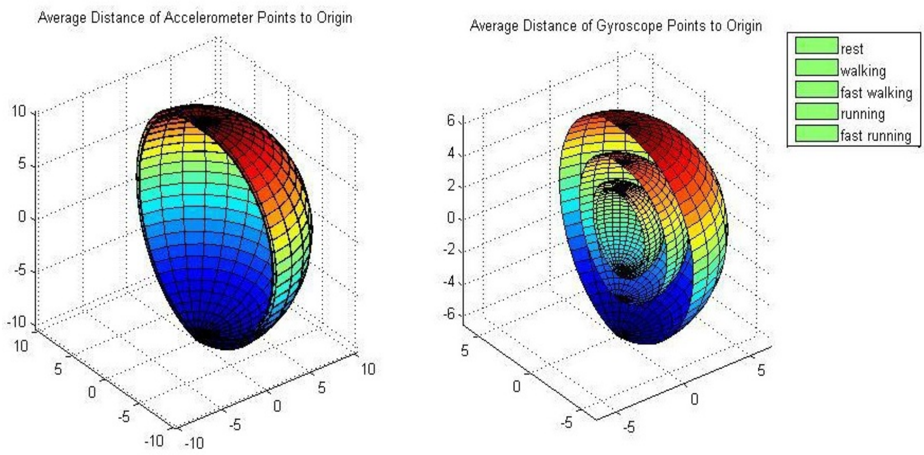
Furthermore, we keep a record of how long a subject is at rest. We take the rest time as sedentary time. By counting the sedentary time, our system will draw a simple graph that indicates the danger ratio of a subject based on his or her sedentary time. In our system, the automatic health threat estimation can only analyze basic activities such as resting, walking, running and driving. It is limited by the algorithm that we used to classify activities. In our system, we integrate the definition of other complex activities into those classified basic activities instead of building more categories. In order to make the analysis results more precise and in case the subject does not carry a phone, we added the manual input as another way to help adjust auto estimation error. We built a manual input UI to allow the subject to choose what activities he or she did (from the 600 activities table) and input how long he or she did each activity. Then we calculate that data, transfer it into MET values and use them as additional help to our automatic threat estimation. A subject can either choose to input his or her activities manually or let the application record or classify the basic activities automatically.

5 Evaluation

We collected training data of five activities for one subject; resting, walking, fast walking, running, fast running. We can see that maximal values are different for each activity; the ranges of fluctuation are different – the more violent the activity is the bigger the range of fluctuation it has. Yet, when we compare walking with fast walking, we find that they are very similar. The only difference is on the limit of positive and negative values.

Then we collected gyroscope data of these five activities in order to make a comparison with the accelerometer. Before the comparison, we calculated sum of the absolute value on X, Y, and Z axis'. Then we calculated the integral of the real time sensor value. Finally, we calculated minimal and maximal values of both the sum and the integration results. We could see that there was overlap between a previous activity's maximal value and the next minimal value in the accelerometer. But for the gyroscope it seemed that there was a better classification with the integration value. Because data in the accelerometer and the gyroscope both have X, Y, Z three values, we drew a three-dimensional graph to compare the difference among different activities. It is obviously from this data we collected from our model phone for one subject, that the gyroscope is better to identify different activities than the accelerometer. Therefore we choose the gyroscope as the primary sensor used to identify and classify activities. Yet, since gyroscope data and accelerometer data are both types of acceleration values, they could both be converted to each other by multiplying or dividing the angle between movement direction and axis of the sensor.

Before calculating average energy, there are some crosses and overlapping between the activities of walking and fast walking. After calculating average energy, the activity line becomes straighter without any cross or overlapping. The difference between walking and fast walking is intuitive and obvious.



(a) (b)

Fig. 1. Gyroscope data and Accelerometer data on three-dimensional space of different activities (a) Accelerometer data (b) Gyroscope data

6 Conclusion

We built a threat monitor system for application on smartphones in order to improve older people`s health and minimize the potential dangers that could happen in future. To reach this goal, we classify basic human activities with the help of the accelerometer and the gyroscope inside of a smartphone. Once activity classification is done, we set up an algorithm to calculate several types of threat for each activity category. When the threat condition is found, our system would alarm phone users of the potential future danger. Since our system is the first step on ensuring the safety of elderly people, especially since it precisely anticipates potential danger by classified activity, we need large amounts of testing data and feedback from the real time users.

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Ambient Assistive Healthcare and Wellness Management – Is "The Wisdom of the Body" Transposable to One's Home?

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Abstract. To cope with the issues of population aging and lack of homecare providers, ambient assistive technologies seem to be a way to explore. Domotics have already flooded our daily living allowing to program the garden watering, the blind opening, the house temperature… They are however ill-suited for the elderly because of their complexity in use. To address elderly needs and lighten the caregiver's burden, this preliminary study proposes a complete architecture of ambient assistive healthcare and wellness at home, whose main innovation is that it differs from the existing ones by its active feature. Indeed, it is not necessary to program all the home facilities one-by-one any longer, they are all centralized and remote-controlled by the system proposed. Moreover, this smart household control system is automatic, unsupervised and entirely adaptive to the user's needs and wishes. It provides optimum home conditions to ensure the inhabitant wellness in accordance with the monitoring of his/her physiological and behavioral variables.

Keywords: Aging in place, Home automation, Personal healthcare, Homeostasis.

1 Introduction

The worldwide demographic aging [1, 2] rises the question of care providing and management of such a frail population. Faced with the absence of enough medical staff and infrastructures, efforts have been focused on the maintaining of the elderly in place as long as possible. This implies our ability to maintain them healthy and

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secure. The lack of homecare providers leads us to rely on technologies to watch over and ensure elderly wellness and then delay their entrance in dependency. Advancements in technology have already flooded our home [3-5] and have considerably facilitated our daily living. Thanks to domotics, most of our actions have become automated. All we have to do is to tune our devices in the wanted position (*e.g.*, our home is heating at automatically at the temperature chosen). Technologies have also allowed to develop home medical care improving the patient management. Therefore, technologies at home have grown in number. The most sophisticated are moreover connected to the Internet allowing us to share or compare our data or experience with others (*e.g.*, physician, family etc.). The reverse side is that most of these devices work independently increasing their cost, their complexity in use and the number of remote control. This frightens elderly people making them "technophobic" in acute cases. The idea is to gather together all the home appliance controls in a unique and entirely automated aware system. Its self-regulation would be based on both contextual data and the physiological and behavioral status of the inhabitant in order to anticipate his/her own evolving needs and support his/her wellness maintaining. In other words, domotics are becoming active, automatic, adaptive, personalized and unsupervised.

Biological considerations which has primarily motivated our approach of healthcare and wellness support are described in the second section. The third one is dedicated to the methodology and the description of the automatic household control system.

2 Biological Background

The ability of the human being to adaptively and purposely self-regulate is remarkable. The most well-known example is the regulation of the blood sugar level. Most of our physiological variables are regulated automatically: temperature, cardiac rhythm, muscular strength, hormone levels, menstrual cycle… Their dynamical equilibrium around a mean value is called "Homeostasis".

External cues may make our physiological variable values move away from this equilibrium. As soon as such a change is detected, our central nervous system integrates it and compensates for it by triggering the activation of regulating mechanisms. These mechanisms are either hormonal or behavioral (*e.g.*, if you are warm, your body sweats and/or you put your sweater off, rise the air-conditioning up...). In a similar way, the aware system proposed would detect changes in physiological variables affecting wellness and compensate for it by adjusting home living facilities functioning (Figure 1). In this way, our environment could act positively on us. Providing such domotics locked to the physiological needs of the person could offer elderly people the possibility to age-in-place well [6-8].

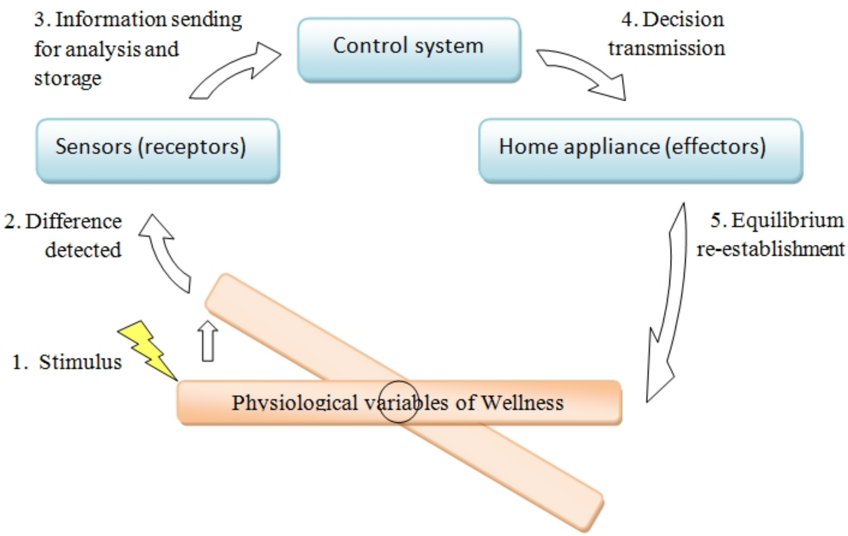

Fig. 1. Household control system for wellness maintaining

2.1 Regulation and Aging

With advancing in age, the level of alertness decreases, elderly become less sensitive or simply do not pay enough attention. Their ability to detect and process external cues diminishes making their behavior less suited [9]. Thus, an assistive, automatic and adaptive management of the home appliance may compensate for this weakening. The system further described below acts in accordance with the physiological variables values of the individual monitored like he/she would have acted if he/she was completely aware of his/her needs.

2.2 Quantifying Wellness

Wellness is a subjective notion difficult to describe for a whole [10]. According to C.B. Corbin [11]: “Wellness is a multidimensional state of being, describing the existence of positive health in an individual as exemplified by quality of life and a sense of well-being.” Wellness includes self-fulfillment, personal development, social interaction, acceptance of the current situation. Although it is well-known that elderly generally suffer from multiple chronic pathologies, this condition does not imply systematically ill-being. Indeed, if the symptoms are controlled and balanced, a state of wellness may be achieved. Therefore, the proposed system aimed at making daily living easier by anticipating the individual needs and wishes. It optimizes the functioning of household appliances by taking into account the physiological and behavioral state of the inhabitant. Environmental data are used to provide deeper insights into the inhabitant’s physiological reaction. It goes without saying that we are unable to act neither on the inhabitant’s mood nor his/her self-fulfillment. The present methodology could constitute a suitable tool which acts only on the physiological well-being, *i.e.*, homeostasis of the inhabitant by optimizing the use of his/her home living facilities.

A lack of wellness would be detected through discrepancies between physiological variable values observed and the "normal" physiological profile specific to the inhabitant developed. For instance, in case of hyperthermia (*i.e.*, a too high corporal temperature), air-conditioning and/or an atomizer would be switched on. It may also be detected through the inhabitant's behavior monitoring. Anxiety, restlessness, irritation, unusual decrease/increase in activity, aggressiveness, pain can constitute indicators of lack of wellness. The following section describes further the management of such situations.

3 Methodology

The smart household control system proposed is split into four sub-systems described in Figure 2.

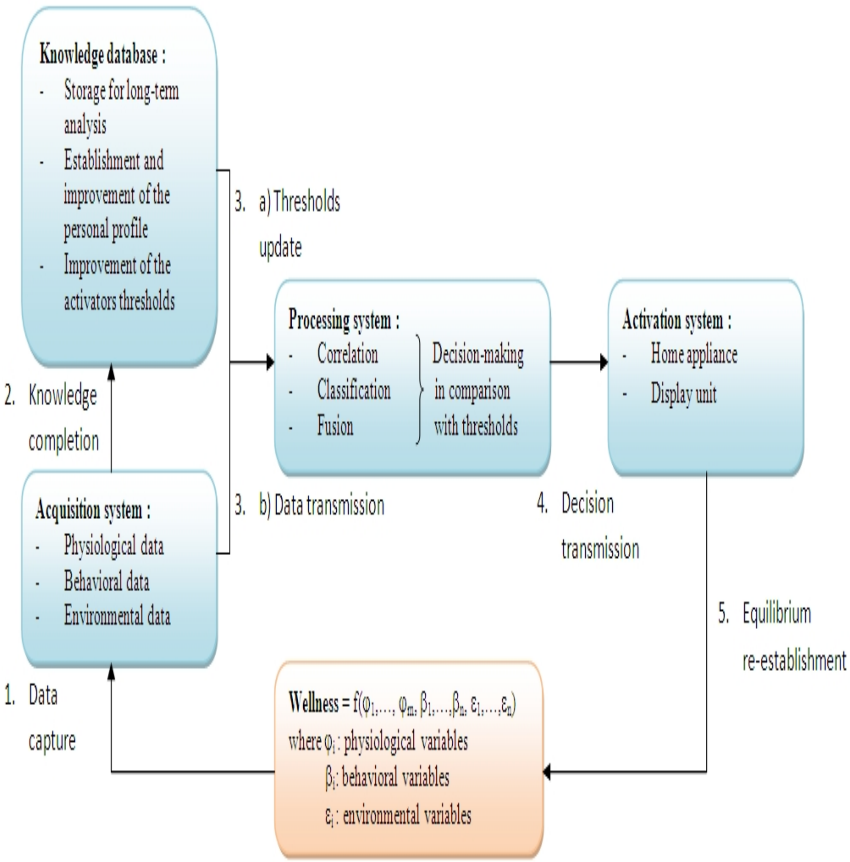

Fig. 2. Smart household control system

The physiological wellness we act on is assumed to be quantified by monitoring physiological, behavioral and environmental signs. A multi-scale data mining would allow to continuously adapt the system to the user by detecting abnormal possible change in his/her habits and control the home appliance from the current data to respond to his/her immediate needs.

3.1 Data Acquisition and Knowledge Building

The number and the nature of sensors would depend on the degree of accuracy we aim at reaching. On the one hand, environmental sensors would monitor information about the context such as time of the day, indoor/outdoor temperatures, humidity, weather conditions, luminance etc. On the other hand, behavioral sensors data (e.g. postural transfer, repetition in action, displacement…) would complementarily give insights into the degree of activity of the inhabitant such as performance of activities of daily living, restlessness, physical activity [12]. The sequence of locations may be provided by movement sensors placed in each place of the house. An actimetric device may further be slipped into the inhabitant's garment. Moreover, magnetic switches may be used on door and on devices of daily living (e.g. furniture, kettle, fridge…). Embedded sensors sewed in the inhabitant's garment would in turn measured physiological data (e.g. temperature, blood pressure, oximetry, moisture, muscle response…). The main idea of ambient and ubiquitous technologies is to make the inhabitant "forget" them. The presence of such an installation should be as discrete as possible.

The activation of the actuators i.e. whatever remote-controlled home appliance would depend on the belonging current data to their corresponding normal ranges. Indeed, a "normal" physiological profile specific to the inhabitant is made from data obtained during a preliminary learning phase. Ranges of "normal" value are established for comparison with receiving data. These ranges allow to take into account both intra-individual variability and fluctuations due to the circadian rhythm (i.e. physiological variables are expected to be different according to the time of day) and, more generally, to biological rhythms [13, 14] which evolve with the biological age [15]. They are continuously updated as new data are recorded. This update is based on a long-term analysis of the data. In order to do this, recorded data are stored all the monitoring long. Trends and patterns would be extracted allowing the refinement of the inhabitant profile.

An entrance for external data may be integrated to the subsystem "Knowledge database". It would be interesting to use medical records to complete the inhabitant's profile or data from the Internet to complete contextual conditions (e.g. epidemic, increasing of daily pollen count during spring…).

3.2 Data Processing

Inputs from sensors and external sources are gathered together for processing. Some data may be used for denoising to obtain an optimal signal.

First, a correlation study is made to detect dependency and redundancy between data. A decision will be more reliable if it is confirmed by many variables observations. Then, a phase of classification is triggered to determine which cluster of variables is the more relevant to described a given behavior (*e.g.*, performance of an activity of daily living). From their fusion, finally, the current state of the inhabitant [16-21] as well as the corresponding reliability score may be deduced. Missing data, technical issue, discrepancy between observations are likely to decrease this reliability contrary to redundancy. Data driven decision would emerge thereof, data processing being based on empirical observations making it adaptive to inhabitants. The decision making is entirely automatic and unsupervised. In case of doubt between 2 close states, the worst one is chosen to take less risk as possible for inhabitant's health.

3.3 Home Automation Actuators

When a change in a particular wellness signs is detected, the activation system triggers the remote control of the home appliance network adaptively to the user's needs. For instance, during spring, air filtering and frequency of respiration monitoring may be increased to prevent pollen allergy. During summer, in case of heat wave, blinds may be pulled down, air-conditioning switched on, the fridge tuned up… To favor restorative sleep, luminosity and temperature of the bedroom may be gradually decreased at the end of the day. A soft wakening may be favored by a progressive blind opening. Beneficial effects of music may also be used to appease agitation [22] as well as luminosity in case of sad mood. The user does not need to anticipate his/her needs, his/her home is able meet them without requiring intervention.

To make this technology architecture complete, it needs to be communicating with the caregivers for alert or simply monitoring (physicians, family…) but also with the user him/herself. Depending on the ability and willing of the user, the display unit may take different shape. Once again, this choice is peculiar to the user. For those who prefer forgetting technologies, the display unit may be an everyday device such as the screen of TV, the user's watch or the telephone for vocal pre-recorded messages. For the others, the mobile phone seems to be the best solution. Information about the user's conditions may be convey regularly or only if need be at the user's convenience. The display unit may be used to make the system more effective. It may allow to issue advice to the user. Indeed in many cases, the user is the only person able to react. If the user does not drink enough and moreover if he/she is prone to urinary infection or water retention, a message may be send automatically to his/her display unit. In the same way, a warning may be sent if a bad posture which is likely to cause backache has been adopted for a long time. As far as this application is concerned, communication may be established through biofeedback systems (*e.g.*, [23, 24].

As any regulation system, a feedback loop should be included to check its effectiveness on the user's condition. Depending on physiological variable the system acts on and the user's reactivity, the expected response time is different. As long as the equilibrium is not re-established, the process repeats. If no improvement occurs, in accordance with the potential risk for the user, external alerts may be triggered.

4 Conclusion

Maintaining elderly at home as long as possible while watching over their wellness is the daily task of their caregivers. With time, this burden becomes too heavy to carry and entrance in institution is inevitable. Relying on assistive technologies may be an, perhaps the unique, way to lighten caregivers' burden. The first purpose of this study is to make domotics more convenient in use for the elderly; the second one is to provide a dependable tool able to ensure their healthcare and wellness. To achieve these two objectives jointly, we propose an active control system of home facilities requiring no intervention from the user and dedicating to his/her wellness. Thus, we assume that both physiological and behavioral states of the inhabitant combined with his/her environmental conditions constitute relevant indicators of his/her physiological wellness. The elderly usually suffer from multiple diseases then the role of the control system is to provide them the optimum conditions to deal with their symptoms at best. It does not manage disease alone, but can act in favor of the "aging well" lifestyle. The control system proposed in this preliminary work is peculiar to the user by adapting itself to his/her profile and current state. In order to do this, sensors are placed throughout his/her dwelling and slipped into a garment especially designed for that purpose. A multi-scale data analysis is proceeded to address immediate needs and update continuously the inhabitant's profile. Abnormal discrepancies from this profile cause the triggering of the activation system. This latter is precisely the key point of our system that is its active part. The activation system is able to switch on/off and tune all the electrical devices of the house connected to it to offer the best suited home conditions to the user state improvement. In addition, it is able to communicate with the user through a display unit on which it issues advices. A feedback loop has been planned to evaluate the effectiveness of the activation system intervention on the user state. In critical cases, if the user equilibrium is not re-established after many trials, alerts may be sent to the caregivers or in the future to a dedicated assistance centre. To go further, such an active intelligent system may be specialized for given pathologies facilitating the management of some chronic diseases at home. For instance, the glycemia may be monitored after each miction or, in case of asthma, the evolution of the daily pollen count may be monitored and a message may be send about the good quantity of drug necessary.

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Facilitating Spontaneous Energy Saving in a Smart Home Using Interruptibility-Aware Reminders with Ecological and Abstract Information Visualization

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Abstract. There has been renewal of interest in green technologies due to deteriorating global warming, which renders energy saving (ES) becoming increasingly important. By recognizing users' on-going activities in a smart home environment, we propose an interruptiblity-aware ES reminder system to facilitate behavioral changes for facilitating energy saving at home. This system provides an ES reminder (one kind of eco-feedback) in the event of an activity transition to avoid constantly disturbing user's on-going activities, and the content of an ES reminder is composed using two kinds of information visualization via ambient displays to improve readability. Through a combination of qualitative and quantitative evaluations, the system can help lead to pro-environmental behaviors in a more human-centric way.

Keywords: interruptiblity-awareness, energy saving, activity recognition, information visualization, reminder service, smart home, persuasive technology.

1 Introduction

Due to deteriorating global warming, energy saving (ES) has become a vital research topic in the fields of ubiquitous computing, human-computer interaction (HCI), environmental psychology, and so forth. To encourage people to become more energy-conscious, persuasive technology has been proven effective [1-12] for helping people realize consequences of an undertaken activity to our surroundings, thus gradually helping them understand the impact that may be caused by their own behavior without resorting to compulsive means [2, 3]. One application of persuasive technology in sustainability is utilizing an ambient display to provide reminders at one's fingertips, which can help remind users about energy usage anytime and anywhere. Therefore, ES reminders via an ambient display show great potentials in urging people becoming more aware of the impact that their daily activities may cause to the environment [4, 6]. To promote energy conservation, one key enabler is the proper choice of the content (what) and the timing (when) in providing an ES reminder via information visualization related technologies [7].

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Regarding the proper choice of the content (what) in providing ES reminders, this work tries to construct an ES reminder with two kinds of information visualization, which combines ecological and abstract visualization methods, in order to make the an ES reminder more visually accessible and comprehensive to the readers. In this regard, the style of providing ES reminders should be more indistinct unless any urgent information needs to be provided in time. As for the ecological visualization, it creates an ES reminder in the form of ecological characters (such as butterflies or trees) to enhance one' s emotional bond to the nature, just like a virtual pet raised in a virtual eco system. Rather than providing an ES reminder in the form of pure numbers about how many Watts have been consumed or how much money is spent on an appliance, abstract visualization, on the other hand, provides ES reminders using abstracted patterns to allow non-fixed and more dynamic contents.

As for the proper choice of the timing (when) in providing ES reminders, this factor is often application dependent. For example, in a working environment, an ES reminder may become disturbing if it keeps interfering with one's on-going activity. If the goal of providing ES reminders is to make users become more energy-conscious in a gradual but less aggressive way, a timely yet little annoying reminder should be more acceptable by users. Recently, in view of the advances in wireless sensing and artificial intelligence technologies, the researchers now can accurately identify people's daily activities [1, 11], especially in a single-user environment. To take advantage of these technologies, we further equip an ES reminder system with the ability to provide information only in the event of an activity transition, i.e. interruptibility-awareness. That is, the system tries not to bother a user unless it detects an appropriate moment to interrupt the user, such as the moment when a user transits from "studying at the desk" to "watching TV." This ideation is based on the research from Ho *et al.* [13], they argued that the moment of an activity transition is a more appropriate moment to provide information. This way, the receiver of an ES reminder will be able to pay attention to the provided information without the feeling of being constantly disturbed by the system.

To sum up, we propose an interruptibility-aware ES reminder system via ambient displays to provide ecologically and abstractly visualized contents in hope of providing ES reminders in a more natural and human-centric way.

2 The Proposed Energy-Saving Reminder System

2.1 System Overview

The system architecture is shown in Fig. 1. When a user interacts with the system, the ambient sensors in the monitored environment can be used to detect both the interactions from users as well as the states of the appliances, and then generate sensing data. Since these newly collected data may be less informative for the system, we need to process them and extract features to obtain more useful information and to greatly reduce the amount of data for later activity inference, which infers a user's on-going activity.

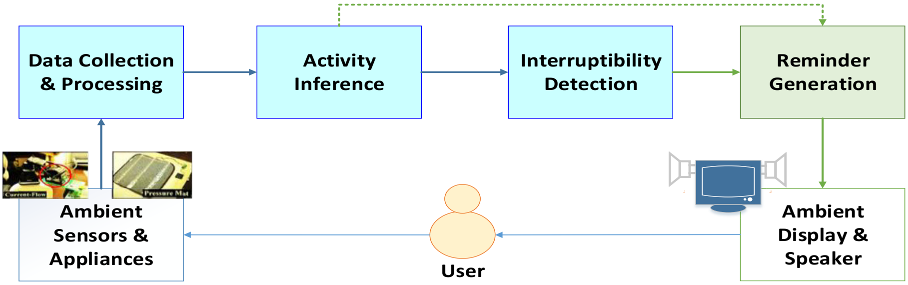


Fig. 1. The system architecture of the proposed ES reminder system

In order to avoid training a model for each subject, an activity is inferred using a rule-based engine based on the gleaned observations from the ambient sensors. For example, if the system detects two features, including "the TV is on" and "someone is sitting on the chair before the TV set", it can be pretty sure that the "watching TV" activity is being undertaken. Note that this example is a simplified case of activity recognition. In a real-life scenario, multiple users can undertake activities simultaneously. In this work, we focus on the cases where there is only one user in the sensed environment as a pilot study.

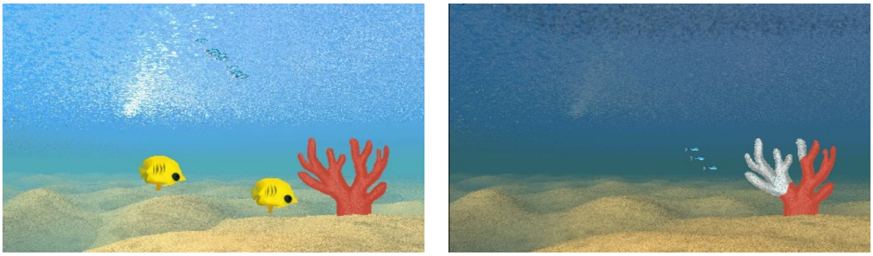
Since the system can detect activities, this enables the system to detect an activity transition, which has proved more appropriate to interrupt a user for providing reminders. That is, the "interruptibility detection" module enables us to provide an ES reminder in a more appropriate moment. Next, the "Reminder Generation" module can generate an ES reminder using two information visualization methods via ambient displays or speakers to facilitate spontaneous energy saving.

To sum up, we have integrated two key features into our proposed ES reminder system. The features include "*ecological and abstract information visualization*" and "*non-obtrusive interruptibility detection*." In the following subsections, we will elaborate these features that can distinguish our system from prior works.

2.2 Ecological and Abstract Information Visualization

Unlike most of prior works focusing on using single type of information visualization [5, 7] to design the content of an ES reminder, we combine two distinct visualization methods in order to make the contents more visually accessible and comprehensive to a user. These two types include:

- *Ecological* Visualization: An ES reminder is one kind of eco-feedback, and it in the form of animals, plants, and other ecological characters can enhance one's emotional bond to the nature [4, 12]. In addition, this type has shown a positive effect in supporting behavior changes [5]. In this regard, our proposed ecological visualization is in the form of undersea corals and fishes, as shown in Fig. 2 (a). The reason is that coral bleaching has become a global issue and it has direct association to global warming and environmental protection. When a user of our



(a) (b)

Fig. 2. The snapshot of the reminder using two kinds of information visualization

system produced energy waste for more than 30 seconds, the virtual corals on the ambient display would gradually bleach and the number of fishes would reduce as well, as shown in Fig. 2 (b). In this study, energy waste is determined by the situation where a user undertakes an activity but using multiple appliances. For simplification, we assume that an activity has a one-to-one mapping with an appliance.

- *Abstract* Visualization: Rodgers *et al.* [7] argue that abstract visualization can draw more attention, and can keep users interested for a longer period. Here we used this type of visualization to complement the effect of ecological visualization, intending to represent electricity waste along with its duration through an animation containing simulated water pollutants as a symbol of electricity waste. As shown in Fig. 2 (b), the pollutants will randomly be generated once the system detects the situation of energy waste (e.g. multiple appliances consume power but only one or no activity is undertaking), and they will begin to pollute the sea water. That is, when the system detects an activity is undertaking and one appliance is operating at the same time, no energy is wasted so there is no undersea pollutant generated. But when several appliances are operating simultaneously but only one activity being undertaken, pollutants start to generate and will continuously accumulate and eventually make the sea water murky and lifeless. Whenever electricity waste ceases, pollutants will stop emitting, but they will last for a period of time on the display so that a user can readily distinguish the degree of electricity waste via the amount of cumulative pollutants. The sea water will be clear again and the number of the fishes will be back to the default value when no energy waste is detected for a predefined duration.

2.3 Non-obtrusive Interruptibility Detection

Since human's daily schedule is highly dynamic, determining a good moment to provide ES reminders becomes challenging. Most of prior works provide an ES reminder without considering user related contexts (especially activities), which may cause annoyance to users due to ES reminders provided at an inappropriate moment. However, some works began to take user related contexts into the design of a reminder system [14]. According to the study from Ho *et al.* [13], detecting interruptibility before providing reminders is important. As a result, we hope to minimize the interference of an ES reminder to a user. In addition, this study deploys a wireless sensor network to collect information regarding user-system interactions, and the generated data are used to infer user's on-going activities without asking users to carry sensors all the time. Consequently, the resultant system is non-obtrusive and the users of the system can naturally interact with the system. This is especially important for a dynamically changing home environment to provide human-centric reminders.

Currently, we have successfully integrated various sensors with a Tmote Sky [15] compatible wireless node, and these wireless sensors can transfer pre-processed information wirelessly to a remote server. In this study, two types of analog sensors to detect current-flow and pressure were integrated into our system as shown in Fig. 1. More specifically, in order to monitor electricity usage, each appliance in the sensed environment is in series connection with a wireless current-flow sensor. The pressure sensor are integrated into a sitting mat to detect the presence (or location) of a user. To make the system activity-aware, we make use of the sensing data to infer the activities of interest using a rule-based engine. Once the system can recognize activities, it can detect an activity transition to make the system interruptibility-aware. For example, in order to detect if a user transits from studying to taking a drink, the system detects the event of leaving a pressure mat in the study room. When detecting an activity transition, the system pops up a warning message and beeps a sound to intentionally remind the user to turn off the unused appliances.

To sum up, an ES reminder in this system is in the form of mixed information visualization, and its reminder provisioning is interruptibility-aware to avoid constantly distracting users.

3 Experiment and Results

In this study, both qualitative and quantitative evaluations have been proposed to preliminarily test the effectiveness of the system. The ages of the target users ranges from 22 to 40 since the users in this age range often need to share the responsibility of earning a living (or paying a utility bill) for a family. There are a total of 12 participants in the evaluation, including 6 males and 6 females. We divided them into two groups: group *A* (with the interventions of the system) and group *B* (without any intervention). The actual ages of the subjects are between 22 and 32, and the gender distribution is balanced, i.e. 3 males and 3 females in each group. Each participant was given a check list to undertake several activities yet in an arbitrary order, including using a PC, watching TV, reading books/newspaper, preparing food using the oven, etc. We observed each subjects about how they interacted with the system via a web-enabled camera. After the experiment, each of them all went through a questionnaire and a semi-structured interview.

3.1 The Effectiveness of the Reminder System

After the questionnaires and the interview, the results showed that all the participants gave a positive response to the proposed system, and most of them correctly comprehended the meaning of the two information visualization methods. About 83.8% of subjects prefer information visualization to pure text representation.

> *…such graphical interface is really helpful to convey a concept to users. Even if one without any technical background can easily understand.* (*A*3)

In order to better understand the effectiveness of the ES reminders, we excluded those originally having an energy-efficient habit (determined by the pre-experiment questionnaire). The subjects in group *B*, i.e. without any intervention from ES reminders, ended up completely bleached corals; on the contrary, most subjects in group *A* maintained the corals in a more healthy or at most slightly bleaching state. Only one exception (*A*6) who pointed out she did not know how to recover the corals back to normal. The results showed that the combination of ecologically and abstractly visualized reminders could have impact on users, and urge them to behave more energy-efficiently.

> *…there's one time with no fishes and all bleaching corals, the screen was dark, and then I knew: Oh! I should reduce electricity consumption.* (*A*1)

> *…after noticing the bleaching corals, and I would remember to turn off the unattended lights if I was not reading the newspaper.* (A4)

During the experiment, some subjects suggested that coral bleaching or death of the fishes make them feel *strained* (*A*5), *horrible* (*A*5) or *terrified* (*A*3), which shows that the ES reminders could arouse an emotional connection between humans and the nature, and prompts them to take appropriate actions. This also conforms with our design that puts moral obligation into the ecological visualization.

Most of the participants in the experiment noticed the changes on the ambient display from time to time. From our observation via the web-enabled camera, there does exist the relationship between user's attention and the ES reminders. The subjects indicated that the visual ES reminders (i.e. corals and fishes) did not cause them any attention burden, and allows them to focus on their original tasks.

> *[It] is like an aquarium. You can take a look any time you want. That's great.* (*A*5)

When the abstractly visualized pollutants on the ambient display appear with more dramatic and rapid changes, this draws more attention for users.

> *[In use of appliances,] I do vaguely notice [the animation changes on the ambient display], but it draws my attention only at the time with drastic changes. (A*1)

In order to preliminarily evaluate whether an ES reminder provided at the moment when the system detects an activity transition would less distract users from their original tasks, the system first needs to recognize activities that a user may undertake. In our prior work using ambient sensors to recognize activities [16], the accuracy ranges from 90+% (for activities pertaining to appliance usage, such as watching TV, using microwave, etc.) to 99% (the "sitting" activity). In this study, we used a rule-based engine to recognize several activities (and locations) of interest, including "using PC", "reading", "preparing food", and "watching TV." When the system detects an activity transition, the pop-up message and the beeping sound will immediately remind users about electricity waste.

> *When I heard the warning sound, I immediately check [if energy is being wasted].* (*A*2)

With the assistance of interruptibility-awareness, the subjects do not have to manually detect energy waste. However, diverting attention at the same time also means it could interrupt activities even though the pop-up message shows up only when one transits to anther activity. Although most of the participants thought that the system did not distract their attention or causes any interference, there were still one-third of the participants who thought the ES reminders could generate annoyance more or less. This is especially true when the system prompts a pop-up message on the PC (the users need to click the confirm button) and beeps a sound. The result of post-questionnaire shows that there are 66.7% of the subjects can accept the way of reminding energy waste via a pop-up message, but only 50.0% of the subjects can accept a beeping sound as a reminder. To address this issue, a participant suggested the sound should be gentler, or just show a less disturbing message on the screen (*A*3). Consequently, we recommend that researchers must take aesthetics and other factors into consideration, such as whether the warning messages cause any stress. We also suggest that the system should allow a user to customize configurations of an ES reminder system, such as providing multiple representation styles for users to choose.

4 Conclusion and Future Work

In this study, we proposed a more human-centric system to provide interruptibility-aware ES reminders with the combination of ecological and abstract information visualization to facilitate spontaneous energy saving. The system can proactively provide an ES reminder in the event of an activity transition. Through the preliminary qualitative and quantitative evaluations, we found that the system has the potentials to bring about pro-environmental behavior in a more natural way. From what we observed in the experiment, we will enhance the ES reminder system with the ability to automatically adjust its notification level based user's interactions with the system, and with the ability to be customizable based on user's preferences towards information carrier (or medium), aesthetics, and feedback contents. Unlike some pioneer reminder services [14] providing information during an activity, this system instead provides an ES reminder at the moment of an activity transition. We believe that taking on-going activities of a user into consideration (i.e. context-awareness) will further improve the usability of the system. In addition, the way the system detects energy waste is somewhat over-simplified in this work, and we will continue explore more mature alternatives in the near future. Finally, in terms of various uncertainties pertaining to human behaviors or devices, we will also address this challenge to enhance the adaptability and the practicality of the system.

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Building High-Accuracy Thermal Simulation for Evaluation of Thermal Comfort in Real Houses

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Abstract. Thermal comfort is an essential aspect for the control and verification of many smart home services. In this research, we design and implement simulation which models thermal environment of a smart house testbed. Our simulation can be used to evaluate thermal comfort in various conditions of home environment. In order to increase the accuracy of the simulation, we measure thermal-related parameters of the house such as temperature, humidity, solar radiation by the use of sensors and perform parameter identification to estimate uncertain parameters in our thermal model. We also implement a communication interface which allows our simulator to communicate with other external simulators. Experimental result showed that our simulation can achieve high accuracy when compared with actual measurement data.

Keywords: Thermal environment, Smart house, Simulation.

1 Introduction

Smart home services nowadays can bring to us a comfortable living environment, but also consume a large portion of electrical energy. Nowadays, the introduction of renewable energy sources, networked appliances and sensors to smart homes gives us the ability to increase energy efficiency in houses. Environment data gathered by sensor networks, such as temperature, humidity, solar radiation can be sent to a service provider, which uses the data to control the operation of energy sources and networked appliances. For example, we can control the opening and closing of windows as well as the operation of air conditioning system to optimize the amount of consumed energy [1].

Verification of smart home services by both simulation and experiments is essential since simulation can save time and resources for system development, while experiments can verify the operation of real systems. Since there are many home services targeting to improve thermal comfort for residents, it is essential to develop a high-accuracy thermal simulator which can simulate the behavior of thermal environment of real houses at different conditions. Furthermore, the simulator should have the ability to communicate with other simulation programs of networked control systems.

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There are many thermal simulators for buildings such as DOE-2 [3], EnergyPlus [4]. However, since these simulators are used for the design of buildings, they require a large number of detailed thermal parameters to be specified. In the case of modeling real houses, many parameters are unknown and needed to be identified by the use of measurement data of external and indoor thermal environment. Several works [5,6] have attempted to identify thermal parameters for houses but their models do not take into account a number of parameters about external environment such as solar radiation or wind velocity. These parameters are essential since they have a significant affect on the change of room temperature.

In this research, we build a thermal model for a smart house testbed, which utilizes external environment data measured by sensors as input. Our model calculates the change of room temperature by calculating heat fluxes coming in and escaping a room based on a number of physical models. We implement our thermal model in MATLAB/Simulink environment and utilize Simulink Design Optimization toolbox to identify uncertain parameters in our thermal model, based on measurement data of room temperature. Comparison of experimental results with simulation results shows that our simulator has high accuracy with the error within 1 degree centigrade. We also design an communication interface to interact with other external simulators, which can be used for verification of smart home services.

This paper is organized as follow. In Section 2, we describe simulation object and simulation model. The next section describes the design of our simulator. Section 4 shows validation results of our simulation. Section 5 concludes the paper.

2 Simulation Model

2.1 Simulation Object

We perform our simulation targeted on a testbed house for smart home services, called iHouse, which is located at Ishikawa prefecture, Japan. It is a typical 2-floor Japanese-style house with 15 rooms (Fig. 1). Appliances in iHouse include air conditioners, wattmeters and sensors, which are connected to the network via ECHONET protocol [7]. A home gateway which allows communications between home network and service providers is set up in the house. Furthermore, house furniture and equipment is installed in the house to allow people to live there.

Since the thermal environment of a house is heavily dependent on the outside environment, we use a number of sensors to monitor external environment. They include a sensor for measuring temperature and humidity, an anemometer for measuring wind speed and direction and a solar heliograph for measuring actual sunshine duration, which is defined as the time that direct insolation is over 120W/m^2.

We measure room temperature and humidity to estimate simulation parameters and evaluate simulation results. Among 15 rooms of iHouse, 11 rooms have

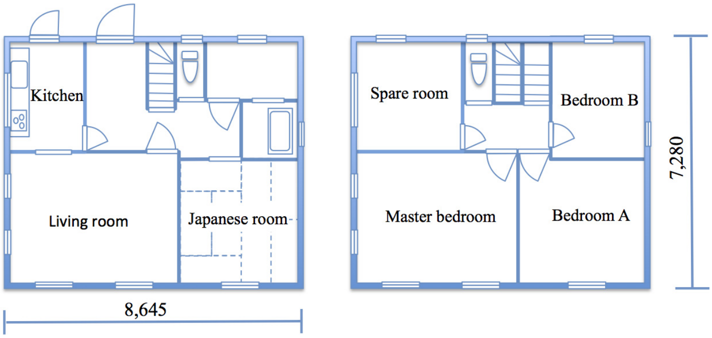

Fig. 1. Structure of iHouse

temperature and humidity sensors. 8 temperature and humidity sensors are installed in each of these rooms, 4 sensors at 4 higher corners and 4 sensors at lower corners.

2.2 Thermal Model

In our model, we assume that the temperature of a room is uniform in all areas of the room. The room temperature T is calculated as follows.

$$\frac{\partial T}{\partial t} = \frac{1}{C_v} \sum_i Q_i(t) \tag{1}$$

where $Q_i(t)$ are heat fluxes going out or coming in the room at time t, C_v is the heat capacity of the room. We model several kinds of heat fluxes as follows.

- Conduction heat flux: We use unsteady-state heat transfer model to calculate conduction heat flux through a wall. This model can take into account the fast change of temperature at surfaces of walls.
- Solar radiation heat flux: We estimate direct solar radiation based on measured data of a solar heliograph and use Reindl direct-diffuse splitting model [11] to estimate diffuse radiation.
- Device heat flux: Device heat is assumed to be constant.
- Air conditioner heat flux: We use PID control to model the control of air conditioning units at each room.

Conduction Heat Flux. We calculate conduction heat flux through windows under steady-state heat transfer conditions as follows.

$$Q_{cond} = U_{win}.A_{win}.(T_o - T_r)(W) \tag{2}$$

Here, U_{win} and A_{win} are the heat transmission coefficient (W/m^2K) and the area (m^2) of a window, T_o and T_r are outside temperature and room temperature(K).

In the case of walls, we calculate conduction heat flux under unsteady-state heat transfer conditions since the temporal and spatial change of temperature inside walls can not be ignored. Due to the work of Milatas et. el [8], the change of temperature at each surface of a wall can be expressed as a triangle wave and Laplace transformations can be used to solve one dimensional heat equation (4) of the wall.

$$C_v \frac{dT}{dt} = \lambda \frac{d^2 T}{dx^2} \tag{3}$$

As results, we obtain response factors Z_j and Y_j of the wall and calculate the heat flux through the wall as follows.

$$Q_{cond}(t) = A_{wall}(\sum_{j=0} Y_j T_o(t - j\delta_T) - \sum_{j=0} Z_j T_r(t - j\delta_T))(W) \tag{4}$$

Here, A_{wall} is the surface area of the wall, $T_o(t-i\delta_T)$ and $T_r(t-i\delta_T)$ are surface temperatures of the wall at time $t - i\delta_T$, δ_T is a time interval.

Since external walls absorb solar radiation and become hot during daytime, external surface temperatures of these walls are calculated by solving the heat balance equation at surfaces of walls.

$$Q_s + Q_a = Q_{conv} + Q_r + Q_{cond} \tag{5}$$

Here, Q_s is absorbed direct and diffuse solar radiation heat flux, Q_a is absorbed radiation heat flux from external air and from ground, Q_{conv} is convection heat flux between external surface and outside air, Q_r is radiation heat flux from wall surface and Q_{cond} is conduction heat flux into the wall.

Convection heat flux between external surface and outside air depends on the velocity of wind and is calculated due to the work of Ito et. al [9]

$$h = 18.6v^{0.605}(W/m^2K) \tag{6}$$

Here, v is wind velocity near the surface of the wall.

Solar Radiation Heat Flux. Solar radiation heat flux Q_r through a window is calculated as follows.

$$Q_r = (ID.\lambda_{ID} + IS.\lambda_{IS}).A_{win} \tag{7}$$

where ID is direct radiation, IS is diffuse radiation, $\lambda_{ID}, \lambda_{IS}$ are solar radiation heat gains of the window .

We estimate the direct radiation with the use of actual measurement data, provided by the solar heliograph. Recent researches attempts to estimate direct radiation and diffuse radiation based on actual sunshine duration but the estimation is performed in an hourly basis [10]. The solar heliograph is a solar battery which voltage is 20mV when the direct insolation is 120W$/m^2$. We measure the highest voltage during the summer and estimate the direct insolation

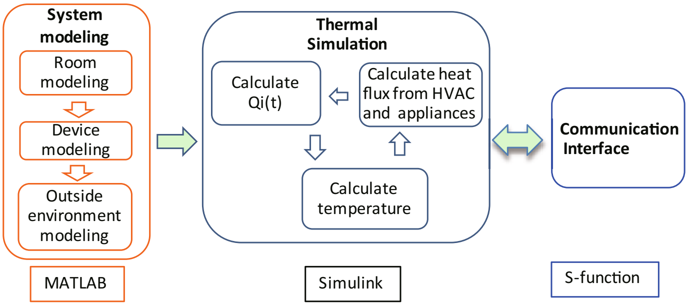

Fig. 2. Structure of thermal simulator

at that time. We assume that the voltage characteristic of the solar heliograph is expressed as a line which passes through the above points and estimate direct insolation based on this assumption.

Diffuse solar radiation is calculated based on Reindl direct/diffuse splitting model [11]. In this model, the ratio of diffuse solar radiation and global solar radiation is estimated based on clearness index, solar altitude angle, ambient temperature, relative humidity. Since the direct solar radiation I_d is calculated based on diffuse solar radiation I_s, global solar radiation I_g and solar altitude angle h, we can estimate diffuse solar radiation to fit with the value of direct solar radiation.

Solar radiation heat does not warm up room air immediately but it warms up curtains, ceiling and floor, which then warm up room air. Therefore, we calculate the heat flux caused by solar radiation based on the historic values of solar radiation.

$$Q_r(t) = \sum_{j=0}^{n} Q_r(t - j\delta_T)\eta_j \tag{8}$$

where $Q_r(t - j\delta_T)$ is the solar radiation heat flux through the window at time $t - j\delta_T$ and $\eta_j, j = 0..n$ are response factors.

3 Simulator Design

Our simulator includes 3 modules (Fig. 2).

- House modeling: iHouse is modeled as a house which includes a number of rectangular rooms and each room contains a number of walls and windows. The module first inputs parameters related to thermal characteristics of walls and windows. It then uses as input sensor data regarding temperature, humidity, wind velocity and voltage of solar heliograph and calculates direct and diffuse solar radiation, surface temperature of walls and windows due to each model.

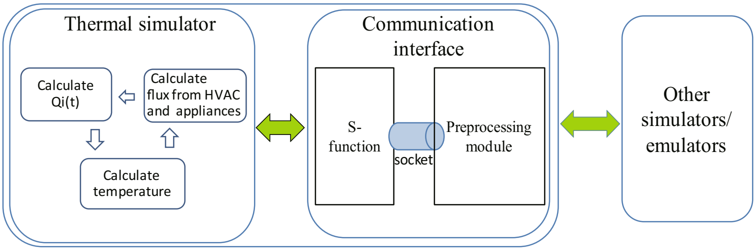

Fig. 3. Design of communication interface

- Thermal simulator: This module calculates heat flux escaping and entering each room, and calculate room temperature for each room of the house using equation (1).
- External interface: This module will receive control information of air conditioner, windows and other appliances from and send room temperature to external programs.

We implement our simulator in MATLAB/Simulink environment which supports user-friendly interface and the ability of analyzing simulation results.

In our thermal model, there are several thermal characteristics of rooms, those are unsettled such as furniture's specific heat, solar heat gain of windows, wall surface's heat radiation and absorbance. Estimation models of external weather such as direct solar radiation, diffuse solar radiation and convection heat transfer coefficient also have margin of errors[12,13]. Therefore, parameter identification is required to improve the accuracy of simulation results.

We use Simulink Design Optimization toolbox[14] to identify uncertain parameters of the model. The toolbox runs the thermal model a number of times and adjusts parameters based on an optimization algorithm such as trust region reflective algorithm. Since the running time depends heavily on the size of the whole model and the number of parameters to be identified, we perform parameter identification for each room and identify a number of representative parameters instead of identifying all uncertain parameters. For each room, we identify from 6 to 10 parameters.

We also use S-function with socket communication to implement communication interface (Fig. 3). A preprocessing module is implemented to receive and process input data from external simulators. This module allows complicated interactions between thermal simulator and external simulators. Data consistency between our simulator and external programs is kept by a simple clock synchronization mechanism.

4 Validation

We have performed data measurement and simulation to validate the accuracy of our model and simulator. 4-day experiment data in July 2012 and 4-day

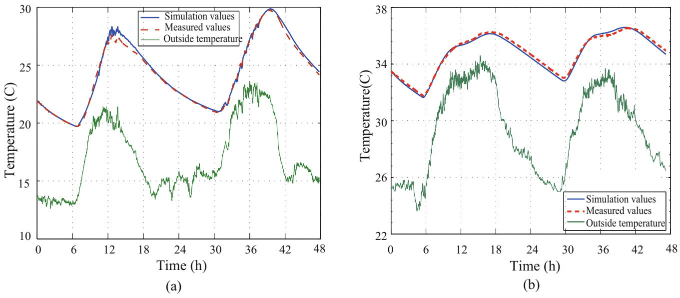

Fig. 4. Simulation and measurement results for 2-day experiment at master bedroom in autumn weather and at bedroom B in summer weather (air conditioner is not operated)

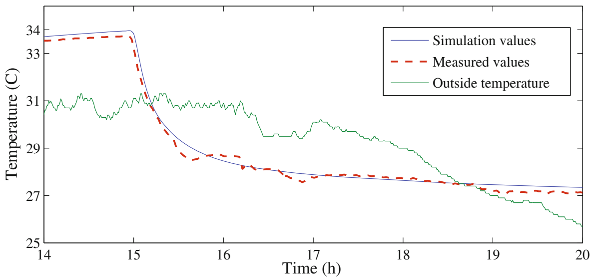

Fig. 5. Simulation result and measurement result of cooling experiment at bedroom B

experiment data in October 2012 were used to perform parameter identification for each room. The measurement interval of external environment was 10s. The measurement interval of room temperatures was 120s. We then validated the simulation results by performing simulations of all rooms using identified parameters.

Figure 4 shows the validation of our model using identified parameters. 2-day experiment data in autumn weather and 2-day experiment data in summer weather are used to evaluate simulation results. Here, air conditioners are not operated. As result, the differences between simulation results and measurement results are maximum 0.9 degree centigrade. The difference is high in the room which temperature changes slightly and is low in the room which temperature changes heavily.

Under the condition that the air conditioner is operated, the difference between simulation values and measured values is maximum 1.0 degree centigrade (Fig. 5). Control information of air conditioner is sent to the simulator via the communication interface.

5 Conclusions

In this research, we have built a thermal simulator which models an experimental house for smart home services. Thermal-related parameters of the house are measured by the use of sensors and a number of physical models were utilized to calculate heat flux coming from external environment. Furthermore, we perform parameter identification to identify uncertain parameters in our thermal model. Therefore, our simulator can achieve high accuracy when compared with actual measurement data. We also design an communication interface, which allows our simulator to communicate with external simulation programs.

In future, we will extend our simulator to model other experimental houses and develop verification programs for smart home services.

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Force Efficient Analysis of a Hybrid Magnetic Actuation System for Minimally Invasive Diagnostics and Interventions

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Abstract. Minimally invasive diagnostics and interventions (MIDI) are emerging as major paradigm shifts in medical technology development and thus significant for elder care. Magnetic or electromagnetic guided devices have been introduced to MIDI due to the remote maneuverability which is critical to control and track the intracorporeal instruments. A category of magnetic actuation mechanism is investigated by the authors based on hybrid magnetic bearing (HMB) that can provide force suspension and locomotion. In this paper, force coefficient is investigated during the locomotion control using HMB. The force coefficient refers to the distribution ratio of permanent magnetic force and electromagnetic force in HMB. According to the definition of force coefficient, it can be concluded that the larger force coefficient is, and then the smaller power loss is.

Keywords: Minimally invasive diagnostics and interventions, hybrid magnetic bearing, force coefficient.

1 Introduction

Towards minimally invasive diagnostics and interventions (MIDI), new procedures are emerging by accessing the intracorporeal cavities or tracts via one of the bodies' natural orifices, e. g. mouth, anus, nose or vagina. In these procedures, magnetic or electromagnetic actuation plays an important role in remote tracking and control for its minimally invasive accessibility.

For minimally invasive surgical interventions, Natural Orifice Transluminal Endoscopic Surgery (NOTES) [1] can be performed by accessing the abdominal cavity via steerable flexible endoscopes [2] or Magnetic Anchoring and Guidance System (MAGS) [3], which aims at controlling the internal instruments through coupling with external magnets. It represents a major paradigm shift in general surgery by operating inside the peritoneal cavity without scars or through small holes.

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This new approach is very appealing from patients' perspectives because it completely eliminates abdominal wall aggression and promises to reduce postoperative pain, in addition to all the advantages brought by laparoscopic surgery [4]. Meanwhile, instrument tracking [5] is of great importance for biomedical applications [6] [7] and can also be accomplished by magnetic technology [8].

For minimally invasive diagnostics and biopsy, capsule endoscopy [9] is introduced to examine the gastrointestinal tract by a pill-like mini-camera, which can be swallowed and excreted through natural digestive tract. Most of the commercial capsule endoscopes are fully passive and might be trapped along the folded segments along the digestive tract, so there are emerging studies on active capsule endoscopes [10] either actuated by internal motors, internal electromagnetic force configurations or interaction with external magnetic fields.

The prevailing magnetic guidance in MIDI is demanding comprehensive theoretical systematic analysis in order to achieve optimal performance especially when the intracorporeal device is interacting with human tissue with limited power resources. Nowadays magnetic bearings have been adopted as effective actuation and suspension mechanism in industrial applications [11][12] and high-speed machines [13]. They can be classified into three types, namely, active, passive, and hybrid bearings. Although the passive magnetic bearing (PMB) presents low power loss because of the absence of current, it is lack of active control ability. On the contrary, active magnetic bearing (AMB) has better control ability, whereas it suffers from high power loss due to the biased current. Therefore, more attention is being paid to permanent magnet biased hybrid magnetic bearing (HMB) [14][15], which combines the merits of PMB and AMB. As for HMB, the permanent magnet generates the bias flux to control the main supporting force. Consequently, the control current can be reduced considerably to get lower power loss compared with AMB. However, the negative displacement stiffness produced by permanent magnet is large in HMB accordingly, which can be caused the instability of the magnetically suspended rotor system.

In this paper, we are focusing on the key parameter for force analysis in the HMB magnetic guidance system, that is, the concept of force coefficient to describe the relationship between distribution ratio of permanent magnetic force and electromagnetic force. The key factors affecting force coefficient are analyzed in this paper.

2 Force Coefficient in HMB

A structure of HMB is shown in Fig. 1. The configuration includes one permanent magnet, eight stator core stacks placed in X and Y directions, which have two groups along the Z direction.

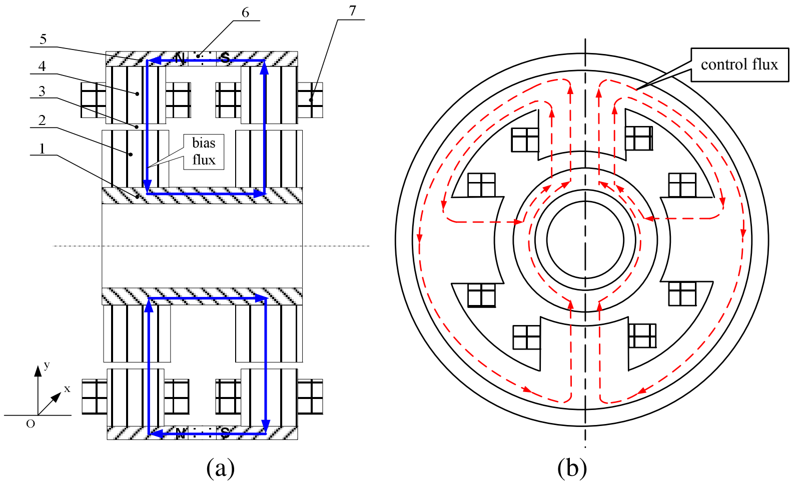

Fig. 1. Permanent-magnet-biased radial HMB. (a) Axial sectional view. (b) End view. 1. Inner magnetic ring, 2. Rotor core stacks, 3. Air gap, 4. Stator core stacks, 5. Outer magnetic ring, 6. Permanent magnet, 7. Coil.

The solid lines denote the flux paths generated by the permanent magnet and the dotted lines indicate the flux paths generated by the coil in Fig. 1. The bias flux generated from the permanent magnet which is axially magnetized is across the inner magnetic ring, the stator core stacks, the air gap, the rotor core stacks and the outer magnetic ring, as shown in Fig. 1 (a). The control flux generated from the coil in the y direction with current flows across the stator core stacks, the air gap, and the rotor core stacks, as shown in Fig. 1 (b).

The equivalent magnetic circuits of the bias flux and the control flux in the radial HMB are shown in Fig. 2 and Fig. 3, respectively.

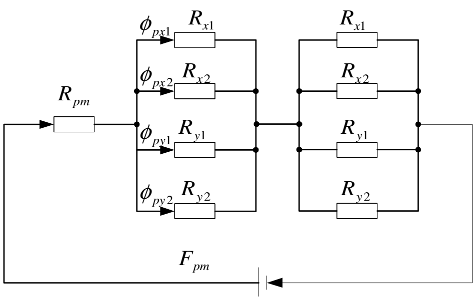

Fig. 2. Equivalent magnetic circuit of the bias flux

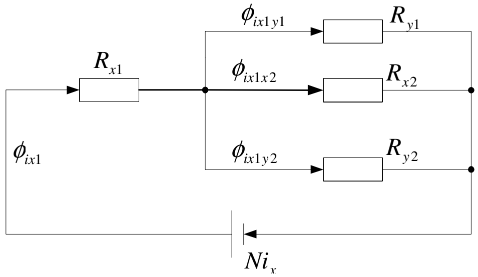

Fig. 3. Equivalent magnetic circuit of the control flux

From Fig. 2 and Fig. 3, ignoring the reluctance of iron core stacks and magnetic ring, the force on the rotor can be simplified by,

$$F_x = \frac{(\phi_{px1} + \phi_{ix1})^2 - (\phi_{px2} - \phi_{ix2})^2}{\mu_0 A} \tag{1}$$

where ϕ_{px1} and ϕ_{px2} are the flux of air gap produced by permanent magnet in the +X direction and -X direction respectively, ϕ_{ix1} and ϕ_{ix2} are flux of air gap produced by current in the +X direction and -X direction respectively.

At the equilibrium position, we can obtain $\phi_{px1} = \phi_{px2} = \phi_{pm}$ and $\phi_{ix1} = \phi_{ix2} = \phi_i$, so the equation (1) can be simplified,

$$F_x = \frac{(\phi_{pm} + \phi_i)^2 - (\phi_{pm} - \phi_i)^2}{\mu_0 A} = K_x x + K_i I_x \tag{2}$$

where x is gap length deviation in X direction from the central position and I_x is coil current in X direction.

Then the displacement stiffness (K_x) in the x direction can be derived according to the equation (2),

$$K_x = \frac{\partial F_x}{\partial x}\bigg|_{I_x=0,x=0} = -\frac{\mu_0 A F_{pm}^2}{\sigma^2 \cdot \delta}\left(\frac{1}{2R_{pm}\mu_0 A + \delta}\right)^2 \tag{3}$$

where F_x is force on the rotor in X direction, F_{pm} is magnetic motive force of the permanent magnet, R_{pm} is reluctance of permanent magnet, σ is leakage coefficient of bias flux, A is area of one of the stator poles, μ_0 is permeability of free space ($4\pi\times10^{-7}$ H/m), δ is gap between the stator poles and the rotor at the equilibrium position.

While the current stiffness (K_i) is derived according to the equation (2),

$$K_i = \frac{\partial F_x}{\partial I_x}\Big|_{I_x=0,x=0} = 2N\frac{F_{pm}\mu_0 A}{\sigma\cdot\delta(2R_{pm}\mu_0\cdot A+\delta)} \quad (4)$$

where N is number of turns in coil.

Consequently, the force coefficient can be defined according to the force produced by permanent magnet and coil current,

$$K_{pmc} = \frac{(K_x\delta)^2}{(K_i I_x)^2+(K_x\delta)^2} = \frac{1}{(\frac{B_i}{B_{pm}})^2+1} \quad (5)$$

Consequently, from the equation (5), K_{pmc} is larger, then B_{pm} is larger and B_i is smaller accordingly. It can be seen that larger B_{pm} will lead to larger K_x , So the coil current I_x will be smaller because of the smaller B_i , then the power loss of magnetic bearing will be smaller.

Equation (5) can also be expressed under the condition that the load capacity of magnetic bearing is known,

$$K_{pmc} = \frac{(K_x\delta)^2}{(K_i I_x)^2+(K_x\delta)^2} = \frac{(K_x\delta)^2}{(\frac{G}{2}-K_x x)^2+(K_x\delta)^2} = \frac{1}{(\frac{G}{2K_x\delta}-\frac{x}{\delta})^2+1} \quad (6)$$

The displacement stiffness K_x can also be given by,

$$K_x = \frac{\frac{G}{2}}{\delta\cdot\sqrt{\frac{1-K_{pmc}}{K_{pmc}}}-x} \quad (7)$$

From the equation (7), the value range of K_{pmc} is 0~1. Meanwhile, K_{pmc} is larger, the displacement stiffness K_x is larger accordingly. However, larger K_x is caused the vibration of rotor, and then the difficulty of control system is increased.

3 Analysis on Influencing Factor of Force Coefficient in HMB

Based on the methods suggested above, the HMB is designed. The key parameters are that δ is 0.25mm, N is 150, σ is 1.4, and the weight of rotor (G) is 60N. Then the results are obtained from simulation about the relationship among the force coefficient, diameter of the permanent magnet, turns of coils, and the offset of rotor.

3.1 Relationship between the Force Coefficient and Diameter of the Permanent Magnet

Curve is shown between force coefficient K_{pmc} and outer diameter of the permanent magnet D_{pm1} in Fig. 4.

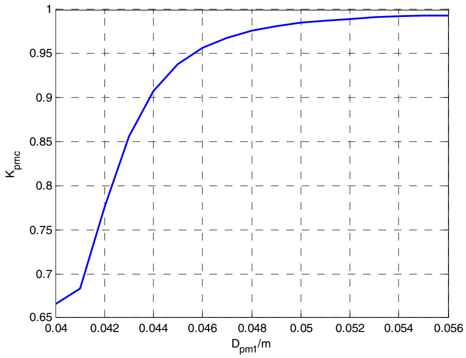

Fig. 4. Curve between force coefficient and outer diameter of the permanent magnet

As the diameter of permanent magnet D_{pm1} is increased, the reluctance of permanent magnet R_{pm} is decreased, and then the displacement stiffness K_x is increased according to the equation (3). So the force coefficient K_{pmc} is increased according to the equation (6).

3.2 Relationship between the Force Coefficient and Turns of Coils

Curve is shown between force coefficient and turns of coil in Fig. 5.

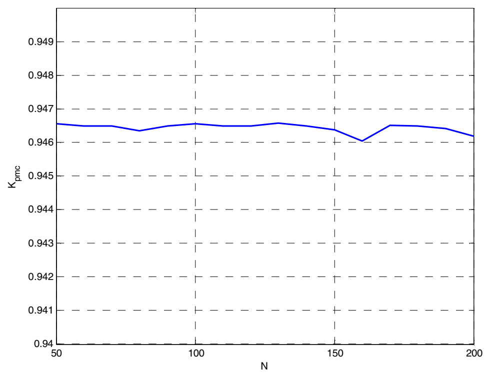

Fig. 5. Curve between force coefficient and turns of coil

As the turns of coil are increased, the displacement stiffness K_x will not be changed according to the equation (3) because the displacement stiffness is not related to turns of coil. The current stiffness K_i will be increased according to the equation (4), while the current will be decreased because of the increment of turns of coil. Hence, the force coefficient will not be changed according to the equation (6).

3.3 Relationship between the Force Coefficient and the Offset of Rotor

Curve is shown between force coefficient and offset of the rotor in Fig. 6.

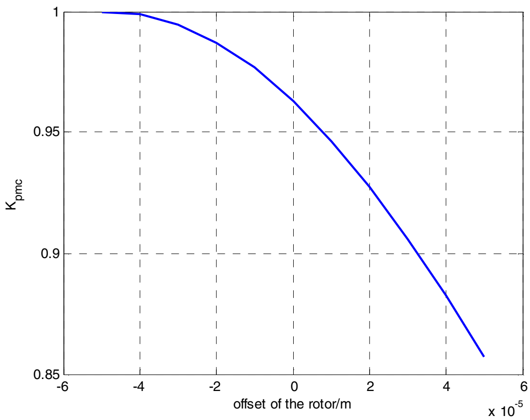

Fig. 6. Curve between force coefficient and offset of the rotor

As the offset of the rotor is deviated by the magnetic center along the opposite direction of gravitation, the displacement stiffness K_x and the current stiffness K_i will be increased, so the force coefficient will be increased. On the contrary, the force coefficient will be decreased. Consequently, the power loss will decrease when the rotor is suspended a certain position at the opposing direction.

4 Conclusion

In this paper, a concept of force coefficient about HMB has been proposed. It refers to the distribution ratio of permanent magnetic force and electromagnetic force in HMB. The force coefficient of radial magnetic bearing has been presented and analyzed some influencing factors. Analysis results have been shown that the relationship between force coefficient and power loss. According to the definition of force coefficient, it can be concluded that the force coefficient is larger, and then the power loss is smaller, considering the parameters such as diameter of the permanent magnet, turns of coils, and the offset of rotor. Consequently, the analytical results are helpful to design HMB for minimally invasive diagnostics and interventions (MIDI).

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Assessing Behavioral Responses in Persuasive Ubiquitous Systems

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Abstract. Existing telehealth systems do not perform as effectively as would be expected due to their asymmetric focus on sensing and monitoring with little support or assurance to affecting or altering behaviors. Many people, especially the elderly, are resistant to change. Such resistance diminishes the efficacy of telehealth systems. Research and supportive technology for intervention and behavior alteration is urgently needed. In response, we developed the Action-based Behavior Model (ABM) that promotes persuasion and enables persuasive telehealth. However, ABM requires an assessment of user behavior responsiveness and compliance to cyber influence. There are many challenging problems that must be overcome to enable such assessment. In this paper, we propose Assess Tree (AT) as a methodology for domain specific behavior assessment under ABM. We present AT and report on preliminary validation.

Keywords: User behavior assessment, assessing behavioral response, assessment methodology, persuasive systems, persuasive computing, trace-driven modeling and simulation.

1 Introduction

Advances in healthcare have led to a longer life expectancy, resulting in an increasing proportion of the elderly population. By 2030, the number of US adults aged 65 years or older will more than double to about 71 million [1]. Moreover, about 80% of the elderly has one chronic condition, and 50% of the elderly population has two or more chronic conditions [1]. Chronic diseases disproportionately affect older adults and are associated with disability, diminished quality of life, and increased costs for health care and long-term care [1].

Many elderly people prefer independent living without caretakers, and industry and academia have put forth considerable effort to support independent living as well as to provide cost-effective solutions to promote healthy aging [2-11].

Telehealth is a cost-effective approach that could support independent living and facilitate tele-care in general. However, many present telehealth systems do not perform as effectively as would be expected due to its asymmetric focus on sensing and monitoring with little focus on affecting or altering behaviors. While sensing and

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monitoring are crucial components of a telehealth system, we believe that intervention and behavior alteration are equally important. Many people, especially the elderly, are resistant to change. Such resistance diminishes the impact factor of telehealth systems. Research and supportive technology for intervention and behavior alteration are urgently needed to counter this resistance to change and promote healthy lifestyles. Simple and naïve approaches for intervention, such as directly telling people what they need to do, have not been overtly successful. Thus, there is a need for more advanced systems. In response, we proposed the Action-based Behavior Model (ABM) [3] that promotes persuasion and enables persuasive telehealth. ABM can be used as a persuasion template to streamline and tap into cybernetic resources to achieve sentience of the user and his/her situation, and to enact an influence on user behavior. ABM requires, however, an assessment of the user responsiveness and compliance to the cyber influence. This is no easy task. There are many challenging problems that must be overcome to enable such assessment.

In this paper, we introduce Assess Tree (AT) as formalism, structure and algorithms for domain specific behavior assessment under ABM. We present formalism and structure and only briefly present the associated algorithms due to space limitations.

2 Action-Based Behavior Model

In this section, we briefly review the Action-based Behavior Model, which is covered extensively in [3]. The model is based on the collective knowledge gained by studying social and behavioral science theories. ABM is proposed as a persuasion template designed by incorporating several persuasion theories into a "cyber model" that computer scientists can understand and utilize. As shown in Figure 1, the model partitions the telehealth system into a cyber system and a set of user actions. The cyber system is further divided into cyber sense and cyber influence.

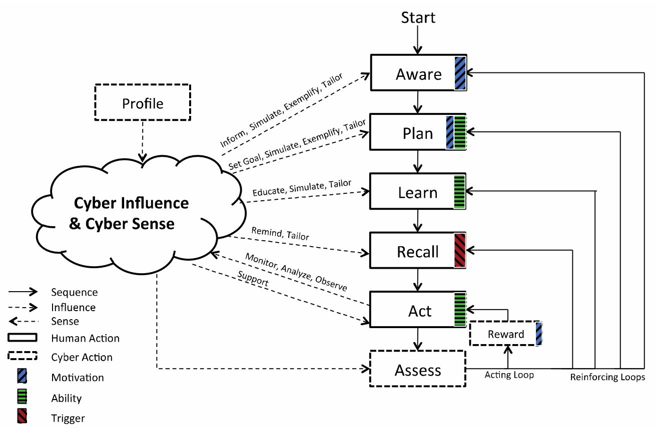

Fig. 1. Action-based Behavior Model

From “Start,” a user goes through each step’s action from Aware to Act. The cyber influence will affect and help the user to take each action. As the user works toward goals, the cyber sense will monitor, analyze and observe the user’s actions. After the initial rounds of acting, the Assess cyber action will evaluate the achievements of the goals and will advise the user to either continue, or roll the user back to the appropriate action based on the achievement and deficit of each action. For positive achievements, the Reward cyber action may give intrinsic, extrinsic or virtual rewards to reinforce the motivation.

3 Assess Tree

As mentioned earlier, ABM requires an assessment of the user responsiveness and compliance to the cyber influence. We introduce the Assess Tree (AT) structure as an assessment instrument for ABM. AT is a five-level tree in which the root represents the Assess cyber action. AT is designed for evaluating user reaction at each stage in ABM and deciding which step to go back to for reinforcement.

Nodes at the second level refer to the action node, nodes at the third level refer to the sub-action node, and nodes at the fourth level refer to the P-Node and N-Node. P-Node and N-Node are denoted by + and - as shown in Figure 2. Nodes at the fifth level refer to leaf node, where positive and negative behaviors are attached.

Action nodes at the second level are designed to match with human actions in ABM. Sub-action nodes further specify the actions into different categories of behavior. Each sub-action node has P-Node as a left child and N-Node as a right child, which represent positive behaviors and negative behaviors of that sub-action node. Leaf nodes have positive behaviors as children of P-Node and negative behaviors as children of N-Node. The positive and negative behaviors are represented by positive and negative situations with the Behavior Measurement Type (BMT). The details of BMT will be illustrated in the next section.

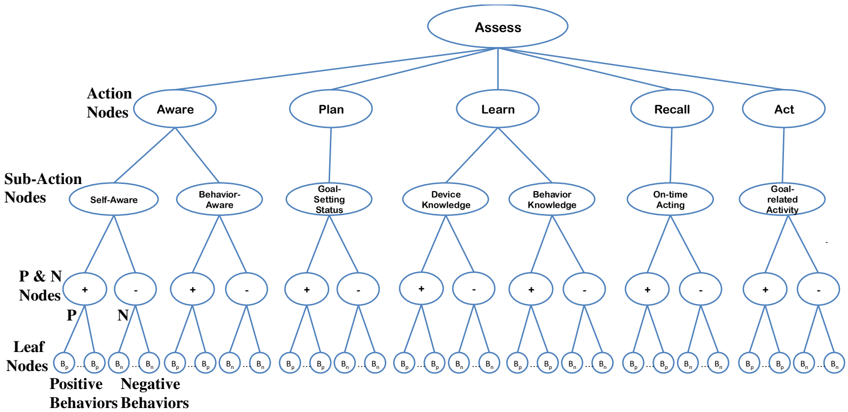

Fig. 2. Assess Tree

The situation can be defined as a triplet of a user's activities, set of devices' actions and contexts, all of which are related to a goal and their relationships over a period of time. Details of situation are covered in "From Activity Recognition to Situation Recognition" [12].

3.1 Behavior Measurement Type

Different types of behavior require different measurement approaches. The following are five different behavior types that we believe are representative of a wide variety of behaviors.

Frequency. How many times the behavior happens is important in this category of behavior.

Duration. In this type of behavior, the number of occurrence is not important but how long this behavior happen is significant.

Completeness. Frequency and duration are not essential in this type of behavior, the crucial thing is whether the behavior is completed or not.

Standard metric. In this type of behavior, the behavior is dependent on the standard metric.

Time. The behavior is only meaningful if the behavior happens at the specific time. This measurement type can have tolerance value, which indicates allowed time interval from the specific time.

Table 1 shows an example of behavior measurement type utilizing single behavior measurement type. Table 2 demonstrates an example of combined behavior measurement type. Of course, there are more combined behavior measurement types depending on the situation. Behavior measurement types (single or combined) are utilized in calculating the reference value of P-Node and N-Node.

Table 1. Behavior Measurement Type Example

BMT	Example
F (Frequency)-Type	Check glucose level three times a day
D (Duration)-Type	Exercise for 30 minutes
C (Completeness)-Type	Join patient care portal
M (Metric)-Type	Drink two liters of water a day
T (Time)-Type	Take medication at noon

Table 2. Combined Behavior Measurement Type Example

CBMT	Example
FT-Type	Take medication three times a day after having a meal
FM-Type	Drink 200ml water 10 times a day
DT-Type	Walk for 30 minutes at 7 am

3.2 Assess Tree Operations

3.2.1 P-Node

The P-Node has positive behaviors defined by situations as children. The value of the P-Node is calculated by the following formula: $f(p) = \sum_{i=1}^{n} W_{PCi} \times \frac{P_{Ci}}{R_{PCi}}$, where i is the number of children of P-Node, $0 \le f(p) \le 1$, $\sum_{i=1}^{n} W_{PCi} = 1$.

W_{PC}: weight of P-Node's children
R_{PC}: reference value of P-Node's children
P_C: value of P-Node's children

R_{PC} has a different value depending on the behavior measurement type. R_{PC} can have either a single value or a combined value. In order to clarify R_{PC}, we provide the examples of R_{PC} in Table 3 and Table 4. In Table 3, T-Type has a tolerance value, which represents the allowed time interval from a specific time as described in the previous section. We explain further using an example of medication to clarify usage of the tolerance value. The T-Type example "Take your medication at noon" is only meaningful when this behavior occurs at noon. If this behavior does not have a strict time requirement, then we can add a tolerance value (30 minutes) indicating that medication 30 minutes before and after 12pm is tolerable.

If a user takes the medication at 12:05pm, then R_{PC} is 30 (minutes) and P_C will be 25 (R_{PC}-time difference). Since P-Node has only one T-Type child, $f(p) = W_{PC1} \times \frac{P_{C1}}{R_{PC1}} = 1 \times \frac{25}{30} = 0.83$.

Table 3. R_{PC} Single Value Examples

BMT	Example	R_{PC}	P_C
F-Type	Check glucose level 3 times a day	3	Actual frequency (ex. 2)
D-Type	Exercise for 30 minutes	30 (minutes)	Actual exercise duration (ex. 25minutes)
C-Type	Join patient care portal	1	Joined (1)
M-Type	Drink 2 liters of water a day	2 (liters)	Actual amount of water consumed (ex. 1.5liters)
T-Type	Take medication at noon Tolerance value: 30 minutes	1 (no tolerance value) 30 (with tolerance value)	Whether actual behavior happens (1) or not (0) - (no tolerance value) Tolerance value – actual time passed (with tolerance value)

Table 4. R_{PC} Combined Value Examples

CBMT	Example	R_{PC}
FT-Type	Take medication 3 times a day after having a meal Tolerance value: 30 minutes	3, 30
FM-Type	Drink 200ml water 10 times a day	10, 200
DT-Type	Walk for 30 minutes at 7 am	30, 1

3.2.2 N-Node

The N-Node has negative behaviors defined by situations as children. The value of an N-Node is calculated by the following formula: $f(n) = \sum_{i=1}^{n} W_{NCi} \times \frac{N_{Ci}}{R_{NCi}}$, where i is the number of children of N-Node, $0 \leq f(n) \leq 1$, $\sum_{i=1}^{n} W_{NCi} = 1$.

W_{NC}: weight of N-Node's children
R_{NC}: reference value of N-Node's children
N_C: value of N-Node's children
Calculating $f(n)$ is same as calculating $f(p)$.

3.2.3 Operators

In this section, we define the operators for several different purposes. First, they act as a comparator capture of net effect of positive and negative behavior. Second, they act as an accumulator of various behaviors (action and sub-action nodes). Third, they act as a selector. Finally, they act as an information fusion network in which influential situations are identified and propagated over the tree. AT operators are divided into four different types of operators: assessing operator, diagnostic operator, propagating operator and analytic operator, as shown in Table 5. The assessing operator is used to assess a user behavior. The propagating operator can be exploited to control and limit transferring data to the upper nodes. The analytic operator can be utilized to check the adequacy of registered P-Node's and N-Node's children.

Table 5. Assess Tree Operators

Type	Operator		Description	Applicable Node
Assessing	$f(p)$		Calculate P-Node value	P-Node
	$f(n)$		Calculate N-Node value	N-Node
	I		Integrate one node value with the other node value	Sub-Action Node, Action Node
Diagnostic	U		Union behavior IDs and values into behavior set	All Nodes
Propagating	C		Forward one node value if it is smaller than threshold	Action Node
	F		Forward the behavior ID and value all the way to the action node	Leaf Node
Analytic	R	R_P	Calculate correlation value between P-Node child value and Act value	P-Node
		R_N	Calculate correlation value between N-Node child value and Act value	N-Node

The assessing operator includes $f(p)$, $f(n)$, and I. $f(p)$ and $f(n)$ are used to calculate P-Node and N-Node values as depicted in the previous section. The I operator is utilized to catch the net effect of positive and negative behaviors by integrating from P-Node and N-Node values, and to integrate effects from two sub-action nodes. The assessment value shows good view of user compliance level but it is hard to see which behaviors contribute to that compliance level. Therefore, the U operator is used to provide a diagnosis of the cause of compliance level. It performs a union of positive and negative behaviors and their values into a behavior set at each node level, and propagates the behavior set all the way to the root node. The propagating operator consists of C operator and F operator. The C operator is used in action nodes to control passing assessment values into the root node. Critical negative situations, which blocks a user to act toward a goal, must be handled even if overall assessment of sub-action node shows high compliance. The F operator is utilized to resolve the critical negative situations. It acts as a flag to indicate a critical negative situation, which should be handled immediately. If F operator is set, then that negative situations will be forwarded all the way to the action node. The R operator is further divided into R_P operator and R_N operator. The R_P operator is used to calculate correlation value between P-Node child value and Act value. The R_N operator is utilized to calculate correlation between N-Node child value and Act value.

3.2.4 Assessment Algorithm

In this section, we briefly outline the assessment algorithm - how we assess a user behavior using the operators explained in the previous section. As shown in Figure 3, the assess tree assessment algorithm consists of four sub-algorithms: Situation Recognition (SR) algorithm, Assess Update (AU) algorithm, Assess Propagate (AP) algorithm, and Assess algorithm.

```
Assess_Tree_Assessment_Algorithm( )
while true do
    if device or activity or context event trigger then
            e ←getDACEvent() // e:event, e = {e_d, e_a, e_c}, e_d:device event, e_a:activity event, e_c:context
event
            Situation_Recognition (e)
    end if
    if situation event trigger then
            s ←getSituationEvent()  // s:situation
            pn ←subscriptionMapper(s)
            pn.Assess_Update (s)
    end if
    if δ(t_c − t_a) = ω_a then  //t_c:current time, t_a:last assessment time, ω_a:assessment window
            Assess_Propagate ()
            Assess ()
    end if
end while
```

Fig. 3. Assess Tree Assessment Algorithm

When device event (e_d), activity event (e_a), or context event (e_c) is triggered, that event (e) is passed to the SR algorithm to recognize a situation using different situation recognition decision method depending on the number of functions defined. Once the situation is recognized through SR algorithm, the recognized situation will be triggered and then the Assess Update algorithm is called to update assessment value in each behavior registered in P and N-Nodes. When current time (t_c) reaches assessment window (w_a), the Assess Tree starts propagating the assessment value to an upper node using the Assess Propagate algorithm. Finally, the Assess algorithm is used to determine whether reinforcement is needed or not based on the propagated assessment value in each action node. We do not describe details of each sub-algorithm due to space limitation.

4 Validation

We validate assess tree using trace-driven modeling [13]. Trace-driven modeling is a technique that combines measurement and simulation in order to create an accurate model of a system.

Our validation is based on the following scenario. Charley is an elderly patient who has been managing diabetes and obesity. Recently, he joined a persuasive telehealth trial study. Charley has been provided devices (glucose meter, weight scale, electronic pill box and smart phone) to influence him to promote healthy behaviors and measure his behavior response to persuasive influence. During the first week, persuasive telehealth system monitors his behaviors and builds his profile including his vital and status information, as shown in Table 6. This profile information is utilized in Aware to calculate assessment values. For example, the assessment value of "walking less than before" in Behavior-Aware is calculated by referencing the average of walking step count in the profile (Table 6). Beginning with the second week, the persuasive telehealth system starts to influence him using cyber actions based on ABM [3]. He goes through each step's human action from Aware to Act in ABM. In the Plan step, He set four goals based on goal setting requirements and guidelines from his doctor. The goals he set are "check glucose level 3 times a day after having a meal within 30 minutes", "check weight in the morning", "take medication as prescribed" and "walk for 5000 steps". After initial rounds of acting, the system begins to assess his behavior response using Assess Tree (AT) from the third week. Table 7 describes device, activity and context artifacts that are utilized in the above scenario. Positive and negative situations registered in AT are provided in Table 8.

Table 6. Profile

Average of checking weight frequency	0.4
Average of checking glucose level frequency	1.6
Average of taking medication frequency	1.2
Average of walking step count	2600

Table 7. Device, Activity and Context Artifacts

Devices	Device Actions	Activities	Contexts
Glucose meter, weight scale, pillbox, and video camera	Turn on, turn off, sense glucose level, sense weight, generate error code, open and close, and sense food	Measuring glucose level, measuring weight, eating, taking medication, and walking	Glucose level, weight, calorie, error code, step count, and time

Table 8. P/N-Node Setting

Action Node	Sub-Action Node	P/N-Node	Situation
Aware	Self-Aware	P-Node	Check more glucose level than before
			Check more weight than before
		N-Node	Do not attempt to check glucose level
			Do not attempt to check weight
	Behavior-Aware	P-Node	Take medication more correctly than before
			Walk more than before
		N-Node	Take medication less correctly than before
			Walk less than before
Plan	Goal-Setting Status	P-Node	Complete set goals as required and guided
		N-Node	Do not set goals
Learn	Device Knowledge	P-Node	Check glucose level successfully
			Check weight successfully
		N-Node	Fail to check glucose level
			Fail to check weight
	Behavior Knowledge	P-Node	Take medication as prescribed
		N-Node	Take medication incorrectly
Recall	On-time Acting	P-Node	Check glucose level 3 times a day on time
			Check weight on time
			Take medication on time
		N-Node	Do not check glucose level within 30 minutes after having a meal
			Do not check weight in the morning
			Do not take medication on time
Act	Goal-related Activity	P-Node	Check glucose 3 times a day after having a meal within 30 minutes
			Check weight in the morning
			Take medication as prescribed
			Walk for 5000 steps

We conducted two different evaluations. In the first evaluation, we aimed to validate if AT can capture a decrease in compliance by using multi-day traces that modulate Charley's behaviors of 100%-20% compliance based on the scenario and goals described earlier. In the second evaluation, we aimed to validate if AT can catch a steady decrease (100%-1%) in compliance over a period of time by utilizing randomly generated traces with a steady compliance decrease. In both evaluations, we assume Charley already set his goals and there is no problem in goal setting so we exclude Plan in this validation.

All traces were randomly generated based on rules that make traces more realistic by excluding impossible cases and enhancing randomness in possible cases. We designed a variable compliance behavior trace generator based on the time sequence of a normal day with different compliance levels. We adjusted compliance level by injecting possible non-compliances. We constructed non-compliance by controlling the time and the way that behaviors perform. For example, non-compliance can be constructed by controlling when checking glucose level behavior occurs and how it performs such as "checking glucose level successfully" and "fail to check glucose level". More details about the variable compliance behavior trace generator and its API documentation are publically shared and accessible from [14].

Figure 4 describes the assessment result of 100%, 80%, 60%, 40%, and 20% compliance traces for 5 days. As can be seen in Figure 4, assessment values of Aware, Learn, Recall and Act are decreasing but there are some variations due to situational differences in traces. In 40% compliance, the Recall assessment value decreases significantly compared to assessment value. This is because on that day, Charley performed fewer behaviors that require timeliness and performed more behaviors for time-insensitive goal (e.g. walk for 5000 steps).

Figure 5 describes assessment results of the case for steady user compliance decrease. The result shows AT can capture steady decrease in user compliance.

Fig. 4. Assess Tree Assessment Result of Step-wise compliance Decrease (5 days)

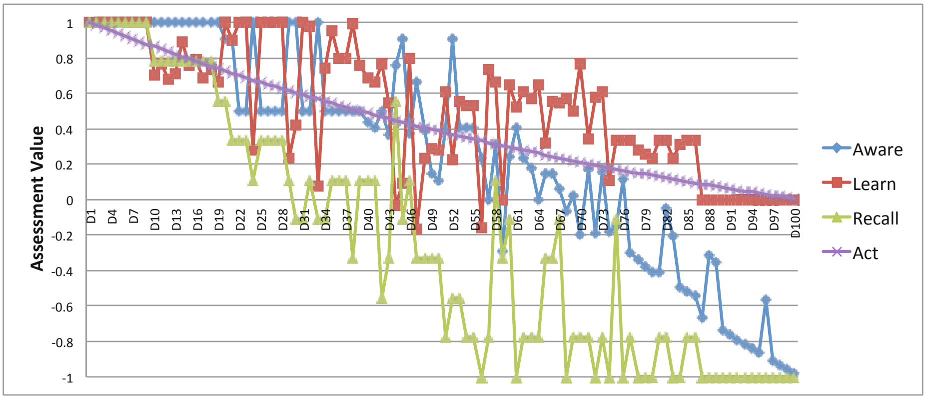

Fig. 5. Assess Tree Assessment Result of Steady Compliance Decrease (100 days)

5 Conclusion

We proposed the Assess Tree (AT) as a mechanism to assess user behavior responsiveness and compliance to cyber influence. We presented the AT structure and operations. Also, we briefly described the assessment algorithm utilizing AT. We evaluated the AT using traces of different compliance levels. The results show that the Assess Tree is adequately sentient to variations of user compliance. Presented results are an initial step to validate AT and we are working on further experiments with different AT operators and parameters, as well as different user profiles.

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Serious Game as New Health Telematics Tool for Patient Therapy Education: Example of Obesity and Type 2 Diabetes

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Abstract. The recent introduction of the serious games technology in medical education allows dispatching the health knowledge in communities not actually still concerned by the e-learning. The medical cyber-universities are giving essentially primary knowledge to medical students and continuing education for MP's, the paramedics being only a secondary target. The patient is rarely considered as a prior customer of the medical e-learning, but the increase of the chronic diseases as those emerging from the sequence overweight-obesity-diabetes of type 2 or from contamination spread facilitated by the new transportation modalities, with complex mode of propagation depending on their contagious (social or infectious) character, pushes to conceive active e-learning tools including a bio-feedback from the patient susceptible to increase its knowledge, level of responsibility, reactivity, compliance and observance with respect to the acute or long-term therapy and prevention policy concerning its disease. The paper presents the serious game as a user-friendly tool susceptible to serve the objective of e-therapy education at home for patients suffering of long term chronic diseases.

Keywords: therapy education, e-learning, serious games, medical cyber-university.

1 Introduction

The recent introduction of the serious games technology in medical education allows the spread of the medical encyclopedic knowledge and health practice in communities not actually still concerned by the e-learning. The medical cyber-universities like the French "Université Médicale Virtuelle" Francophone UMVF [1] and the Indian Medvarsity [2] are giving essentially primary knowledge to medical students and continuing education for MP's, paramedics being only a secondary target. The patient

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is rarely considered as a prior customer of the medical e-learning, but the increase of the chronic diseases as those emerging from the sequence overweight-obesity-diabetes of type 2 or from infectious contamination spread facilitated by the new transportation modalities, with complex mode of propagation depending on their contagious (social or infectious) character, pushes the medical informatics community to conceive active e-learning tools. These tools will include bio-feedback facilities extracting biomedical and sociological information from the patient susceptible to personalize its access to e-learning tools like serious games conceived to increase its knowledge, level of responsibility, reactivity, compliance and observance with respect to acute or long-term therapy and/or prevention policy concerning its disease. The paper presents serious games as a user-friendly modality of e-therapy education at home for patients suffering of long term chronic diseases, like type 2 diabetes, and after, techniques of evaluation of such a new didactic approach will be discussed.

2 Examples of Medical Cyber-universities

2.1 UMVF

The French Université Médicale Virtuelle Francophone UMVF was born in 2003 as a consortium of 8 French universities in the context of calls for projects launched by the Ministry of Higher Education & Research within the National Network Technologies for Health (RNTS), directed by J. Demongeot and J.L. Coatrieux [1]. Now, the 33 French medical faculties have joined the project. Their mission is to implement information and communication technology in education (ICTE) for the initial and continuing medical training. The virtual university is also an interactive resource center in the field of health, because it is intended to be both an information and prevention tool for public, and dissemination and promotion way of medical knowledge for professional. Nevertheless, its main tasks are to produce resource materials which complement courses for medical students, *e.g.*, for students preparing the national hospital resident competition, UMVF provides a database collecting various items and clinical cases to allow the training of users. UMVF contains more than thirty digital campus disciplinary campus online including: biophysics and nuclear medicine, embryology, microbiology, neuroanatomy, rheumatology, emergency, etc...

Universities represent only 10% of the training market throughout life. The British "OpenU" Foreign already offer courses in French and display thousands of students enrolled in all areas. In France, the situation is clearly a state university almost empty and therefore very weak universities face a market in place. The aim should be to touch a wider variety of audiences and professions for professional retraining. For that purpose, the project TIL "TRANS-INNOV LONGEVITY" of UMVF [2,3] was awarded in the framework of the the "Excellence Initiatives for Innovative Training" (IDEFI) by the Ministry of Higher Education & Research. The solution adopted was to cross the digital knowledge bases excellence of the university with the integration of professional tutors. More, the increasing number of elderly people raises important public health issues. This demographic phenomenon brings new needs for services and support around a new economic dynamics called the "silver economy". New businesses are emerging and there is no suitable university. IDEFI-TIL could contribute to increase the supply of university education in gerontology and structuring new fields of initial and continuing training, tailored to the multiplicity of businesses affected by the lengthening of life. These new courses of training excellence training must be exported internationally and particularly to developing countries which are confronted with an aging population at a rate much faster than today in developed countries and, for the most part, not have a supply of higher education in gerontology.

2.2 Medvarsity

Medvarsity, “Education anytime... anywhere...” [4], is the India's first medical cyber-university launched in 2000. Its mission corresponds to two kinds of services: courses/training programmes for doctors and paramedics, in order to deliver quality distance education to the healthcare providers (HCP), using information technology enabled e-learning tools, aimed at improving the standards of medical and paramedical education and practice. MP’s are also helped by Medvarsity to keep abreast with the latest updates in the medical field through online general courses as well as short focused practical programs. Concerning the paramedics, specialties such as rehabilitation have a special offer of formation to help them to specialize, keeping always in mind the necessity to ensure social and medical well being of the patient.

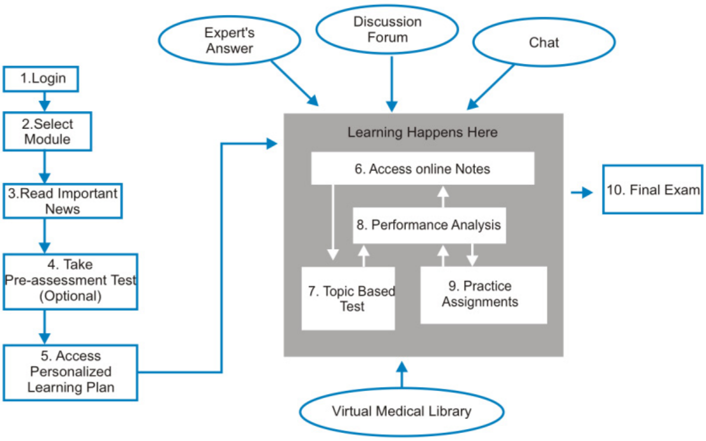

Fig. 1. Organization of the services offered by Medvarsity to medical and paramedical professionals [4]

2.3 Open Knowledge

The health knowledge at the disposition of the patient constitutes a difficult challenge, because the site providing the knowledge has to avoid an information too abstruse or too distressing, and privilege an information provoking the desire to know more about the management of its health, focus on understanding the primum movens of its disease, observing its therapy and preventing complications. A pedagogic tool respecting these constraints is the serious game, *i.e.* a game designed for a primary purpose other than pure entertainment, here for therapy education of the patient.

3 Serious Games

3.1 Serious Games Technology

The serious games is a new e-learning tool, which uses the same technology as ludic games [5], but they are more focused on the patient self-training and use bio-feedback loops based on hand-eye or foot-eye co-ordination and reaction times recording. The Beth Israel Hospital shown for example a close correlation between the performance of surgeons during a training course based on serious games with their effectiveness in surgical theatre [6]. Games "engines", like those from Cassidian® and Dassault Systems® help to create realistic 3D environments by using novel simulation techniques developed, such as high-fidelity mannequins [7,8], anatomic avatars [9] or physiologic clones [10] allowing health professionals in their practice, improving their performance and ability to optimize the quality and safety of their care. Such training simulator technology come often from know-how about simulators developed in aeronautics and astronautics considered historically as the oldest "serious" uses of computer game technology. and the dissemination of very powerful machines with sophisticated graphics have contributed to increase the realism and efficacy of serious games as tool of e-training especially in medical and surgical applications, like those related to emergency cases, in which a doctor has to rapidly recognise the signs of patient deterioration and trigger the adapted therapy.

3.2 The Example of the Type 2 Diabetes

In the case of type 2 diabetes, often resulting from the sequence "overweight-obesity", we can mention the following achievements:

a) The master work by A. Wijers makes explicit the needs of patients by age and sex, allowing a clustering of the patients not based on age, duration of the disease nor the existence of complications, but on the motivation to change lifestyle (non-intenders, intenders and responsible actors) valuable in characterizing different groups in diabetes type 2 population. It describes also the different stages of serious games development with a review of the literature until 2009 for type 2 diabetes (cf. Fig. 2 and [11,12]);
b) "The Birman case", designed by the association Diablotine and the Service of Endocrinology-Diabetology of the University Hospital of Caen, is available on the site [13]. The game is more oriented towards children with type 1 diabetes: the game proposes to the young patient to solve puzzles on her illness, managing it at best by the technique of functional insulin. It is also very informative for adults with type 2

diabetes, especially those who are insulino-dependent. A study on the impact of this game among young patients is available at [14]. On the site [13], we can also find the game Meli-Melo Carbohydrate, composed of a quiz to learn to identify the contribution in nutrition of carbohydrate foods;
c) "Escape from Diab" is a serious game that emphasizes the virtues of preventive diet and adequate physical activity [15];
d) Some games are aimed at practitioners GPs, as [16], which reminds them of recent proceedings of insulino-therapy;
e) “Defence and Power” gives information on diet and adapted physical activity [17].

Author(s)	Game title	Game type	Game elements	Functionality	Target group
Thompson et al. (2007)	• Escape from Diab • Nanoswarm	Diet& physical activity	1)Story/fantasy 2)Decision making (strategic)	1) Appendix G 2) Plan an escape plan (D). Choosing healthy food and activities (N)	Children
Peng (2009)	RightWay Café	Diet& physical activity	1)Story/fantasy 2)Competition and challenge 3)Decision making	1) Appendix G 2) Competitor in tv show. Player that can best manage his daily diet in a healthy way will win 3) Choosing breakfast, lunch, dinner, and snacks for his or her avatar/character in the game	Adolescents
Lieberman (2001)	• Packy & Marlon (P) • Bronkie the bronchosaurus (B)	Other health related behavior	1)Story/fantasy 2)Interaction 3)Decision making 4)Competition	1) Appendix G 2) With other players 3) Choosing appropriate amounts of insulin, choosing foods containing a good balance of food exchanges (P) Avoiding asthma triggers (B) 4) Not reported	Children/pre-adolescents
Kato et al. (2005)	Re-Mission	Other health related behavior	1)Story/fantasy 2)Decision-making	1) Appendix G 2) Strategic decisions related to self-management	Adolescents/ young adults
Silverman et al. (2002)	Heart Sense	Other health related behavior	1)Decision making	1) Regarding a potential myocardial infarction	Adults
Baranowski et al. (2003)	Squire's Quest	Diet	1)Story/fantasy 2)Challenging goals 3)Decision making 4)Rewards	1) Appendix G 2) Eating more fruit and vegetables 3) Choosing favorite fruits and vegetables 4) Getting points	Children

Fig. 2. Table describing some serious games for type 2 diabetes

4 Examples of New Serious Games for Type 2 Diabetics

4.1 Objectives of the New Strategy

Building a strategy not yet addressed in existing serious games consists in focusing on understanding the mechanism of the target disease and prevention of its major complications. The objectives of serious games proposed in the French project VHP (VisioHome Presence inter@ctive) led by Spie Communications® are focused on:

a) improving the self-care practice, taking into account the experience of illness and its management by the patient and comprising:

- Relieve symptoms, taking into account the results of the self-monitoring;
- Participate in the maintenance of sensors and effectors;
- Adjust the dose of medication;
- Lear gesture care techniques;
- Implement changes in lifestyle (balanced diet, exercise program, ...);
- Prevent avoidable complications;
- Deal with financial and social problems caused by the disease;
- Involve caregivers in managing and treating the disease, with resulting impacts;

b) developing the self-determination and the capacity to act of the patient, mainly in the areas like weight control, diet and exercise, by covering the following dimensions:

- Know yourself and have confidence;
- Know how to manage his emotions and controlling stress;
- Develop creative thinking and critical thinking vis-à-vis hir illness;
- Observe, evaluate and strengthen his own understanding of the disease evolution

This strategy leads to a prioritization in the development of serious games for type 2 diabetes to be validated by patients and the Medical Committee of the VHP project:

1) explanation of the genesis of the diabetic retinopathy as a micro-circulatory disease with functional visual impact on the conservation of the ability to see visual illusions;
2) elucidation of the social, metabolic and endocrine causes of type 2 diabetes, especially the role the social determinants of the sequence overweight-obesity;
3) information about the dietary planing and its feedback on its observance;
4) information on physical activity and biofeedback on its practice;
5) information on drug therapy and biofeedback on its compliance;
6) information about the diabetic foot and test of the capacity to prevent falls;
7) information about diabetic nephropathy and its mains symptoms;
8) information about respiratory troubles and bio-feedback in the sleep apnea [18].

4.2 Example of a Serious Game Testing the Ability to See the Visual Illusions in Diabetic Retinitis

The type 2 diabetes causes a retinopathy, which is the major cause of sight impairment, responsible of a progressive loss of visual acuity and a final blindness, but provoking early the diminution of the ability to see visual illusions. like the Hermann-Hering illusion [19]. The microvascular degeneracy causes indeed macular œdemas and macular ischemias altering the cellular organizations of the retina, in particular those at the origin of the lateral inhibition [20]. A user-friendly presentation of successive illusion organized in a didactic and ludic way allows to follow the degradation of the visual illusion perception (cf. Fig. 3).

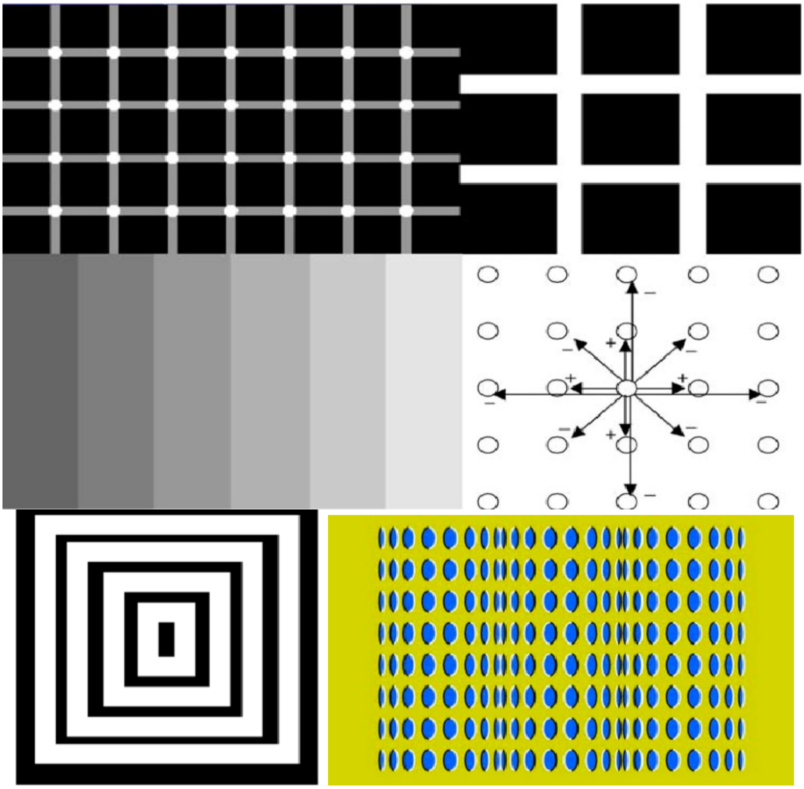

Fig. 3. Contrast illusions. Top left: Hermann illusion with bright points at the intersection of grey stripes. Top right: Hermann illusion with grey squares at the intersection of white stripes. Medium left: Mach bands illusion with enhancement of the vertical lines separating the different grey zones. Medium right: lateral inhibition with activation at short range (nearest neighbour neurons) and inhibition at medium range (second Manhattan sphere). Bottom left: Kanizsa pyramid. The lateral inhibition causes the sensation of seeing a 3-dimensional pyramid. Bottom right: rotating cylinders, commonly used in psychophysical experiments.

4.3 A Serious Game Testing the Ability to Understand the Role of Social Networks

One of the main determinant of the spread of obesity, declared social contagious pandemic by WHO [21,22] is the existence of social network transmitting socially inherited bad practice of nutrition and sedentarity. The serious game aims to explain in which category of professional, familial or educative network is included the patient and what behavior he has to perform in order to escape his social determinant (see on Fig. 4 different possibilities of social networks).

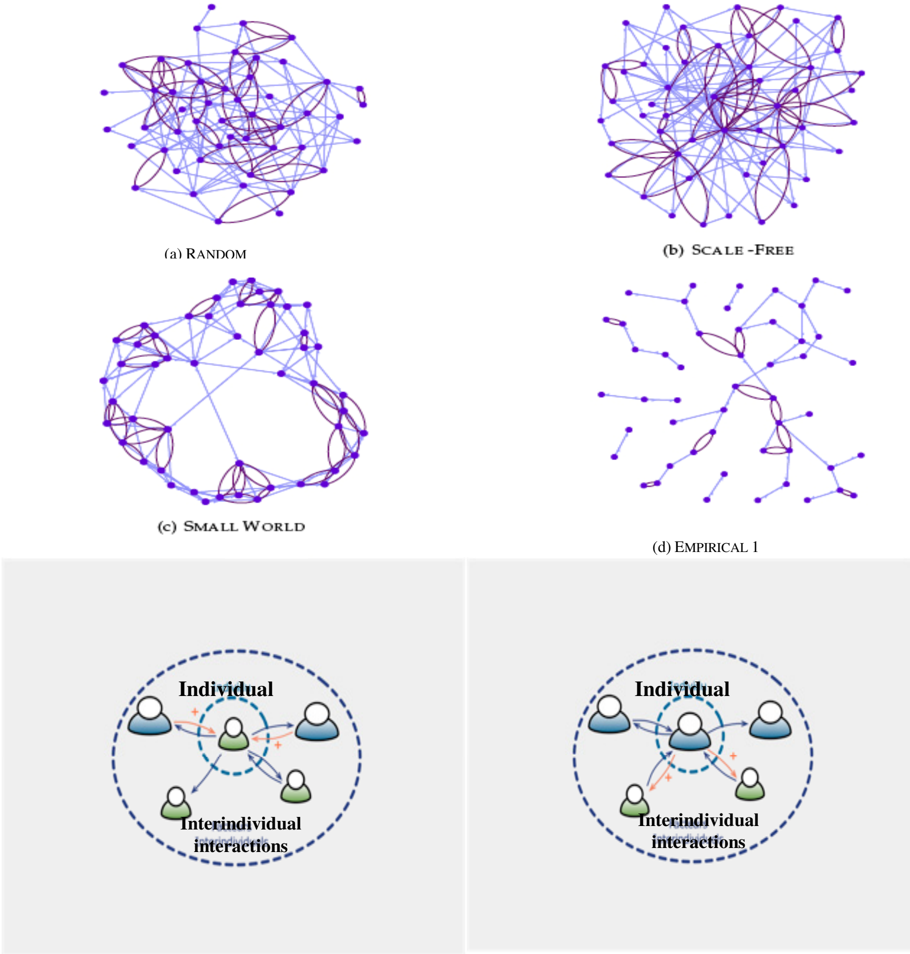

Fig. 4. Top: Simulation of various initial architectures: random, scale-free, small world, empirical. Bottom: Relationship between obese (blue) and non-obese (green) individuals.

5 Assessment Methods

5.1 TEMSED Method

TEMSED (for Technical, Ergonomic, Medical, Social, Economical and Deontological) is a methodology for clinical and medico-economic assessment). It is particularly avalaible for quantifying the benefit of a medical service, procedure or device to the patient [23]. The evaluative framework of TEMSED includes various dimensions corresponding to all phases of the assessment process, summarized in a diagram having 2 axes (Fig. 5), one axiological involving six areas of values and the

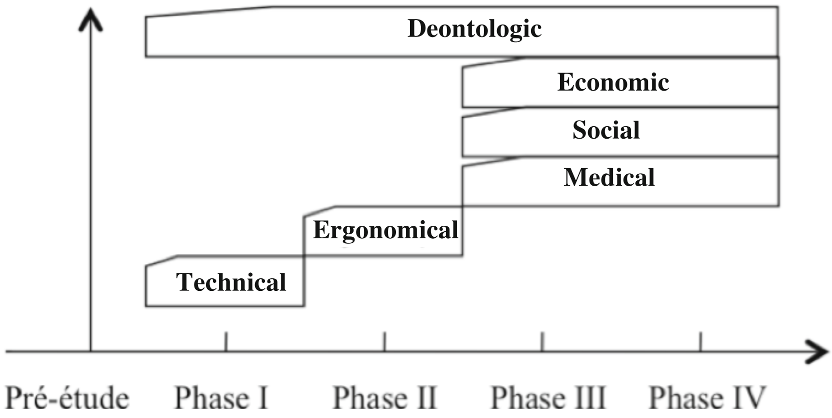

Fig. 5. TEMSED methodology schedule

other diachronic defining four phases similar to those used in clinical trials. The six domains of values can be summarized as follows:

• Technical dimension concerns evaluation of performance, robustness and reliability of drugs, instruments, devices and protocols, in terms of referenced indicators;
• Ergonomic dimension concerns the evaluation of the efficiency and comfort of user with respect to the drugs, instruments, devices and protocols;
• Medical Service Rendered dimension concerns the drug, instrumental and human therapy practices (*e.g.,* based on observance schedule, dietary rules,…), the adaptability of the device depending on the evolution of the disease and the optimization of homecare protocol;
• Social dimension concerns the evaluation of Social Service Rendered, *e.g.*, the "coaching" of the home services to the person;
• Economic dimension concerns the building of cost indicators and actual earnings in all aspects of economic and social life;
• Deontologic or ethical dimension concerns the evaluation of technologies in terms of compliance with duties and rights of stakeholders, clarity and reliability of contracts, existence of remedies in cases of conflict.

TEMSED approach provides a general framework for structuring the medico-economic assessment of the project, with production of a mid-term report and a final report, each stage of the project being analyzed following the grid above (Fig. 5).

5.2 GEMSA Method

GEMSA (Multidisciplinary Evaluation Grid for Evaluating Health project based on ICT) is a methodology for assessing effectiveness of project engineering in the health and social sector [24]. It is a methodology based on the respect of the project strategy, implementation schedule and deployment of the solution from the R&D prototype to the final industrial product through the intemediary demonstrators, with interim reports at the end of each years, noting the observed delays, delays threats, near-misses and actual accidental mishaps.

5.3 MAST Method

The assessment of the large scale pilots project conducted on several regions be can use the MAST methodology (Model for Assessment of Telemedicine), which aims to produce a methodical and multidisciplinary evaluation of the impact of the personalized health systems (PHS) and integrated telemedicine services, in assessing the effectiveness and contribution to quality of care of their applications [25]. Accordingly, the evaluation of a telemedical project includes the following elements:

- A scientific trial protocol including a detailed description of objectives, design, methodology, outcomes, and statistics;
- The selection/elaboration of questionnaires for collecting the opinion of the different categories of stakeholders and/or for measuring impacts which cannot be measured through the automatic analysis of collected data or relevant databases;
- The Training of local project teams in the use of the MAST model;
- A multicentre web-based clinical database for data collection and analysis;
- The evaluation of outcomes based on the MAST model, taking into account the primary outcomes agreed for the whole project and secondary ones agreed for individual pilots.

The expected result of the MAST evaluation is:

- a validation of piloted PHS and telemedicine services using MAST model;
- a validation of the MAST model itself through real life pilots.

6 Conclusion

We have shown in this paper the necessity to introduce new pedagogic tools of e-learning, in order to to empower the patient with type 2 diabetes, explaining the genesis of his illness and, through serious games, making him play his own role in the context of critical situations (*e.g.*, hypoglycemia with soft fall or transient aphasia), or by testing its performance in sensory-motor and/or cognitive exercises, in order to enabling him to develop early prevention strategies before the phase of complications.

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Measuring People Activity with Smart Homes

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Abstract. This work describes the use of smart homes to assess the health and wellbeing of people by measuring and displaying their activity at home. This is accomplished by the use of motion sensors, switches, pulse counters and touch screen displays. Pulse counters keep track of events and paths. An event is the triggering of a sensor, and a path is the distance between two sensors. There are counters for measuring positive and negative activities. Activities like walking, pedaling a static bicycle, and showering are displayed hourly, daily, and monthly with the same displays used for metering water and electricity. The activity patterns show hours of quietness, sleeping time, time without activity and their interruptions, like waking up in the middle of the night to go to the bathroom. Several hours of continuos inactivity during the day may trigger a panic call in the burglar alarm central, requesting a call back.

Keywords: Home Automation, Smart Homes, Wellbeing, Activity Monitoring.

1 Introduction

Medical health systems are decreasing hospital rehabilitation days and, therefore, increasing the rehabilitation days spent at home. Consequently, there is interest at improving the monitoring of patients during the recovery time within the privacy of their homes. There is already, a senior housing facility that has used automation for Embedded Health Assessment [1] to detect changes in activity patterns to alert clinicians. Also, there are ongoing research projects to monitor [2], analyze walking speed [3], and prevent falls [4] using motion sensor devices.

In this manuscript, we describe how smart homes could be adapted for Embedded Health Assessment of people by monitoring motion sensors and metering electricity and water to make users, or their support system, aware of changes in health or behavioral patterns that may indicate a health problem. A smart home can log events related to people's motion, use of lights, status of doors and windows, and utility usages. It is also capable of implementing actions, based on rules, resulting in sending e-mails, and/or originating calls when unusual pattern are detected. A touch display can help the user to control the several devices in the home and, simultaneously, show the correlation of the usage of utilities and other information related to user's wellbeing. Health activities, that affect wellbeing, may also be part of a rehabilitation process, like walking between two distant rooms, walking on a treadmill, pedaling a

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static bicycle, or using the stairs instead of the elevator, which are considered positive activity. Examples of negative activity are: going to the fridge during late hours in the night, using the elevator, walking in rooms with the lights off, and using electrical energy when there is not enough production of solar energy. In this paper we describe how a smart home was adapted to meter activities related to the wellbeing.

An unusual pattern of behavior can be considered an abnormal activity; for example, a person falling and non completing the path between two rooms. water running in the bathroom for unusually long period of time, or having doors or windows open that were supposed to be closed. A smart home should issue alerts when an abnormal activity is detected.

2 Implementation

Smart homes have sensors to trigger alarms during intrusions when the burglar alarm system is armed; but the same sensors can be used, while the burglar alarm system is unarmed, to control lights, sound buzzers, and sense events. Figure 1 shows the location and pointing direction of the six sensors in an apartment. S1 covers the elevator hall. S2 covers the stairs. S3 covers the access to the services area composed of kitchen and laundry rooms. S4 covers the access to living and dining rooms. S5 covers the presence in the corridor, and S6 covers the access to the entrance. An event is generated every time a sensor is triggered by motion.

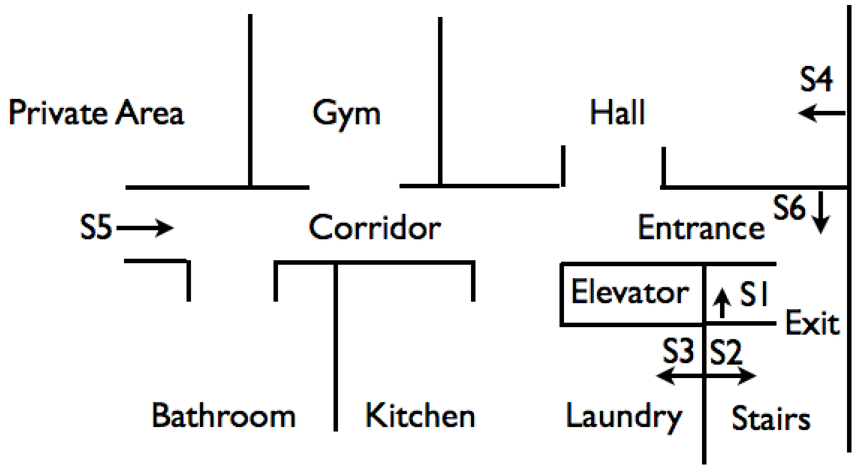

Fig. 1. A smart home with six motion sensors distributed over the house to trigger events

Figure 2 shows the home automation implementation. The burglar alarm system initiates telephone calls in response to panic events. The energy system consists of Event and Path Counters, and Touch Screen Displays. Not shown in Figure 2, there are also current sensors (toroids) to measure the generation and consumption of electricity, and water meters to measure the irrigation and house water, separately. All the accumulated values in the counters are shown in histograms by hours, days, and months, using the same Touch Screen Display or the Web Server. The automation system consists of Controller, Web Server, Touch Screen, Activity Switches, Relays, and wall commands not shown in Figure 2.

The Controller has scenarios that convert events into actions with rules. Some of the scenarios are used to build timers needed to trigger a panic call by closing a Relay to actuate the Panic Switch. Other scenarios convert the pulses from the sensors into commands for the Activity Switches to increment Event Counters and Path Counters. While Event Counters meter every time a user passes in front of a sensor, Path Counters meter the number of times a user passes in front of a pair of sensors during a time interval. The automation system has a Web Server used for remote monitoring of Counters and for sending e-mails after an event created by the Controller.

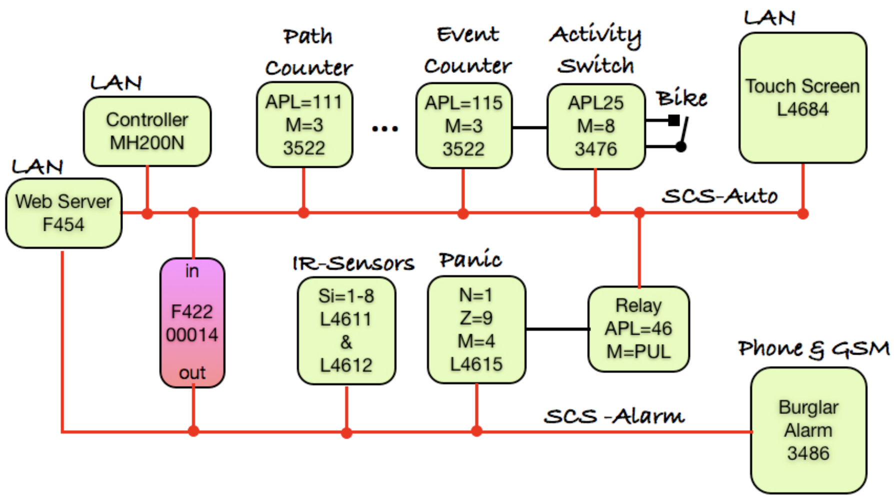

Fig. 2. The smart home has Burglar Alarm and Automation Systems with a Touch Screen Display, Sensors, Switches, Web Server and Controller. There is an interface, F422, to interconnect the SCS-automation bus with SCS-Alarm bus.

The Controller has variables (counters and booleans) used to implement time-out functions in scenarios, to detect periods of inactivity, before actuating the Panic Switch. For example, to create a 2-hour time-out counter, a counter variable is set to a value of 12 every time that there is a new event. This counter is decremented every 10 minutes until it reaches zero (2 hours without events), when it triggers a scenario to generate a signal for the burglar alarm central to call for help by dialing several phones, in sequence, until it gets an answer. The algorithm for this time-out counter is implemented by the following scenarios:

```
•SCEN1: # An activity is detected from sensor Sx for x=1 to 6
 When Sx=ON; Execute Counter1=12;
•SCEN2:  #  10 min at 01,11,21,31,41,51 of any hour
 When Time="**/*1"; Execute Counter1=Counter1 -1
•SCEN3: # after 2 hours of inactivity
 When Counter1=0
 Execute Panic=1; delay=1 sec; Panic=O
```

Lack of motion during unexpected hours may generate a panic call. For example, a service person did not show up for work as expected. The length of the period for the down counters is preset in the scenarios, but different scenarios can be enabled/disabled using the Controller web interface. Different periods of inactivity may be set to account for sleeping and resting times. Some of the triggering events may be related because they happen simultaneously or sequentially over a period of time; therefore, the controller may trigger a panic call only when one of the two events happens. For example running the water while the burglar alarm is armed, and all lights are OFF.

An Event Counter meters all activity generated by each motion sensor; but, using the touch screen display, or the burglar alarm central, sensors can be disabled by deselecting their zones of pertinence. Figure 5 shows an Activity Switch that was directly connected to a dry contact of a static bicycle to account for the rotation of its wheel during a daily exercise. The number of wheel turns should increase with the number of training days, as users get better trained. There is also an additional Event Counter to meter quite time. The Touch Screen Display can show up to two years history for any Counter.

Path Counters are impulse counters that count sequential events. Paths are useful to measure magnitude and direction of movements. Every completed path increases its counter. There may be counters for positive and negative paths, and they may be displayed in a graph with opposite signs. A panic call may be triggered when the pair of events is not completed during an expected time interval.

The algorithm of a path is defined by two scenarios, implemented by sensors S5 and S3, to account for a walk along the corridor to the Kitchen shown in Figure 1.

```
SCEN4: # First sensor event
When S5=ON
Execute Boolean5=True

SCEN5: # Second sensor event increment counter by 1
When S3=ON Only_IF Boolean5=True
Execute Activity Switch=0.5sec, Boolean5=False
```

A single Path Counter is used to add several paths of different walk distances. For example, in a walk from the Private Area there several paths, therefore, we use 1 pulse for a 4 meter walk to the Kitchen, S5-S3; 2 pulses for an 8 meter walk to the Hall S5-S4; and 3 pulses for a 12 meter walk to the Entrance, S5-S6. Four additional Path Counters are used to account for the two exits and entrances to the home (stairs and elevator). EXITS: S6-S1 when using the Elevator, and S6-S2 when using the Stairs. ENTRANCES: S1-S6 when using the Elevator, and S2-S6 when using the Stair.

3 Wellbeing

The objective of this work is for users to review, measure, and improve their wellbeing in the privacy of their homes. Once the energy system is in place, it is quite simple to adapt the pulse counters to monitor people's activity and explore how changes in life style may impact their wellbeing. For example, a single Touch Screen display enables users to observe their sleeping patterns by showing graphically motion, and energy and water consumption during the night.

The generation of electrical energy from solar cell panels is also a kind of wellbeing; because, it generates income by selling energy to the grid, increases user savings by using alternative energy. A single solar cell panel, 100 Wp, 12 VDC system, charges the backup batteries for the home automation system, so our smart home does not require more electrical energy, from the grid, than a conventional home. There is also a 6 kWp, 230 VAC solar cell panel system to lower the cost of running the electrical appliances, and to generate electricity for the grid, during the day, when the appliances are not used. Figure 3 shows a terrace of the apartment with solar cell panels and the generated energy on a sunny day. A smart home has metering capabilities to display generations and consumption of electricity to help users to sync their energy usage habits with the generated alternative energy to avoid expensive energy bills.

Fig. 3. Left: the terrace and roof are used for solar cell generation systems. Right: graph showing histogram of the generated energy in kWh during a sunny day on June 20, 2012.

The Touch Screen display is the main user interface to the home. Users control their home, learn how much and when alternative energy is generated, study weather pattern (wind and temperature), and keep a history of their physical activity and sleeping patterns. Figure 3 (right) shows the energy generated during a day. Figure 4 (left) shows the energy generated during the month of May, 2012. Figures 4 (right) shows the water consumption during a day. It shows a water consumption the middle of the night and an outing for the rest of the day, starting at 11:00 AM. Figure 5 (left) shows the static bicycle used to exercise and the display (right) showing the average hourly event activity during November 2012.

Fig. 4. Left: touch screen showing energy generated daily during May 2012. Right: water consumption on July 27, 2012 indicating waking up in the middle of night.

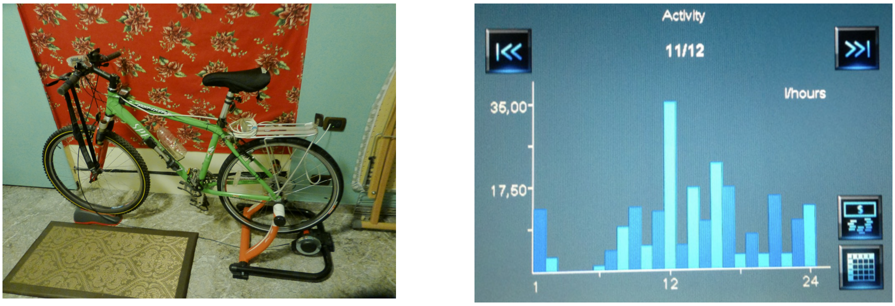

Fig. 5. Left: stationary bicycle with contact that closes and opens at every wheel rotation. Right: display showing average daily activity for the month of November 2012.

The smart home has also a network camera that sends an e-mail with images every time a person approaches the top of the stairs. The images show the days a person has balance, motion and postural problems. The idea is to have a type of "Time Machine" to see and explore people evolution within the privacy of their homes, and be alerted of unexpected habits to prevent future health problems.

4 Conclusions

A smart home can record and display values related to people activity continuously. Users may review the data accumulated in pulse counters, during a period up to 2 years, in the privacy of their homes. The data collected can be displayed locally, using the touch screen display, or remotely, using the web server. With this implementation, we demonstrated the capability of smart homes to collect data inconspicuously to keep track of user activity, rehabilitation, and changes in user normal conditions. Further work is needed to analyze the data collected to created models and applications for wellbeing.

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AQUEDUC: Improving Quality and Efficiency of Care for Elders in Real Homes

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Abstract. Elderly care is facing the challenge of the disequilibrium between the increased number of old people and the low number of personnel in the elderly care. The emerging pervasive technology has revolutionised the way of assistance in elderly care. Current solutions usually focus too much on technology, and fail to address the usability issues. In this paper, we offer a comprehensive system for both elderly care providers and elders. The system enables coordinators to manage care-givers and elders in an efficient way to improve service quality. For instance, care-givers can be scheduled in a real-time manner with mobile phones. We also deploy several sensors in their homes to monitor daily routines to ensure their safety. Alerts will be sent and accessible by coordinators immediately once detected, then elderly care services can be provided accordingly. We test our system in a real home for over 2 months. Finally, we offer a statistical study about the collected data and the reported alerts.

1 Introduction

People are now stepping into population ageing society. The number of people over 60 years old is over 0.6 billion world-wide. As reported in the State of Ageing and Health in America 2007, by 2030, there will be 71 million American older adults for roughly 20% of the US population. Even in developing countries like China, they are also suffering from the population ageing problem. Important overall problems regarding the elderly care are raising, causing by the imbalance between the increased demand of healthcare and difficulties to recruit and retain personnel in the elderly care [7].

With the rapid development of pervasive technology, the way of assistance in elderly care has been revolutionised. A plenty of elderly care systems have been developed to assist elderly people to live independently [2,5,8]. However, current systems are often facing various problems, such as the usability issues, and convincing solutions are still immature [5]. What's more, the studies put too strong focus on the technology, rather than the user perspective [2,4]. For instance, elderly people are asked to wear several sensors in some current systems, which is uncomfortable in daily life. On the other hand, the ignorance of the privacy issue also fails everyone to benefit from current solutions [4].

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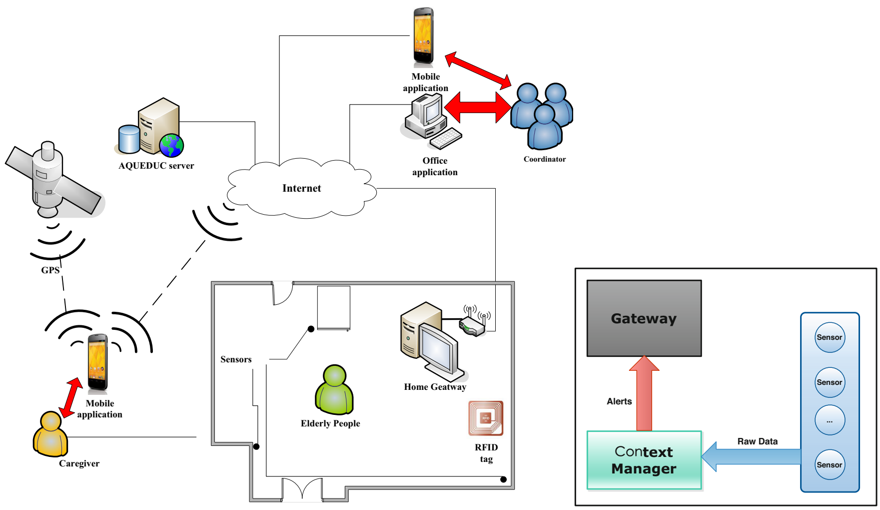

Fig. 1. Overall system architecture (left) and three components of the smart home part (right)

Different from current solutions which require no/less care-giver intervene although it is proved caregivers play an essential role in assisting elderly care [6], in our AQUEDUC [1,3] project, we provide a comprehensive solution for elderly care companies to serve the elders more efficiently and more delicately. Specifically, for caregivers, they can be scheduled based on their states, and report their tasks with mobile phones in a real-time manner. For elders, we apply pervasive technology to monitor their daily routines (i.e. when to get up, eat, toilet, etc.) to ensure safety. In summary, the main contributions of this paper are three-fold.

1. We develop a comprehensive system which can benefit both the elder care providers (care-givers, coordinators) and elders. A natural graphical user interface (GUI) is also developed to allow elders and care-givers to communicate with coordinators friendly and conveniently.
2. To ensure the safety of elders, several pervasive sensors are deployed in their homes to monitor daily routines. Alerts can be sent to coordinators immediately, then elderly care services can be provided accordingly.
3. We test our system in a real home for over 2 months. We further perform a statistical study about the collected data and detected alerts.

2 Overall System Design

2.1 System Architecture

The goal of the AQUEDUC project is to build a system to manage coordinators, care-givers, and elderly people in a better and more efficient way. Fig. 1

(left) shows the system architecture. The system is composed by three main service parties: coordinators, care-givers and elderly people. The communication between them goes through the AQUEDUC server. For the care-giver, with the AQUEDUC mobile application, he can consult and operate his intervention agenda. For instance, the care-giver can declare and modify his agenda with the application. The details about the elder can be also known. For the elder, he consult his agenda, send requests to the coordinator, and even edit his interventions by postponing or cancelling some of them. For the coordinator, he has both desktop and mobile version of the application. He can create new interventions, edit the existing plans, answer the elders' requests, and provide necessary services to the elders according to the alerts generated by the smart home part which is installed in the elders' homes. How the system works will be detailed in the following use cases.

Anna is a coordinator in an elderly care service company. Bob is a care-giver and John and Mary are two elders. One day, as planned, Bob has an appointment and will go to John's home to clean the floor for him. He consult the information about John (age, home address, etc.) from the AQUEDUC server with his mobile phone. Meanwhile, his state is reported on service. Due to the heavy traffic, Bob sends 30-minute delay message to the server with his mobile phone. John will be informed by a message that his next intervention has been postponed. This delay will also appear to Anna in her control board. After arriving at John's home, Bob has to scan an RFID tag at John's home with his mobile phone, and before departure, he also has to scan again to record the time information about his intervention which will be sent to the gateway automatically. Meanwhile Anna knows that Bob's state will be free and available to be scheduled.

Another day, Bob prepares to go to Mary's home and cook meal for her as scheduled. Before leaving, he is told that the appointment has been cancelled because Mary made a Cancel request for this intervention from her GUI and this request was validated by Anna.

For both use cases, the information about the next intervention which would be displayed in the GUI will be updated automatically after the care service.

In addition, we also develop a smart home part which is installed in the elders' homes. It can monitor the elders' daily routines, and detect predefined alerts by applying pervasive technology to ensure the safety of elders. The details will be introduced in the next section.

2.2 The Smart Home Part

The smart home part is developed to ensure the safety of the elders with the pervasive technology. It needs less intervene of care-givers and can monitor the elderly people's daily routines. Behaviours which deviate from their daily routines will be reported as alerts to the coordinators through the gateway. And then necessary measures would be taken (e.g. emergency treatments or let the care-giver check with the elders afterwards).

As illustrated in Fig. 1 (right), this part has three components: the context manager, the deployed sensors, and the gateway. The working process is: 1) the data collected by the deployed sensors is firstly transferred to the context manager; 2) the responsibility of the context manager is to infer high context from the data got in 1); 3) the alerts if detected are then pushed and stored into the AQUEDUC server for the access of the coordinator.

3 System Evaluation

3.1 Predefined Alerts and Sensing Logic

In the AQUEDUC project, we have defined nine alerts after interviewing several experienced staffs. They are believed to be very essential in the daily life of elders, and the detailed information can be found in Table 1. The first three alerts are about the elderly people's sleeping patterns, while the remaining alerts are about their eating patterns. Note that the figures are configurable parameters and vary among different elders. If these alerts are detected frequently, it is very probably that the elderly people behave abnormally (e.g. suffering from some diseases).

Table 1. Detailed information about nine alerts and their respected sensing logic

ID	Description	Sensing logic
1	Get up before 9:30 am	Use the presence sensor to detect
2	Get up after 9:30 am	Use the presence sensor to detect
3	Go to the toilet at night for more than 4 times	Use the presence sensor to detect
4	Fridge is not opened during 24 hours	There is no light in the fridge
5	Fridge is opened for over 2 hours	There is light in the fridge
6	Temperature inside the fridge is above 15°C	Temperature value is above 15°C
7	Fridge is not opened during breakfast time	There is no light in the fridge
8	Fridge is not opened during lunch time	There is no light in the fridge
9	Fridge is not opened during dinner time	There is no light in the fridge

With the raw sensing data, we can not know whether the alert is taking place directly. We adopt sensing logic based on simple rule reasoning to infer high level context (i.e. alerts). For example, the presence sensors which are installed in the front of doors can detect when the elderly people enter and leave the respected room (we assume the elders live alone). The time when the elderly people first leave the bedroom in a day is the get up time. Alert 2 is also reported as we want to know the specific get up time if they get up later because some elderly people may pass away in their sleep. Alert 6 would be reported if the temperature value in the fridge is above 15°C, which is an indicator of the food condition in the fridge. Sensing logics of alerts are listed in the third column of Table 1.

3.2 In-the-Field Testing

We tested our system in an elderly lady's home from May to June in 2012, and collected rich data.

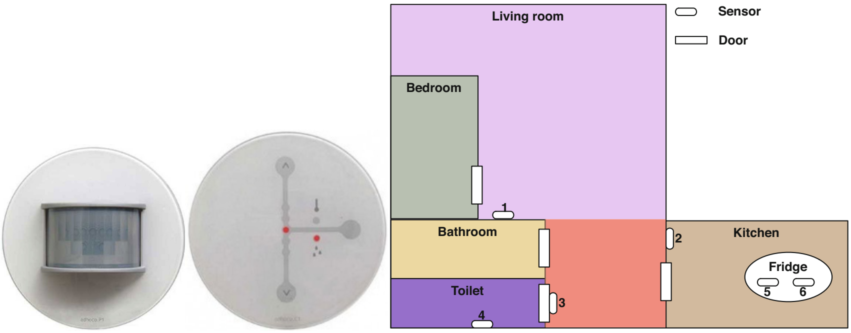

Fig. 2. Images of motion sensor (left) and temperature sensor (middle); Layout of the apartment and sensor install positions (right)

Sensor Deployment. As discussed previously, three types of sensor are used to detect the alerts, the presence sensor, the light sensor and the temperature sensor. To detect alerts, we have deployed 6 sensors in total in the elderly lady's home, five *Adhoco* motion sensors, and one *Adhoco* temperature sensor (can be seen in Fig. 2). One of the motion sensors is installed inside the fridge to record its lighting condition, while the others are used to be as presence sensors. Fig. 2 (right) shows the layout of the testing apartment and sensor positions.

For all sensors deployed in our system, they have the same data format and sampling rate. Their format of a single log is: ⟨*Sensor Tag, Value, Timestamp*⟩. For the sampling rate, it has two different states. If the monitoring environment stays unchanged, the sampling rate is one per hour; otherwise, it will have an extra sample when the environment changes (i.e. the light/temperature changes, a person appears/disappears under the presence sensor).

Statistical Study. Here, we give a statistical study of the data collected by our system, and also the detected alerts as well.

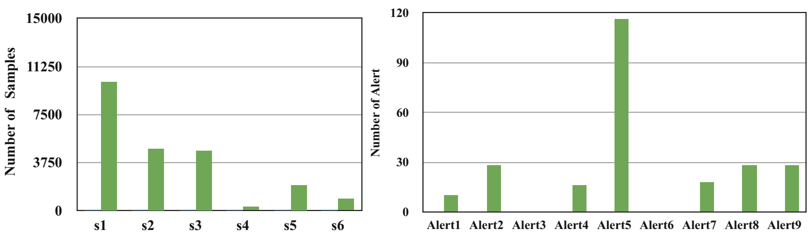

Fig. 3. Statistics information about the collected data (left) and detected alerts (right)

Our experiment began on 10th May, 2012, and ended on 12th July, 2012. The system was turned off from 14th to 21st May. Fig. 3 (left) displays the data size information (measured by the number of sensor samples). We have totally collected over 22,835 samples. The presence sensor deployed in the toilet (s4) has the smallest number of samples, which coincides with the fact that elders spend the least time in the toilet. The elderly lady moves frequently between bedroom and living room, which leads to sensor s1 has the largest number of samples. The temperature sensor (s5) has relatively more samples than the light sensor in the fridge (s6), meaning the temperature in the fridge is more unstable and changes more commonly.

Fig. 3 (right) shows the statistics of the reported nine alerts for the studied elderly lady. There are totally 244 alerts have been detected during the experimental time. No Alert 4 is detected, which indicates the elderly lady had a very normal toileting pattern during night. Also no Alert 6 is reported as well, meaning the food is always in good conditions. The most reported alert is the Alert 5, that is, the elderly lady often forgot to close the door of the fridge.

4 Conclusion

In this paper, we present an elderly care system which can benefit both the elderly care providers and the elders. For instance, it enables coordinators to schedule care-givers real time. Also the service hour of care-givers can be recorded and transferred to the AQUEDUC server automatically.

For ensuring the safety of elders, we further build a smart home part in the elders' homes to monitor their daily routines. We evaluate it in a real home for over two months. This part can detect nine alerts, which are believed to be quite important for elders. We further make a statistical study on the collected data and detected alerts. Finally, we have collected over 22,835 sensor readings and detected 244 alerts.

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Towards Improving Reliability of Computational RFID Based Smart Healthcare Monitoring Systems

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Abstract. Advances in networking and small sensors (motes, RFID tags, etc) have made it possible to monitor and provide medical assistance to people in need at their homes. Recently, WISP tags, one advanced technology of Radio Frequency Identification (RFID) tags, have been used to monitor indoor activity, vital signs, sleep quality, and health status remotely. These types of systems take collaborative decision based on the data collected from all the WISP tags of the system. Any missing tag data within the environment may introduce critical error in the system's decision and this eventually may jeopardize system's decision reliability. In order to maintain system's reliability, a monitoring protocol needs to be executed frequently and it should be made efficient in terms of execution time. This paper studies the problem of monitoring a large set of WISP tags and identifying the missing ones. In this paper, based on probabilistic methods, we propose a monitoring protocol for WISP based Smart Healthcare Monitoring Systems. The goal of this protocol is to improve the security and reliability of a smart healthcare monitoring system by detecting missing tags and reporting back only the data of the existing tags.

Keywords: WISP, Accuracy, Security, Reliability, RFID.

1 Introduction

The world is facing problems to provide high quality healthcare services at a reasonable cost due to the increasing percentage of graying population. To improve the overall quality of healthcare, we should develop low cost smart healthcare monitoring systems available to home usage for aging population and people of all age in general. The employment of new technologies like ubiquitous computing allows the development of various smart healthcare monitoring systems.

Two kinds of sensors, motes and Radio Frequency Identification (RFID) tags, are usually deployed in smart healthcare monitoring systems. Most common are small motes that allow deployment of wireless sensor networks (WSNs) in many real-world problems. RFID tags have been used in a number of biomedical and healthcare applications, such as dental implants and molds [1], hospital workflow monitoring, intra-hospital patient and equipment tracking [2]. Despite these successes, WSNs and RFID systems are not seen to be embedded in everyday life of people.

Most future and innovative smart healthcare systems will require tags that can also perform minimal sensing, computation, and storage. One recent advanced version of

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RFID, known as *Computational RFID (CRFID)*, presents exciting possibilities for ubiquitous computing applications [3, 4, 5, 9, and 10]. Wireless Identification and Sensing Platform (WISP) is an example of CRFID tags [6]. CRFID combines the advantages of RFID tags with those of sensors. However, unlike RFID tags, WISP tags have two types of data - tag ID and sensor data. The tag ID is used to identify the object it is attached to and the sensor reading is used to identify the status of the object. Recently, WISP tags have been used in indoor activity recognition, vital signs identification, sleep quality, and other health status monitoring systems [5].

The deployments of WISP tag based smart healthcare monitoring systems have the potential to replace majority of the existing heavy weight sensor based systems that are used in our everyday life. In WISP tag based smart healthcare monitoring systems, the decision making process of the system depends on all the WISP tag data of the system. Therefore, the absence of any tag in the system may raise question to system's reliability issue. If the missing tag event goes undetected and any wrong decision is taken by the system, it can be even more critical from the point of view of the system's user. Therefore, to ensure system's functionality accuracy and reliability, missing WISP tag detection is an important problem, especially in smart healthcare monitoring systems where critical decisions are taken based on tag's data to determine patients' health status. In order to maintain reliability in such systems, a monitoring protocol needs to be executed frequently that will collect the data of each WISP tag as well as identify the missing WISP tags in the environment. Most related is a recent paper by Tan, Sheng and Li [7], who designed novel protocols to detect missing tags with certain probability. However, the protocols cannot detect missing tag with certainty (i.e. 100%) and more importantly, they cannot tell which tags are missing. Identification of missing tags is also investigated by Li et al. in [8]. They proposed a series of probabilistic missing tag detection protocols that employ novel techniques to reduce the execution time. But, those protocols are proposed for RFID tags rather than WISP tags. To address the above mentioned problems, we make the following contributions in this paper–

- We consider the problem of how to accurately and efficiently monitor a set of WISP tags for identifying the missing ones in a smart healthcare monitoring system.
- We propose a tag monitoring protocol, *MTD* (*M*issing *T*ag *D*etection) that does not require the reader to collect *ID*s from each WISP tag, but is still able to accurately monitor for missing ones. This protocol also collects the data of each WISP tag while identifying the missing tags of the environment.

The rest of the paper is organized as follows. In Section 2, we present the system model of a WISP based smart healthcare monitoring system. Section 3 describes the Reliable MTD protocol. Relevant related works are discussed in Section 4. We conclude the paper in Section 5.

2 System Model

There are mainly four components in the system:

Issuer: The issuer initializes each tag during the deployment by writing the tag's information into its memory. The issuer also authorizes the reader access to the tags.

WISP Tag: The issuer assigns a unique identification id_i to the ith tag WT_i .

Reader: Reader R is connected to the backend server through a secure channel and it receives all secret keys by the issuer during deployment.

We assume that the reader and all the WISP tags in the system has the knowledge of XOR operation and $h(.)$, an irreversible one way hash function. There are many efficient hash functions in the literature such as SHA-1, SHA-2. In this protocol, we assume that WISP tags resolve collisions using a slotted ALOHA [11] like scheme.

2.1 Preliminaries and Assumptions

We assume that the reader has access to a database that stores the IDs of all tags. If the database is lost due to a database failure, we can recover the information by reading the IDs from the tags one at a time. In this case, we will not detect the tags that have already been lost because we have no way to know their existence in the first place. After collecting the ID's of the existing tags, our protocol can monitor the intactness of this set. Communication between the reader and the tags is time-slotted. One or more tags respond in the subsequent time slots. We assume that a reader is able to distinguish the slots with no reply, single reply, or multiple replies. We define these slots as empty slot (E), single-reply slot (S), or collision slot (C) respectively. In each types of slot, there can three possible responses – 1) A bit string of 0 - meaning that no tags have replied, 2) A bit string of sensor values- meaning that one tag has replied sensor data in that slot, and 3) Collision - meaning multiple tag has replied in that slot. We assume an attack model for our system where the attacker is benign and will not introduce any error in the system by replying in any slot or by launching replay attack. However, the attacker is able to eavesdrop and track.

3 Reliable MTD (*Monitor and Collect*) Protocol

In this section, we describe our protocols. We consider an RFID reader, R and a set of N WISP tags, $WT*$. We denote the frame size as *f* and the random number generated by reader/tag as *r*. The server contains a table of tag entries. Each entry of the table contains the corresponding tag *id*. Table 1 summarizes the notations.

Table 1. Notations for MTD protocol

Symbol	Meaning
SP	Slot position within frame
BR	Bit Record generated by the reader with the replies of tags
BR_{server}	Bit Record generated by the server ahead of time
e_dat	Encrypted sensor data
r_dat	Raw sensor data

Our protocol has two phases: *Learning Phase* and *Execution Phase*. The learning phase is executed only once, at the beginning of a protocol when the tag monitoring system is launched for the first time. After that point, only the execution phase will be executed by the MTD protocol to detect missing tags and to collect existing sensor information. The execution phase has two steps– *Monitor Step* and *Collect Step*. The goal of the monitor step is to detect missing tags and the goal of the collect step is to collect sensor data from the tags.

Learning Phase: Since the reader is connected to the database using a secure connection, it can collect ids of all the tags directly from the database. The reader can then use this ids to authenticate one tag at a time. Reader can use any standard authentication protocol [23]. If the reader can successfully authenticate all the tags, the set of tags is intact. Otherwise, tags that cannot be authenticated are considered as not existing. Using this process, the reader can learn about the tags that currently exist within the system. From then on, reader can perform the Execution phase of the MTD protocol to detect missing tags within this set of tags.

Alg 1: *Interaction between server & reader*

Server sends (f, r) to the reader R
R executes Algorithm 4
All nearby tags executes Algorithm 3
Pre-compute BR_{server} for all tags $WT*$
Receive BR from R
for $i = 1 : f$ **do**
    if $(BR_{server}(i) == 1))$
        if $(BR(i)$ ***not empty***$)$
            i *th tag is present*
        else i *th tag is not present*
end

Fig. 1. Interaction between server and reader

Alg 2: *Interaction between tags & reader*
Reader broadcasts (f, r) to all tags $WT*$ Each tag WT_i executes Alg. 3 Reader executes Alg. 4 Reader returns BR to the server

Fig. 2. Interaction between tags and reader

Alg 3: *Algorithm executed by WISP tags*

Receive (f, r) from R
for Each tag WT_i (where i = 1 to N)
    compute $SP_i = h(id_i \oplus r) \bmod f$
    compute $e\_dat_i = h(id_i) \oplus r\_dat_i$
end
while R broadcasts Slot Position (SP) **do**
    if (SP = = SP_i) **then**
        return e_dat_i to R
end

Fig. 3. Process executed by tags

Alg 4: *Algorithm executed by reader R*

Define BR of length f
Initialize all entries of BR to 0
for Slot Position $SP = 1$ *to* f **do**
    Broadcast SP and listen for reply
    if $(reply\_string\ != collision)$
        $BR[SP] = reply$
    else
        $BR[SP] = r$
end
return BR to the server

Fig. 4. Process executed by the reader

3.1 Detail of Reliable MTD Protocol

Alg. 1 shown in Figure 1 illustrates the overall interaction between the reader and the server. Each tag in the set executes Alg. 3, shown in Figure 3, independently. The reader executes Alg. 4, shown in Figure 4, to generate the BR and return it to the server. Figure 2 shows the algorithm for interaction between WISP tags and reader.

3.2 Protocol Description

***Monitor Step*:** In this step, the reader first broadcasts a frame size and a random number, (f, r), to all the tags. Each WISP tag WT_i uses its own tag id_i and r to generate $SP_i = h(id_i \oplus r) \bmod f$. At the same time, each tag calculates its own sensor data, $e\_dat = h(id) \oplus r\_dat$. When the slot position broadcasted by the reader matches with SP_i, tag WT_i replies e_dat in that slot position to the reader. At the time of receiving replies from different tags, the reader forms the Bit Record (BR) of length f (frame size) to transmit to the server. Initially reader assigns 0 to all the slot positions. However, the reader stores $reply\_string$ in those slot positions where it receives a reply. The reader stores a random number in the slot position where it receives a collision. This technique of bit assignment allows our search protocol to be secure against some major attacks which we will discuss in next section. The BR is then transmitted to the server. The server calculates Bit Record, BR_{server}, for all the tags ahead of time. We assume that the frame size (*f*) is large enough to accommodate enough number of tags in the first round without collision. Next, the server compares between received BR and BR_{server}. If any slot position of BR_{server} contain 1 and that slot position of BR does not contain any data, the server becomes sure that the tag data is missing. For the tags that faced collision in the first round, the reader broadcasts those ids one after another. If the reader does not receive sensor data for any particular tag, it is detected as missing.

Collect Step: Collect phase is executed by the server after Monitor phase is over. In this phase, the server determines the raw sensor data from the $reply\_string$ corresponding to each tag. The $reply\_string$ is an encrypted form of the raw sensor data. However, only the server can determine the correct sensor value since ids for different tags are only known by the server. The server can compute the hash of the id, i.e. $h(id)$. The server can XOR the hash, $h(id)$, with e_data to determine r_data using the following steps:

for Each tag WT_i (where i = 1 to *N*)
    compute $r\_dat_i = h(id_i) \oplus e\_dat_i$
end

4 Related Works

Aging-in-Place [12] and Aware Home [13] explore biosensors, audio-video sensors, and RFID tags for monitoring vital signs and movements. Recently WISP tags have been used in recognizing daily activities [5]. In [8], WISPs are used for sensing and monitoring of exercises involving free weights. Hoque et al. [14] proposed a sleep monitoring system based on the WISP tags. Recently WISP has been used for low power wireless security research [15, 16, 17]. However, most of this works fall into the category of hardware based improvements of WISP tags.

The main challenge in tag ID collection is to resolve radio contention when the tags compete for the same low-bandwidth channel to report their IDs. Other work studies the *tag-estimation problem*, which is to use statistical methods to estimate the number of tags in a large system [18]. Collision is a critical problem in RFID systems when processing a batch of tags. In the literature, tag anti-collision algorithms can be categorized into Aloha based algorithms [15] and tree based algorithms [19]. Aloha based protocols are known for their low complexity and computation, making them attractive for RFID networks. Most related works on missing tag detection are menitoned Introdtuction Section [7, 8]. However, both of these protocols are proposed for RFID tags rather than WISP tags.

5 Conclusion and Future Work

In this paper, we consider the problem of ensuring reliability in CRFID based smart healthcare monitoring environments by identifying the missing tags of the system. To address this problem, we propose *reliable MTD* protocol to monitor for missing tags and also for collecting sensor values from existing ones only. Future research can be to investigate privacy issues in such environments.

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Formal Modeling and Analysis of Context-Aware Medication Management System for Smart Houses

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Abstract. Medication management systems are useful aids in assisting elderly people in compliance with their medication, and reduce the risk of serious health concerns or hospitalization. These system share the characteristics of safety critical systems, thus analysis of such system behavior is important to avoid serious problems. Formal methods are among powerful tools that can be used for modeling and verification of systems components and their behavior. We present in this paper formal modeling of a context-aware medication management system designed to support elderly people in smart house.

Keywords: Medication Adherence, Formal Methods, Design Analysis, Context-awareness, Smart House.

1 Introduction

Non-adherence to medication regime may result in serious health concerns and hospitalization. Medication adherence refers to whether a patient follows and continues their medication regime as prescribed, including forgetting medication schedules, ordering and picking-up medication from pharmacy, etc [5]. Although adherence to prescribed medication regimens is difficult for all patients, however it is particularly challenging for the elderly people. Elderly people who live independently find it hard to follow their medication regime, which causes a serious threat to their lives and increase hospitalization [11]. Clinical method to assess the medication adherence includes direct patient questioning, prescription refill records, medication blister pack, etc. These methods tend to address adherence problem, however they require considerable resources that prevent their adaptability. Recent proliferation in Information Communication Technology (ICT) has allowed to design medication management technological solutions (*a.k.a* Medication management system) such as medication reminders alarms [13], digital pill boxes [4], etc, that can help elderly people to remember their medication regime and manage their medication.

Medication management system (MMS) are useful aids in assisting elderly in compliance to their medication, however for MMS to function properly it is important to design these solution without functional errors. MMS systems

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share the characteristics of safety critical systems thus analysis of such system behavior is important to avoid serious problems. Formal methods are widely used for rigorous analysis of computing system. These approaches are based on mathematical foundations that provides frameworks to specify and verify the specification and implementation of the system. In this paper, we present our analysis about using formal methods in modeling the behavior of MMS system for Smart House.

The rest of the paper is organized as follow, section 2 presents the state of art, section 3 presents the system overview of context-aware medication management system, section 4 presents our system modules and their formal specification, and finally we conclude the paper in section 6.

2 Related Work

Numerous formal techniques and tools have been applied for analyzing safety and security properties of medical information system. Lee [9] report the need of reliable software and hardware engineering techniques for medical information system and pointed out the potential use of verification and validation techniques for ensuring system safety. Cehlot et al. proposed a verification and validation toolkit (V2T) to be used in the analysis of wireless patient-care-device systems [2]. They used stochastic Petri nets to model the patient monitoring system. Similarly there are other approaches where authors have proposed to use model driven design & development along with formal methods for design and verification of healthcare system [8,7].

The work presented in literature advocates the use of formal methods and related tools in design and analysis of medical information system. Most of these solution are applied in a setting where user input and environment constrained are not included in analysis. Context-aware system such as MMS heavily depends on the environment data and user interaction with the system. In our recent work [3], we applied formal methods i.e. model-checking as a new layer to strengthen the design and the understanding of specifications in the development process of safety related applications in smart houses. In this paper, we present our analysis of context-aware system that include user interaction with the system and environment data to make decision. In next section, details of this work is presented.

3 Context-Aware Medication System Overview

To address the medication adherence problem in elderly, we model the context-aware MMS (based on the context-aware framework presented in [1]). The system is designed for Smart House where various sensing and actuating components are installed that capture environment data, process it, assist and alerts its habitant's. Context-aware MMS has four modules: (1) Sensing module, (2) Inferring module, (3) Reminding module and (4) Actuating module. In the current phase of the project, we have considered only medication reminders at home, the system reminds user's about their medication on the predefined schedule provided by the pharmacy. Following, we present our MMS modules and its modeling specification.

3.1 System Design and Modeling Approach

Design and modeling context-aware systems is very complex job and requires lots of attention in its requirements and specification. Context-aware MMS share the characteristics of safety critical system, where every detail of a system is important to design the system, so that the system perform its task as required and is safe & dependable. We propose to use formal method for modeling and verifying the behavior of MMS at early stage of its design. Our motivation of modeling and verifying system at early design phase is based on the fact that if the system design i.e. the functional requirements of the system are correct, it implies that system meets the minimum safety requirements and is dependable.

Context-aware MMS requires formal methods that support the concurrency among process running in the system and helps to specify the mobility of application and users. Consequently, an expressive language is needed to model and analyze system behavior. Although there are many formal tools and framework available to specify systems, we studied process algebra for the purpose of this project and focused on using Communicating Sequential Processes (CSP)[6]. CSP is a high level very expressive language with rich set of operators for modeling the behaviors of the concurrent system. In CSP, system behaviors are describes as processes that are well supported by algebraic laws. In this project, we used communicating sequential programs (CSP#) as a modeling language to model and verify system components (interested reader are refer to [12,10]). In the following section we present the specification of each modules.

1. **Sensing Module**
   Sensing module detects activities in Smart House to assist users in doing their daily tasks. We have consider RFID reader for user identification and medication tracking. The RFID reader at the home door detects when user enters or leaves home, this information can be used to remind users about their medication if user is leaving home and his/her schedule medication is due in coming hour or so. Similarly, a RFID reader is placed in the medication cabinet that reads the RFID tags attached with medication containers to detect which medication is placed or lifted. This information helps to remind user about the correct regime of medication if they pick the wrong medication, and can also help in consumption reporting. *HomedoorRFIDReader* process is defined to detect the presence of user in home or outside, this process takes the input of home RFID re ader that helps to infer about the status of user. Similarly, we define a process of *MedRFIDReader(i)* which reads the RFID tags attached with the medication bottle. These two process are combine to one process i.e. *Sensitization* using interleave operator for keeping process in concurrent state.

$$HomedoorRFIDReader \mathrel{\widehat{=}} (enterHome \rightarrow rfid\_Homedoor\ !(outsideHome)) \rightarrow \text{Skip}$$
$$\Box\ (leavesHome \rightarrow rfid\_Homedoor\ !(insideHome)) \rightarrow \text{Skip}$$

$MedRFIDReader(i) \mathrel{\widehat{=}} (MedRFIDReader!\text{i} \rightarrow \text{Skip})$
$Sensitization \mathrel{\widehat{=}} HomedoorRFIDReader\ |||\ MedRFIDReader(\text{i})$

2. **Inferring Module**
Inferring module is an important component of the system. It translates raw sensor data to the required information. For instance, sensor data coming from door RFID reader will help to infer about user presence in home or otherwise. The inferring module runs an inference engine that has pre-defined rules, these rules are triggered when conditions are satisfied or some action is committed. All data coming from sensors are treated as sensor events, inference engine then matches the rules with sensor events and triggers the respective action based on the satisfied condition. Two activities are monitored in our system, first the presence of user in home or outside, second status of medication bottle when user lift and place medication bottle. We defined *Precensemonitoring* process that infer on sensor information about the presence of user inside or outside home. Similarly *Medicationmonitoring* process is defined that infer with the information from *MedRFIDReader(i)* about which medication bottle is lifted or placed. Definitions are presented as follow.

   (a) **Presence of User in Home**
   $Precensemonitoring \mathrel{\widehat{=}} (rfid\_Homedoor?(status) \rightarrow$
   $[status == outsideHome]\, detectenterHome \rightarrow \text{Skip}$
   $\Box\ [status == insideHome]\, detectleavesHome \rightarrow \text{Skip}); Precensemonitoring$

   (b) **When User Lifts/Place Medication Bottle**
   $Medicationmonitoring \mathrel{\widehat{=}} (MedRFIDReader?(i, status) \rightarrow$
   $[status == lifted]\, detectstart\_med.i \rightarrow \text{Skip}$
   $\Box\ [status == placed]\, detectfinish\_med.i \rightarrow \text{Skip}); Medicationmonitoring$

3. **Reminding System**
The reminding module generates alerts for user about their medication. It takes input from the inferring module to activate/deactivate the correct reminder. For instance, when inference engine evaluates that user is leaving house and has to take medication on a schedule time, it triggers a reminding event. Based on this information reminding module translates this information and generates alerts to prompt user to take medication along with him/her. This will help user to not skip medication on time while he/she is away from house.

   – **Take Medication reminder**
   This reminder alerts users to take their medication on time. The reminder is very precise and trigger on the schedule time of medication. This reminder takes two parameters, (i = medication that has to be taken and ct = current time). In addition it also takes the sensor input to detect

whether the user is at home or not. Following we define the reminder that alerts user for taking medication.
$Take\_med\_reminder(i, ct) \; \widehat{=} \; ([detectinhome]alert!(Take\_Medication.i) \to \text{Skip}$
WHERE $(med\_timetable.i = ct) \to \text{Skip}); \; Take\_med\_reminder(i, ct)$

– **Take the correct medication**
This reminder is very important to address the medication adherence problem. It is triggered after system detects whether user lifted the correct medication or not. The correct regime is pre-store in the system. If the user follows the correct regime, it will prevent serious consequence of taking the wrong medication. Following we define the reminder that alerts user for taking the correct medication.
$worng\_med\_reminder() \; \widehat{=} \; ([detectlifted] \to alert!(wrong\_medication.i) \to \text{Skip});$
$worng\_med\_reminder()$

– **Bring medication while going out**
This reminder is triggered when system detects user is leaving home and his/her schedule medication is due in coming hour or so. This kind of reminder is helpful for user to follow their medication schedule even if they are out of their homes. Following we define the reminder that alerts user to bring his/her medication while going out.
$bring\_med\_reminder() \; \widehat{=} \; (dectectleavesHome?true \to alert!(Bring\_Medication)) \to \text{Skip}; \; bring\_med\_reminder()$

4. **Actuating Module** Actuating module is consist of output modalities in Smart House (e.g audio, video, display). It takes input (reminder to be display or played) from reminding module and notify user about various reminders.

4 Conclusion and Discussion

Non-adherence to medication regime is serious concern in elderly population. The paper presents the design of context-aware MMS for Smart House that helps elderly people in their medication management. MMS shares the characteristic of safety critical system, thus design and analysis of such system is difficult. We studied formal method and presented the process of formal modeling of system behavior. The characteristics of context-aware system such as (context awareness, mobility, dynamicity, heterogeneity, etc) are different from traditional systems which makes existing formal frameworks inadequate for the complete system specification and verification. Presentation of complete system analysis and verification of safety properties will be presented in subsequent articles.

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Designing a Matchmaking Platform for Smart Living Services

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Abstract. Much of the literature on smart homes, smart living and eHealth focuses on either technology issues, such as home automation and sensor technology or the acceptance and adoption of smart home services. However, even smart home services that are technologically feasible and acceptable are not taken off as end-users cannot find them in today's fragmented marketplace with an overload of information. Basically there is a demand and supply mismatch. We argue that a matchmaking or brokering platform is required that helps end-users to search for smart living services and on the other hand support (service) providers promoting their products. In this paper, we propose a conceptual design for such a platform based on two series of exploratory interviews with stakeholders in the domain.

Keywords: smart homes, smart living, eHealth, (service) providers, service platform.

1 Introduction

For 40 years smart homes has been considered a highly promising field. Traditionally, smart homes utilize several computing devices and appliances in order to automate and support domestic tasks [1], such as dishwashers and washing machines. Thanks to an increasing number of IP-enabled devices and technologies, like networked sensors, smart homes are changing from simple home automation systems towards more advanced ICT-enabled services, including wearable/implantable systems and assistive robots, [2], [3]. Healthcare providers find increasingly ways to utilize sensor networks and smart devices to enable elderly and disabled people to stay and live in their personal environment independently as long as possible, i.e. through eHealth solutions [4]. eHealth can be defined as the use of emerging information and communication technology, especially the Internet, to improve or enable health and health care [5].

The concept of smart living is broader than just smart homes and eHealth as it involves connecting our daily activities at home, along the way, or anywhere else, that can be supported by integrated ICT. In the last decade service providers from different industries (i.e. energy sector, security sector, telecommunication sector and health sector) have become interested to offer smart living services [6]. Services can

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be viewed as several types of activities that supports value creation for consumers [7] and smart living encompass a wide range of different services. However, smart living concepts have not reached the mass market yet and failed to achieve anticipated results [8], [9]. Demand has been slack, mainly because of price/performance issues and the supply of smart homes technologies is not tailored to the needs of end-users [10]. Service providers find it difficult to create awareness among end-users about smart living. In practice end-users are often unaware of how technology can help them and (service) providers are unaware of the specific needs of end-users. In other words, a bridge is needed between the technology-focused smart home solutions and the demand and daily life of end-users. Although numerous researchers study the smart living domain from the perspective of users [11], [12] or technology, [13], [14], no research, to the best of our knowledge, addressing the match between (service) providers and end-users or the role of a common service platform in this domain.

The objective of this paper is to present the first results of a design project for a matchmaking platform between (service) providers and end-users in the smart living domain. This platform should not only create awareness among end-users on what services and technologies can help them, but also assist in matchmaking between (latent) needs and (yet unknown) services. The project falls in the design research tradition, which is a well-established sub-branch of information systems e.g. [15], [16]. We follow the design cycle as suggested by Kuechler and Vaishnavi [17], i.e. comprising the stages of problem awareness, suggested solution, prototyping, implementation and evaluation. In this paper, we include the first two stages: ‘problem awareness’ and ‘suggested solution’. The conceptual design of the platform is based on two series of exploratory interviews with stakeholders in the smart living domain and is a first step in a research project in which such a platform will be designed, prototyped, implemented and evaluated in reality.

To achieve this objective the paper is structured as follows: section two provides a background of the changing healthcare. After that, in the third section we give a review of the problem description and the fourth section provides a first hunch of the platform. Finally, in the last section the challenges and an outline of the next steps are provided.

2 Background: Changing Healthcare System

One of the main demanding markets in the smart living domain is that of the elderly. The UN Population Division [18] foresees an increase of the global population over the age of 60 from 810 million in 2012 (11% of the world population) to just over 2 billion in 2050 (22% of the world population). The World Health Organization, but also the European Commission and national governments promote the concept of ‘active aging’ and define it as the process of optimizing opportunities for health, participation and security in order to enhance quality of life as people age [19]. If elderly become more vulnerable, it becomes harder to take responsibility themselves. This requires solidarity (not just financially) from society. Neighbours, friends, family, elderly themselves and volunteers can help each other. Given these challenges, there is largely consensus that innovative ICT solutions are required to both reduce costs and have people live longer at home [20]. To overcome the societal health problems different approaches to integrate the medical and the social domains have been proposed. The Chronic Care Model by Wagner [21] and the expanded Chronic Care Model by Barr [22], is currently central to the formulation of European healthcare policy. They hold an important role for social support organisations, informal carers and their community, and indicate self-management and support by the community as key elements. The proposed paradigm shift in healthcare systems comprises a transition: 1) from mainly a mono-disciplinary to a multi-disciplinary care provision, 2) from a curative approach to preventive medicine and public health, 3) from institutional care to community care, and 4) from professional care to informal care [22]. Despite the attractiveness of the integrated and more bottom-up care system in terms of costs and patient focus, the fragmented healthcare market puts strong requirements on the elderly person in finding relevant services. In a situation where public (health) service will be minimized, end-users will increasingly be expected to find healthcare services themselves, and without support and guidance large groups of users will likely be unable to make informed choices on what services to use.

3 Problem Description

This section focuses on the first stage of Kuechler and Vaishnavi's design cycle: the definition of the problem. The problem description that the platform in this paper should solve is based on several steps of research. In 2011, we conducted eleven semi-structured interviews with stakeholders (i.e. decision makers on a strategic level from knowledge institutes, installation sector and service providers) in the smart living business ecosystem in the Netherlands. The interviews focused on the question why smart living and eHealth services were not taking off, and encompassed the broad area of services, consumer adoption, technology issues, business models, inter-organizational collaboration and knowledge sharing. Based on multiple rounds of coding, supported by qualitative analysis software (Atlas-ti), we found that two major problems were identified by the stakeholders. First, there is a lack of information and knowledge sharing in the sector. As a result, service providers and other actors do not collaborate and do not exchange best practices and typical business models to deal with smart living and eHealth solutions. Sharing knowledge and fostering collaboration in the smart living domain is thus required, taking into account that actors are from different sectors like health, ICT, buildings and technology installation. Second, consumers lack awareness of what kind of smart living services are available and how they could fill their needs. The highly fragmented market makes it difficult to find services, and the predominantly technological focus of service providers makes it difficult to understand how services fit end-user needs. End-users typically pass different stages of impairment and need for healthcare interventions at home, and they are often unaware as to what services they could use at a certain point in time. At the same time, service and care providers find it difficult to reach end-users and to market and promote their products and services. A matchmaking platform would enable system integrators to create and provide integrated, comprehensive solutions to users. However, the platform does not focus specifically on service provision and context-awareness [23].

Except a few online service platforms that connect caregivers and end-users, there are hardly any interactive matchmaking platforms between (service) providers and end-users in the smart living domain in the Netherlands. Most of the existing platforms are aiming at end-users and caregivers from the profit sector (www.zorgdienstenonline.nl and www.mijnzorgnet.nl). The platform www.zorgvoorelkaar.com meets a part of the requirements about interactivity between end-users and more than one type of stakeholders in a way that there is a mix of caregivers in the profit and the non-profit sector to match with end-users. At least, in the best of our knowledge, there are no examples of matchmaking platforms that involve more than one group of stakeholders in the smart living domain (i.e. energy, ICT, building and health).

4 Suggested Solution

This section focuses on the second stage of Kuechler and Vaishnavi's design cycle: the initial suggestion for a solution to the problem. In 2012, we conducted 59 more follow-up discussions with various stakeholders. The discussions were semi-structured conversations mainly aiming to explore the issues identified in section 3 and to look for possible solutions. All conversations were transcribed and bundled in a diary (program Evernote) and prepared to fit in a stakeholder analysis. This intermediate phase led to a first general idea about a novel artifact in the smart living domain. The interviewees came from three groups: 1) strategic level stakeholders (i.e. decision makers on a strategic level from knowledge institutes, health sector, government and funding partners): 31 interviews, 2) affiliate level partners (i.e. decision makers on a technical level from the industry): 16 interviews and 3) end-users: 12 interviews.

The strategic level stakeholders mainly argued how a matchmaking platform for smart living could add value to different stakeholders, the organization of such a platform and how to get both sides (i.e. service providers and end-users) on board. The interviewees from government suggested if and how a platform could support the intervention role from municipalities in case of health and wellbeing of citizen. Due to new regulations in the Netherlands, municipalities become in the lead to provide care to citizens. Therefore, the stakeholders from government were interested in a smart living platform that could support them. The affiliate level stakeholders raised issues about the viability of the platform and how to deal with the chicken-and-egg problem to reach 'critical mass' (i.e. to find a sufficient number of adopters of the platform, to support further growth). They were sceptical about cooperation between different parties and linking of content with database of providers. On the other hand the affiliate level stakeholders were enthusiastic about de potential of a smart living platform. The end-users had more practical issues, like how you get access to the platform, why it should be online (and not offline) and last but not least, how easy such a platform could be reached and used. These concerns are not so easy to resolve. Therefore, in the next phase we have to think about how to deal with this issues. Also the chicken-and-egg problem needs to be taken in consideration, because suppliers are unlikely to invest without the assurance of access to a critical mass of end-users. End-users in turn are unlikely to join the platform unless they have confidence that complementary goods and services will be available. Although the angle of the conversations was a slightly different all the stakeholders agree on:

1. the need of a practical and easy-to use solution that could support the nationwide ageing problem
2. the opportunities for an one-stop shop for smart living (online and offline) to enhance the quality of life
3. the need to start with a small (local) but scalable matchmaking tool

The 70 conversations about smart living lead to a general first idea (proposal) about a novel artifact that can be applied in the smart living domain: to construct a smart living platform matching platform to enable end-users to enhance their quality of life.

5 Challenges and Next Steps

Taken into account that this paper describes the start of our research, and our next step is to conduct a stakeholder analysis based on the interviews, it can be seen as a starting point addressing the practical gap between (service) providers and end-users in the smart living domain to design a matchmaking platform. To elaborate the first hunch of the platform demands collaboration of (service) providers in multiple sectors to contribute required resources and to find catalyst innovators to start and accelerate a catalytic reaction. To get multi groups on board at the same time to create value in an exchange platform is a big challenge. Moreover, issues such as access methods, information storage, control and protect data, but also user adoption are important topics. Next to privacy and security, also business models and pricing strategy provide further challenges. Last but not least the technical characteristics of the platform may have an impact to reach ‘critical mass’. Our future research aims to study these issues using platform and design theory which provides a theoretical lens to build a smart living platform.

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Identifying Factors for Human Desire Inference in Smart Home Environments

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Abstract. To date, there have been numerous studies focusing on how user's activity can be identified and predicted without considering motivation driving an action. However, understanding the underlying motivation is a key to activity analysis. On the other hand, user's desires often generate motivations to engage activities in order to fulfill such desires. Thus, we must study user's desires in order to provide proper services to make the life of users more comfortable.

In this paper, we describe what possible factors are relevant to determining user's desire. To achieve this, a full-scale experiment has been conducted. Raw data from sensors were interpreted as context information. We observed the user's activities and get user's emotions as a part of inference parameters. Throughout the experiment, a complete analysis was conducted whereas 30 factors were considered and most relevant factors were selectively chosen using correlation coefficient and delta value. Our preliminary results show that 11 factors (3 emotions, 7 behaviors and 1 location) are relevant to inferring user's desire. By applying such factors into Dynamic Bayesian Network to infer desire, both complexity and scalability as our biggest research challenges can be more adequately tackled.

Keywords: human desire, smart home.

1 Introduction

Up to now, intensive studies on human-computer interaction (HCI) have been focusing on investigating user modeling and intelligent assistance system to understand, explain, and augment user actions. Context-aware applications traditionally focus on what is generally considered "rational aspects of user behavior", designed and implemented automatic agents to assist and make users feel more comfortable in their daily work and life [1, 2]. Although an intelligent assistance system can sometimes be systematically planned to overcome uncertain observations and user's changing mental states, human desire is essential to understanding human mental states, but oftentimes can be difficult to observe [3]. Historically, human desire has been identified as a philosophical issue, not a main subject in HCI field, even though it represents a

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motivational aspect of human behavior [4]. This study is a first step forwards realizing computational methods for researchers to begin seeing desire and intention as measurable, quantifiable traits that can help us design, implement and improve software for smart environments.

The main focus of the presented study is to find a possible path towards inferring human desire. Our pilot study collected datasets for desire inference based on internal mental states and external, observable behaviors. We establish a correlation between contextual and behavioral factors and desire, and identifying the relevant factors for desire inference. To our best knowledge, this is the beginning of a pioneering comprehensive study on desire inference moving beyond traditional cognitive sciences [5], and it enhances the state of the art in HCI.

The remainder of this paper is organized as follows: Section 2 depicts our pilot study to identify and clarify relevant factors. Section 3 states data analysis using correlation. Finally, Section 4 concludes this paper and suggests future work.

2 Human Desire Inference Process

In order to infer human desire, the elements of the desire inference process including environmental, behavior and emotional contexts are hereby considered. That is, for this study, $situation_i \overset{\text{def}}{=} (M, A, E)_i, i \in Time\ domain$, in which M is a set of the user's affective states, A is a set of the user's actions to achieve a goal and E is a set of context values with respect to a subset of the context variables [6]. The perceived situation, or the sets (M, A, E), is first derived from raw sensor data. However, each element has a number of sub-factors that play a key role in inferring desire. Because this is an initial pilot study, we identified the most relevant factors for desire inference through this pilot study.

2.1 Objectives of Desire Inference Pilot Study

The objectives of the pilot study are 1) to collect quantitative data and context information suitable for desire-inducing; 2) to establish the correlation between environmental contexts, observed user behaviors, identified user emotions and the changing desire of the participants based on the data; and 3) to identify the relevant factors for desire inference.

While in traditional cognitive science and in user modeling studies, factors including perception, users' knowledge, decision-making, and learning were focused on understanding the human capacity to explain and predict user's observable action in terms of mental states such as beliefs and desires [5].

We consider the observable dynamic factors (i.e., facial recognition and keyboard logging, not static factors). To develop and evaluate a computational model, we identify and verify key observable factors for effective and accurate user desire inference. We establish the correlation between the potential key factors and human desire. In this pilot study, we identify several hypotheses. We seek desire inference through identifying relationships among three parameters (i.e., M, A, E) and sub-parameters. These factors constitute the conceptual framework within which the experiment is conducted. Hypotheses are as follows:

1) Desire inference can be derived from three types of parameters, based on Bayesian Belief Network (BBN) and DBN.

2) Three types of parameters have sub-parameters.

3) Affective states can be derived from another three types of recognition parameters (Facial, Speech & Gesture Analysis).

4) Affective states can help infer desire.

5) Behavior can be affected to help infer the desire.

6) Some factors in the environmental contexts can be affected to change the desire.

2.2 Setup of Experimentation

Aiming for realistic data collection, we conducted the experimentation in controlled environments in our sensor-rich Smart Home Lab (SHL). The SHL was configured, for the pilot study, to resemble a studio apartment with isolation from outside distractions. The entire study was conducted in the SHL and is observed by all participants in a controlled environment. Within SHL, there are multiple computers with various sensors and appliances. Digital recordings of experimental sessions were taken from the SHL control room using multiple camcorders and microphones. During the experiment, we observed and annotated the participant's actions, gestures, and speech patterns.

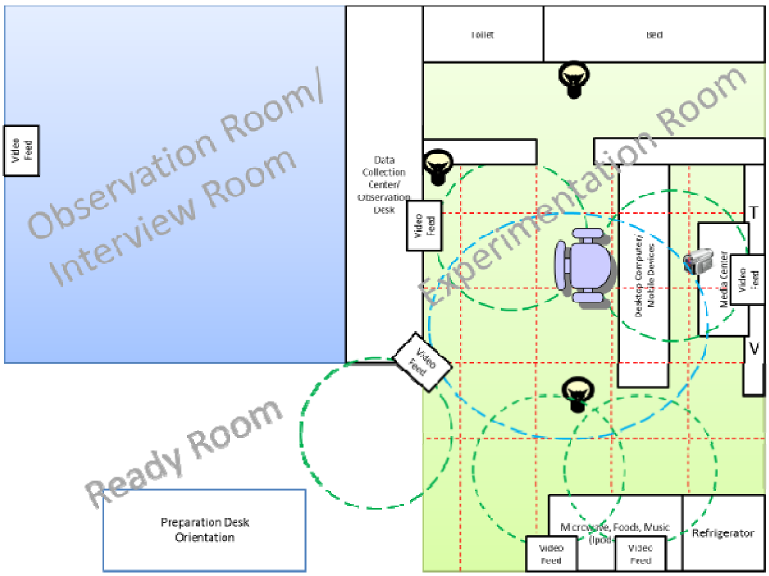

Fig. 1. Overview of the experiment environment in Smart Home Lab

In the SHL, several sensors were deployed on different objects, and the location of each object is illustrated in Fig. 1 and Fig. 2. During each session, about 1 hour of sensory data were recorded. The dataset was collected in 3 weeks through 24 volunteers.

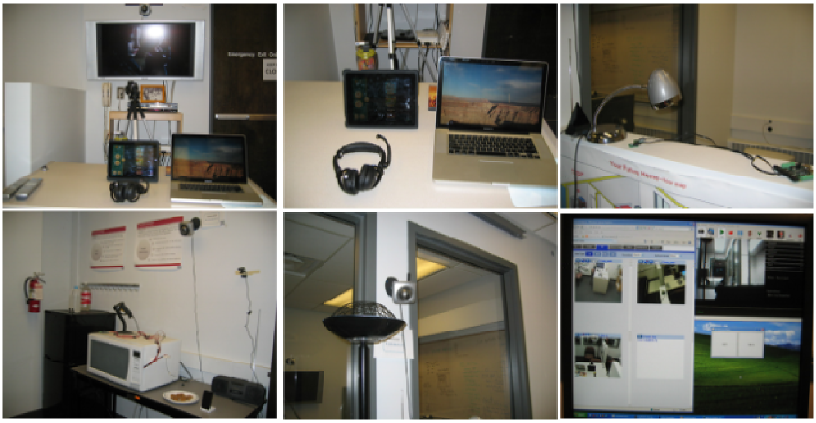

Fig. 2. Setup of experimentation in SHL. Turning on the lamp was used to synchronize the starting point when the study was started.

In Fig. 3, we list all activities with their configurable activity states designed into our experimental environment. A set of annotation terms can be defined in a configuration to indicate the possible states. For example, a movie could be in either turning on, watching, change, pause, or turning off state.

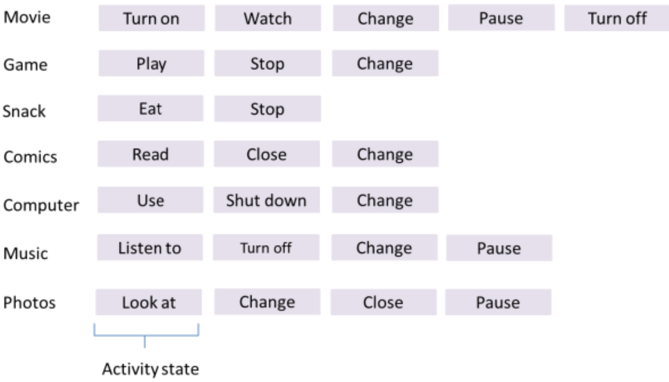

Fig. 3. Configurable Activity States

During each experimental session, the participants were told that they were free to do whatever they chose do within the SHL. However, they should explicitly identify the activity "they would like to do now." Throughout the course of the study, additional stimuli typical to student's life in their own dorm room, such as movies, comic books and novels, video game consoles, food and drink, were introduced and removed every 5 minutes to induce changes in participant's desires and behaviors. Desires were not forced but induced. At the end, each participant was asked to fill out a questionnaire, and go over the audio and video recording to provide additional comments and insights into their thought process and mental status. This information was annotated to the recordings to supplement the data. The environmental contexts were recorded via the existing SHL software. User's behaviors were recognized both by behavioral recognition software and by human inspection.

3 Data Analysis for Relevant Factors

We collected the data on each participant using the instruments - videotaping, observation, think-aloud, questionnaire, post-experiment interview and review of taped videos, emotion analysis software and keyboard/mouse activities logger.

This part of our study aims at non-intrusive human behavior recognition.

3.1 Data Coding

For analysis, data needed to be coded to an analytical process in which data, in both quantitative form (such as questionnaires results) and qualitative form (such as interview transcripts), were categorized to facilitate analysis [7]. Data coding means the transformation of data into a form understandable by computer software. The classification of information is an important step in preparation of data for computer processing with statistical software. One code should apply to only one category and categories should be comprehensive. There should be clear guidelines for coders (individual who do the coding) so that code is consistent. Some studies will employ multiple coders working independently on the same date. This minimizes the chance of errors from coding and increases the reliability of data.

In our study, we processed data coding scheme from raw data to CSV data format for statistical tool R. As a result, we created 30 input formats which included 3 kinds of emotions (facial recognition, speech and brainwave), 24 configurable activities and 3 environmental contexts (location, temperature and light). Fig. 4 is an example of data coding of facial recognition of emotion.

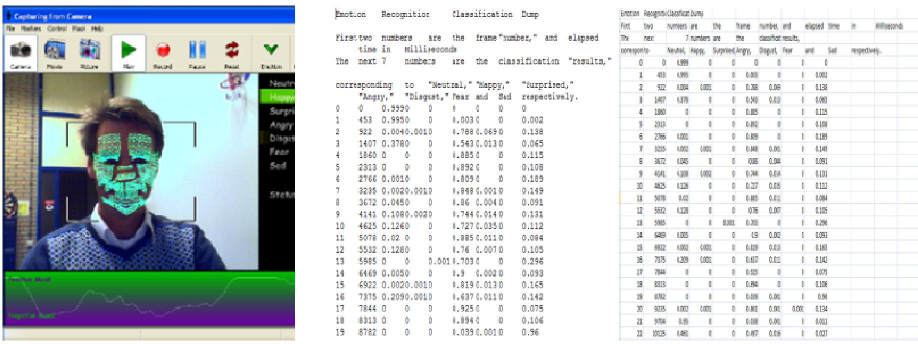

Fig. 4. (a) Raw Data (b) Log file (C) CSV file

3.2 Statistical Analysis

During the study, real-time emotion software (eMotion) [8] was used to collect emotion data. The emotion data through facial recognition was captured in real-time with the web camera. Emotion capture was problematic for participants wearing hats or otherwise obscuring their facial features. In the end, once these cases were removed, we used data from 21 participants.

Data analysis through video capture needs. The experimentation session was 35 minutes long. When the moving picture was displayed, each frame was flashed on a screen for a short time (nowadays, usually 1/24, 1/25 or 1/30 of a second) and then immediately replaced by the next one. In North America and Japan, 30 frames per second (fps) is the broadcast standard, with 24 frames per second (24 frames/s) now common in production for high-definition video. In much of the rest of the world, 25 frames per second are standard. Thus, we used 24 frames per second and 1 person had 50400 frames for each session. For preparation of data, totally, we considered 1058400 frames for behavior, 838923 frames for emotion and 1058400 frames for environment. For calculation, we defined desire-states space as numbers.

Correlation. Correlation is any of a broad class of statistical relationships involving dependence that is any statistical relationship between two random variables or two sets of data [9]. Normally, there are 3 different kinds of method, namely Pearson, Spearman and Kendall. Pearson is the most common measure of dependence between two quantities. Thus, we adopted Pearson method using the cor. test function in R [10].

- *High correlation :* 0.5 to 1.0 or -0.5 to 1.0
- *Medium correlation :* 0.3 to .5 or -0.3 to 0.5
- *Low correlation* : 0.1 to 0.3 or -0.1 to -0.3

Table 1. Each Desire-Emotion Correlation

Desire / Emotion	Watch Movie	Eat a Cookie	Play the Game	Use Computer	View a photo	Listen to music	Read Comics	Wild Card
Neutral	0.269	0.004	0.420	**0.655**	0.273	**0.870**	**0.939**	**0.825**
Happy	**0.567**	**0.530**	**0.535**	0.001	0.004	0.002	0.004	0.002
Surprised	0.115	0.40	0.024	0.287	**0.618**	0.062	0.042	0.134
Angry	0.012	0.028	0.001	0.001	0.002	0.004	0	0
Disgust	0.001	0	0	0.012	0.015	0.017	0.003	0.009
Fear	0.034	0	0.008	0.002	0.022	0.001	0.009	0.002
Sad	0.004	0.002	0.005	0.032	0.043	0.037	0	0.022

Table 1 is one example of the correlation results. Also, the result (=0.983) between desire and behavior is highly correlated. In case of correlation between desire and environments, the results of light, temperature and location are 0.003, 0 and 0.797.

Table 2 shows the correlation between desire and brainwave. The electroencephalograph (EEG) measures brainwaves of different frequencies within the brain. The electrical signals were emitted by neuron firing in the brain. The patterns and frequencies of theses electrical signals can be measured by placing a sensor on the scalp. There are five brainwave types: Delta (0-3Hz), Theta (4-7Hz), Alpha (8-12Hz), Beta (12-30 Hz) and Gamma (30-50Hz). Each brainwave type provides a mental state and the corresponding condition [11, 12].

Table 2. Desire-Emotion Correlation

Desire \ EEG Brain-wave	Delta	Theta	Low Alpha	High Alpha	LowBeta	High Beta	Low Gamma	High Gamma
Desire	**0.980**	**0.812**	-0.087	0.065	0.340	0.327	0.493	**0.711**

Based on our experimentation, we obtained several results as follows:

1. Desire inference can be derived from three types of parameters (*Emotions, Behaviors, and Environments Contexts*).
2. Three basic emotions (*Neutral, Happy, and Surprised*) with the highest correlation in the OCC model [13] can be indicative to desire inference. It means that clear emotions can help infer desire.
3. We allowed exceptions for environments (*Temperature, Light*).

4 Conclusion

In this paper, we suggested a starting point in which we can begin the desire inference process based on emotional, behavioral and environmental context information. We illustrated a method to identify and verify key observable factors for effective and accurate user desire inference. Prior work in this area is virtually nonexistent. The contributions of our work include (1) the pilot study has been conducted to collect human-centered dataset and (2) the correlation between the potential key factors and human desire has been established.

If we consider every factor, both complexity and scalability will be a huge challenge. As a future work, we will work further to fully develop our DBN framework using the data already collected that will be divided into two parts, train and test datasets. After that, we will apply our framework to infer human desire by conducting more experiments for further evaluation.

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Fall Detection System Based on Kinect Sensor Using Novel Detection and Posture Recognition Algorithm

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Abstract. Elderly suffers from injuries or disabilities through falls every year. With a high likelihood of falls causing serious injury or death, falling can be extremely dangerous, especially when the victim is home-alone and is unable to seek timely medical assistance. Our fall detection systems aims to solve this problem by automatically detecting falls and notify healthcare services or the victim's caregivers so as to provide help. In this paper, development of a fall detection system based on Kinect sensor is introduced. Current fall detection algorithms were surveyed and we developed a novel posture recognition algorithm to improve the specificity of the system. Data obtained through trial testing with human subjects showed a 26.5% increase in fall detection compared to control algorithms. With our novel detection algorithm, the system conducted in a simulated ward scenario can achieve up to 90% fall detection rate.

Keywords: Fall Detection, Kinect, Posture Recognition.

1 Introduction

The progressive aging of population has become a major social challenge for countries around the world. As more elderly begin living with health problems and are home-alone, they require increasing assistive support in daily activities. For the elderly, involuntary falls are frequent. Annual statistics show that one in every three adults age 65 and older in the USA have recently suffered a fall [1]. Falls cause a loss in quality of life for the fallen elderly and can be more dangerous due to the fact that the victim can easily lose consciousness and thus become unable to seek help if they are home alone, which is detrimental to their long-term health if the accident is serious and undetected [2]. Thus, in order to avoid this scenario, fall detection systems that are capable of identifying and notifying caregivers when the elderly fall are very much essential in the bid to provide assistive services to the elderly.

Current fall detection systems have fall detection rates of 70% to 80% [3], which satisfies certain consumers' requirements, but might be lacking in specificity for others. Therefore, there are teams that also developed systems consisting of floor

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sensors [4] and have fall detection rates of about 90%, but there are trade-offs where the system is limited in its usage, such as vulnerability to spillages etc.

We aim to develop and test a fall detection system that utilizes the Microsoft Kinect sensor and our novel fall detection algorithm to determine automatically if a fall has occurred. We propose our fall detection system which is optimized using current preliminary datasets and when used in conjunction with our novel posture recognition algorithm, help us to achieve a significantly higher specificity rate of fall detection, up to 90% accuracy rate in an actual test with a real human subject.

2 Fall Detection System

In this project, we aim to create a fall detection system (Fig. 1 & 2) for use in confined areas like the bedrooms or washrooms in single room apartments. This constraint is in place as the project is targeted towards the detection of falls for home-alone elderly who normally live in such apartments. The Kinect sensor is placed in a tilted position to maximize its coverage of the room, although one or two more sensors could also be employed to cover all blind spots. Our system is also able to operate in situations with little or no light, therefore making it possible for the Kinect to track human activity both in the day and night [5], something that conventional stereo video camera systems are unable to do. This makes it especially useful as most falls by the elderly happen at night when visibility is poor, improving the effectiveness of our fall detection system.

Depth images of the surroundings captured by the Kinect are processed by the Microsoft Kinect SDK to return a pipeline of information that provides our fall detection system with skeletal data. Up to 2 user's skeletons can be tracked, with the skeletal data of the user then subsequently passed to our algorithm as described in section 3 for further processing. If a fall is detected, we would relay a signal to an alarm system to sound an alert.

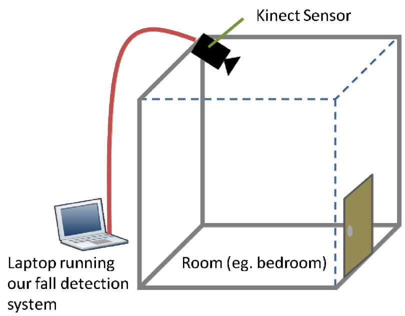

Fig. 1. Setup of our fall detection system

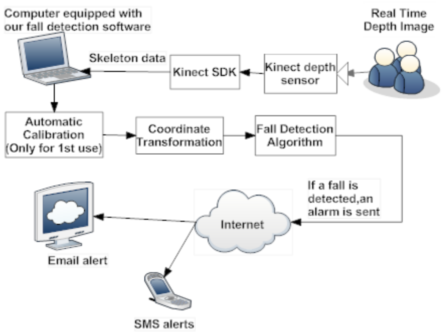

Fig. 2. Block diagram of our fall detection system

3 Fall Detection Algorithm

3.1 Our Fall Detection Algorithm

Skeletal data received from the Kinect sensor is processed by functions 1 & 2. If both functions return a positive result, a fall is tentatively indicated. After that, our postural recognition algorithm is then applied to reduce the amount of false positives returned by our fall detection algorithm, resulting in a fall detection algorithm that manages to achieve relatively high sensitivity and specificity. A preliminary dataset of 10,479 frames of skeletal data from the Kinect comprising 34 fall and non-fall events were used to optimize our enhanced fall detection algorithm.

3.1.1 Function 1 (Checking Position of User's Centre of Mass)

Our algorithm checks if the real world coordinates of the user's hip centre (roughly representative of the person's centre of mass) obtained from the Kinect is within a certain threshold distance from the floor.

3.1.2 Function 2 (Checking Velocity of User's Centre of Mass)

Many current algorithms that make use of the centre of mass are unable to accurately detect slow falls because the measured vertical velocity in slow falls tends to be relatively lower than that measured during a normal fall. Therefore pre-set threshold values are normally not exceeded and the slow fall is not detected. Figure 3 shows the different velocities of the user's hip centre joint where the vertical velocity of the slow fall did not exceed the threshold, resulting in no falls being detected.

Our algorithm separates the velocity of the user's hip centre into two components. The first component is the vertical velocity of the hip centre, while the second component is the velocity of the hip centre with respect to the vector sum of the displacement of the hip centre in both the x and z directions, thus giving us the horizontal component of the hip centre's velocity.

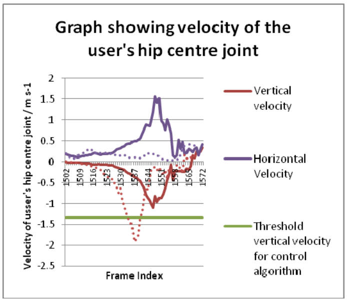

Fig. 3. Graph showing different velocities of the user's hip centre joint for both the slow fall (solid lines) and the vertical fall (dotted line)

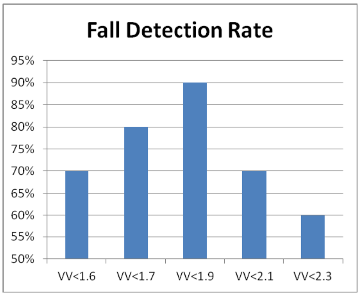

Fig. 4. Diagram fall detection rates when the threshold corresponding to score 3 in table 1 is varied. As the value of VV<1.9 gave us one of the highest fall detection rates it was used in our table of scores (table 1).

The different velocities of the user's hip centre are given different scores for the vertical and horizontal velocities (an example is shown in Table 1). Our fall detection algorithm checks if the combined scores for both the vertical and horizontal component exceed our pre-set overall threshold score.

The table of scores shown in Table 1 was optimized by varying the parameters individually (Fig. 4) until a maximum fall detection rate on the preliminary dataset of falls was obtained.

Table 1. Table showing how the scoring system was applied for vertical velocities

Score	Vertical velocity of user's hip centre, *VV* / m s^{-1}	Remarks
0	*VV* > -0.9	Representative of negligible vertical velocity typical of everyday activities
1	*-0.9> VV* > -1.4	Representative of a small vertical velocity that is typical of a slow horizontal fall, but not low enough to be triggered by everyday activities
2	-1.4> *VV* > -1.6	Representative of a moderate vertical velocity typical of a fast horizontal fall
3	*VV < -1.6*	Representative of a large vertical velocity typical of a vertical fall

This new method of fall detection provides two main benefits:

1. It is more sensitive to falls in any direction than conventional fall detection systems as both the horizontal and vertical components of velocity of the user's hip centre are taken into account.
2. It is less prone to false positives generated by large horizontal movements by the user than conventional fall detection systems.

3.1.3 Postural Recognition Algorithm

Due to the multiple similarities between falls that are classified as false positive and actual real falls, most current fall detection systems have difficulty differentiating between these two classifications [6]. We demonstrate this similarity with results in Figure 5 using our own data, where the monitored subject's velocity is similar for an actual fall and an action of just bending down. To resolve this problem, we developed a novel postural recognition algorithm that separates the false positives from actual real falls by checking the user's posture to determine the likelihood that the user has been involved in a fall when previous functions 1 and 2 return positive results.

In order for our postural recognition system to correctly identify these postures, two main defining features were identified in order to separate fallen postures from other possible postures. These two features were refined and checked against previously obtained skeletal data of postures to ensure their specificity.

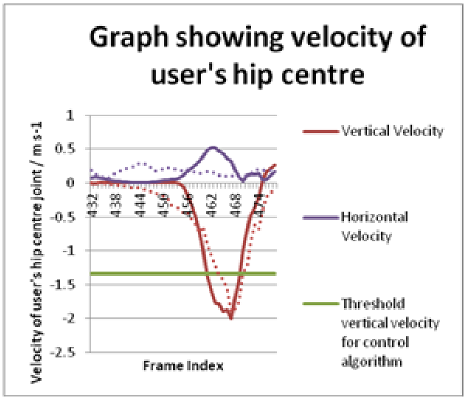

Fig. 5. Graph showing different velocities of the user's hip centre joint for bending down (solid lines) and for an actual fall (dotted line)

Table 2. List of false positive postures

	Posture	Classified using rule no.
1	Sitting on the floor – both legs folded behind	1
2	Kneeling on the floor	1
3	Squatting	1
4	Bending down (to wear shoes or tie shoelaces)	2

Rule 1: User's ankles have to be below the user's hip centre

Rule 2: One of the user's legs is either folded below his body or one knee is significantly higher than the other

4 Results

In order to test the actual effectiveness of our system, we conducted a trial experiment that was simulated as closely to the actual conditions where our fall detection system would be deployed. We want to test the robustness of our fall detection system by conducting tests within a setting that is previously unknown to the system. A nursing ward was recreated within our laboratory to provide a realistic setting that is similar to wards found in Lee Ah Mooi Old Folk's Home. A hospital bed was placed in the corner of our ward, with PVC pipes representing the walls of the ward and the Kinect sensor was deployed at the top corner of our ward.

The three kinds of falls that frequently occur within the Home were then simulated by our volunteers to replicate the kind of conditions that our fall detection system will face when deployed at the Home. Fig. 6 shows our experimental setup, while Fig. 7 shows a screenshot of our fall detection system user interface during the experiment.

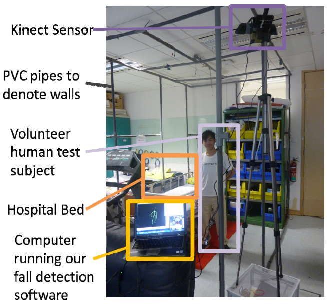

Fig. 6. Picture showing experimental setup

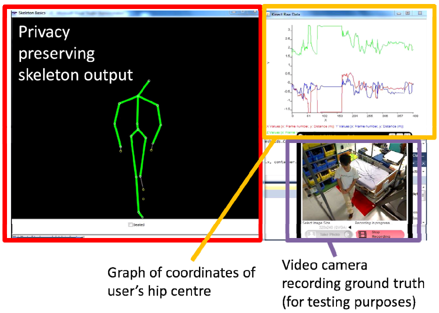

Fig. 7. Screenshot of fall detection system user interface running on laptop

Our fall detection system is capable of processing incoming sensor information and displaying of results concurrently without a loss in processing speed or performance degradation. By connecting an SMS gateway or alert module to the system, we can detect falls within half a second of the fall and subsequently alert the caregivers. The system automatically starts when someone enters the field of vision of the Kinect sensor. By producing a stickman display (Fig. 7) for display purposes which users can choose to hide, we also managed to preserve the user's privacy.

Initial results show that most falls that include falling from the bed or in open spaces were accurately identified by our fall detection system. Multiple other kinds of non-fall events were also accurately detected by our fall detection algorithm and correctly classified, mainly due to the assistance from our novel posture recognition algorithm that points out abnormalities in the data obtained through the sensors, thus demonstrating the usefulness of our posture recognition algorithm in recognizing and differentiating falls. Our system is able to achieve an overall specificity rate of up to 90% and our algorithms helped improve the fall detection rate such that we could detect all falls (100%) in certain situations, where conditions are optimal. This includes situations where more sensor information allows us to perform inference in order to provide a more accurate assessment.

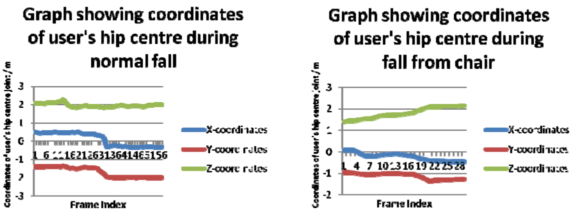

Fig. 8. As can be seen, during the fall from the chair, the coordinates of the user's hip centre starts from a much higher position (-1.0 as compared to -1.4). which results in the smaller.

However, further analysis showed that there were occasions where the system was not able to classify actual falls. For example, a user falls off the chair and is undetected, due to the fall taking place closer to the ground. The system has lesser time to measure the increase in user's velocity while he is falling, hence not being able to correctly detect the fall. We have detailed data (Fig. 8) and information regarding this kind of misclassification and also have a solution for this problem and are currently working on correcting this issue so as to ensure that it does not occur again in subsequent modifications.

5 Conclusions

Our fall detection system is able to detect and identify falls using the Kinect sensor within confined spaces at a relatively high specificity rate when compared to usage of control algorithms. The system also uses our novel posture recognition algorithms to enhance our detection rate and ensures robustness during deployment. Overall, with sufficient sensor information while maintaining user's privacy, our fall detection system is able to automatically recognise falls and notify healthcare services to provide timely assistance to elderly who have fallen.

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From Activity Recognition to Situation Recognition

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Abstract. Activity recognition is important to many critical human-centric applications. Despite success in activity recognition research, there seems to be a quest for a richer sentience that is more expressive than human activity. In particular, situation has received intense attention lately with a multitude of overlapping definitions motivated by a variety of different goals. With the goal of assessing user behavior response (compliance) in persuasive systems, we propose a specific definition of situation along with a framework for designing situation recognition algorithms.

Keywords: Situation, situation recognition, user behavior, persuasive systems.

1 Introduction

Activity recognition is often utilized in many different human-centered pervasive applications including surveillance systems [1] and healthcare monitoring systems [2]. Depending on the type of sensors used to monitor activity, activity recognition can be classified into two main approaches: vision-based activity recognition [1,3] and sensor-based activity recognition [2,4]. The most popular activity recognition algorithms are HMM (Hidden Markov Model) and CRF (Conditional Random Field) [5,6,7]. Both HMM and CRF are used to find a sequence of hidden states based on observed sequential visual data or sequential sensor data.

Despite success in activity recognition research, there seems to be a quest for a richer sentience that is more expressive than activity. In particular, situation has received intense attention lately with a multitude of definitions motivated by a variety of goals. For instance, Chang [8] defined situation as a triplet of a user's desire, a set of the user's actions and a set of contexts for service evolution in services computing. Cho [9] defined situation as a temporal sequence of contexts for exception detection for safety in pervasive systems. Kim [10] defined situation for assurance-oriented activity recognition as a set of activities and contexts.

Through our recent work in persuasive systems [11,12] in which we developed cybernetics to influence the user to change his/her behavior, we realized the need for a specific definition of situation that involves contexts, activities and devices. We found that in order to sense a user's persuasion demand, and assess the user's response to persuasive influence, it is necessary to keep track of the user situation to learn what

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the user is doing (activities) and whether (and how properly) the user interacts with devices in given contexts. User activity information alone was not adequate to accurately capture and characterize important differences in the detailed performance of the activities. For example, in order to accurately detect a user response to persuasive influence that affects a user to check his/her glucose level, we needed to differentiate between three situations: “try to check glucose level”, “check glucose level successfully” and “fail to check glucose level”, in the same user activity (“measuring glucose level”). In response to this problem, we developed a new definition of situation and situation recognition algorithms, which we present in this paper.

2 Situation

We described the problem and limitation of utilizing user activity to capture a user response to persuasive influence. In this section, we introduce situation as mechanism to detect persuasion needs and keep track of changing needs as well as changes in how a user responds to persuasive influence. We define situation informally as a triplet of a user’s activities, a set of devices’ actions and contexts over a period of time.

Figure 1 shows two situation examples. The first demonstrates the situation describing “check glucose level successfully”, which consists of a triplet of a device’s action (glucose meter senses glucose level), a user’s activity (measuring glucose level), and a context (glucose level). The second example represents the situation “fail to check glucose level” defined by a device’s action (glucose meter generates an error code), a user’s activity (measuring glucose level), and a context (the error code).

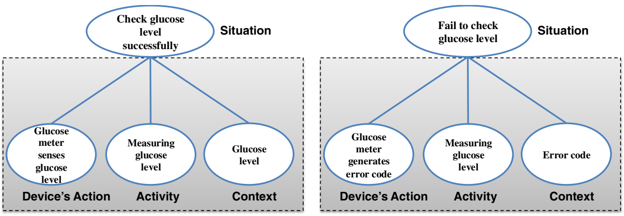


Fig. 1. Situation Examples

Our definition of situation stems from observation that context is needed but it is not sufficient to characterize different user behavior response in a persuasive system. Also, even though activity is direct information of the user behavior response, it is not adequate alone and cannot be relied upon exclusively due to accuracy issues. We also observed that in most existing definitions of situations only sentience abstractions (activities, context, phenomena, events) are used to infer user situations, but direct cybernetics such as devices are not used to measure or recognize situations. The situation is specifically designed not only to capture user behavior responses to cyber influence but also to capture all other necessary situations that can happen while a user interacts with a persuasive system to change his/her behavior. For example, a one device action (e.g., "smart phone shows text message to remind a user to check glucose level") can be a situation. Therefore, situation is a bigger concept than user activity.

2.1 Formal Definition of Situation

Definition 1. User Activity

User activity is defined as the activity set related to a goal $A = \{A_1, A_2, \ldots, A_n\}$. The user activity is further divided into active activity and passive activity. Active activity (A_a) is defined as the activity caused by the user himself which could cause devices' passive actions when the active activity is related to the devices. The devices' passive actions are formalized in Definition 2. Passive activity (A_p) is defined as the activity that is not caused by the user but other influences including devices' active actions. Thus, the user activity has a causal relationship with the devices' actions. This can be denoted by:

$$A = \begin{cases} A_a & if \quad A_k \to D_i^j \\ A_p & if \quad D_i^j \to A_k \end{cases}$$

A_a: active activity
A_p: passive activity
A_k: certain activity
D_i^j: devices' actions
i: device index
j: action index

Definition 2. Devices and Devices' Actions

Devices are represented by a device set $D = \{D_1, D_2, \ldots, D_n\}$. The actions of a device are denoted by $D_i^j = \{D_i^1, D_i^2, \ldots, D_i^n\}$, where i: device index and j: action index. Those devices' actions are categorized into active actions that affect a user's activity and passive actions that are affected by a user's activity. This concept is defined as follows:

$$D_i^j = \begin{cases} D_i^a & if \quad D_i^j \to A_k \\ D_i^p & if \quad A_k \to D_i^j \end{cases}$$

D_i^a: active action
D_i^p: passive action

Definition 3. Context

Context is defined as the set of contexts related to a goal, where $C = \{C_1, C_2, \ldots, C_n\}$. Devices' actions could produce some information, which could be context. Thus, the device and context have a producer-consumer relationship.

Definition 4. Situation

Situation is defined as a triplet of a user's activity, devices' actions and contexts, all of which are related to a specific goal and it is denoted by $S = (\mathrm{D}, \mathrm{A}, \mathrm{C})$. In some cases, it is not possible to define one or two elements among S, thus we allow a situation to be defined by one or more elements of a user's activity, devices' actions and contexts.

3 Situation Recognition

As context and activity require algorithms and models for detection, situations are also needy of the same. Situation recognition should not be very difficult because situation is composed of these higher concepts with established recognizers. Nevertheless, we have to have an explicit model for situation recognition. We propose to utilize a logical/fuzzy-logical approach to situation recognition assuming availability of recognizers for situation's constituents.

3.1 Situation Recognition Algorithm

Situation recognition utilizes $S(x)$, which refers to the situation function that returns 0 (unrecognized) or 1 (recognized). $S(x)$ is dependent on $D(x)$, $A(x)$ or $C(x)$, or combination of these functions.

$D(x)$, $A(x)$, and $C(x)$ refer to the device's action function, activity function, and context function that represent device's action, activity, and context, which could manifest the situation respectively.

It is not always possible to outfit a cyber sense that can allow for all three functions to be implemented. We use a different decision method to recognize situation according to how many functions are possible to define.

3.1.1 Three Functions Defined

All three functions are not always accurate so there might be errors. In order to tolerate the errors and maintain accuracy, we utilize quorum-based decision. If two or more functions are true out of the three functions, it returns 1, and otherwise it returns 0. $S(x)$ is defined as $S(x) = \big((D(x) \wedge A(x)) \vee (D(x) \wedge C(x)) \vee (A(x) \wedge C(x)) \vee (D(x) \wedge A(x) \wedge C(x))\big)$.

3.1.2 Two Functions Defined

Quorum-based decision method cannot be utilized because only two functions are defined so we use a fuzzy-based decision method to handle indistinct situation when either one of two functions is 1.

The fuzzy logic [13] was introduced by Lotfi Zadeh with the proposal of fuzzy set theory in 1965 in order to deal with imprecise and uncertain knowledge. The fuzzy logic is multi-valued logic and it is derived from fuzzy set theory. The fuzzy set theory is an extension of classical set theory and it allows its members to have different degree of membership determined by a fuzzy membership function ranging between 0 (completely false) and 1 (completely true). The fuzzy set A in X is expressed as $A = \{x, \mu_A(x) | x \in X\}$, where $\mu_A(x)$ is a membership function, $\mu_A(x) \in [0,1]$. The fuzzy set has the following operators: fuzzy intersection operator, fuzzy union operator, and fuzzy complement operator.

Fuzzy Intersection Operator ∩ (fuzzy AND). Fuzzy intersection operator applied to two fuzzy sets A and B with the membership functions $\mu_A(x)$ and $\mu_B(x)$ is $\mu_{A\cap B}(x) = \min\{\mu_A(x), \mu_A(x)\}, x \in X$

Fuzzy Union Operator ∪ (fuzzy OR). Fuzzy intersection operator applied to two fuzzy sets A and B with the membership functions $\mu_A(x)$ and $\mu_B(x)$is $\mu_{A\cup B}(x) = \max\{\mu_A(x), \mu_A(x)\}, x \in X$

Fuzzy Complement Operator ¬ (fuzzy NOT). Fuzzy intersection operator applied to the fuzzy set A with the membership functions $\neg\mu_A(x)$ is $\mu_A(x) = 1 - \mu_A(x), x \in X$.

We describe how fuzzy-based decision method is used to recognize the situation when two functions are defined.

$S(x)$ utilizes a situation fuzzy membership function, which is defined by exploiting combinations of two functions among device, activity, and context fuzzy membership functions. Each fuzzy membership function use accuracy information to determine the degree of membership and it is defined as follows:

The device fuzzy membership function

$\mu_D(x) = max((1-\alpha_D) \times \neg D(x)), (\alpha_D \times D(x))$, where α_D is accuracy of $D(x)$, $0 \le \alpha_D \le 1$

The activity fuzzy membership function

$\mu_A(x) = max((1-\alpha_A) \times \neg A(x)), (\alpha_A \times A(x))$, where α_A is accuracy of $A(x)$, $0 \le \alpha_A \le 1$

The context fuzzy membership function

$\mu_C(x) = max((1-\alpha_C) \times \neg C(x)), (\alpha_C \times C(x))$, where α_C is accuracy of $C(x)$, $0 \le \alpha_C \le 1$

It is further divided into three cases depending on which two functions are defined.

- **$D(x)$ and $A(x)$ are defined**

When either $D(x)$ or $A(x)$ is set to 1, the situation fuzzy membership will follow the one that has higher accuracy. For example, let $D(x)$= 0 and $A(x)$ =1, and α_D= 0.95 and α_A= 0.80. In this case, $\mu_S(x) = \frac{0.05+0.8}{2} = 0.425$, therefore $S(x)$ will be 0.

The situation fuzzy membership function

$\mu_S(x) = \frac{(\mu_D(x)\cap\mu_A(x))+(\mu_D(x)\cup\mu_A(x))}{2}$, where $S(x) = \begin{Bmatrix} 1 & if\ \mu_S(x) > 0.5 \\ 0 & otherwise \end{Bmatrix}$

- **$C(x)$ and $A(x)$ are defined**

The situation fuzzy membership function

$\mu_S(x) = \frac{(\mu_C(x)\cap\mu_A(x))+(\mu_C(x)\cup\mu_A(x))}{2}$, where $S(x) = \begin{Bmatrix} 1 & if\ \mu_S(x) > 0.5 \\ 0 & otherwise \end{Bmatrix}$

- **$D(x)$ and $C(x)$ are defined**

The situation fuzzy membership function

$\mu_S(x) = \frac{(\mu_D(x)\cap\mu_C(x))+(\mu_D(x)\cup\mu_C(x))}{2}$, where $S(x) = \begin{Bmatrix} 1 & if\ \mu_S(x) > 0.5 \\ 0 & otherwise \end{Bmatrix}$

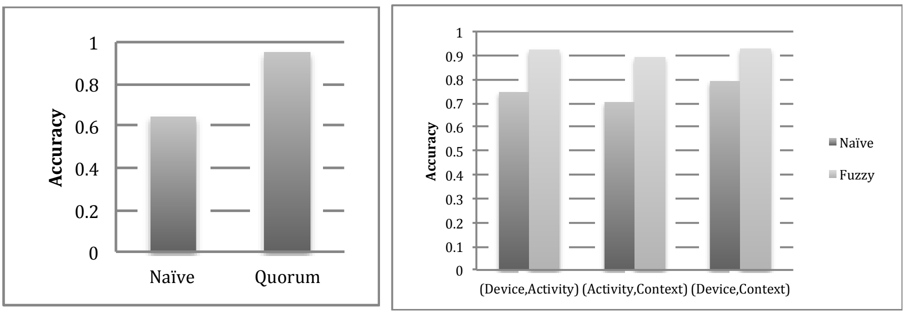
3.1.3 One Function Defined

$S(x)$ utilizes a detection-based decision method. Detection-based decision relies on detection of the defined function. $S(x)$ is denoted by $S(x) = (D(x) \vee A(x) \vee C(x))$.

3.2 Evaluation of Situation Recognition Algorithm

We evaluate the performance of situation recognition algorithm by comparing naïve method (on the one hand) with quorum- and fuzzy-based methods (on the other hand). The naïve method is decision method that returns 1 (recognized) only if all defined events are detected.

In our experiment, we assume device, activity and context events happened 1000 situations. The device, activity and context events are randomly generated based on their accuracies. We set detection accuracy range for device, activity and context events as the following: $\alpha_D = [0.85,0.99]$, $\alpha_A = [0.65,0.99]$, and $\alpha_C = [0.75,0.99]$. Based on the generated events, we use naïve decision method, quorum-based decision method and fuzzy-based decision method to recognize a situation. We repeatedly run simulation by incrementing the detection accuracy of device, activity and context events and get average recognition performance. As described in Figure 2-a, quorum-based situation recognition shows higher accuracy than naïve situation recognition. Figure 2-b shows situation recognition performance difference between naïve situation recognition and fuzzy-based situation recognition when the two functions are defined.



(a) Naïve and Quorum-based SR (b) Naïve and Fuzzy-based SR

Fig. 2. Situation Recognition Performance Comparison

4 Conclusion

It is not easy to accurately capture user behavior response to persuasive influence and characterize and differentiate subtle differences in similar user behavior situation. We proposed a new definition of situation, which integrates and combines context and activity along with direct cybernetics (devices). We believe that this definition is suitable and beneficial to persuasive systems as it allows for one element of that situation definition to compensate for another. Also, we described the blueprint of a new framework to design situation recognition and provided preliminary performance comparisons. This work is a first step to effectively employing a useful definition of situation in support of persuasive computing, particularly in recognizing persuasion need situations and assessing convergence and compliance to persuasive interactions.

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Fuzzy Logic Based Activity Life Cycle Tracking and Recognition

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Abstract. Human activity has a life cycle that could be tracked to provide crucial information that increases activity recognition performance. Life cycle tracking also enables powerful and more versatile programming models over the sentience of human activities. This paper introduces a new activity recognition approach that is based on fuzzy logic and activity life cycle tracking. We conduct preliminary performance validation and show how activity life cycle tracking offers higher accuracy when compared to the traditional approach of no-life cycle activity recognition.

Keywords: Activity recognition, Activity life cycle, Fuzzy Logic.

1 Introduction

Activity recognition (AR) technology is an essential component of many human-centric smart systems; activity recognition enables the system to interact with humans intelligently and ergonomically [11]. The utilization the state-of-the-art AR technologies in real world situations is limited by their low accuracy.

Many AR systems, especially real-time AR system, make activity recognition decisions at early stages of an activity's execution where there may be limited sensor data [2][3]. Drawing conclusions from sensor data prematurely can result in high error rate. Therefore, it is necessary to postpone an activity recognition decision until sufficient sensor data is collected. It is possible to collect sensor data for a long duration prior to making a recognition decision. Choosing a longer duration addresses inaccuracies resulting from premature decision-making, but if the set duration is too long, recognizing simple activities may require an inordinate amount of time.

To address the aforementioned issues, we developed a new activity recognition approach, which relies on a combination of fuzzy logic and activity life cycle pattern recognition. Tracking activity life cycle can help avoid recognition errors from premature decisions in early stages of an activity's life cycle. Recognizing activities by tracking their life cycle is novel and unique as it allows for a variable decision time based on sensor data and activity semantics. For instance, an AR program could make preliminary, non-committal decisions as the life cycle of a given activity begins to show up on the application "radar". As more sensor data gets collected during the remainder of the life cycle, the AR program may make more conclusive decisions and

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modify or reject the preliminary recognition results. This and other flexible, variable approaches should be compared to a recognition system, which outputs only yes/no (timeout) responses with some characteristic accuracy. Our approach changes the way activities are recognized and forge a new application and programming model that utilizes activity semantics. To support the notion of activity life cycle tracking, we utilize fuzzy logic, which we found to be well matched with activity life cycle characteristics. Unlike probabilistic models that strictly choose the highest probability value when there are multiple outputs, fuzzy logic accepts both high and low values as valid members of a fuzzy set. This characteristic allows continuous tracking of activities. Therefore, it can avoid recognition error when activities do not generate sufficient sensor data in the early stages of their life cycle.

This paper is organized as follows. In Section 2, we review related research literature. Our proposed approach is described in Section 3. In Section 4, our experiment and results are presented. Finally, we lay out future research directions in Section 5.

2 Related Works

In some activity recognition research, probabilistic machine learning techniques such as Hidden Markov Model (HMM) or Conditional Random Field (CRF) are used [2][3]. In such approaches, activities are continuously performed, and each activity is composed of several activity components such as tool or motion in temporal sequence. Therefore, in this approach, temporal relationships between activities are important. Even though temporal sequence information is useful for recognizing activities, it is not practical to apply this technique to real-world activity recognition because there are too many possible sequences in which activity components may be performed. It is almost impossible to track all possible temporal cases.

3 Fuzzy Logic-Based Human Activity Recognition Approach

A human activity has a finite life cycle, which spans from initiation through termination. An activity is usually initiated in response to a requirement or a stimulus.

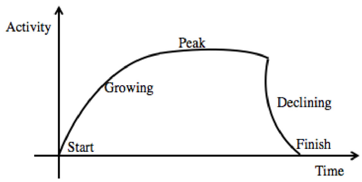

Fig. 1. Activity life cycle stages

The termination of an activity is often close to or coincides with fulfilling a certain goal. Activity Life Cycle (ALC) information can improve activity recognition accuracy and enhance the utility of the recognition results.

As shown in Fig. 1, ALC is composed of four stages: “starting”, “growing”, “declining”, and “finishing”. In Fig 1, recognition results may be tentative at the early stage of an activity’s execution. When an activity starts, there may not be sufficient sensor data for making decisive conclusions. If the collected sensor data is related to multiple activities, it may be difficult to clearly identify the performed activity. For example, if it is observed that a person holds a cup, it is not clear why the person holds the cup even though it is obvious the person may be performing an activity.

This ambiguous start is called “Tentative Start” and recognition decision is postponed until more sensor data is collected. ALC stages can be captured by a finite set of five states as explained below:

Started. An activity is considered “Started” if the Fuzzy Value (FV) of the activity becomes greater than zero (0→ positive) and it is the only activity recognized from a sensor set.

Tentatively Started. When multiple activities show their fuzzy value change from zero to positive from a sensor set, it is difficult to determine which activity is actually performed. This ambiguous start is referred to as “Tentatively Started”. An activity life cycle will stay in this state until the system can recognize which activity is really being performed.

Paused. Sometimes the human actor pauses in the middle of performing an activity. For example, while cooking, if a friend calls, then the human actor may stop cooking, answer the phone, and resumes the activity after briefly talking on the phone. In this case, cooking should be considered a single activity despite the pause, instead of two cooking activities.

Performing. After an activity starts it will stay in “Performing” stage if the fuzzy value of the activity is positive.

Finished. After the computed fuzzy value of an activity returns to zero for a certain period of time, the activity is “Finished”. Initially, it is difficult o know if the activity is paused or finished. It is determined as “Finished” if the activity does not start in maximum pause period.

Fig. 2 shows all possible state transitions of ALC based on fuzzy values and other system parameters.

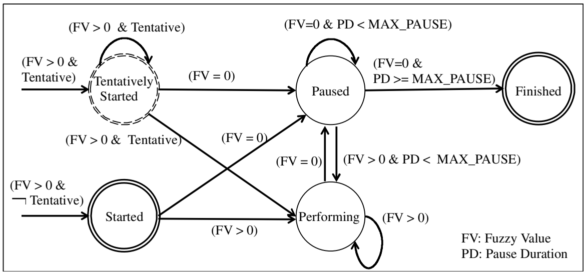

Fig. 2. Activity life cycle state transition diagram

For tracking ALC, AR systems should be able output the stage in which an activity is in. Also an AR system should present stage changes of an activity with the value associated with the activity. Fuzzy logic is well matched with ALC in two ways. First, fuzzy membership function prevents errors due premature recognition decision. To illustrate, when multiple activities are recognized from a sensor set, some activities are really being performed, while others may not. Sometimes, although an activity is being performed, the sensor data available during the early stage of its life cycle may not be enough to recognize it. This has been shown in the Fig. 3. Fuzzy logic based AR approach is more transparent than other machine learning approaches that require training. In fuzzy logic based AR approach, activities are recognized by computing their fuzzy value by fuzzy operations and activity models. Therefore, it is possible to estimate the fuzzy value of an activity whose activity model is known. This feature greatly simplifies system design, understanding and debugging. On the other hand, machine-learning approaches such as neural networks that require training typically rely on large amounts of training data. The training data for real-world applications typically has high volume; the large data obscures the proper estimation of recognition results of the AR system.

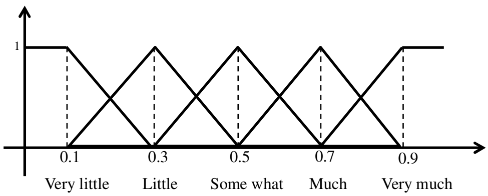

Fig. 3. Decision indices of a recognized activity. A fuzzy logic system does not rule out an activity based on low recognition value.

4 Validation

We conducted a preliminary experimental study to validate our proposed approach. First, our ALC based AR approach will be compared against the traditional yes/no AR approach. Second, the performance of fuzzy logic based AR approach will be compared with that of a neural network based AR approach that accounts for activity life cycle. For studying the performance of fuzzy logic based activity recognition, a setup consisting of two AR systems and activity datasets is used. These components are described below:

Activity Dataset. Two activity datasets are used for this experiment. Three people performed activities for four days in the Gator Tech Smart House at the University of Florida to collect daily living activity data sets. Among several collected activity datasets, “MakingHotTea” and “Eating” datasets are used for this experiment. As shown in Table 1, Bluetooth enabled devices, Android platform smart phones, and several sensors are used for collecting the activity datasets.

Fuzzy Logic (FL) Based AR System. Fuzzy logic based AR system reads sensor data in every time window and transforms the sensor data values to fuzzy values. It builds activity recognition tree according to activity model and computes weights and fuzzy values of activities. Finally, it determines the activity life cycle to identify which activity is performed.

Multi Layer Neural Network (MLNNK) Based AR System. MLNNK based AR system and fuzzy-logic based system will be compared to determine which approach is better suited for handling activity life cycle. MLNNK based AR system was developed at the University of Florida. For this experiment, two MLNNK setups were built—one supports activity life cycle and one does not. A detailed description of MLNNK based AR system can be found in [2].

Table 1. Sensors and devices used to collect "MakingHotTea" & "Eating" activity data

Activity	Sensors and devices used	Installed location
MakingHotTea	Android phone	Portable
	RFID reader (Bluetooth enabled) [6]	Wearable device
	RFID Tags [6]	Kettle, Spoons, Cup, Tea bottle
	Touch sensors	Stove switch
	Temperature & Humidity sensors [7]	Kitchen
	Sensor interface board [7]	Kitchen
Eating	Android phone	Dining room
	RFID reader (Bluetooth enabled) [6]	Wearable device
	RFID Tags [7]	Plates, Spoons, Forks, Knifes.

4.1 Analysis of Experimental Results

Fuzzy Logic (FL) based AR and MLNNK based AR approaches are compared. Fig. 4 shows the results for an "Eating" activity. Both AR approaches show that the graph of activity life cycle increases consistently when AR approach manages activity life cycle. On the other hand, in both AR approaches, their graphs show both increasing and decreasing of the membership or probability values of recognized activities. As an activity is continuously performed, more and more sensor data gets collected. Therefore, AR approaches with activity life cycle management is better aligned with real-world situations.

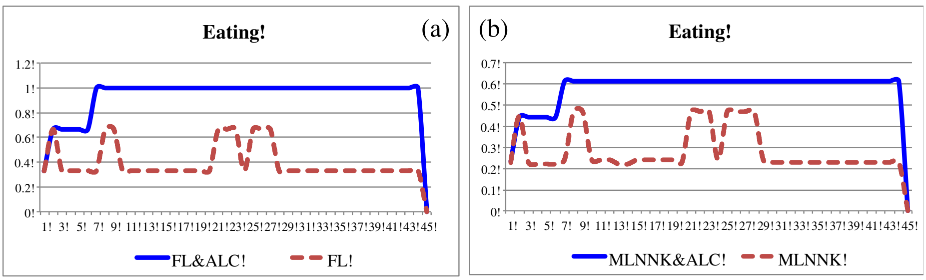

Fig. 4. Tracking the life cycle of "Eating" activities

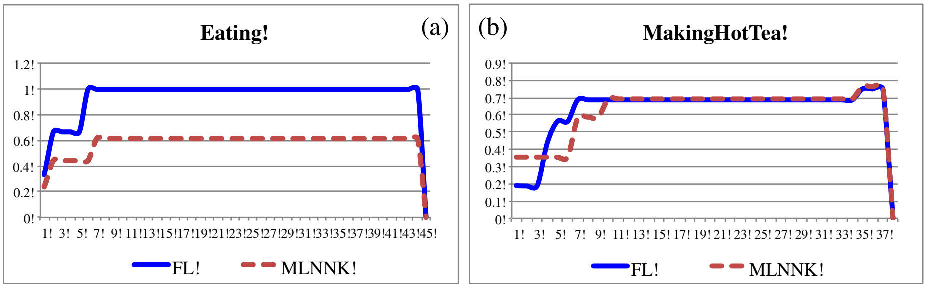

Fig. 5. Activity life cycle of “Eating” and “MakingHotTea” activities

Fig. 5 compares FL and MLNNK with activity life cycles of “Eating” and “MakingHotTea” activities. FL based AR approach reaches the peak of the activity life cycles a little faster than MLNNK based AR approach. Because of this difference, FL based AR approach shows better accuracy than MLNNK based AR approach as shown in Fig. 6.

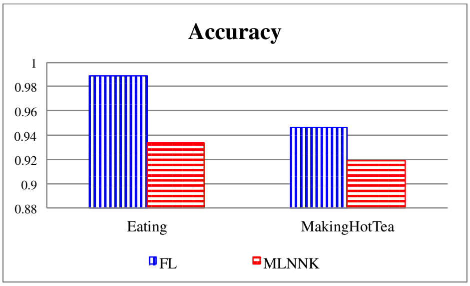

Fig. 6. Accuracy comparison between FL and MLNNK based AR approaches

To compare two AR approaches, accuracy is evaluated. The detailed method to compute accuracy is described in [2][3]. In Fig. 6, FL based AR approach shows slightly higher accuracy compared to MLNNK bases AR approach.

5 Conclusion

A new activity recognition approach that combines fuzzy logic and activity life cycle is proposed. Experimental results show that fuzzy logic is superior to probability based approaches for tracking activity life cycle and improving recognition accuracy.

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Automatic Fall Detection System with a RGB-D Camera using a Hidden Markov Model

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Abstract. Falls in the elderly is a major public health problem because of their frequency and their medical and social consequences. New smart assistive technologies and Health Telematics make it possible to provide elderly with more security and well being at home. A smart home can automatically monitor home activities for early warning in health changes or detecting dangerous situations. One of our objectives is to design an automatic system to detect fall at home, which in its final version will be made up of a network of RGB-D sensors. In this paper, we present a simple and robust method based on the identification and tracking of the center of mass of people evolving in an indoor environment. Using a simple Hidden Markov Model whose observations are the position of the center of mass, its velocity and the general shape of the body, we can surprisingly monitor the activity of a person with high accuracy and thus detect falls with very good accuracy without false positives. An experimental study, that is reported here, has been driven in our smart apartment lab. 26 subjects were asked to perform a predefined scenario in which they realized a set of eight postures. 2 hours of video (216 000 frames) were recorded for the evaluation, half of it being used for the training of the model. The system detected the falls without false positives. This result encourages us to use this system in real situation for a better study of its efficiency.

1 Introduction

According to a French statistic agency (INSEE), 1 200 000 people, in France, will be dependent in 2040 against 800 000 today. That obviously presents a problem of funding, as most of dependent elderly people are moving into long–term care units. The development of new technologies such as those provided by Robotics or Ambient Intelligent researches could offer an alternative allowing elderly people with loss of autonomy to stay longer at home than they do today by providing them with efficient assistance, especially when they live alone at home.

"Smart houses" for assisting and telemonitoring elderly people at home is not a new idea. In France, in the end of 90ths, TIMC-IMAG laboratory (Grenoble) [1] proposed the concept of HIS (Health Smart Home) and LAAS laboratory in Toulouse [2] launched at the same time the "PROSAFE" project. More recently,

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we can quote the Gerome project in Nice or the Adream project by LAAS. Inria, launched too, two years ago a national program called Pal ("Personal assisting living") in which our group is implied. Several Intelligent home laboratories have been built within this project especially in Nancy where our group stays. A large number of projects about smart houses are ongoing all around the world dedicated either to the management of energy and well being of people or on the development of new services for elderly people. Let us quote "MavHome", "House of Matilda", "Gator Tech Smart House", "Aware Home Research", "Easyliving", "Sensorized Environment for LiFe", "Intelligent Sweet Home".

Fall detection is a service, which is often mentioned by researchers in this domain, elderly people associations, and caregiver. Elderly fall is one of the major health issues affecting elderly people, especially at home. The importance of this problem is shown by the figures of the INPES (2005), which reveal that one elderly people out of three falls in the year. The consequences in term of autonomy for a person experimenting a fall are often dramatic and furthermore increase her risk of mortality. It's not rare that people stay all night on the ground after a fall before someone could assist them. The falls can have serious physical consequences (for example fractures), and also psychological ones (fear of falling again). Generally fallers face far greater problems because they carry out less daily life activities which increases their fragility.

Mainly, two categories of systems exist to detect falls. The first category consists in systems with sensors, that the person wears on her, as the accelerometers, the gyroscopes or the goniometers ([3], [4]). In this category we can add the systems with alarm button where the person must press herself on a button to alert after the fall. The problem of this category is that the person may sometimes forget to wear it. The second category of systems detecting falls is based on environmental sensors. Among them, video camera have greatly attracted the research community. This article is related to this last category of ambiant sensor approach, a RGB-D camera (Kinect) is chosen to detect the falls because it's a low-cost system which may be used by day and by night.

2 Proposed Approach

Several methods have been developed so far to detect falls from video cameras. Some authors build a blob around the person [5]. Others track an element of the person's body as the head [6], the head and the feet [7] or human centroid [8]. Finally, the methods to detect falls may be based on the detection of a person near the ground [8], the vertical speed [9] or the scene training of inactivity places [10]. We propose to fusion 3 simple indicators with a Hidden Markov Model (HMM) for filtering RGB-D camera images in order to detect falls.

2.1 Feature Extraction

In this paper, we argue that three simple features are sufficient for detecting falls and discriminating them from other similar situations like sitting or squatting. As presented in Figure 1, we extract the background from depth camera images

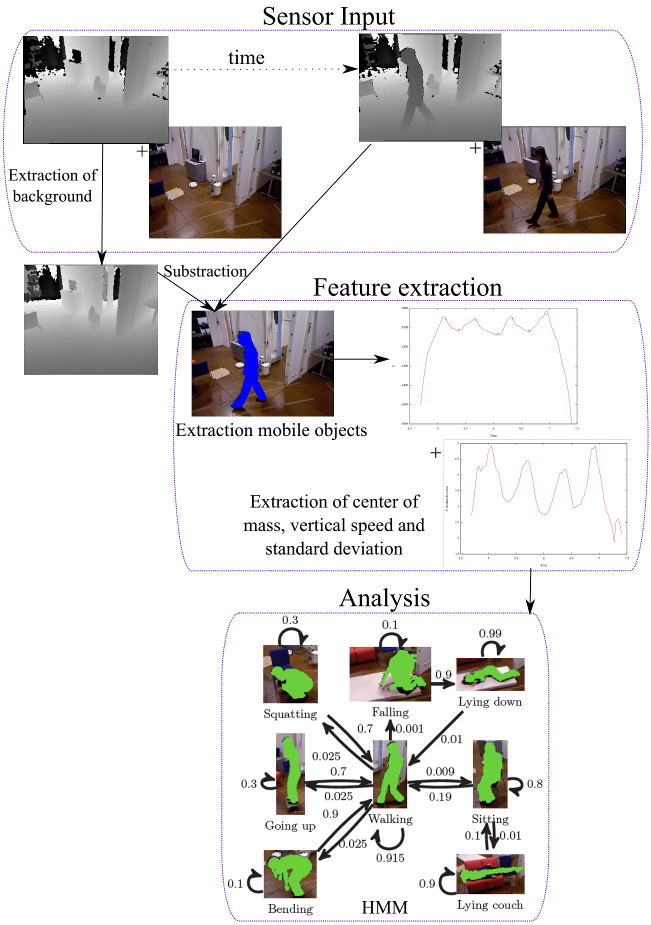


Fig. 1. Fall detection method

to obtain the mobile points and calculate the position of the center of mass, the vertical speed and the standard deviation of the mobile points.

Extraction of Background. Several methods can be used for detecting mobile elements in the scene like Gaussian Mixture Model [11], occupancy grid [12]. In this article we use a simple and fast method which consists in averaging the depth map for learning the background [11]. At each time we substract the background distances from the current distances to keep only mobile points. The real world coordinate system is obtained by using the Kinect factory optical parameters and we compensate the camera tilt angle (read from the camera accelerometer sensor) by a rotation on X-axis. We use OpenNI for Kinect to real world transformations.

Tracking a Person and Her Center of Mass. The aim is to gather the mobile points (2D pixels) belonging to the same object so as to be able to distinguish several persons in the scene. To gather the mobile points the method "Component labelling" [13] is used. Then we extract the features. The center of mass of the person is calculated as the average location of all the mobile points. The vertical speed is calculated from the position of the center of mass. And the vertical standard deviation is extracted from the point cloud of the person. The image entitled "Extraction mobile objects" of Figure 1 shows the result obtained with the running average and component labelling algorithms. All the mobile points belonging to the same person are gathered in color. The first image entitled "Extraction of center of mass, vertical speed and standard deviation" is the displacement of center of mass of a person on the vertical plane. In this figure, each point represents the center of mass in time. This curve is filtered with the Kalman method [14]. The second curve is the variation of the standard deviation in time.

2.2 Recognition of the Activity of a Person

In this part we present the method used to recognize the activity of a person more particularly to detect the falls. Our method is based on a Hidden Markov Model.

The aim is to create a model allowing to distinguish the falls from other activities. To define these other activities we were inspired by the article of Noury et al [15] where he described scenarios for the evaluation of fall detectors. We retain seven activities (other that falling), postures that a person can take: walking (including the position upright), lying (on a bed, on a couch for example), sitting, lying down, squatting, going up on an obstacle (a chair, a footboard for example) and bending. These eight postures are represented by the eight states of our HMM. The representation of this HMM is shown in Figure 1 in the block "Analysis". The meaning of each state is represented by the picture.

The model and these probabilities were deduced intuitively respecting the following assumptions:

- the most probable states are "walking" and "sitting", for a people at home, and the other states have a small probability in comparison;
- the difference between the state "lying couch" and the state "lying down" is the preceding state. In the case of lying on the ground, the preceding state is "falling" and the probability of this state is small. In the case of lying on a couch the preceding state is "sitting" because we sit down before lying on a couch.

In our HMM, the observations are the three features extracted as described in Section 2.1: the vertical position of the center of mass, the vertical speed and the standard deviation of all the points belonging to the person. The observation function follows a multidimensional normal law whose parameters are calculated from the data of 16 subjects visiting the eight states of the HMM. More explanations on this experiment are given in Section 3.

To calculate the probability to be in one of the eight states of HMM, we implemented the Forward-Backward algorithm and to calculate the best path we implemented Viterbi [14]. These two algorithms are compared in section 3.2. We assign the same initial probability to each state (1/8). We make the hypothesis that it's possible to be in each state at the beginning of the analysis.

3 Results

To test our algorithm an experiment is made with 26 subjects. These tests were made in a smart room. Only one camera is placed on the corner as shown in Figure 2. Each subject perform eight situations corresponding to the eight states of the HMM. In Figure 1 concerning the HMM we can see eight pictures corresponding to what was requested from the subjects. To learn the observation function as shown in Section 2.2, the data of 16 subjects are used and the validity of the HMM is tested with the data of 10 other subjects. We test and compare the two algorithms, Forward-Backward and Viterbi.

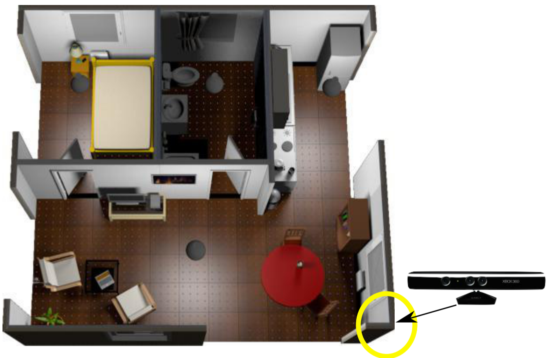


Fig. 2. The smart room and the position of the camera surrounded in yellow

3.1 Observation Function Parameters

As described in Section 2.2 we learn the mean and covariance matrix of the feature vector composed of the vertical position of the center of mass, of the vertical speed and of the standard deviation of all the points belonging to the person for each situation performed by the 16 subjects. The results are shown in Table 1. The state "going up" and "walking" have a high vertical position whereas "lying down" has a small vertical position. The state "falling" distinguishes itself from the other states by the vertical speed. And concerning the standard deviation there is a difference between "walking" and "going up" on the one hand and "lying down" and "lying couch" on the other hand.

3.2 Result with Forward-Backward and Viterbi

We have tested in which state was classified each situation of the 10 subjects not belonging to the learning group by using the Forward-Backward algorithm and

Table 1. Mean of the gaussian for each state of the HMM

	Vertical position	Vertical speed	Standard deviation
Walking	-1163	52	372
Bending	-1299	-41	308
Squatting	-1424	4	240
Going up	-975	117	333
Falling	-1505	-352	216
Lying down	-1871	-6	102
Sitting	-1370	-10	303
Lying couch	-1569	-3	210

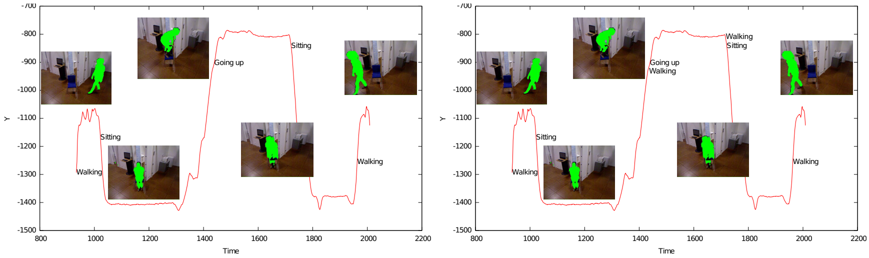
the Viterbi algorithm. The two algorithms give the same classification results. For sitting, squatting, lying on a couch, lying down, walking and going up the sensitivity (capacity to detect a state when it is present) is 100%. On the other hand for the 10 situations where each subject is bending the algorithm replaced by state "sitting" or by the state "squatting". The problem is that the observation doesn't allow to dissociate this state enough from the states "sitting" and "squatting", even visually. Concerning the classification of falls, one fall was not detected. This non detected fall corresponds to a subject who rose immediately after he fell, the fall itself being mitigated so the fall was not realistic. This subject doesn't pass in the state "lying down". However, according the HMM that we have defined in section 2.2, to be in the state "falling" it's necessary to pass in the state "lying down". For falls we can add that the specificity (the capacity of the system to detect the absence of a state when it doesn't appear) is 100% i.e. there are no false positives.

According to the HMM a person can fall only after the state "walking" which doesn't correspond to reality. We want to know if our algorithm is really robust for detecting the falls. We asked a subject to sit and fall from his chair. The algorithm is robust because it detects the fall even if there are no transition between the state "sitting" and the state "falling" in the HMM.

A last notice, we didn't see differences between Forward-Backward and Viterbi algorithm exept the "transition state". Viterbi give more state for a same situation. We asked a subject to sit and go up on a chair without walking between these two situations. We analysed the results with Forward-Backward algorithm and Viterbi algorithm, as presented in Figure 3. We can notice that Viterbi provided more states. To pass from sitting to going up the subject didn't walk as correctly inferred by Forward-Backward in Figure 3(a) but Viterbi inferred the state walking. It's not correct but Viterbi stick at the contraints provided by the HMM. In the HMM we have proposed that after the state sitting we have the state walking before passing to the other state. Thus in figure 3(b) Viterbi pass by the state walking even if the subject doesn't walk.

3.3 Result in Real Time and Discussion

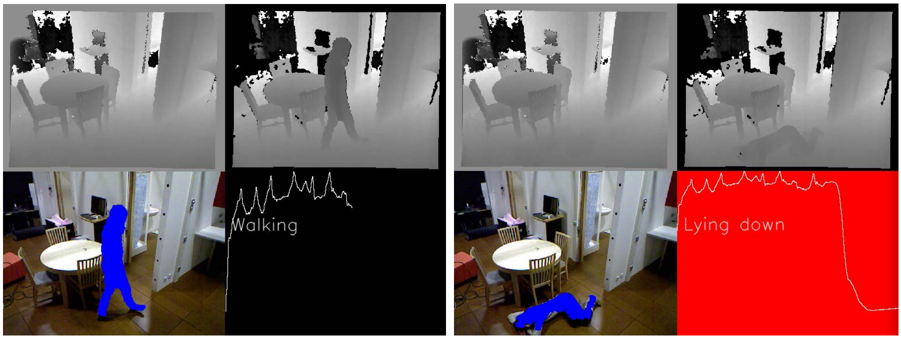
In introduction we said that we wanted to develop a system for detecting falls. The results show that our algorithm allows a correct identification of the falls.



(a) Analysis with Forward-Backward algorithm (b) Analysis with Viterbi algorithm

Fig. 3. Difference between Forward-Backward and Viterbi algorithm

But these results were obtained by analyzing video sequences. We implemented our algorithm in real time to launch the analysis at the same time as the person is viewed by the camera. Figure 4 shows a person walking and falling. In the top left-hand corner of this figure the image is the depth background learnt and on the right is the current depth image of the camera. In the bottom left-hand corner is the current RGB image with the object detected as foreground drawn in color. And in the bottom right-hand corner the center of mass on the vertical plane is drawn and the algorithm deduced the state in which the person is. We can see in this figure that the algorithm detects correctly the walk and the fall of the person. We can imagine a system which would allow to send a signal to a physician or to a member of the family when it detects that the person has fallen as in Figure 4(b). This system uses a computer and low-cost cameras. Another advantage is that this system allows to preserve the privacy of the person since it works with extracted features and the images don't need to be stored.



(a) Detection of the walking (b) Detection of the fall

Fig. 4. Real time fall detection

4 Conclusion

In this paper we presented a system based on RGD-D camera able to detect falls of elderly people while preserving their private life. Our algorithm tracks the center of mass of the person. To know if the person falls we create a HMM with eight states corresponding to eight situations of daily life. The results show that our model distinguishes correctly the falls from the others activities (as sitting, lying on a couch...). The experiment was made on healthy subject and without occlusions. In the future we plan to explore these two problems.

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A Rehabilitation Exercise Assessment System Based on Wearable Sensors for Knee Osteoarthritis

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Abstract. In order to enable the knee OsteoArthritis (OA) patients to manage their own rehabilitation progress, this study develops a rehabilitation exercise assessment system for knee OA using three wearable sensors mounted on the chest, thigh and shank of working leg. The system derives 51 features from the calculated angles, spectrum, and means of the acceleration signals to judge the exercise type and determine whether their postures are correct or not. After ten subjects performed three kinds of rehabilitation activities, we got 99.29% accuracy for exercise type classification, and 90.14% accuracy for wrong exercise recognition. The experimental results demonstrate that the proposed system can help the physician and patients to monitor the rehabilitation progress efficiently.

Keywords: Knee joints rehabilitation exercise, wearable sensor, rehabilitation assessment system.

1 Introduction

Since the knee joint bears the heaviest weight of the human body, it is the body part most susceptible to OsteoArthritis (OA) [1]. Treatments for knee OA include surgery, medicine and exercise therapy. Above all, exercise therapy is the most effective interventional treatments [2]. Knee OA patients receive exercise therapy through a series of rehabilitation program that is beneficial to joint mobility and body metabolism. The early rehabilitation stages last for approximately six weeks, during which the patient works with the physical therapist several times each week. The patient is afterwards given instructions for continuing exercise at home [3]. An appropriate rehabilitation exercise can relax joint capsules and ligaments, prevent osteoporosis, strengthen muscles around the knee and increase active weight-bearing ability. However, improper rehabilitation exercises not only put patients on the risk of slower recovery, but also cause more damage by adding stress to injured parts of the knee. Therefore, developing a knee OA rehabilitation exercise assessment system that monitors patients' rehabilitation movements at home can play an important role on the patient's recovery process. In this work, we used the signals of three tri-axial accelerometers attached on the user to calculate features of time domain, frequency domain and angle information. The assessment system used those features to identify

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the type of rehabilitation exercise by decision tree classifier and detects improper exercise movement by Hierarchical model. The knee OA rehabilitation exercise assessment system can help patients to self-manage their rehabilitation progress at home, and provide error feedback mechanism to let patients know whether they should modify their movements. Moreover, in the medical follow-ups, doctors can assess the patient's progress and how effectively the physical movements were carried out through the record of the system.

The rest of the paper is organized as follows. Section 2 introduces related work of rehabilitation assessment system. Section 3 describes the experiment setup and analysis method. Section 4 presents our results; and section 5 concludes the work.

2 Related Work

Brutovsky et al. used tri-axial accelerometers and a handheld Personal Digital Assistant (PDA) to track the movement of a patient engaging in exercise [4]. The system gives instructions to patients via PDA and provides feedback on the rate of progress. The system allows clinicians to monitor patients' rehabilitation progress through telecommunication on PDA. Rehabilitation assessment is beginning to be recognized as an important part of home telecare system. Taylor and colleagues used wearable sensors to detect improper rehabilitation movement [3]. They used peak detection method to divide signals into time segments, and then used features of frequency domain and time domain extracted from each window to detect improper movement through classification algorithm. Their system was applied in three knee OA rehabilitation exercises, and was able to let their users know how to modify their movements. However, their system was unable to detect multiple errors at once; and the accuracy of their results was affected by labeling inconsistency.

3 Materials and Method

3.1 Hardware Architecture

We use three tri-axial accelerometers to be worn on the patient's chest, thigh (close to the knee) and shank (close to ankle) of the working leg, as shown in Fig.1 (a). The access point receives data of accelerometers wirelessly from the sensor nodes and transmits those data to the workstation through USB connection. Finally, the accelerations are processed on the workstation using MATLAB. Each wearable sensor is 48.5x36.5x13.5 mm, weighs 22 grams, and has sampling rate of 40Hz. These lightweight, tiny sensor nodes allow subjects to exercise without obstruction.

3.2 Rehabilitation Exercise Types and Labeling Improper Movements

In this study, data was collected from 10 subjects (5 males and 5 females, 163.9±8.9cm height, 56±10.11Kg weight). Three types of rehabilitation exercise commonly prescribed to knee OA patients were: Short-Arc Exercise (SAE), Straight Leg Raise (SLR), and Quadriceps Strengthening Mini-squats (QSM), as shown in Fig.1 (b) to (d). We labeled several improper alternations of those three rehabilitation exercises based on the suggestion of a physical therapist. Each subject performed each altered movement 10 times, as shown in Table 1.

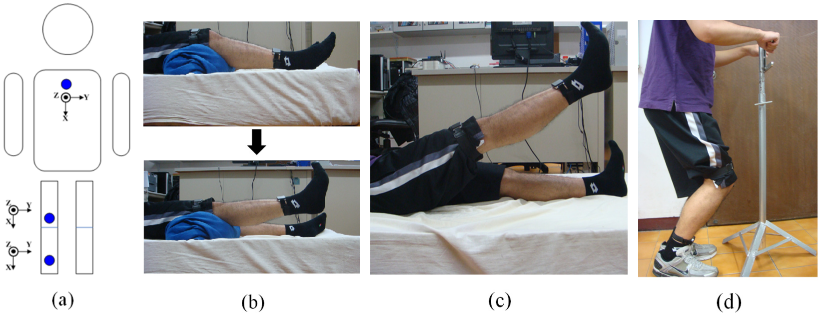

Fig. 1. (a) Wearing positions of the sensors. (b)SAE. (c) SLR. (d) QSM.

Table 1. Alternations of three rehabilitation exercises

Rehabilitation Exercise	Label	Times
Short-Arc Exercise	1. Normal	10
(SAE)	2. Initial angle >25°	10
	3. Knee not fully extended	10
	4. Occurrence of both 2 and 3	10
Straight Leg Raise	1. Normal	10
(SLR)	2. Knee not fully extended	10
	3. Hip joint external rotation	10
	4. Raise angle not approx. 45°	20
	5. Occurrence of both 2 and 3	10
Quadriceps	1. Normal	10
Strengthening	2. Trunk bent forward	10
Mini-squats	3. Knee angle approx. 45°	10
(QSM)	4. Occurrence of both 2 and 3	10
Total		140

3.3 Angle Calculation

We converted the gravity force components in three axes of the accelerometer into tilted angles. These angles can be calculated by equation (1) to equation (3):

$$\rho = \tan^{-1}\left(\frac{A_x}{\sqrt{A_y^2 + A_z^2}}\right) \tag{1}$$

$$\varphi = \tan^{-1}\left(\frac{A_y}{\sqrt{A_x^2 + A_z^2}}\right) \tag{2}$$

$$\theta = \tan^{-1}\left(\frac{A_z}{\sqrt{A_x^2 + A_y^2}}\right) \tag{3}$$

The angles, ρ, φ, and θ, are the tilt angles between x, y, z axis and the ground. A_x, A_y, and A_z are gravity force components in x-axial, y-axial and z-axial respectively. We used the signals of tri-axial accelerometers to calculate the angle of thigh raise, knee flexion, hip external rotation and trunk forward bending to evaluate whether rehabilitation exercises were properly carried out. We would also use angle information to make exercise type judgment.

3.4 Rehabilitation Exercise Type Classifying and Assessment Method

In the proposed system, we firstly classify the types of rehabilitation exercise, and then evaluate whether the exercise movements are proper. The system function diagram is shown on Fig.2.

In the first step, the accelerations should be filtered by Median Filter (MF) with n=3 and Low Pass Filter (LPF) with cut of frequency at 0.5Hz. MF can remove any abnormal noise spikes produced by the accelerometers. The gravity force components in the three axes would pass through the LPF, and acceleration components would be filtered out, making the angular calculation more accurate. Regarding the division of time windows, almost all the knee OA rehabilitation exercise involves periodic angle variations of the shank, so the system utilized peak detection method on shank angle variation to define start and end point of every movement.

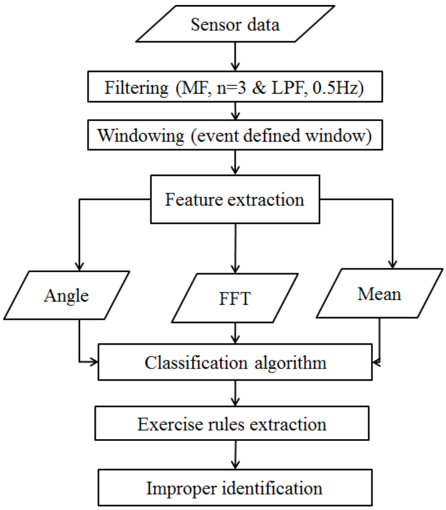

Fig. 2. System function diagram

On the previous study of feature extraction, Preece et al. compared time domain, frequency domain, and time-frequency domain features based on the same classifier and experimental environment; and they concluded that the first five components of Fast Fourier Transform (FFT) method can get the best accuracy [5]. In this work we chose that method as our feature extraction method to classify exercise type. In addition to FFT method, we used the angles information and mean values depending on the characteristics of those exercise to assist exercise types classification. However, the calculated angles may contain deviations because sensors were placed on the human body instead of a flat platform. In order to calculate the variation of angles more accurately and compensate for the deviations caused by noises and initial angles of sensors position, we get the angles variation by subtraction between median of 10% largest value and median of 10% smallest value on each time window.

In exercise classification stage, we used decision tree classifier for its high accuracy and minimal computational complexity in the area of activity recognition [6]. Then exercise rules would be extracted based on the results of exercise classification. Finally, the improper movement is identified by exercise rules we defined before. As shown in Fig.2, we used angles information to identify improper movements, because improper movements almost always involve movement angles exceeding tolerance threshold. Using angle information to identify improper rehabilitation movements is more intuitive. It is also more flexible when it comes to modifying exercising rules.

4 Results and Discussion

We used 10-fold cross-validation to verify the proposed rehabilitation exercise assessment system. The proposed system classified the types of the users' rehabilitation exercise, and then identified whether their exercise movements were proper.

The decision tree we developed for classifying exercise types is shown in Fig.3 (a). "Mean_xT" represents the mean value of the thigh sensor on the *x* axis; "AngT" represents the highest thigh raising angle of each movement; "S4", "T2" and "T3" are the components of FFT. According to the training results of decision tree, we can perceive that the time domain feature, frequency domain feature and angle information can all be used as discriminating features in decision tree for exercise classification algorithm.

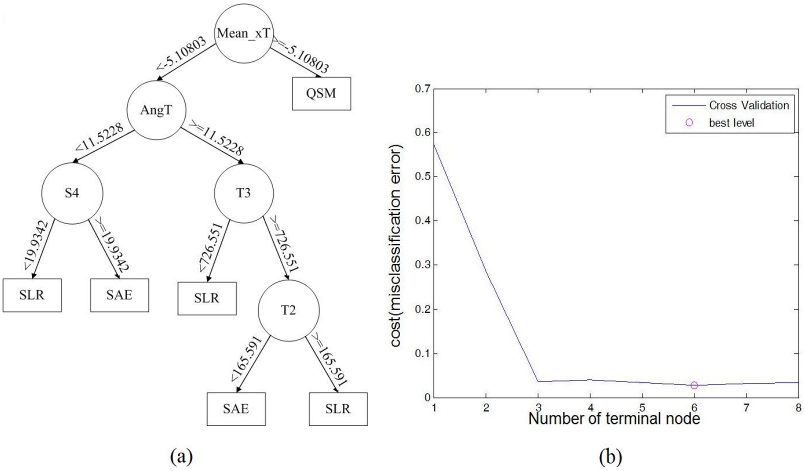

Fig. 3. (a)Decision tree classifier. (b)Number of terminal nodes and cross-validation error curve on implementing decision tree.

The accuracy of exercise type classification was 99.29%, as shown in Table 2. Since the error would be minimized while the tree has 6 terminal nodes. We pruned the tree based on the results shown in Fig.3 (b). The accuracy of improper exercise

Table 2. 10-folds cross-validation

Exercise	Type classification accuracy	Improper identification accuracy
SAE	99.25%	93%
SLR	98.83%	86.17%
QSM	100%	93.25%
All	99.29%	90.14%

detection achieves 90.14%. This result may be affected by the accuracy of exercise type classification and the artificial errors that occurred while the user couldn't meet the movement requirements.

In this study, we consulted a physical therapist to defined general criteria of exercise rules. If some patients needed to do rehabilitation exercises with different rules, we could change the improper exercise criterion conveniently for improper movement detection.

5 Conclusion

In order to enable the physician and knee OA patients to manage the rehabilitation progress, we developed a rehabilitation exercise assessment system that can identify the type of exercise movement the user makes and detect deviations from a correct exercise movement, which can allows knee OA patients to take the full benefits on rehabilitation exercise. This system used three wearable accelerometers as signal source, and extracted the signal's time domain feature, frequency domain feature and angle information to identify the type of exercise movement. In the improper identification stage, we used angle information to detect improper rehabilitation movements. The experimental results have demonstrated that the proposed method provides high accuracy of exercise type classification and improper movement detection. It fulfills the requirements of rehabilitation exercise assessment system.

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Identifying Phases of Gait and Development of Walking Model from Pressure and Accelerometer Data and It's Ramifications in Elderly Walking

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Abstract. Locomotion is a feature of all animals. Whereas quadruped are fast and stable, human's bipedal gait is less stable and less efficient. Human gait analysis is going on for a long time. Such analysis usually used force data applied on the ground during different phases of gait. In this paper, we have analyzed the pressure data collected from pressure sensors placed on shoes along with accelerometer data collected from cell phones during walking activity. We identified different phases of walking activity using the pressure data. We also have developed a biomechanical model of gait based on the pressure and acceleration data.

Keywords: Gait analysis, plantar pressure sensor, gait cycle, Elderly care.

1 Introduction

Humans use their legs most frequently for locomotion. Walking is the most frequent form of locomotion for human. Studies of human locomotion have a long history [1, 2]. The reasons behind interest in the study of human locomotion have been changed over the history. Even the Greek philosophers in 500-300 B.C. studied human locomotion. Their motivation was to place harmony to nature. Recent interest in the study of gait is motivated by several factors. Doctors, for example, study human locomotion to identify the causes of problems in gait as a way find solutions. Forty-eight gait abnormalities have been identified as common occurrences by the Rancho Los Amigos Pathokinesiology and physical therapy staffs [3]. To treat these gait problems, understanding of gait is important. Prosthetic limb developer also study gait as they try to emulate human gait and other limb motions. Researchers in sports industry also study different biomedical movements of humans.

Like any other fields, study of gait needs to analyze data. Various modalities of data are used in gait analysis. For example, video data collected by multiple cameras where markers are placed in lower body locations during gait is used to analyze gait. Also, force plates are used to measure ground reaction force applied by feet during gait. One of the problems is the errors that come from measuring tools. We here propose architecture of in-shoe plantar pressure measurement system to analyze gait.

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Our major contributions:

1. We proposed a new mode of data collection system in the analysis of gait. We discussed an in shoe plantar pressure sensor system to collect data for gait analysis.
2. We analyzed the pressure sensor data collected from the shoe system and identified different stages of gait cycle. We showed how pressure data from shoes are consistent with observations from observations from other system.
3. We developed a biomechanical model for walking from the collected pressure data. We developed a similar biomechanical model for walking from data collected from phone accelerometer carried in the pocket while walking.
4. We explored the idea of applying this analysis techniques in elderly care context as a way of developing biomechanical model for elderly walking.

Section 2 discusses related works in this area. Section 3 discusses our system and gait cycle. Section 4 is discusses how pressure data collected during walking are able to identify different phases of walking. Also a biomechanical model for walking is discussed in this section. It also discusses our findings and ramifications of our findings in the analysis of elderly walking. We conclude in section 5 with a discussion of future work.

2 Related Works

Physical activity monitoring of the elderly people provides valuable information for health aware services. Most of the elderly care related research is based on video data rather than a simpler system. It is commonly observed and shown by several recording methods that freely walking people choose a certain velocity and gait pattern. At any given speed people can vary their walking pattern by changing the step length and the step frequency [7] tending to walk with optimal velocity and cadence with minimal energy expenditure [8] and [9].

Earlier, many researchers have talked about mobility and the privacy issue [5] but they didn't discuss wearing any sensors. Moreover, they do not take into account the cost effectiveness of the system. Plantar pressure distribution is related to walking speed and with increasing velocity the vertical ground reaction forces increase at heel-strike and toe-off while decreases during mid-stance [6].

It is important to be careful while interpreting observations from measurements. The ability to observe and interpret measurements of human movement has been very important factors in limiting growth of the field. Works of Ebenhart [10] and Inman [11] formed the basis for many fundamental techniques for currently used human locomotion. Currently, one of the primary techniques being used is the measurement of skeletal movement from markers placed on the skin.

3 Background

None of the existing systems for collecting data for gait analysis is perfect and suffers from different limiting factors. Either it is encumbering or expensive or requires a large fixed system. First we will discuss gait cycle during walking and then we will present the system that we used for gait data collection.

3.1 Gait Cycle

As we are concern the walking activity only, we first explain the gait cycle. There are different approaches traditionally used to address gait cycle. Each gait cycle has two phases: stance and swing. During the stance period, the foot is in contact with the ground. At the end of stance period, the toe puts pressure on the ground. So the stance period starts with a high pressure in the heel (low pressure on toe) and ends with a high pressure on the toe (low pressure on heel). During the swing period, the foot is on the air. As a result, there is no ground reaction force (GRF).

Stance again has three subdivisions. Initial double stance, single double support, and terminal double stance. The timing distribution of different phases of gait cycle is roughly as follows: Initial double stance takes 10% of time, single double stance takes 40% of time, terminal double stance takes 10% of time and swing state takes 40% of time. The duration of these gait cycle intervals varies with the walking velocity. At the normal 80m/min rate of walking, the stance and swing periods represent 62% and 38% of the gait cycle respectively. Swing also has four stages: pre-swing, initial swing, mid swing, terminal swing.

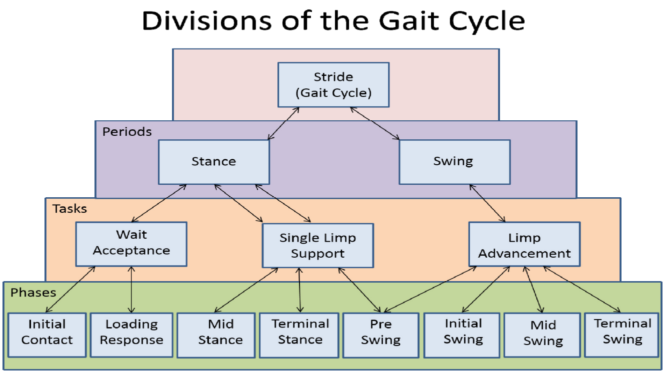

Fig. 1. Phases of Gait Cycle

3.2 Our Data Collection System

Here we used a plantar pressure system for pressure data collection from shoes developed by Lin Shu and his colleagues [4]. Eight pressure sensors are placed on each shoe. Four sensors in the front and four sensors in the back below the heel are used to collect the data. The collected data is transmitted over Bluetooth in a cell phone. We collected data for walking of a normal healthy young male subject. At the same time, we also used the phone to collect acceleration data. The phone was placed on the right pant pocket of the subject.

4 Gait Cycle from Pressure Data and Walking Model

4.1 Identification of Phases of Walking

Pressure sensor 1 and 2 are placed below heel, pressure sensor 3 and 4 captures mid foot pressure and pressure sensor 5, 6 and 7 is below the front part of the foot. Pressure sensor 8 is below the great toe capturing pressure from this part of foot. Here are the graphs from left foot while walking from pressure sensor 1 and 2 (PS1 and PS2). Pressure is measured in kilo Pascal (kpa).

Figure 2 shows how the pressure reaches peak for both PS1 and PS2 simultaneously reflecting heel strike capture by these two sensors. When the heel hits the ground, the pressure reading is highest.

So two consecutive high peak values indicates hitting of the ground by left heel twice consecutively which means a complete stride. We can see from the figure below that pressure reading from pressure sensor 8 reaches peak after pressure sensor 2. It supports the normal heel-strike-first model. We did similar graph for pressure sensor 1 and 8 and found that ps8 follows ps1 which is consistent with our expectation.

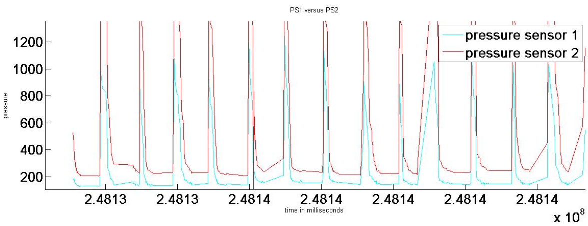

Fig. 2. Pressure in kPa at PS1 and PS2 against time

So, the very short time between red and green peak roughly reflects stance phase. According to the placement of sensors in the shoes, first ps1 and ps2 reaches peak simultaneously, then ps3 and ps4 reaches peak simultaneously, then Ps5, ps6, and ps7 reaches peak simultaneously and then ps8 reaches peak. But ps8 and ps7 should be very close and may not be differentiable.

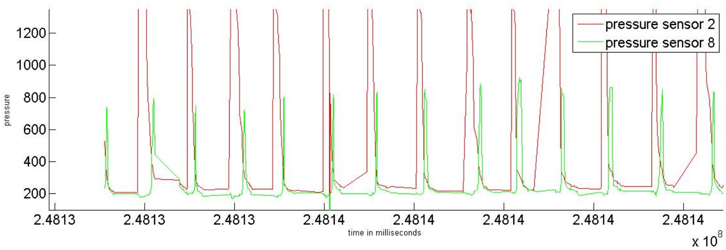

Fig. 3. Pressure in kPa at sensor 2 and sensor 8 against time

We generated similar graphs which showed that peak of ps6 and ps7 are simultaneous whereas they both reaches peak after peak of ps1. This is consistent with our observation that heel strike the ground before forefoot strike ground. All of these above figures show that stance phase is well captured by this shoe system.
From the figure below, we can see that the swing phase is also well captured. Here we are showing the graphs of left shoe against right shoe for corresponding pressure sensor. So, for example, pressure sensor 6 of left shoe is shown with pressure sensor 6 of right shoe against time. Also same pressure sensor is placed in similar place in both shoes.

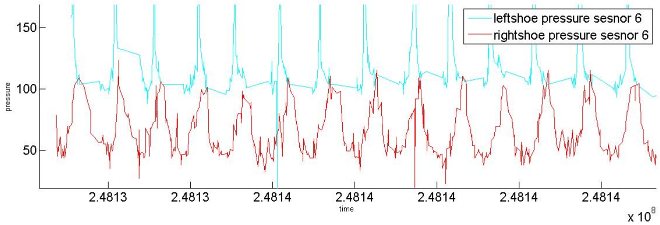

Fig. 4. Pressure in kPa at PS6 left and PS6 right against time

We can see that when the left shoe reaches peak, it is low pressure reading in the right shoe reflecting the swing phase in right shoe at that time. It is natural that the shapes of these graphs are different as the two shoe systems are not identical. Though the pressure sensors were placed in approximately similar position of both shoes, no two sensors are identical. So the different shapes are not surprising. This has been verified in case of ps6, ps7 and ps8 as we generated similar graphs for these sensors too.

4.2 Walking Model

By observing the change in pressure during walking, the first simplest approximation of the graph is a convolution of an impulse function. We will assume that the pressure curve for walking is approximated by, $p = \frac{F}{A} = \int_0^t e^{-\alpha(t-\tau)}\beta \, d\tau$ where, $0 \leq t \leq T$ and A = area = constant.

To find the impulse of the pressure, we need to integrate the signal,

$$I = \int F \, dt$$

Or,

$$I = \frac{A\beta}{\alpha} \int [e^{-\alpha(t-\tau)} + B] dt$$

$$I = \frac{A\beta}{\alpha^2} \left[e^{-\alpha(t-\tau)} + Bt\right] + C$$

Where, B, C, α, and β, are constant and B and C is unknown. We can calculate the unknown parameter by using two boundary condition and finding maxima and minima. Also assume that A is constant.

We also generated similar walking models from the accelerometer data. These accelerometer data was captured by phone carried in the pocket by the subject. The impulse, I, of a step of running and walking I s given by, $I = \int F \ dt$, where F is the force. Using Newton's second Law, $F = ma$ and $a = \frac{F}{m}$ Where, a = Acceleration and m= mass.

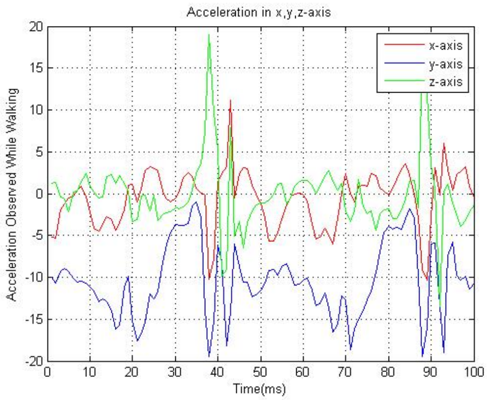

Fig. 5. Acceleration Observed with normal walking

Fig 5 is the acceleration observed for x, y, and z axis. The first simplest approximation of the graph is an impulse function. We will assume that the acceleration curve for walking is approximated by a Sinc function, $a = \frac{F}{m} = \frac{Sint}{t}$ where, $0 \leq t \leq T$

To find the impulse of the acceleration, we need to integrate the signal,

$$I = \int F \, dt \quad \text{Or,} \quad I = m \int \frac{Sin(t)}{t} \, dt$$

$$I = m \int \frac{1}{t} [t - \frac{t^3}{3!} + \frac{t^5}{5!} - \frac{t^7}{7!} + \cdots \ldots\ldots] dt$$

$$I = m[t - at^3 + bt^5 + ct^7 + D]$$

Where, a, b, c and D are constant and only D is unknown. We can calculate the D by using two boundary condition I(0)=0 and I(T) = 0. Also assume that m is constant.

By using the boundary condition we can express the impulse function as,

$$I = m[t - at^3 + bt^5 + ct^7]$$

5 Conclusions and Future Work

In this paper we presented how smart phone-based shoe system captures gait cycle. We showed that this system was able to capture different phases of gait cycle. We also developed a walking model from the pressure data captured during walking by the same system. Similar model was developed from accelerometer data. As a result this system can be used in the gait analysis in gait labs. In this paper, though we discussed only walking, in future, we plan to analyze and identify different phases of other activities. The system has the advantage of being portable and thus has potential to be more effective in gait analysis.

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Meaningful Integration of Online Knowledge Resources with Clinical Decision Support System

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Abstract. Clinical Decision Support System (CDSS) is becoming as one of the key components of current health information systems. Contemporary CDSS system requires more attention to design and implement. The crucial aspect of KB is the richness with respect to domain knowledge which is mainly dependent on domain experts. Domain experts have understanding of the domain and wisdom to create the knowledge. However, they often seek help from online knowledge resources to find new evidences about certain disease and clinical practices. This fact is especially true for cancer disease where improvements occur more frequently. Literature has proved that online knowledge resources are capable providing answers to questions that might not be answered relying only on clinician wisdom and experience. This paper provides the technique for meaningful integration of online knowledge resources with Smart CDSS. Clinicians can get enormous benefits from this approach to fulfill the gaps in the decisions during patients' diagnosis and treatment.

Keywords: CDSS, Online Knowledge Resources, Meaningful Integration, Knowledge Manager, Knowledge Base.

1 Introduction

Clinical Decision Support System (CDSS) is the key component of contemporary health information systems like EHR/EMR. The main purpose of any CDSS is to assist physicians in the clinical processes of patient care. It improves the physicians' performance which ultimately results in overall improved performance of the healthcare organization. CDSS is composed of several components including KB as the most important.

The success of any contemporary CDSS is based on KB upon which it is built [8]. The crucial aspect for KB is the richness with respect to domain knowledge which is mainly dependent on domain experts. Domain experts have lot of understanding of

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the domain and wisdom to create the knowledge in KB. However, they should not be limited to rely only on the knowledge existed in their heads. Rather, they should look at the new research to find evidences handling new patient cases with respect to certain diseases or improvements in the existing clinical practices. This fact is especially true for cancer disease where improvements occur more commonly. The research papers holding this new knowledge and evidences are called practice changing papers in the clinical terminology. Finding such papers to help in clinical practices like patient diagnosis and treatment is a true problem for physicians. Additionally, the emergent nature of medical domain contributed toward difficulties in the adoption of CDSSs as highlighted in [10]. Physicians have no established mechanism to get into these new developments in the domain. They spend a lot of their precious time on searching process. If they find the information, they don't have any proper method to convert it into knowledge. This time spending results not only in degradation of oncologist performance but also affects the patient care.

Typical CDS systems are lacking in contextual integration with online knowledge resources in a meaningful way. They rather, rely on the existing knowledge in KB. Decision support systems that possess the capability of adapting new knowledge from the current research are called Evidence-Adaptive CDSS in literature. The KB of an evidence-adaptive CDSS is based on current evidence and its recommendations are routinely updated to incorporate new research findings [11]. This paper proposes a novel approach of acquiring new knowledge from the online knowledge resources to evolve the KB of Smart CDSS. Smart CDSS is a recommendation system that assists oncologists in Head and Neck (HNC) cancer patients' diagnosis and treatment [9]. The same service can be shaped towards smart home environment by providing expert guidelines to patients from approved clinician knowledge base at their home environment.

2 Background

Generally, a CDSS is an interactive computer-based information system that assists physicians and other healthcare professionals in the process of clinical decision making. Its goal is to reduce the time of physicians, spent on the clinical tasks that could otherwise be achieved through the use of CDSS. Any typical CDSS has three major components; KB, Inference Engine and User Interface [4]. Among these three components, KB is the most important and is the success determiner for any contemporary CDSS [8]. However there are several other desirable features that any contemporary CDSS should possess to satisfy the user requirements. Maintenance of the KB is one of these desirable features [4] and the same is included in [1] as one of the Ten Commandments. Sometimes a CDSS system is strong from its capabilities but due to misfit into the workflow of a system, the chance of acceptance by the physicians is low. The reasons behind this lack of success included inadequate integration of CDSS into clinical workflow and inadequate integration of CDSS with EMR [6]. Since, we are implementing this system into a real environment to link Health Management Information System (HMIS) of SKMCH&RC so we are confident to break this barrier of inadequate integration. HMIS of SKMCH&RC has very well matured patient workflows to manage cancer patients for their diagnosis and treatments. The system lacks in integrating CDSS results to cover the time spent on tasks that would otherwise be done by the computer. From technical perspective we can use either standard based or non-standard based approach for this integration. Standard based approach is preferable over non-standard due the factor of eliminating the need for developing custom APIs with significant reduction in integration costs [3]. HL7 developed Context-Aware Knowledge Retrieval Standard (Infobutton) [5] is becoming popular and is considered for implementation by different entities around the world. There are two implementation guides provided by HL7 so far; URL based Implementation and Service Oriented based Implementation. In our approach we will prefer to use the later one. Infobutton only, however cannot satisfy the overall requirements. Our goal is not only to retrieve knowledge from the online resources and present them to the physicians in as-it-is format, rather to transform the retrieved information in a more easy to use manner. In addition, we also arrange them into a more logical format for the physicians to validate and generate knowledge rules from them.

3 Abstract System Architecture

The integration of Online Knowledge Resources is a process of connecting a health system with online resources in a way to collect meaningful information, present it to the user (oncologist in our scenario) and make it part of the KB of CDSS (Smart CDSS in our case). This function of integration has several sub-functions to perform as depicted in Figure 1. The KB of Smart CDSS is connected with Knowledge Manager through Input Request Generator which in turn connects to the list of subscribed online resources. The Output Response Formulator module of Knowledge Manager is connected to Knowledge Representation which then connected to Knowledge Verification and Knowledge Publisher. The selection and subscription of online resources is subject to authenticity and credibility. We considered the knowledge resources based on the selection of oncologist as finalized in the survey.

3.1 Knowledge Manager

Knowledge Manager is the main module of architecture and has a special role during the input request generation and output response formulation. When an input request is generated from within the workflow of a health system, it might not be in a format to be directly sent to an online resource. Other than conversion to standard format, it is required to add the clinical terminologies or adding new attributes or deleting the extra elements. Similarly, when the output information collected from the resources, again it might not be in format to be used by the physicians to extract knowledge. Knowledge Manager with Input Request Generation and Output Response Formulation components perform all these functions to enable the meaningful communication between health system and online resources.

3.2 Input Request Generator

This module performs the function to set the query parameters required to fetch relevant information from the appropriate online knowledge resource. It takes the input request with contextual information from the workflow of health system where CDSS is deployed and filter the unnecessary information. The unnecessary information is the one having no importance to be used as a query parameter when the input request runs at the resource side. At the same stage, new elements will be added if required in order to make the input more useful. Sometimes the information coming from within the workflow of health system is not enough therefore; we add more information to get into the right information. Upon the completion of data the input request is linked to an appropriate resource(s) based on the best match strategy.

3.3 Output Response Formulator

Once we have the final response, we need to transform it into a readable format. This transformation process requires deep analysis of the patterns in the information. Due to diverse nature of the information extracted from the resources, it is more appropriate to use semi-automatic approach assisting the physicians to structure the information in required format. After structuring, the response is converted into Arden Syntax [7] which is directly usable by the Smart CDSS system. Validation and verification is required before publishing the Arden Syntax rules into the KB.

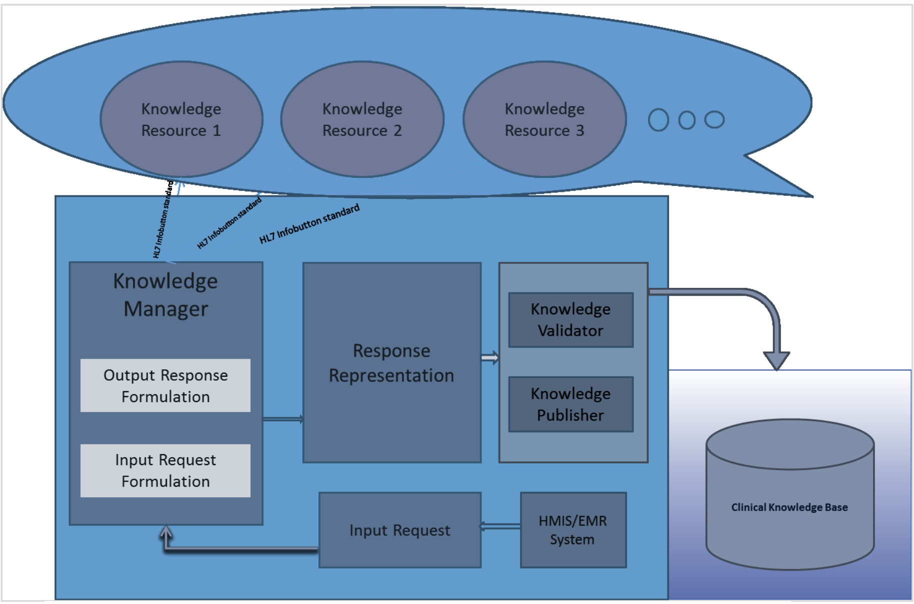

Fig. 1. System Architecture

4 Methodology

We selected HNC part of the cancer disease due to the fact of physicians' feedback and support availability. We analyzed the system and realized the need for CDSS based on mutual understanding with physicians. Based on our analysis we identified that our Smart CDSS system will function at different areas like diagnosis, staging and treatments after deployment. We conducted a small survey from **10** oncologists related to HNC cancer patients' diagnosis and treatment. The survey is performed in two formats; questionnaire and interview. Results of both the methods are combined, compiled and analyzed to prove the hypothesis of our research that online knowledge resources are playing major role in the process of HNC cancer patient care. When asked; how often you visit online knowledge resources at time of HNC patient diagnosis/treatment? 80% replied with **very frequently**. The term very frequently here means that they consult the online resources on frequent bases at different times during the course of patient care. Similarly when asked; how you approach to an online knowledge resource? 60% replied with **Google** and other 40% replied with directly typing **URL**. Based on these findings, we started for the next step as how to channelize the useful online resources into Smart CDSS context. We come up with several design options like; getting into a required resource by using simple HTML request or making context aware standard approach. The selected resources and the major purpose of these resources are shown in Table 1. We divide the resources into categories as oncologists are more interested to know about the nature of the resources. In some cases they want to refer to clinical trials to study the trials occurred on experimental bases. But sometimes, they are more interested to check the results of current published research in credible journals and books. However, in few cases, they are only interested to see the ultimate guidelines if available.

We tested the links to clinicaltrials.org, PubMed and NGC by taking input from within the HNC system for selected patients and verify the results from oncologists. Although the work was at elementary level but the feedback and comments of physicians were encouraging. A lot of time has been saved for them by providing them automatic and contextual querying facility to link to a particular resource from within the system rather to type all the entries manually to get the required information.

5 Conclusion

In light of recent development in healthcare domain, advanced computerized decision support systems became the core desire for physicians to connect to the very recent research development in the domain. Smart CDSS envisioned as an evidence-adaptive CDSS to assist oncologists in diagnosis and treatments of HNC patients. By adding this capability of meaningful integration with online knowledge resources, the system is expected to remain updated with practice changing research and will provide better results as compared to the conventional CDSSs. More significantly, it is envisioned to save the physicians' time making them able to treat more patients. The integration process of online knowledge resources has more space to improve especially in the area of accessing appropriate information and the process of transformation. Similarly, the semi-automatic process of rule generation can be made automatic to a maximum level by the use of Machine Learning techniques.

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Guardian: A Pervasive Environment to Monitor Elderly People in Medical Treatment at Home

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Abstract. The worldwide population has been aging at an accelerated rate. The main factor has been attributed to this process is the life expectancy. The old people are the most susceptible age rate to contract chronic diseases. In most cases they need to take a lot of medicines daily. Therefore it is really hard to handle with different medicine schedules, especially, when the elderly has been living alone. Therewith, we propose a pervasive health environment for medical treatment at home wherein the family and/or close friends are characterized as remotely caregivers.

Keywords: Monitoring, Medical Treatment, Elderly People, Pervasive System, Health Care, Computer Vision, NFC.

1 Introduction

The worldwide population has been aging at an accelerated rate. The main factor has been attributed to this process is the life expectancy. In 2010 the life expectancy in European Union – EU was 79.76 years old; in 2050 it will be more than 82 years old. The Germany has the biggest population in European Union and the third biggest elderly population in the world [1]. According to Münz [2] Europe's demographic situation is characterized by low fertility (about 1.42 children per mother) and an increasing life expectancy. That situation does not happen only in EU. Several countries also are sharing the same situation. Therefore, in the next years the number of elder people will overlap the number of children [3].

According to United Nations – UN in 2005 had about 90 million of elders in the world that lived alone (one in each seven elderly people of the worldwide population) [4]. Old people are more susceptive to contract chronic diseases. Therewith, elder people need to take a lot of medicines every day [5] [6] [7]. Due the quantity of medicine several elders have been committing negligence as forgetting to take the medicine and extra dose intake, the most fatal [7] [8]. Therefore, how may I have sure whether the patient who lives alone is following all the treatment recommendations?

Therefore, in this paper we propose a pervasive health infrastructure that will provide to the old people the monitoring of their medical treatment through a network high reliable. Family, relatives, close friends and even health professionals may monitor the patients through this infrastructure. This work is part of a PhD project in

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course. Thus we will expose the first results that it contemplates the technical part such as the environment architecture, Computer Vision – CV for face tracking on time to take the medicines and alert messages.

2 Related Works

According to Mark Weiser's definition [9], pervasive computing describes a kind of technology that which is essentially invisible to use. To bring computers to this point while retaining their power will require radically new kinds of computers of all sizes and shapes to be available to each person. Tanenbaum [10] completes, the distributed pervasive systems are characterized by their stability where the nodes are fixed and have a more or less permanent and high-quality connection to a network.

In the literature there are several works that have only focus on the monitoring of the elderly people at home [11] [12]. However, these works only have kept the focus under the old people welfare. Therewith, these systems have included fall detection and inactivity detection based in CV [13] [14] as the main points to monitor elderly people and to keep them safe.

In [13] a framework for assisting elders at home called ANGEHLA was proposed. That work has presented a solution based in a middleware that integrates a network of sensors and actuators such as: Cameras, Microphones, RFID, GPS, and Infrared etc. There is a central (Human Interaction) that monitors the elderly people and manages the members for aid situations. In emergency cases as fall, the elder will send a SOS message through a wearable device (RFID card) to the center. Then, the center gathers and sends members (unknown people are available) that are the closest to the elderly who needs help. In [14] an infrastructure without human interactions to create a safe living environment for elderly people named *Altcare* was proposed. The system was based in CV technology and in client-server architecture. The architecture presents 2 cameras that were placed at different points of the elder home, the first one was pointed to sofa and another one was pointed to bed, both located in the wall, to keep the privacy the elder's body was masked on video. In case of emergency the client side, located at elder home, will detect the emergency situation by itself and warns the server side.

3 Pervasive System to Monitor Medical Treatment

The pervasive system proposed in this paper has been called *The Guardian*. Their main goal is providing the monitoring of the elderly people who are in medical treatment at home. The *Guardian* gathers several devices such as: Camera, Smart TV, Mobile Phone, PDA, Tablet, Notebook and Sensors as RFID. As well as the interface for human-computer interactions, the *Guardian* web portal. It gathers all information about the monitoring. These devices and technologies are in use to ensure to the max that the patient will take their medicines correctly.

The Guardian acts as *Agent* that manages each specific step in the treatment, as well as caregivers and alerts; in summary, every message has been exchanged between patient and caregivers will be known by *Agent* that will compose an event history. This system can handle with the following processes: Keeping organized all medicines schedules; Warning both elderly and caregiver about the medicine schedule; Alerting elderly about no intake of medicine on the right time; Alerting caregivers about no intake of medicines on the right time; Tracking the elderly inside and outside home; and Warning the elderly and caregivers about special conditions.

The verification process of medicines schedules may be listed through web portal. Therewith, to access the portal it is necessary any device with a Browser, besides an Internet connection. The web portal was developed with the Java Server Faces – JSF technology and all data have been storing in the Database whose is managed by the PostgreSQL.

The alert process occurs in 3 cases: the elder and the caregivers will receive a message 15 minutes before taking the medicine, on the right time to take it and when the patient does not take it. When that situation happens the *Agent* sends alert messages by the different ways (SMS, Mail, Sonorous at the elder's house and Web Portal), it is trying to get some help answer from caregivers or a confirmation answer of the medicine intake from elder. Avoiding the alert situation by the no intake of medicine, the *Agent* monitors the elder through a set of devices. That set gathers a specific camera has been pointed to the remedies box that will recognize the elder's faces, as well as a RFID reader will recognize each RFID tag attached in each medicine box and will inform which medicine the elder is taking at the moment.

A specific way to check out whether the elder has been taking their medicines is recording a short video that starts 15 minutes before the remedy time and ends 15 minutes after it. Therewith, the caregivers may check whether the elder took or not the medicine. This process has been executed by a CV algorithm that tracks the human face and stores the video on server. The caregivers also may watch the video later. The tracking process has been performed inside home through the cameras and sensors scattered in different rooms; outside home this process has been performed through the mobile phone with GPS technology that sends the position information to the *Agent*.

3.1 Architecture

The architecture (see Fig. 1) describes how all components are linked and how they are communicating each other. The component 'Sever' gathers both Database System and Web System. The subsystem 'Web' provides an interface HTTPS so that the caregivers can access the monitoring system. The '*Agent*' component is linked directly with the 'server' component and your main goal is monitoring the medical treatment of the elderly people. The *Agent* gathers the others components to gain their main goal, components such as: the 'Vision' component that tracking the elder at home, the 'Sensor' component that is composed by RFID Tag reader (Mobile Phone) and RFID tags in the medicines boxes, the 'Alert' component that works based on the information that were extracted by the devices on this architecture, this component sends messages for different devices and paths; the 'Devices' component gathers a wide range of devices that offers an intuitive and accessible Web interface so that the elder can handle easier with the system. The caregiver also may access the system through several devices such as: Smart Phone, Tablet, Notebook etc.

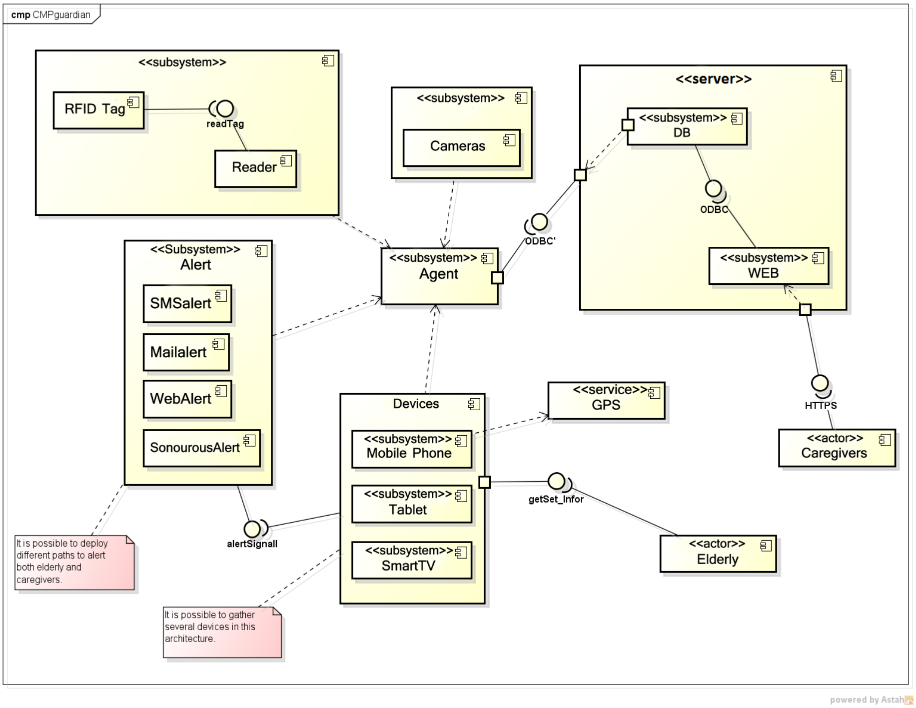

Fig. 1. Health Pervasive System Architecture

3.2 Experiments

All experiments were performed in experimental environment at *Fraunhofer-Institut für Software- und Systemtechnik ISST*. At this first moment we have not used old people in our experiments, because it is necessary we have our modules duly built and calibrated to expose them to a real health monitoring environment.

The CV module has used a webcam Logitech model C210 with 1.3MP (640x480) to monitor the process of putting the pill in the mouth (see Fig. 2a) as well as taking pictures and recording videos. We have used a Near Field Communication tag (NFC Tag) with 1024 Byte attached in the medicine box.

The tag gathers information about the elder and the medicine that will aid the elder in the intake confirmation process (see Fig. 2d). The tag directs the elder to an easy interface wherein the elder needs just press a button to confirm the medicine intake. The caregiver may access all data by an easy interface (See Fig. 2b) that permits monitoring all data from elderly people, alerts that were issued for elderly people, as well as updating them.

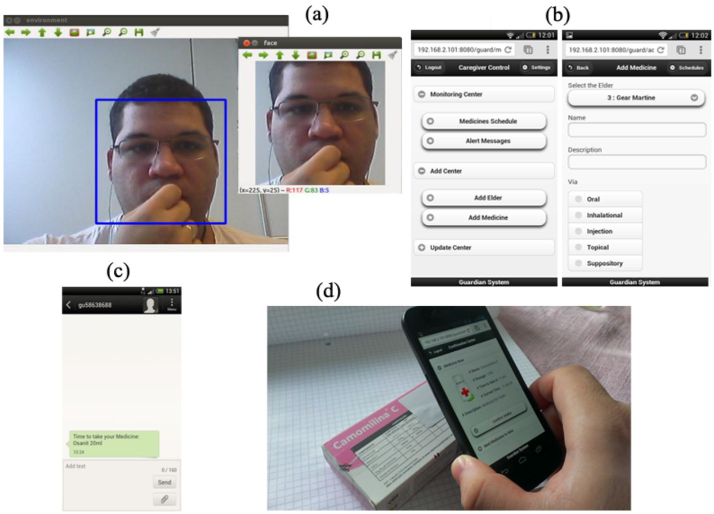

Fig. 2. (a) Putting the pill in the mouth; (b) Caregiver center; (c) SMS alert; (d) Using a NFC Tag in the medicine's box to get confirmation.

4 Result and Conclusion

The system has presented itself stable when it has been running. No crashes were noted in all experiments. It was noted that when the *Agent* module is running it raises the CPU usage in about 70%, even with the CPU has elevated it does not harmed the performance of any another process. In all experiments that we have performed in a laboratory environment, 100% of attempts to send the alert messages were performed successful. In the alert tests the SMS alert message (see Fig. 2c) has presented a greater delay than by email, but both SMS alert and email alert have arrived inbox of the destiny person. The SMS message has taken about 3 minutes more than the mail alert message to arrive on destination inbox. The delay has attributed to the Free SMS gateway service from United Kingdom (Textlocal Company) has used in the experiments. In all our experiments that have used the NFC it has showed us all information from elder that have needed to get the confirmation that the elder has taken the right medicine.

Therefore, the use of NFC tag has been presenting as easier way for medical intake confirmation than other methods that need insert some information to access the interface of confirmation as writing a message to someone or only tracking method using camera that it has not a good accuracy in this kind of operation. We have used a different approach to get the best accuracy at the current and not so well explored problem of medicines intake by the old people. This approach gathers a pervasive computing environment with several devices, non-paid caregivers that may aggregate a low cost to monitoring the old people, as well as intuitive interfaces that facilitate the understanding and the access by the old people. This project is part of a PhD project in course, therewith it has been in progress; therewith, for future works we will continue developing the modules, improve the alert times, as well as extending our health system to obtain more accuracy in the medical treatment at house.

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Challenges, Experiences and Lessons Learned from Deploying Patient Monitoring and Assistance System at Dementia Care Hostel

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Abstract. With growing aging population around the world, there is urgent need of effective solution to improve the quality of life of demented elderly. In order to provide real-time monitoring and timely assistance to elderly in their home settings, we designed and developed a system employing model-based scenario verification, sensing-assisted activity recognition and semantic service reasoning. In this paper, we present the results achieved and lessons learned from conducting clinical trials with our developed solution at a dementia hostel. From trial data analysis, we could determine good system performance but no concrete evidences obtained on how the daily care operations and quality can be improved. Especially, we gained technical experiences and learned usability issues from end-user perspectives that could lead to designing and developing better elderly care solutions in near future.

Keywords: Demented elderly, clinical trial, scenario verification, activity recognition, service reasoning.

1 Introduction

With growing aging population everywhere, some of the elderly suffer from one or more chronic health conditions like Dementia, Alzheimer's disease, etc [1]. Those old folks face problems with Activity of Daily Living (ADL) affecting their safety and independence resulting in reduced quality of life (QoL). These growing needs coupled with shortage in care giving resources demands technological solution to avert such global issues [2]. Minimally, around the clock monitoring and timely assistance to the elderly is desirable for maintaining their independence and desirable QoL. Especially, personal hygiene, tasks completion and safety are their major daily needs [3].

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Among various approaches [3], Ambient Assisted Living (AAL) is the most promising solution to observe activity and well-being of the elderly unobtrusively and continuously in daily settings [4]. A spectrum of AAL solutions ranging from safety monitoring [5] and cognitive assistance [6] to understanding behaviours of elderly [7] can be seen in various research projects. In contrast, our solution is aiming to empower demented elderly in staying independently through personalized just-in-time assistance leveraging microcontext sensing and adaptive multimodal user interaction design [8]. Service oriented approach [9] is adopted in implementing eAID to provide desirable timely assistance and adaptive monitoring services. In this paper, we present the design goals, trial deployment scenarios as well as experiences, lessons learned and challenges in order to design and develop such monitoring and assistive system to meet the needs of demented elderly.

2 eAID: Enabling Assistance and Independence to Dementia

The goal of eAID is to enable continuous monitoring and render assistance to elderly in their daily needs without affecting their independence. The first design consideration is to develop an integrated sensing and reminding solution with easy deployment, configurability and scalability. A set of ambient sensors with wireless connectivity enables distributed patient monitoring in different environment settings. Different user activities and ambient contexts can be inferred through atomic events detected from these multimodal sensors. By applying first order logic based rules engine, reliable microcontexts classification can be a viable option [8] enabling modification of business logic dynamically without disturbing running application.

The second design aspect is to design a reliable system seamless integration of sensing, intelligence and reminders into everyday clinical practice. Assistive service provisioning through semantic reasoning enables personalized and adaptive user interface design delivered to elderly and nurses. The recognized micro contexts from ambient sensors can not only identify abnormality of user but also serve as triggers to issue appropriate timely assistive services. This improves the safely and independence of the elderly without around the clock attendance from care givers.

The final design aspect is to provide independence to elderly while ensuring their safety and achieving high care standards. Generally, the exact behaviours from real subjects are usually difficult to simulate in lab settings in order to evaluate true effectiveness developed algorithms. So we adopted extensive model checking and verification using PAT [10] to evaluate complex operation and improve the reliability. From initial prototype, more than 90% of bugs hidden in complex logic such as deadlock, conflicts, duplications, etc can uncover to improve the business logic. This iterative process will not only improve contexts recognition performance but also reduce potential errors and timing conflicts during the actual deployment [8, 13].

As shown in Fig. 1, distinct types of devices are involved in eAID deployment at different physical locations such as patient's room, nurse station and cloud. A set of wireless ambient sensors are strategically deployed inside patient room together with gateway, wireless router and RFID reader system. The cloud server mainly acts as a central data logger and statistical activity profiles analyzer. Similarly, actuators for alerting and notification purposes are also configured to accept controls to activate or

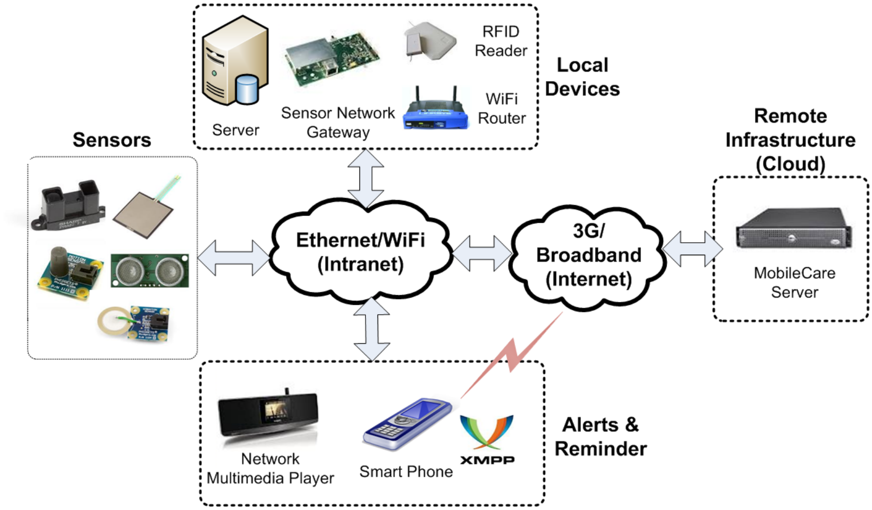

Fig. 1. eAID System: Distributed Architecture and Connectivity among sub-systems

deactivate reminders. Knowledge representation [11] and semantic reasoning services manage timely and appropriate delivery to targeted users. The developed semantic model (ontology) can infer desirable assistive service to activate or deactivate as well as the relevant devices for interaction depending on the recognized user contexts.

3 Trial Deployment and Validation at Dementia Hostel

After successfully testing with mockup subjects in the lab, ethical clearance was obtained from local Institutional Review Board for conducting clinical trials. Then, eAID was deployed at a dementia hostel to conduct clinical trials in three phases over nine months. The first two trial phases only consist of a single room with two demented elderly whereas the third phase includes three rooms with eight subjects. The numbers of care services in three phases varied from abnormality detection to support wandering detection, risks identification and hygiene advice. The following Fig. 2 demonstrates how sensors and devices were installed during clinical trials. The details of their setup and operation can be found in [12].

According to our trial protocols, care givers usually record hourly activities and states of elderly along with performing their care giving routine tasks. Different data types including raw sensor readings, activities/events, services activated, etc were recorded along with hourly recorded manual data sheets by nurses. They also checked patient coarse-grained activities such as locations, shower status, tap usage, any abnormality upon receiving notifications from our system. These manual observations will be used as ground truths to validate the effectiveness of deployed services and functionality. During these trials, system uptime of 80%, 90% and 70% achieved respectively in three phases due to various deployment and usability issues [12]. Among the collected data, we only had complete data sets of about 68%, 83% and 65% in each trial phase in order to further conduct performance evaluation. The low

Fig. 2. Deployment of sensors and devices in nursing home

percentages of complete data sets were mainly due to the missing manual records, intermittent network connectivity issues and hardware robustness problems in real care settings [12].

4 Usability Evaluation and Performance Analysis

Comparing with manual activity logging, average sensitivity and specificity of 99% and 95% respectively was achieved using inference engine outputs. This can be proven in comparing the sensing outputs with manual log data as there is high correlation between them. We applied active learning approach [15] due to the difficulty in getting highly accurate labeled data during deployment. From recognised activity densities over the time, differences among patients' relative activity in different locations can easily be identified. This can potentially be used to determine either medical or behavioral problems associated to individual subjects; enabling to provide timely interventions.

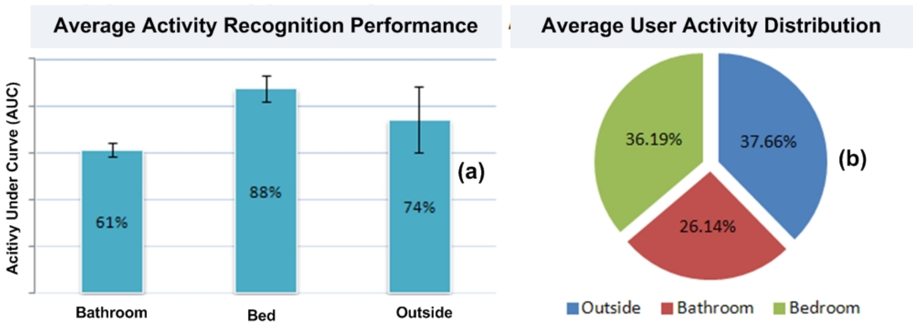

Fig. 3. Clinical Trial Analysis and Results (a) Average activity recognition performance (b) Average activity records from manual log sheet

Overall, we achieved good average recognition and prediction performance of coarse-grained user's activities relative to bathroom, out of bedroom, and bedroom activities as shown in Fig. 3(a). From collected location statistics, time spent at different locations by subjects can easily be identified as shown in Fig. 3(b). This time-based user profile along with recognized activities can be used in adaptive service provisioning, providing assistive services at appropriate places and modes of delivery [12].

4.1 Limitations, Lessons Learned and Challenges

During design phase, issues of missing critical data and redundant events exchanges among system components were identified through model checking [10]. Although eAID can be successfully run during the trial, we experienced various hardware and software issues while operating under 24/7 continuous manner. The frequent failures of hardware devices, battery failure and wireless connectivity losses affect not only real-time performance but also offline data analysis. As a result, the delivery of assistive services achieved 70% success rate [12]. So the reminders could not be issued directly to the elderly as this may cause discomfort for testing with real subjects. The detection of binary primitives from sensors is not enough to support observation of fine-granularity behaviors and social interactions [14] essential to the well-being of the elderly. Also, evaluation on effectiveness of providing assistance through in-situ reminders for sustaining elderly independence cannot be quantified and proven clinically [13]. Lack of centralized management of system services as well as real-time monitoring of data logging incurs loss of critical events.

We witnessed advantages of model checking techniques on identifying unexpected bugs and designing robust intelligent logic. Moreover, it is interesting to apply scenario verification directly with actual collected information from trial to build business logic catered to salient user and environment states. The main challenges for such verification are inability to incorporate every possible real-world scenarios and difficulties faced with typical state space explosion problems [10]. Although the concept of UI plasticity on reminders is useful to attract attentions from elderly, the deployment of such systems faced usability challenges at actual environment. So, it is important to design and develop eAID to blend into daily essential care giving practices; thus motivating nurses using assistive technologies to improve quality of care and QoL of demented elderly.

5 Conclusion

The outcomes from clinical trials demonstrate eAID can be a feasible monitoring and assistance solution to demented elderly although there are still several technical and clinical issues to be resolved. The integration of scenario verification, wireless sensing, activity inference and semantic reasoning with service oriented approach yields high applicability and scalable deployment. By conducting technical validation and clinical performance analysis through trials at dementia hostel, several usability implications, operational difficulties and performance issues can be identified. Moreover, serious limitations and challenges are also figured out to be resolved in order to support effective and efficient monitoring and assistive solutions in dementia care. We are hoping that experiences and lessons learned from current works will be beneficial to the research community in designing and developing viable solutions to the daily care giving needs of the demented elderly.

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Design and Evaluation of a Telepresence Robot for Interpersonal Communication with Older Adults

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Abstract. Aging is associated with an increased risk of isolation. Interpersonal communication with family members, friends, and caregivers is crucial to healthy aging. This paper presents a telepresence robot "$TRiC_{mini}^{+}$" which can be used as an agent of the children or caregivers in an older adult's home environment, to duplicate three dimensional face-to-face interpersonal communications. $TRiC_{mini}^{+}$ can be separated into the "brain (a tablet)" and the "body (the robotic vehicle)". With this structure, the robot control software is an App which can be downloaded, maintained and updated easily through the Internet. $TRiC_{mini}^{+}$ is integrated with social network services such as Google Talk and *Facebook*, to provide a wide range of communication and information sharing easily and conveniently. The effectiveness of using $TRiC_{mini}^{+}$ in communication is evaluated. The results showed that the telepresence performance in both verbal and nonverbal ways is better than the traditional telepresence robot without nonverbal way of interpersonal communication.

Keywords: Interpersonal communication, telepresence robot, nonverbal communication.

1 Introduction

Aging is associated with an increased risk of isolation. Interpersonal communication with family members, friends, and caregivers is crucial to healthy aging. With the help of information and communication technologies, the older adults may expect more on communicating with their children and caregivers, as well as sharing life experiences and feelings, in addition to transmitting vital sign monitoring data for healthcare purposes.

Communication tools such as mobile phones and video conferencing systems did facilitate remote verbal communication. Nevertheless, nonverbal communication, such as facial expression, body language and haptics, is more powerful and efficient in conveying ideas, thoughts, and emotions. Mehrabian and Ferris reported that in face-to-face communication, clues from spoken words, voice tone, and facial expression contribute 7%, 38%, and 55% respectively to the total comprehension [1].

In 1980, the term "telepresence" was coined by Marvin Minsky, which means that an operator receives sufficient information about the teleoperator and task environment, displayed in a sufficiently natural way, that the operator feels physically

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present at the remote site [2]. Robotic telepresence is a newer variant that proposes to integrate ICT onto robotic vehicle and enable to operate in a remote location. Derived from the idea of a mobile robot with videophone embedded, Michaud et al. [3] presented a teleoperated robot called Telerobot with wheels. Later on, the commercial product of telepresence robot with mobility such as VGo [4] was launched into the market. Telepresence is provided for both ends with auditory and visual information. But the feeling of "staying with the person at the same place" is however limited due to the machine-like appearance.

"TRIC", a Telepresence Robot for Interpersonal Communication, was developed for the daily use of older adults in the home environment [5]. "$\text{TRiC}_{\text{mini}}^{+}$" (Figure 1) presented in this paper is a more advanced version used as an agent of the remote user in a local user's home environment, to duplicate three dimensional face-to-face communication. By providing both verbal and nonverbal elements of interpersonal communication, the robot can better serve as the avatar of the children or family members for expressing their care to the older adults at home.

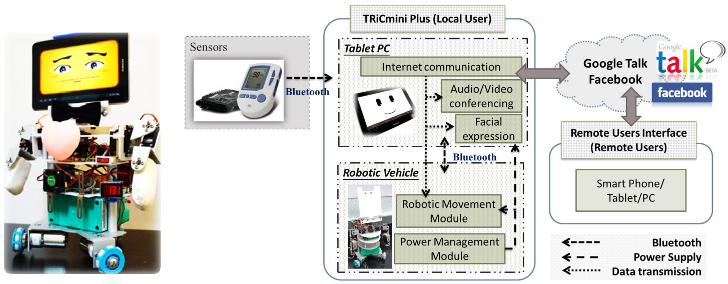


Fig. 1. Prototype of $\text{TRiC}_{\text{mini}}^{+}$ and its system structure

This paper presents the design and evaluation of $\text{TRiC}_{\text{mini}}^{+}$. Section 2 introduces the system structure and functions of $\text{TRiC}_{\text{mini}}^{+}$. Section 3 describes the evaluation procedure and results. Finally, conclusions and future works are drawn in Section 4.

2 Design of $\text{TRiC}_{\text{mini}}^{+}$

$\text{TRiC}_{\text{mini}}^{+}$ has an innovative system structure which separates the "brain (a tablet)" and the "body (the robotic vehicle)". The remote user manipulates $\text{TRiC}_{\text{mini}}^{+}$ through the user interface on a tablet/PC to freely move it around and communicate with the local user, who is staying with the robot in the home environment. The system structure and user scenarios are presented in this section.

2.1 System Structure of $\text{TRiC}_{\text{mini}}^{+}$

According to Figure 1, tablet of $\text{TRiC}_{\text{mini}}^{+}$ is used to receive commands from the remote site via the Internet, perform audio/video conferencing, as well as the "face" of $\text{TRiC}_{\text{mini}}^{+}$. The tablet can also be easily removed from the robotic vehicle for personal use. The robot control software is an android App on the tablet. The robotic vehicle is equipped with a power management module and a robotic movement module to provide omnidirectional mobility and body motion. The robot movement commands received by the tablet are relayed to the robotic vehicle via Bluetooth.

In audio/video conferencing, the neck design of the $TRiC_{mini}^{+}$ allows the camera on the tablet to be controlled by the remote user to trace the local user. For more engaged user experiences, $TRiC_{mini}^{+}$ is given the ability to produce multiple whole-body emotions by combining facial expressions and whole-body motions. Facial expressions are built as animations displayed on the tablet which allows the remote user to switch among the 6 universal facial expressions. In addition, the servo motors in the movement module help to create $TRiC_{mini}^{+}$'s arm gestures.

$TRiC_{mini}^{+}$ is connected to the Internet for data/command transmission via 3G/wifi wireless communication of the tablet. Referring to Figure 1, $TRiC_{mini}^{+}$ is tele-operated by the remote user via the Internet. Two-way audio and video communication is achieved by social network messenger, such as Google Talk or Skype. Robotic movement commands are also sent through Google Talk as text messages. With this structure, communication and tele-operation can be achieved without knowing the IP address of the tablet. Commands from the remote user are transmitted to the tablet to trigger facial expression and audio/video conferencing function, or are relayed to the movement module of the robotic vehicle via Bluetooth to control robot movement.

The robotic vehicle contains a power management module and a movement module. The core of the movement module in the robotic vehicle is an Arduino Mega 2560 microprocessor equipped with Bluetooth shield for data transmission between the tablet and the robotic vehicle. There are 3 sets of omnidirectional wheels and motors controlled by a motor controller. Once a command from the remote user is received by the tablet and relayed to the movement module, the controller will run the algorithm to determine how the motors will trigger the omnidirectional wheels. In this way, $TRiC_{mini}^{+}$ can freely move around with the speed of about 12 cm/s. The 3 ultrasonic sensors will help to detect the objects in the surrounding environment. Besides, the power module includes a 12V LiFePO4 battery and a power management circuit board. An LED light on the power management circuit board will warn the local user about the electricity consumption by flashing.

2.2 User Scenarios

From the interaction point of view, there are two different kinds of user scenarios, the communication mode and the home telehealth mode. The communication mode is used while there is a remote user logging in to communicate with the local user (the older adult). In addition, the personal health management for older adults with chronic disease can be achieved in their home environment with the home telehealth mode.

At the local site, older adults can use the video and audio communication function to do the verbal communication with their families/caregivers through $TRiC_{mini}^{+}$, which is similar to using general video conferencing services. Remote users can tele-operate the robot and add in the nonverbal communication elements by choosing the facial expressions and robotic movements on the user interface. As discussed earlier, $TRiC_{mini}^{+}$ is given the ability to present facial expressions and whole-body motions among the 6 universal facial expressions.

A home telehealth App, “Care Delivery Frame (CDF)”, is also implemented on the tablet of $TRiC_{mini}^{+}$ to achieve home telehealth function. CDF is an App designed for older adults who are not familiar with the operation of computers and Internet as a channel for transmitting vital sign measurement data [6]. Besides, CDF is also integrated with social network service such as *Facebook* in order to provide a wide range of information sharing easily and conveniently. Actually CDF can be a “friend” to the children/family members on *Facebook*. Vital sign data monitoring, remote photo sharing and caring messages can all be done from *Facebook* by the remote user.

3 Performance of Telepresence in the Communication Mode

In this research, the telepresence performance of $TRiC_{mini}^{+}$ in remote communication mode is of great concern and interest. Therefore, 20 subjects (12 males, 8 females) with the age ranging from 18 to 25 were recruited to join the prototype evaluation. Most of the subjects (15) did not have any experience about interaction with robot. Each subject was asked to serve as the local user and have a 5-minute interaction with the remote user (a staff) though $TRiC_{mini}^{+}$. The responses were collected from the questionnaire based on the Temple Presence Inventory (TPI) [7]. For all questions, a 7-point Likert scale was used where “1 = Not at all” and “7 = To a very high degree”. Besides, the eye-tracking system was used to analyze the behavior of the local user.

In Table 1, the first column shows the average score of each TPI index in communication mode of $TRiC_{mini}^{+}$. Basically, most of the scores are among the middle point 4 except the spatial presence which means the performance of telepresence in the communication mode of $TRiC_{mini}^{+}$ is acceptable. The low score of spatial presence may be caused by the face size of $TRiC_{mini}^{+}$. The 7 inches tablet in communication mode of $TRiC_{mini}^{+}$ containing only the face of the remote user without more information about the remote environment. The best performance of telepresence is found in social richness, with the score of 6.00. It may be due to the multimodal interpersonal communication of $TRiC_{mini}^{+}$, which provided both verbal and nonverbal aspect of communication.

The second column of Table 1 shows the average scores in TPI indices of another telepresece robot – Giraff [8]. Giraff is a typical telepresence robot with a screen to perform the video conferencing function and a robotic vehicle to support its mobility. Table 1 shows the telepresence performance either in verbal way (Giraff) or in both verbal and nonverbal ways ($TRiC_{mini}^{+}$) of interpersonal communication. According to Table 1, the score of $TRiC_{mini}^{+}$ is higher than the Giraff in each TPI index. It is expected that $TRiC_{mini}^{+}$ has better performance than Giraff in telepresence because of combining video conferencing with robotic facial expressions and whole body movements. Nonverbal aspect of communication seems to be able to improve the telepresence performance of a telepresence robot.

In addition to quantitative information, the qualitative data was also collected in this study. In order to analyze the user behavior while interacting with $TRiC_{mini}^{+}$, we recorded not only the track of the eye in communication mode of $TRiC_{mini}^{+}$ but also the communication with real persons. As shown in Table 2, in a 5-minute communication with a real person, 41% of the time is spent on looking at the human face, and 51% of the time is spent on looking at other places. It is because that the local user often looked on the places where the dialoguer (who was communicating with the local user) points to. However, the eye tracking behavior of the local user while using $TRiC_{mini}^{+}$ is significantly different. The local user spent about 83% of the time looking at the tablet, i.e. $TRiC_{mini}^{+}$'s face, which indicates that the local user took $TRiC_{mini}^{+}$ seriously as a dialoguer. On the other hand, this also indicates that there is still a gap between the communication through $TRiC_{mini}^{+}$ and the real interpersonal communication. The body movements of $TRiC_{mini}^{+}$ may not provide sufficient stimulation to attract the local user's attention. Currently the body movements of $TRiC_{mini}^{+}$ are mostly for expressing emotions, in which natural humanoid movements are critical. How to catch the motion and tempo of real human movements is being studied. Functional gestures (e.g. waving, pointing, etc.) will also be added.

Table 1. The average score of TPI indices in two communication methods

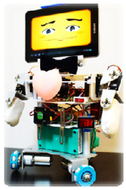
TPI index	*$TRiC_{mini}^{+}$* 	*Giraff* 
Spatial presence	3.72	3.05
Social presence – Parasocial interaction	5.24	N/A
Social presence – Passive interpersonal	5.69	4.98
Social presence – Active interpersonal	4.68	N/A
Engagement (mental immersion)	4.69	4.99
Social richness	6.00	4.64
Perceptual realism	5.57	N/A

Table 2. The percentage in average of eye gaze in the two communication scenarios

Index	Real human	$TRiC_{mini}^{+}$	P value
Looking at the face (Tablet)	41.09	82.98	**0.00***
Looking at other places	51.13	12.84	**0.00***
Looking at the feet	0.00	0.45	**0.04***
Looking at the hands	6.71	1.01	**0.01***
Looking at the trunk	1.06	2.78	0.18

*Significant difference is found between the two scenarios.

4 Conclusions and Future Works

Care through communication from the family members or caregivers may be what the older adults really expect for. $TRiC_{mini}^{+}$ has been developed to provide both verbal and nonverbal aspects of interpersonal communications. Three-dimensional face-to-face interaction is duplicated with two-way audio communication to create the feeling of "staying with the person at the same place". By integrating with the home telehealth App CDF, $TRiC_{mini}^{+}$ demonstrates the extensive capability to provide different levels of "care delivery" to older adults through robotic movement, vital sign monitoring, and other forms of communication, even if no one logins to control $TRiC_{mini}^+$ from the remote site.

$TRiC_{mini}^+$ delivers an innovative system infrastructure of a telepresence robot by using the tablet as the control center. The robot control functions are developed as an independent App to be used on the tablet, which can be downloaded, maintained and updated easily through the Internet. Besides, according to the evaluation results, the telepresence performance (in both the verbal and nonverbal ways) of $TRiC_{mini}^+$ is proved to be more acceptable than the traditional telepresence robot (with only the verbal way) provided by the users. The nonverbal way of interaction did improve the telepresence performance of the robot for interpersonal communication purpose. However, there is still room for improvement in the nonverbal features such as the animation of the facial expressions and the humanoid moving tempo of the robotic movements.

In addition, more advanced functions such as automatic charging system, indoor navigation, are being investigated. The goal is to make $TRiC_{mini}^+$ a practical robot that can be easily used in the home environment. Finally, the effectiveness of interaction in two modes will be evaluated in real application scenarios (senior users in their own home environment) to confirm whether the "care delivery" provided by $TRiC_{mini}^+$ meets the expectation of older adults.

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Tactile Recognition in PetH Robot for Wellbeing of the Elderly

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Abstract. This paper presents a tactile recognition system in the PetH robot. The presented PetH robot can be expected to improve wellbeing of the elderly in the future. We first describe the system overview of PetH robot. The next focus is on proposing the real-time tactile recognition system, which includes selection of touch pattern, extraction of features, building the memory and touch recognition based on Bayes classifier. The experiment results demonstrate that the recognition system is robust and highly accurate.

1 Introduction

The study in [10] shows that world population are aging rapidly and that from 2000 the proportion of people over 60 will double its size in 50 years. Robots have been expected to assist people in having a healthy and safe life at home. Nowadays, there are many different types of healthcare robots such as surgical robots [4], rehabilitation robots [7] and some other social robots to help people [2] and [3]. In [1], it points that developing healthcare robots can be an aid in taking care of the elderly. However, it is very important to understand which kind of robots can be acceptable and appealing to the old people. The acceptance by old people will decide if the proposed robots are successful.

Recently, a new investigation based on home studies finds that social robots can reduce loneliness and improve psychological wellbeing among the elderly [8]. From the user study in [8], most of the participants were unsatisfied with the current social robots. Furthermore, the existing social robot cannot provide mental challenges and improve social interaction although a few social robots have been built to provide companionship for the elderly such as Paro in [11], [9] and Aibo in [1]. This investigation motivates us to design a new social robot of more acceptance to improve wellbeing of the elderly. Affective touch is taken as a important element of early human development, social bonding and emotional support [12]. In this work, we will focus on detecting human's emotion from tactile sensors in human-robot interaction. We first show a system overview for the proposed PetH robot in Section 2, and the description of tactile recognition

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system based on short-term memory is given in Section 3. Furthermore, simulation results are demonstrated in Section 4. Section 5 conclude the work and list the suggestions for our future work.

2 System Overview

In the home studies aimed to understand if and how social robots can help improve the wellbeing of the elderly in [8], all participants expected the robot to have the responses to voice and touch. Some of participants suggested that the robot should respond to the user and the environment. This means that the robot should have the ability to recognize the human's emotions or mood and give its own response emotion accordingly. This provided a very good and important information for our researchers in this area. In our work, we expect to propose the emotion recognition system for our designed robot called PetH shown in Fig.1. PetH is a current robotic platform aimed to be capable of performing pet therapy and recognizing verbal and non-verbal emotions for the elderly. In this paper, the focus will be on the emotion recognition through tactile sensors.

Fig. 1. Prototype of PetH robot

The tactile sensors used are force sensitive resistor SEN-09375. Its resistance can vary from more than $1k\Omega$ when no pressure applied to less than $1k\Omega$. To mount the sensors on the robot head, which is produced by rapid prototype, a layer of foam is attached to the robot head first, so that sensors can be mounted firmly shown in Fig.2. Double-sided adhesive tape is used to mount the sensors. Only half of the sensitive part is stick to the adhesive tape for the purpose of reducing data noise. Three sensors are arranged linearly and another layer of foam is used to cover them to represent the skin and fur shown in Fig.2.

Real-time recognition means that the system should recognize the touch pattern in each specific time when a human touch the robot's head. The architecture of online touch recognition system includes: a preprocessor to filter the raw data; extracting the features and a touch recognition by integrating the memory information and Bayes classifier.

Fig. 2. Overview of a tactile sensors and interface in the Robot's head

3 Tactile Recognition System

3.1 Selection of Touch Pattern

The possible touch patterns are summarized into the Table 1 in [6]. According to the features such as the contact time, the incidence of a repeat, the force and so on, these patterns can be categorized into the short time and long time. The patterns in the short time include no repeat such as hit, jab, smite and punch and repeat such as stroke and pat. According to the definition of hit, pat and stroke, we summarize the feature states of three touch motions in Table 1.

Table 1. Features of Three Touch Patterns

	Force	Contact time	Repeat	Contact area change
Hit	High force	Short	No	No
Pat	Low force	Short	Yes	Yes
Stroke	Low force	Long	Yes	Yes

3.2 Extraction of Features

Actually there are no standard features in the tactile recognition. In [5], they provided eleven parameters such as maximum force, time to reach the maximum force, contact duration as features. In this paper, we use the two methods to extract the features. The first way is to choose the four parameters listed in Table 1 : force magnitude, contact duration including the time and area and cycles of repetition as touch features. In Fourier spectrum, for the gentle touch such as pat and stroke, there would be higher amplitudes for lower frequencies, while for strong touch such as hit, there would be higher amplitudes for higher frequencies. This implies that there are different Fourier spectrum for different touch patterns. Thus, the other method is to choose the Fourier spectrum to express the differences of different touch patterns.

3.3 Building the Cognitive Memory

The process of building memory is to decide the attractors for the different gesture motions. According to the features in the above subsection, assume that $F(p(i), c(j))$ represents k different touch motions for the $j-$th class pattern and $i-$th person. Self-organizing map (SOM) is used to produce a two-dimensional state to find the center of this feature matrix. By observing, we find that the features for each type of touch motions always cluster into a small region. Thus we choose the centers of $[F(p(1), c(1)) \quad F(p(2), c(1)) \quad F(p(3), c(1))]$ as the first attractor denoted $C(1)$. Similarly, $C(i), i = 2, 3$ is denoted as the attractor for second and third touch types.

3.4 Touch Recognition

Naive Bayes classifier is applied to make the classification. This method only requires a small amount of training data to estimate the parameters. The advantage of this method brings a great convenience for building the robot's memory.

If F is m-dimensional vector $f_1, f_2, \cdots, f_m$ representing m measured values of m features, the classifier will predict F belongs to the class with the highest posteriori probability, conditioned on F. F is predicted to belong to the class $C(i)$ in the robot's memory if and only if $P(C(i)|F) > P(C(j)|F)$ for $1 \leq j \leq n$ and $j \neq i$, where n is the total number of touch types. From Bayes theorem, the classification by comparing the probability of $P(C(i)|F)$ can be changed into measuring the probability of $P(F|C(i))$ by $P(F|C(i)) = \Pi_{k=1}^{m} P(f_k|C(i))$. For the feature k, if it is continuous-valued and assumed that Gaussian distribution is with a mean μ_k and the standard deviation σ_i, $P(f_k|C(i)) = \frac{1}{\sqrt{2\pi\sigma_k^2}} \exp^{-\frac{(x-\mu_k)^2}{2\sigma_k^2}}$.

4 Experiment

In this section, we will show touch recognition results for different users. The first step is to recognize each touch period. The PC will keep receiving input from the three tactile sensors every 35 ms. Each touch period starts when there is a change of magnitude greater than the threshold (20 is chosen for our experiment) and ends when there is no change for about 1s. For the first extracting methods described in Section 3.2, the maximum value of the data will correspond to the force magnitude. The number of values which are greater than their neighboring values (i.e. peak values) corresponds to the cycles of repetition. To differentiate touch duration, the standard deviation of the nearest three normalized values at each peak is investigated. If the touch is of short duration, the values will change rapidly. In contrast, if the touch has a longer duration, the values will change more moderately. Hence, if the standard deviation is big, it can be inferred that the touch duration is short, and vice versa.

Before making the classification, the mean and standard deviation of the features for each touch pattern should be calculated. Therefore, each touch pattern

Table 2. Features of Three Touch Patterns: 'M' is short for "Mean" and S represents "Standard deviation"

	Force magnitude		Contact time	Number of peaks		Standard deviation at peak	
	M	S		M	S	M	S
Hit	205	22.48	Short	1.0	0.0	0.5432	0.0374
Pat	137	22.93	Short	3.9	1.5	0.5583	0.0258
Stroke	150	14.2	Long	2.3	1.0	0.0458	0.0314

Table 3. Recognition results for the proposed algorithm

		Predicted		
		Hit	Pat	Stroke
True	150	48	51	51
Hit	50	48	1	1
Pat	50	-	50	-
Stroke	50	-	-	50

was made 10 times for five different people consecutively and carefully at the training stage. The mean and standard deviation of the features for each touch pattern are given in Table 2. The memory of the robot can be built from the features in this table.

In order to online test the performance of the proposed system, users are required to do different three touch motions in a random order. Table 3 shows the recognition accuracy for a user based on Bayes classifier. Overall, the proposed approach can classify 98.67% of the examples correctly. Out of 150 testing examples, two misclassification errors occurred for 'Hit' pattern. By observing the raw data of the two misclassifications, one misclassification happened because the human did not touch the sensitive areas. And this brought the failure to direct contact with sensors. Moreover, we attribute the other failure to the longer contact time. Since the touch duration should be very short from the definition of 'Hit', we have put the short contact time as one of features in the memory. Furthermore, we also test the system with five different users. The results also show the system is robust with an average accuracy 95%.

5 Conclusion

In order to achieve a natural human-robot interaction for the wellbeing of the elderly, in this paper a framework with emotion recognition was presented for the PetH robot. The PetH robot could detect and understand the human's emotion through the tactile information. We focused on proposing a real-time touch recognition system by incorporating the memory and probability method. Through the proposed recognition system, three touch patterns, representing different emotions, 'Hit', 'Pat' and 'Stroke' could be easily recognized. After testing with different users, the recognition system was verified to be robust and accurate, with an accuracy rate of about 95%. In our future work, we will study more touch patterns to represent more human's emotions. Furthermore, the robots reaction will also be considered.

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Supporting Care Networks Using the "Daily Care Journal"

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Abstract. The "Daily Care Journal" is a platform that aims at allowing a care taker to stay at home as long as possible. This should be achieved by providing means to build and coordinate care networks between professional and informal care givers, including the care taker. It allows the informal care to document their measures and observations. Additionally it provides care related information that might strengthen the informal care. Synchronized with a professional care information system it allows both, the professional and informal care givers, to exchange care related information with each other and to coordinate their activities. One key technology is the usage of a tablet pc that allows the care taker to document and to actively build and take part of his care network. The "Daily Care Journal" has been developed and evaluated together with a professional care provider.

Keywords: Ambient Assisted Living, Smart Home, Mobile Computing, Care Network.

1 Introduction

The goal of 'Ambient Assisted Living' (AAL) is to connect new technologies and the social environment in order to improve people's living quality in all life stages [1]. AAL technology can be used for example to support an elderly person to live as long as possible in his familiar home environment. Such technology can be found in home automation, ubiquitous computing or in robotics. Based on such technology AAL services can be offered which are integrated into the daily life of the user and provide intelligent support. Examples for such AAL services can be found in [2].

The aim of the project 'Daily Care Journal' (DCJ)[1] [3] is to support the coordination of care activities by relatives, friends, neighbors and professional care providers within the care taker's home environment by providing a care network. Part of the project is the conception, development and piloting of the DCJ platform, which

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can be used to build such a care network. The platform includes services, which allow the participants of the care network, including the care taker, to document and exchange information on the actual well-being and problems. Thereby the different information of the participants can be collected centrally and be used for improving the coordination of care processes within the network. For example relevant information documented by the neighbor can be provided as part of the tour information of the care giver. Additionally the patient can be included intensively into the care process and be motivated to participate actively.

The DCJ service can be used by the care taker within his home environment via a tablet PC. Additionally the patient will be assisted in the documentation of his situation and the performed care actions by selected sensors. The caregiving relatives or friends can use the DCJ service via the internet. For the professional care provider the DCJ service is integrated into a professional care management system. We have developed and tested the DCJ platform and services together with a professional care giver.

In the following chapter we give an overview on the state of the art. Then we describe the architecture of the DCJ platform and the functionality of selected services. In chapter 5 we describe some results of the trial. Finally we give an outlook to planned future work.

2 State of the Art

There are a number of research projects focusing on the development of AAL technologies and frameworks for the implementation of AAL services. For example in [4] sensors for reliable fall detection are explored, which also ensure privacy and user acceptance. Sensors and actuators can be inter-connected using existing approaches of home automation. Technologies from ubiquitous computing enable an intelligent and natural integration of these technologies into the natural environment of the user [5]. One aspect of ubiquitous computing is the context-awareness of services [6]. Within EU and further national research programs a number of frameworks have been developed, which can be used for the implementation of AAL services. An example is the middleware platform, which is being realized within the "PERSONA"-project [7]. Furthermore many social projects have been promoted, which deal with social structures, residential quarter neighborhoods and care structures. For example in the project "Pflegebegleiter" [8] education concepts are being developed, which support the caregiving relatives in the accomplishment of practical and daily life activities. The DCJ project supplements such concepts in the aspect of building and supporting care networks, linking the informal with the professional care, providing AAL technologies that go beyond the state of the art.

3 DCJ Platform

The DCJ platform allows the informal care to document the care measures and observations of a care taker. It provides a secured database with personal care related information and information on the care taker's care network, e.g. family, friends, neighbours or other professional service providers. It is hosted within a secured environment, e.g. at the professional care giver.

The care taker has the control regarding the information that is provided between the participants of his care network. He can add participants to his care network and provide them with adequate access rights. The platform provides access control and functions for the management of the care network, the coordination of appointments and mail-like communication between the different participants. Sensors within the care taker's home environment can be registered to the platform, which derive certain care related situations. The platform will then select the appropriate DCJ services and provide them proactively the care taker, e.g. provide the drink protocol, when a drinking situation has been detected.

The participants can access the DCJ platform and available DCJ services using a tablet PC or a web browser. A specific DCJ app for tablet PCs has been implemented, whose user interface is adapted towards the specific needs of Elderly. For example the interaction concept is limited to simple point and activate, and the size of the font and buttons is enlarged.

The DCJ platform provides interfaces that allow synchronizing and exchanging information with a professional care management system. Using these interfaces the professional care has access to documentations and information that is provided by the informal care and vice versa. Also scheduled dates are synchronized between the systems. That way the care taker will be reminded and can see when the professional care giver will come.

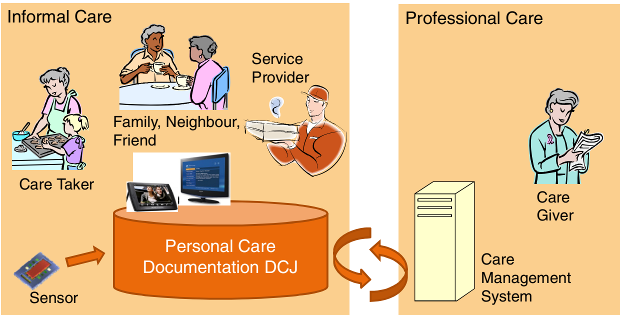

Fig. 1. Architecture of the Daily Care Journal

4 4DCJ Services

Different care related services are provided to the informal care. These services enable the informal care and the care taker to

- document care measurements performed,
- document observations regarding problems and the health status,
- access care related information that support and strengthen the informal care, e.g. tutorials or information on existing auxiliary means,
- get informed about local service providers and to make use of the service offer, e.g. meals on wheels.

We have implemented 24 services that allow the documentation of care measures and health or care related problems in the following categories:

- Communication: A 'contact protocol' allows documenting the contacts that the care taker had with participants of his care network. A 'hearing aid protocol' allows documenting the measurements and problems regarding the hearing aid. 3 additional services allow to document problems: 'Hearing deficits', 'Speech deficits', 'Sight deficits'.
- Motion: An 'activity protocol' allows documenting the activities that the care taker has done, e.g. going out for a walk. Using the 'fall protocol' a fall and its circumstances and consequences can be documented.
- Vital parameters: 6 services that cover different vital parameters: 'Blood pressure', 'Blood sugar', 'Pulse', 'Weight', 'Body temperature' and 'Felt temperature'.
- Hygiene: 2 services allow to document personal hygiene measurements and problems.
- Excretion: There are 4 services in this category. One protocol allows documenting a stoma pouch replacement. The excretion protocol documents daily excretions. 2 specialized protocols are provided to document problems regarding defecation and urine.
- Nutrition: 2 protocols allow documenting drinking and eating activities. These services offer reminder functionalities. Additionally a 'nutrition deficit' protocol allows documenting different nutrition related problems.
- A pain protocol is provided where the care taker can document the location, type and strength of pain and the intake of pain-killing drugs.

These services can be selected and used by the care taker or participants of his care network depending on the defined access rights. In the following figure some screenshots of these services are presented.

Fig. 2. Screenshots of the DCJ service 'Blood pressure'

5 Evaluation

Within a period of six months we have evaluated the concept of care networks and the DCJ platform together with a professional care provider. The participants included six care takers and 12 professional care givers. The care takers were in the age between 44 and 89. None of them needed intensive care. They were able to live independently in their own apartment and needed minor support by professional care givers. Half of them had computer experience before, but only one had experiences with a tablet PC.

The care takers documented different care related aspects using the DCJ services. The professional care givers were then able to access this documentation using the care management system.

At the end of the evaluation period the participants were asked about the acceptance and the relevance of the different DCJ services, using a questionnaire. The feedback was then statistically evaluated. In the following we present some selected results. We show the result of the answers grouped into the evaluation of the first quartile (best 25%), the median, the third quartile (worst 25%), and the arithmetic mean. We also show the range of the answers.

Figure 3 shows the answers of the professional care givers regarding the importance of the cooperation of professional and informal care and how DCJ is able to support that cooperation.

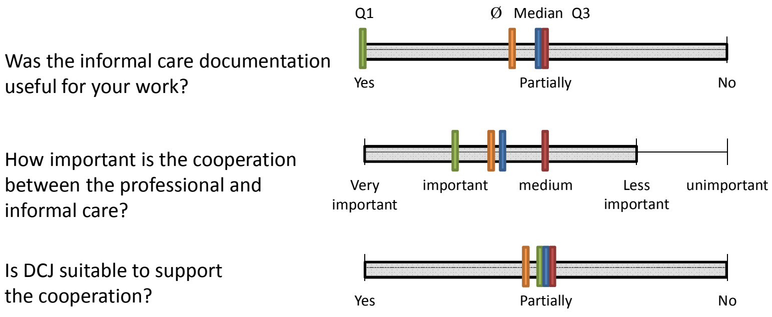

Fig. 3. Relevance of care networks and DCJ for the professional care givers

Some of the information that was provided by the informal care was useful for the work of the professional care givers. Most of them said that the cooperation between the professional and the informal care is of importance. In the average the care givers said that the DCJ platform was partially suitable to support that cooperation.

The care takers said that they had a medium to high benefit from using DCJ. Most important was the communication to the professional care giver. Also important was the consideration of the informal documentation by the professional care giver. Medium to less important was the coordination of appointments. The relevance of the different services for the care takers depends on the specific health and care situation of the person. A high relevance could be seen for the contact protocol, the activity protocol, the drinking protocol and the weight protocol. From the professional care giver point of view most of the protocols were of medium to high importance. Here especially the drinking protocol has been seen of high value.

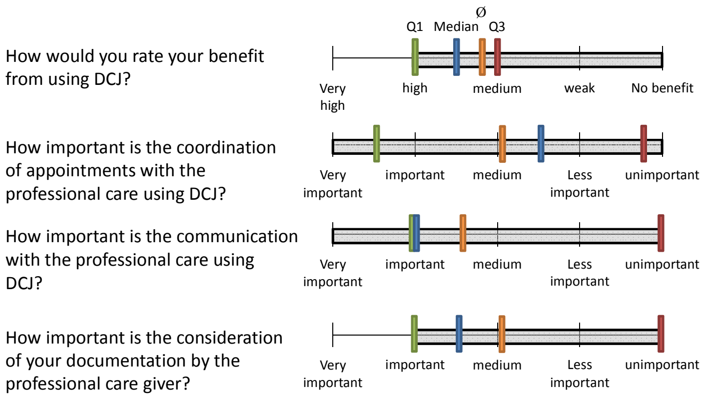

Fig. 4. Benefit for the care taker

6 Outlook

We have seen that the informal care documentation can help to support care networks between the professional and informal care. Nevertheless the care givers said that DCJ is only partially suitable to support that cooperation. In further steps we have to improve the integration into the professional care management system in order to ease access and automatically filter relevant information. The evaluation then has to be extended to a higher number of participants, including the informal care.

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The Development of a Support Bar without Structural Modification of the Domestic Environment

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Abstract. A removable support bar without structural modification of the environment, was developed. Assistive technology (AT) is a multidisciplinary science that combines knowledge of health professionals and the exact sciences area. This study is based in the methods of engineering product design and its relation to the development of resources. This paper aims to present the development process of a removable support bar that is easy to use, requiring no technical knowledge and no change the constitution of the walls and floors in the houses. Based on the methodology design the study was divided into five stages: informational (questionnaire with closed questions and an essay from the target population for use of the bar); conceptual (technical specifications, design, standards, solutions and decisions); preliminary design (design and drawing fully bar, and prototype (project preparation and design of the bar, prototyping and evaluation), validation (validation of the prototype). As the results, the support bar have been developed with seven parts for assembly in several configurations that can attend the populations needs in terms of available room: the parts are: base, tube, tee, elbow, elbow 30o.; elbow 60o. and elbow-tee. Volunteer's priority are to employ it in the bathrooms and bedrooms. The attachment configuration has small height (0,90 m) and is glued with thermo wax resin that is easy to assemble, and fixation, is removable causing no damage to the floor surface and is secure.

Keywords: Domestic Adaptation, Product Development, Assistive Technology, Occupational Therapist.

1 Introduction

Assistive technology (AT) is known to be a multidisciplinary discipline aggregating the knowledge of health professionals who deal directly with the individual's care and the exact sciences/technology in order to apply mathematical, technical and scientific knowledge for creation, improvement and implementation of devices such as products, instruments, equipment or technology adapted or/and especially designed to improve, increase or facilitate the individual's functional performance in terms of personal autonomy in task to be performed [1].

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In the Brazil, a South American country, have been processed an improvement of economic, social and scientific development of the major the population. However, the population is still divided into economic classes: low, medium and high, and the lower class and lower middle represents the vast majority of the population. Because of this, low income reflected in financial difficulty the population has to access the basic services such as housing, health and education. There are still many families living in rented houses, unable to buy their own home and added to this, much of this population has limited access to technological resources as well.

Because of this, in Brazil, the Occupational Therapist (OT) has limited products and equipment market and their assistive technology knowledge is geared towards the user's needs. One mechanism the therapists use to overcome this limitation is developing with creativity specific equipment to their patient/client/user, but without complementary knowledge. Moreover, in Brazil, the population's access to AT resources is restricted, requiring that the OT produces mainly low cost and easily used resources.From this, it was thought to develop an assistive technology resource that can help people with difficulty lifting / sit and do not compromise these financial income as well as meet the need of developing a product that is easy to use, requiring no technical knowledge and can be used by the population, especially the ones that reside in rented houses and are not allowed to change the constitution of the walls and floors, or have no money to have that type of work done.

Product methodologies are philosophical representations of a series of events occurring in a chronological sequence. There is a great variety of product methodologies development and different models presented by Ashimow (1968), Urban & Hauser (1993), Baxter (2003), and Pahl & Beitz (2005). This study was divided into four stages: informational; conceptual; preliminary and detailed design. [2]

The objective of the present study is exhibit the development process of a removable modular support bar that is easy to use, requiring no technical knowledge and no changes the constitution of the walls and floors in the houses, and have low cost.

2 Design of an Assistive Technology

2.1 Informational Project

Based on the researchers 'clinical practice with patients/users who present imbalance or decrease muscle strength in their lower limb, by different reasons like neurological, orthopaedic and rheumatologic conditions or the aging process, that observe an important difficulty during the sitting-to-standing movement and vice-versa (STS), what can lead to personal harm like fall down due to the lack of balance and security and the possibility to cause back lesions, fractures or pain. All these factors can affect users' occupational performance and social participation, causing passiveness and isolation.

The need to include assistive resources for STS movements is justified as it allows individuals to perform activities in a safe way and autonomously without causing pain and/or harm to the body structures, because the consumer/user can associate the upper extremity muscle force to the lower limb with security, giving to them more balance.

2.1.1 Need´s Recognizing

The need for this product is based on the client's requirements (statements). The objectives were to determine the needs/wishes of the consumer/user by translating imprecise and poorly defined statements into technical requisites.

With the research ethics approvals 100 individuals that has difficulties in performing STS-movements was interviewed in the Clinical Hospital of Medicine Faculty School in Ribeirao Preto. They were asked about daily life activities impairment, strategies employed to perform STS-movements, opinion about a support bar regarding the possible materials to be used, height that they prefer and places they will use the device.

All participants, (100%) refers that standing up/sitting down brings difficulty to perform their activities of daily life (ADL). The places they have more difficulty in performing STS movements are from/to: 82% the bed, 83% the couch, 86% chairs during meals and 83% the toilet. The strategies that were adopted: 100% used the surrounding furniture to support themselves in order to perform STS movements. All of them (100%) approved the support bar idea for STS and 77% prefer a removable modulate support bar. Places priority for installing the support bars were: 50% in the bathroom and 23% in the bedroom.

2.2 Conceptual Project

These data were used to perform the specification phase of the product.The evaluation of materials, dimensions and standardization of handrails were made taking by grand 150kgf load and 1.2 m of maximum distance between supports. A lot of materials were researched, like steel pipes, stainless steel, PVC, and copper. The decision for the bars material was the aluminium alloy tubes 6063-T5 1 ½¨ (38,1mm) outside diameter and thickness of 1/8”(3,2mm)were also researched and had the advantage of having mechanical strength and safety factor-2, as well as oxidation resistance and low cost (materials and workmanship).The base was aluminium alloy machined and the connections were aluminium by foundry.

2.3 Preliminar Project

Virtual models have been developed composed for seven parts for assembly in several configurations to attend the needs in terms of available room: base, tube, tee, elbow, elbow 30°.; elbow 60°. and elbow-tee (Figure 1).

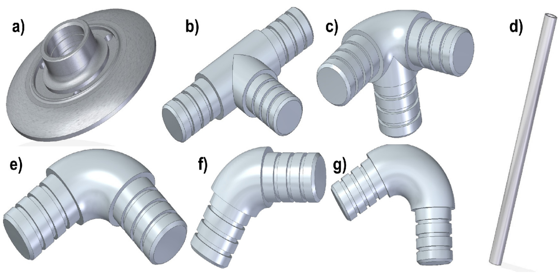


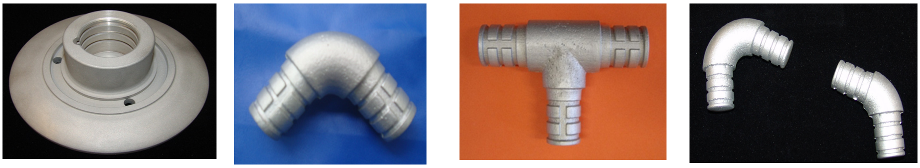
Fig. 1. a) Base, b) Tee, c) Elbow- Tee, d) Tube, e) Elbow 90º, f) Elbow 60º. g) Elbow 120º

2.4 Prototype

Through the program CAD - Solid Edge the base of the support bar was drafted for machining part in the machinery lathe. The raw material used was aluminum disk. The figure 3 shows the base machined with 200mm of diameter (front, back).

The tube used to support vertical and horizontal configurations of the different support bar is made of aluminium alloy 6063-T5ϕ 38.1 x 31,72 and made the necessary cuts.

The technique used for prototyping of the other parts of the support bar was the rapid prototyping, prototyping plaster and silicone molds. The figure 2 shows the base, the elbows and tee prototypes.



a) b) c) d)

Fig. 2. a) Base machined b) Elbow 90° c) Tee d) Elbow 60°. and Elbow 120°.

2.4.1 Fixing System

The bars fixing system to the floor, wall and between components (base, connections, and tube) were thermo-reversible adhesive, what is a combination of the components of rosin, paraffin and beeswax that was applied like wax using the heating gun. (Figure 3)

Fig. 3. Thermo-reversible adhesive

Each of these elements mixed confer the essential features to apply the adhesive term, and can mention the beeswax that gives plasticity, that is the property of the material to deform permanently cease assuming different shapes or sizes without suffering breaks, cracks or strong structure changes when subjected to pressure or shock compatible with their mechanical properties. Paraffin confer fluidity and reverse viscosity, that is a set of chemical features which gives motion to the molecules, and allows chemical interactions, in particular between solutes and solvents and it is considered that the higher the fluidity of the solvent, more easily are the solute dissolved. And the rosin confers rigidity to the resistance of an elastic body to deflection or deformation by applied force being an inherent quality of the material.

The base is glued with thermo wax resin that is fixed and removed with the heating gun and caused no damage to the surface, being easy to attach and to desattach. Tests were performed to verify the wax fixation capacity and security, using MTS - Servohydraulic Bionix Test System, fixation in different floor types and with the volunteers.

Another option for fixating is with the screw that was also considered as an option for the floor and for the wall, depending on user's preference.

Based on ASTM D2095 - 96 (reapproved in 2008) were performed mechanical tests with MTS - Servohydraulic Bionix Test System, a machine that allows characterizing the dynamic properties of biomedical materials and components. The mechanical tests in order to meet the adhesion of metal to resin were performed on metal - resin applicable term - metal, 316 stainless steel, with an area of 62 mm^2, prepared with acetone. The tensile tests were performed to simulate in a displacement of 0.05 mm / s, a length of 0.1 m / s with 1 decimeter resin term applies.

The mechanical testing with the composition of resin (60% rosin, 20% paraffin and 20% beeswax) showed that the strength was equal to 5103.1 N, the breakdown voltage equal to 1.64 MPa and the resin was tack on both surfaces, intil the rupture of the resin on the surface occurs.

Tests were performed to verify the wax fixation capacity and security, fixation in different floor types and with the volunteers.

We tested the adhesion of resin on the main floor types used in homes in Brazil: in tile and granite was good adhesion of the resin, the floor was not damaged. Due to the large Brazilian population still have disadvantaged in terms of income and access to better housing conditions, the resin was tested in the cement floor burned "vermilion" and concrete. In both situations, the resin showed excellent adherence and also was no damage to the surface.

2.5 Validation

Four volunteers took the support bar with removable modular handrail fixed on the tile. And after use, they were asked about their opinion regarding the effectiveness of the support bar and the positives and negatives points of using this type of support bar. They opined positively to the use of the support bar, reported the need for different lengths of the tube for the support bar that adapt to different local at home. They also appreciated the fact that the bases of the support bar can be attached and removed without damaging the floor or the structure of the house.

They tested the security of fixing of the bases of the support bar, performing motion STs, and applying horizontal and vertical force on the pipe horizontally. It was noticed that the resin adheres better on floors not waxed or prepared with acetone.

After this process, the support bar was applied in different settings in real environment in a residence, as shown in the figure 4 below.

a) b) c) d)

Fig. 4. a) and b) example one in the bathroom c) and d) example three the support bar near the bed

3 Conclusions

Taking into account user demands, we chose to adopt as parameters guiding the characteristics described by Soares, Martins (2000) as critical for products designed for people with disabilities. Critical analysis performed well on the final product developed (prototype), meets the following specifications: physical security, portability, usability, physical fitness and personal comfort, ease of assembly and maintenance, and ease of repair and cleanliness. [3]

The use of the thermo-reversible adhesive enables both possible uses for the population assisted financially as well as for low-income populations.

We are sure that the use of this new support bar and the safety promoted by it in the performance of motion STS bring improvements in the quality of life of the user / consumer comfort, fall prevention as well as improves functionality promoting independence in performing daily activities.

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SIMS: Self-adaptive Intelligent Monitoring System for Supporting Home-Based Heart Failure Patients

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Abstract. This paper presents our research work to develop an advanced Self-adaptive Intelligent Monitoring System (SIMS) to help patients, families and clinicians manage chronic conditions associated with heart failure more effectively at home. SIMS takes advantages of a number of advanced technologies from software intelligence, data/knowledge retrieval, data mining and database. SIMS is able to provide a number of advanced functions. It can effectively prioritize patients, provide automatic recommendation for checking frequency and risk assessment, and carry out correlation analysis in order to pinpoint relationships between external factors and the development of patient's heart condition overtime. All these functions can significantly reduce patients' burden for checking, build up their self-confidence of health and enhance their general quality of life.

Keywords: Self-adaptive technology, home-based healthcare, risk analysis, recommender system, correlation analysis.

1 Introduction

Healthcare spending is growing at unsustainable rates in most OECD countries; cost pressures and challenges of access and affordability are commonly reported [1]. Whilst treatments and outcomes for chronic diseases have improved they require extensive, long-term application and chronic diseases are increasing as causes of mortality [2]. With Baby-boomers now entering their late-60s it is critical to incorporate smart technology-enabled solutions to facilitate the delivery of cost-effective home care and address many of the challenges of managing chronic diseases.

There is interest in available Telehealth and smart home technologies but adoption remains low despite its expected value in timely and cost-effective management [3]. One of the reasons for this recalcitrance may be the lack of studies that have progressed beyond pilot scale; there is also criticism of the quality of the available evidence [4]. The better known large studies are the UK's Whole System Demonstrator projects [5] and the USA Veterans' Administration's implementation [6]. These found significant reductions in hospital admissions and re-admissions, and

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other benefits. This paper draws upon work of the CIs and others internationally to integrate SIMS intelligent software with home Telehealth technology; it will integrate with smart home technologies and the PCeHR (Personally Controlled Electronic Health Record).

The case of HF (Heart failure) is selected for this project because of their massive impact, the expectation of benefits indicated by our pilot project and also because of their diversity as chronic diseases. Over 2.5% of Australians aged 55-64 years have heart failure increasing to 8.2% for those aged 75 years or over [7]. Australians with heart failure in 2004-05 numbered 263,000. It is a major cause of hospital admissions with readmission rates of 30% and 60% at 30-day and 12 months respectively following discharge. It is associated with high levels of health-service utilisation across all settings of care as the disease progresses. Management of risk factors such as smoking, lack of exercise, obesity, excessive alcohol use and poor diet can greatly reduce the impact of heart disease. There is also evidence that cardiac rehabilitation can help decrease the risk factors [7].

A key in the effective treatment of chronic diseases, such as heart failure, is regular monitoring and management [9]. Home-based healthcare support can assist patients to proactively manage their conditions through self-monitoring and early intervention; it can help prioritise home visits and decrease visits that are for only routine check-ups. Existing chronic illness outreach services such as those at the project hospitals lack a strong technology support for effectively prioritising patients. Monitoring systems can highlight the occurrence of abnormal readings for further investigation. When there is a large volume of abnormal readings, which is common with seriously ill patients, then it can be difficult to triage patients to identify those in most urgent need. SIMS will assist with triage and also help identify patients who are stable and their visits could be reduced.

2 Limitations of the Current HF Services

The development of SIMS aims to address the following three key limitations associated with the current HF services:

- **A Lack of Automatic Patient Prioritisation and Risk Assessment**

The current HF service lacks automatic patient prioritisation and risk assessment mechanisms. Patient prioritisation and medical risk assessment aim to prioritise patients on the basis of their health status and treatments in order to optimise the deployment of resources to the patients who are in most need. Sorwar and Hassan [12] proposed a similar integrated tele-monitoring framework exploiting agent technology; that work was theoretical only. Lucien et al. [13] also proposed a sensor based tele-monitoring system, while Yuan and Herbert [14] proposed a real-time web-based remote monitoring system for healthcare. These models did not take account of temporal dimension in the medical data, which is important to depict the change in and accurately describe the patient's medical status. Focusing on the temporal dimension in medical data analysis, Cui et al. [15] introduced a Semantic-Web based framework called CNTRO (Clinical Narrative Temporal Relation Ontology), which contains three major components: time normalizer, SWRL

(Semantic Web Rule Language) based reasoner, and OWL-DL (Web Ontology Language) based reasoned but does not provide decision-support. SIMS will adaptively learn a temporal patient profile based on patient self-reported data, patient monitoring data and compliance monitoring to provide an innovative decision support system and help deliver personalised healthcare to patients.

- **A Lack of Automatic Prediction and Recommendation**

The current HF services do not provide automatic prediction and recommendation in order to support high-level decision making. Tawfik et al. [10] proposed a semantic search approach to study semantic meanings including and beyond health records and try to reduce cognitive load in health care. Building a recommender system is a preferable approach as it can provide high-quality decision support to health carers, not only a search tool to facilitate data location. Our work will provide targeted monitoring based on patient self-reported data, patient monitoring data, and compliance monitoring and offer important recommendations as to the testing frequency that patients need to follow and necessary medication need to be provided to patients. Our work will build on that of Neuvirth et al. [11] who conducted a study on recommendation based on two criteria: the need for emergency care services and the probability of the treatment producing a sub-optimal result, by exploiting data mining techniques. SIMS will assist clinicians in assessing risk of clinical deterioration through multiple domains.

- **A Lack of Intelligent Discovery of Correlation Patterns for External Factors**

Current chronic illness outreach services do not provide analysis functions which can offer data–based evidence and insight regarding the correlations between patient's conditions and various relevant lifestyle factors. These external influencing factors include nutrition, obesity, alcohol use, physical exercise, quality of sleep, and others.

3 System Architecture and Innovative Features of SIMS

The system architecture of SIMS is presented in Figure 1. There are three major components of the whole monitoring and analysis system, that is, heart failure patients, SIMS itself, and doctors and nurses. The patients take their readings of heart-related measurements such as heart rate, blood pressure and weight, etc in a particular frequency (such as every day or every two days) according to the instruction given by their doctors and/or nurses at their home. The test results are taken by various portable measuring devices and transmitted to SIMS via wireless/3G communication. SIMS then carries out complex monitoring and analysis of the data it receives and produces the results and relevant recommendations which can be reviewed by doctors and/or nurses through a wide variety of media such as mobile devices, desktops or laptops. If necessary the doctors and/or nurses will contact the patients for follow-up discussions and, should emergency occurs, the emergency division such as hospitals will be informed in the first instance.

More specifically, SIMS contains three core functional modules which deliver the following innovative features:

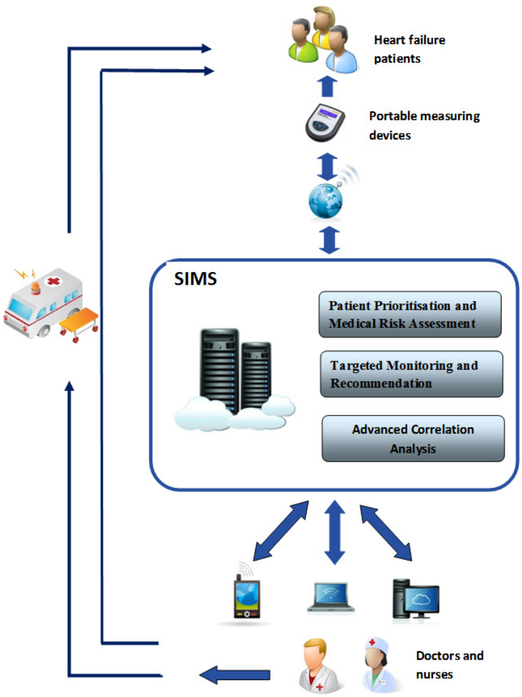

Fig. 1. System architecture of SIMS

- **Innovation 1: Automatic Patient Prioritisation and Medical Risk Assessment**

SIMS will evaluate the urgency of the heart failure patients by ranking them based on their readings and also on the trends that that have been displayed, which a strong indicator is showing whether their condition is improving or deteriorating over time. Medical risk assessment aims to prioritise patients on the basis of their medical status and treatments in order to optimise the deployment of medical resources to the patients who are in most need of healthcare. Evaluation of massive data in various types remains the greatest challenge for assessing risk. Generally speaking, the raw data reflecting patients' medical status and treatments can be categorised into two types:

a) *Quantitative clinical data* is collected by medical instruments when monitoring patients. The data is continuous, discrete, structured and quantitative. Such datasets are complex, massive, sometimes inconsistent, sparse, and/or noisy (i.e., containing irrelevant data). These are challenges for risk assessment, such as extracting features for reducing dimensionality, cleaning data to improve data quality, and transforming data into an analytic model;
b) *Qualitative clinical data* is collected from prescriptions, carers' reports, and patients' questionnaires. It could be in Boolean type (e.g., the answer to "Do you feel better today?"), nominal (e.g., medicines in prescriptions), ordinal (e.g., the answer to "Rate the level (1-5) of pain you feel when …"), or textual (e.g., the

answer to "Describe the symptoms of …" in the patient report). Such qualitative data, especially textual data, is difficult to model for data analytic, due to the characteristics of high dimensionality, heterogeneity, unstructured, and ambiguity.

- **Innovation 2: Targeted Monitoring and Recommendation for Heart Failure Patients**

SIMS will manage the heterogeneous data collected from patients, including the time series data, binary answers (yes/no) to predefined questions and free text. Specific healthcare services, such as clinic/home monitoring can then be delivered to patients targeting on their personalised medical status, treatments, and demand. Highly individualized prediction and recommendation are carried out. For example, a patient with severe symptoms may need to take three measures per day using multiple methods; whereas another in recovery phase (or stable phase) may only require a single method of measurement every 3 days. Decisions for when, how, and what medical monitoring methods a patient requires will be supported by the SIMS intelligent system providing recommendations for personalised, targeted monitoring. Specifically, the following several components are developed for deliver the functions of targeted monitoring and recommendation:

a) A generic user model to formally describe HF patients' behaviour including symptoms, monitoring methods, treatments, demands, and feelings, etc. Though user modelling has been studied for decades, there is much to learn in user modelling for HF;
b) An adaptive learning algorithm to temporally profile individual HF patients, based on the generic patients' user model. The temporal patient profile will reveal the changes in the patients' medical status, and help uncover the relationships within different tuples in the profile. The adaptive algorithm will learn patient profile exploiting expert knowledge in the domain ontology. It will help access patients' individual medical status and personalised demands;
c) An intelligent recommender system to provide decision support for targeted medical monitoring, such as when the patient should take next test. The intelligent recommendations are made based on the patient's individual medical status and personalised demands specified in the temporal patient profile, as well the inference rules defined in the axiom repository with heart failure domain ontology. The intelligent system is an innovative applicable contribution to transform expert knowledge to practice in personalised health care.

- **Innovation 3: Advanced Correlation Analysis of External Factors**

SIMS will conduct advanced correlation analysis between conditions of patients and the external influencing factors to uncover interesting and critical correlation patterns existing between the patient's conditions and external lifestyle factors. Existing associate rule mining techniques are not able to effectively discover correlation patterns. The reason is that those correlation patterns are unique in the sense that they are typically time-shift patterns as there may be some time delay before symptoms are observed. Our new algorithm will take into account the unique feature of time delay to effectively discover the time-shift correlation patterns.

A novel time-shift association rule mining algorithm will be developed and incorporated into SIMS to effectively discover unique patterns. One of the most crucial technical challenges for time-shift association rule mining is that different external lifestyle factors will feature varying possible time delay durations. By utilising an advanced correlation analysis module, SIMS will be capable of providing data-based evidence which is individualised for each patient. The input information required for the correlation analysis can be easily collected through clinician-developed on-line questions to patients which will take only a few minutes to complete. Input of this information every day is desirable but not required as the module can conduct the correlation study in a coarser time granularity such as per week instead of each day. This feature can significantly enable both clinicians and patients to better understand not only which external lifestyle factors that may have affected their chronic condition but also how they exert influence. Customised articles and newsletters can be automatically subscribed to different patients based on the discovered contributing factors to assist patient self-care.

4 Methods

The development of SIMS is at the confluence of several fields including computer science, behavioural sciences, health and design and involves the study, planning, and design of the interaction between people (users) and computers in healthcare. From the perspective of computer science and information technology, SIMS takes advantages of a number of advanced technologies from software intelligence, data/knowledge retrieval, data mining, and database. Next, we discuss in more details the technical tasks that we need to accomplish in SIMS.

- **Pre-processing Patients' Data for Feature Extraction**

Patients' data are generated continuously in a dynamic operating environment, with huge time series data and free text data. It is impossible to store such data streams completely in a data warehouse. Such vast-sized raw data make the follow-up analysis and prediction extremely difficult. To find interesting or unusual trends variation, it is essential to perform efficient feature extraction, which enables the efficient solutions for several subtasks with different data set including real-time warning, online indexing, querying and efficient storage.

- **Designing a Time-Series Based Model for Patient Prioritisation and Risk Assessment**

The measurement readings of patients (e.g., weight, heart rate, blood pressure) are collected at most once every day, which are by nature time series data considering the time dimension involved. A key feature of the time series data is the trend that the data exhibits, which is fully considered in the process of patient prioritisation and risk assessment in our system. Specifically, we considered two criteria for each of the health measurements under study based on the time series data for ranking purpose. The first criterion is the deviation of the observed value of reading from the normal range and the second one is the recent reading tendency that is observed during a time window. Both of these criteria can be quantitatively calculated.

Since there are two different criteria associated with each measurement, we thus utilise the technique of multi-objective ranking which guarantees that the patients with abnormal reading and worsening situation are assigned with higher priority scores in the ranking results. The multi-objective ranking is based on a notion called *dominance* that has been used in the area of multi-objective optimisation. A patient p_1 is said to dominate another patient p_2, denoted as $p_1 > p_2$, if both of the two criteria of p_1 are worse than those of patient p_2. For each patient, we can calculate the number of other patients in the whole patient population that are dominated by this patient based on the definition of dominance. In this way, the ranking score from the time series data can be generated with the patients with worse heart conditions being assigned with a higher dominance score.

We can further classify patients based on these two criteria into the following four broad categories in order to provide more informative interpretation of the time series data (with Category 1 having the highest urgency while Category 4 having the lowest one):

Category 1: abnormal reading and worsening situation
Category 2: abnormal reading and stable/improving situation
Category 3: normal reading but worsening situation
Category 4: normal reading and stable situation

- **Designing Text Mining Algorithms for Free Text Data**

The patients will be provided with opportunities to provide free text input in the user interface where they or their family carer can input through the Telehealth device or other input devices; free text can range from several sentences to a few paragraphs to report their symptoms. This provides the patients with a much higher level of freedom to describe their symptoms and express their concerns that may not be covered and captured by the yes/or questions. Natural language processing techniques are utilised to parse those free text and extract key words which are represented as features. Domain-specific ontology, the carrier of domain knowledge containing the semantic meaning and weights of different keywords and terminology, is used to quantify the severity of symptoms described by patients. The domain ontology can be generated with the help of domain experts.

5 Conclusion

The adoption of smart home and telehealth technologies for chronic disease support has been disappointing despite evidence of the benefits. In this paper, we present our latest research work in developing an advanced intelligent monitoring and analysis system, called SIMS, for supporting heart failure patients. SIMS will improve the adoption and effectiveness through providing a system that will continually learn about patient patterns and trends. SIMS will assist patients in self-care and also better help carers and clinicians monitor the progress of the patient's conditions and the effectiveness of interventions.

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