OULU 2018
A 722

ACTA UNIVERSITATIS OULUENSIS

A
SCIENTIAE RERUM NATURALIUM

Muhammad Zeeshan Asghar

REMOTE ACTIVITY GUIDANCE FOR THE ELDERLY UTILIZING LIGHT PROJECTION

UNIVERSITY OF OULU GRADUATE SCHOOL;
UNIVERSITY OF OULU,
FACULTY OF INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING;
NARA INSTITUTE OF SCIENCE AND TECHNOLOGY,
GRADUATE SCHOOL OF INFORMATION SCIENCE

ACTA UNIVERSITATIS OULUENSIS
A Scientiae Rerum Naturalium 722

MUHAMMAD ZEESHAN ASGHAR

REMOTE ACTIVITY GUIDANCE FOR THE ELDERLY UTILIZING LIGHT PROJECTION

Academic dissertation to be presented with the assent of the Doctoral Training Committee of Information Technology and Electrical Engineering of the University of Oulu for public defence in the Arina auditorium (TA105), Linnanmaa, on 2 November 2018, at 12 noon

UNIVERSITY OF OULU, OULU 2018

Acta Univ. Oul. A 722, 2018

Supervised by
Professor Petri Pulli
Professor Hirokazu Kato

Reviewed by
Professor Tapio Takala
Professor Do van Thanh

Opponent
Professor Yoshitsugu Manabe

ISBN 978-952-62-2048-2 (Paperback)
ISBN 978-952-62-2049-9 (PDF)

ISSN 0355-3191 (Printed)
ISSN 1796-220X (Online)

Cover Design
Raimo Ahonen

JUVENES PRINT
TAMPERE 2018

Asghar, Muhammad Zeeshan, Remote activity guidance for the elderly utilizing light projection.
University of Oulu Graduate School; University of Oulu, Faculty of Information Technology and Electrical Engineering; Nara Institute of Science and Technology, Graduate School of Information Science
Acta Univ. Oul. A 722, 2018
University of Oulu, P.O. Box 8000, FI-90014 University of Oulu, Finland

Abstract

Natural ageing brings with it many physical and cognitive impairments in the elderly, which challenges them in independently performing their daily activities. Many assistive technologies such as alarms, mobile phones, and video conferencing are available to support the elderly and their caregivers. However, these technologies require constant interaction and attention. Augmented Reality (AR) can be used to remotely guide the elderly in their daily tasks. From all known techniques, projection-based AR is suitable for the elderly because the digital information can be displayed on any real surface or any object without interaction or holding the devices.

This doctoral thesis focuses on developing solutions to remotely guide the elderly in their daily activities through a caregiver. We adopted the design science methodology to iteratively design, implement and evaluate these solutions. Two constructs were developed for navigation activities utilizing laser projection and four constructs were built for cooking activities using fixed projection. We evaluated each construct in terms of feasibility and usability with actual elderly people, some of them have some form of memory problem.

The results demonstrate how remote collaboration systems can be developed to guide the elderly in daily activities through a caregiver. The existing devices can be equipped with projection-based AR technology and elderly are willing to use it. The findings also suggest that augmented reality could help design systems for other daily activities such as shopping, or cleaning dishes, in order to improve the autonomy, quality of life, safety and well-being of the elderly.

Keywords: assistive technology, augmented reality, caregivers, daily activity, elderly, guidance, projection, remote collaboration

Asghar, Muhammad Zeeshan, Vanhusten toiminnan etäopastus valoprojektiolla.
Oulun yliopiston tutkijakoulu; Oulun yliopisto, Tieto- ja sähkötekniikan tiedekunta; Nara Institute of Science and Technology, Graduate School of Information Science
Acta Univ. Oul. A 722, 2018
Oulun yliopisto, PL 8000, 90014 Oulun yliopisto

Tiivistelmä

Vanhusten ikääntyminen tuo mukanaan fyysistä ja kognitiivistä kunnon heikkenemistä, mikä haastaa heidän kykyään suoriutua päivittäisistä askareista. Apuvälineet, kuten erilaiset varolaitteet, puhelimet ja videoneuvotteluyhteydet, ovat vanhusten ja heidän avustajien käytettävissä. Nämä apuvälineet vaativat yhteydenpitoa ja huomiota. Lisättyä todellisuutta (AR-tekniikkaa) voidaan käyttää etäopastamaan vanhuksia päivittäisissä askareissa. Näistä tekniikoista erityisesti projektiopohjainen lisätty todellisuus soveltuu vanhuksille, koska opastustieto voidaan näyttää millä tahansa pinnalla tai esineellä vaatimatta vanhukselta toimenpiteitä ja käyttämättä laitteita.

Tämä väitöskirja kohdentuu kehittämään ratkaisuja vanhusten päivittäisten tehtävien ohjaukseen etäällä olevan avustajan toimesta. Menetelmällisesti tämä tutkimus soveltaa suunnittelutiedettä, jossa ratkaisuja suunnitellaan, toteutetaan ja arvioidaan toistuvina iteraatiokierroksina. Työssä kehitettiin kaksi ratkaisua ulkotiloissa tapahtuvaan jalan liikkumisen opastukseen laservalolla ja neljä ratkaisua sisätiloissa tapahtuvaan ruuanlaittoon kiinteästi keittiöön sijoitetuilla projektoreilla. Näiden ratkaisujen käyttökelpoisuus ja käytettävyys arviotiin käyttäjäryhmällä, joka koostui vanhuksista, joista osa kärsi muistin vajaatoiminnasta.

Tulokset demonstroivat joidenkin kohteeksi valittujen toimintojen osalta, miten voidaan kehittää vanhusten päivittäisen toiminnan opastusjärjestelmiä, joissa on etäavustaja. Olemassa oleviin vanhusten käyttämiin käyttöesineisiin, laitteisiin ja tiloihin voidaan lisätä lisätyn todellisuuden valaistusvarustus. Tutkimustulokset antavat myös viitteitä lisätyn todellisuuden laajemmasta soveltuvuudesta muihinkin päivittäisiin toimintoihin, kuten ostoksilla käyntiin ja astioiden tiskaukseen, ja siten parantaa vanhusten itsenäistä selviytymistä, elämänlaatua, turvallisuutta ja hyvinvointia.

Asiasanat: avustaja, avustusteknologia, etäyhteistyö, lisätty todellisuus, opastus, projektio, päivittäinen tehtävä

Dedicated to my family and friends who trusted me and prayed for me to achieve that I never dreamed of and to my father who never saw it happen.

Preface

The work presented here is a result of a double-degree agreement between the University of Oulu in Finland and the Nara Institute of Science and Technology in Japan. I thank both these universities for the opportunity to participate in this collaboration.

In the name of Allah, the Beneficent, the Merciful.

After finishing my Master's degree at the Department of Information Processing Science (former TOL), University of Oulu, Finland in 2010, I got a chance to work in Professor Petri Pulli research group. The group was focusing on how to develop and design assistive technologies for elderly people, which was an interesting research area to me. After working as a teaching and research assistant for 2 years, Professor Pulli recognizing my potential, suggested me to apply for full time PhD Infotech position. In 2012, I got 4 years teaching and research assistant position that started my official journey towards the PhD studies. During this journey, I met many professionals, expanded my research network, and made many friends along the way. I will try to acknowledge some of them, as it is difficult to praise everyone because that list is long. Therefore, to start with, I would like to thank everybody who played a role whether big or small in this journey of mine.

First, I would like to thank my supervisor Professor Petri Pulli for his guidance and mentoring throughout my PhD journey. Without his guidance and support, I would not have been able to achieve this milestone. I really admire his vision, his insights about latest and innovative technological research. Whenever you talk to him his mind is always full of innovative ideas and suggestions to foster research, of which this thesis is a reflection. He was also the one who helped and encouraged me to apply for double degree program between the University of Oulu and NAIST Japan. I am also grateful to Professor Hirokazu Kato who took me in as a student and guided me during my one year stay in Japan. During that stay in IMDB lab, I met multi-cultural people, from experts to those who were just starting their studies. I would like to thanks everyone there, especially, Senior Lecturer Goshiro Yamamoto who supported me and guided me during my stay in Japan and later during many of his visits to Finland. I learned many things from him, from basics of research to complex theories, from computer vision concepts to projector technology domain, and from how to present my research work in the lab to the International conferences. I would like to thank all the Interactive media design lab

members including and foremost Dr. Takafumi Taketomi, Associate Professor Christian Sandor, Professor Kiyoshi Kiyokawa and Yuichiro Fujimoto.

I am thankful to Professor Yoshitsugu Mannabe for serving as an opponent in the doctoral defence, as well as the official reviewers: Professor Tapio Takala and Professor Do Van Thanh, for reviewing my thesis. Dr. Mikko Rissanen for helping me to compile and write the thesis and listening to my repeated questions. I would like to extend thanks to the members of my follow-up group, Dr. Seamus Hickey, Dr. Peter Antoniac and Professor Harri Oinas-Kukkonen.

I am grateful to my colleagues and co-authors Niina Keränen, Maarit Kangas, Sei Ikeda, Goshiro Yamamoto, Yuki Uranishi, Tomi Sarni, Yahui Li, Jaakko Hyry, Saima Batool and Research Dawadi. I appreciate the support and assistance of my colleagues in OASIS research group: Babar Chaudary, Aryan Firouzian, Eeva Leinonen, Iikka Paajala, Dr. Pasi Karpinnen, and Dr.Piiastiina Tikka. Thanks to Professor Raija Halonen and Dr. Jouni Markkula for helping me to improve and strengthen my research methods approaches.

I would also like to extend my gratitude towards several institutions for enabling me to do my research work in Finland and Japan: Infotech and the Academy of Finland. Several grants were approved, and I would like to most humbly thank the Academy of Finland, the University of Oulu grant foundations and SeGaBu (Serious Games Platform for Business and Education).

I am very fortunate to have wonderful friends in Oulu. Dr. Waqar Nadeem, Dr. Ijaz Ahmad, Dr Ovais Ahmed, Haresh Kumar, Azhar Rana, Salman Qayyum Mian, Hasnain Virk, Asadullah javed, Ikram Asharf, Muzammil Ahmed and Nouman Bashir have always been available to support me in whichever way possible. I am lucky to have them as friends and deeply thankful to you guys for the cheerful company, team sports, and thoughtful discussions. When it is time to thanks the dearest ones, the words seem to disappear. My mother, her love and continuous prayers provided me strength to keep continue in this tough journey. My late father must be proud to see me achieve this milestone, as struggled hard all his life to provide quality education to me and to all my siblings. Thanks to my elder brothers, Kashif Asghar and Asif Asghar, they have always supported me and guided me throughout my doctoral studies. I am grateful to my two uncles, Muhammad Ovais and Junaid Ahmad, they have guided me and suggested me to choose the computer science field for higher studies.

Last but not the least, my adorable wife Madiha Zeeshan, who stood by me and faced all the side effects of this journey, and always encouraged me and supported me throughout the hard times and the good when I was down and upset, especially

during the end process of studies. Finally, when my beautiful daughter Momina Zeeshan was born in June 2016, when I was starting to finalize my studies. Her cute smile and small hugs kept me fresh, motivated and were the source of realising all my stress, God bless you.

Abbreviations

AAL	Ambient Assisted Living
AD	Alzheimer’s Disease
ADL	Activities of Daily Living
AR	Augmented Reality
HMD	Head-Mounted Display
IADL	Instrumental Activities of Daily Living
ICT	Information and Communication Technology
MCI	Mild Cognitive Impairment

Original publications

This thesis includes the following six original publications, which are referred to throughout the text by their Roman numerals:

I Yamamoto, G., Chen, A., Pulli, P., Hyry, J., Asghar, M.Z., Uranishi, Y., & Kato, H. (2013) A laser projection-based tele-guidance system embedded on a mobility aid. Proceedings of the 7th International Symposium on Medical Information and Communication Technology (ISMICT), IEEE: 139-143.

II Tervonen, J., Asghar, M.Z., Yamamoto, G., & Pulli, P. (2013) A navigation aid for people suffering from dementia using a body worm laser device. Proceedings of the 7th International Symposium on Medical Information and Communication Technology (ISMICT), IEEE: 178-182.

III Ikeda, S., Asghar, Z., Hyry, J., Pulli, P., Pitkänen, A., & Kato, H. (2011) Remote assistance using visual prompts for demented elderly in cooking. Proceedings of the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies (p. 46). ACM.

IV Yamamoto, G., Asghar, Z., Uranishi, Y., Taketomi, T., Sandor, C., Kuroda, T., Pulli, P. & Kato, H. (2014) Grid-pattern indicating interface for ambient assisted living. Proceedings of the International Conference on Disability, Virtual Reality and Associated Technologies. pp. 405-408.

V Yahui, L., Asghar, Z., & Pulli, P. (2013) Visually-aided smart kitchen environment for senior citizens suffering from dementia. International Joint Conference on Awareness Science and Technology & Ubi-Media Computing (iCAST 2013 & UMEDIA 2013) (pp. 584-590). IEEE.

VI Asghar, Z., Yamamoto, G., Taketomi, T., Sandor, C., Kato, H., & Pulli, P. (2017) Remote Assistance for Elderly to Find Hidden Objects in a Kitchen. EAI Endorsed Transactions on Pervasive Health and Technology, 17(12): e3. http://dx.doi.org/10.4108/eai.7-9-2017.153065.

Contents

1 Introduction

Globally, the population is ageing significantly, primarily due to advancements in technology, public healthcare, nutrition and medicine (Beard et al., 2012). Ageing results from demographic transition, driven by fertility and mortality. This eventually leads to smaller proportions of children and larger proportionate shares of older people in the population (United Nations, 2013). This significant shift in demographics will continue to influence society, due to rising life expectancy, declining birth rates, and infant mortality (United Nations, 2013).

In addition, the old age dependency ratio will increase rapidly due to the increase in longevity. The ratio is defined as the number of elderly people to those of working age (Debes et al., 2016). Countries such as Japan, Germany, Italy, Spain and Poland have now exceeded a 50% ratio (Muszyńska & Rau, 2012). While, Finland is situated at the top of the developed countries with an aged population. According to Statistics Finland's (2015) latest population projection, those aged 65 or over in the population are estimated to rise from the present 19.9% to 26% by 2030 and to 29% per cent by 2060. Accordingly, those aged under than 15 in the population will decrease to 14% by 2060. The main reason for the declining share of young people is an inadequate birth rate.

The dependency ratio is based on the simple concept that all persons under 15 and those 65 or older are likely to be in some sense dependent on the population of the working ages of 15−64 (United Nations, 2013). Based on the above projections, in Finland the dependency ratio limit was 57.1% at the end of 2014. This limit can be assumed to reach 60 dependents in 2017 and 70 dependents by 2032. Overall, the disparity between the elderly and younger people is growing and will go up soon. Like Finland, the situation of the elderly population in Japan is an increasing concern and it is frequently considered to be home to the world's most aged population. According to World Population Ageing, 33% were aged 60 years or over in 2015 in Japan (United Nations, 2015). Figure 1 depicts the total population of Finland and Japan in three different age groups, which clearly shows the gap between the elderly and younger age group (United Nations, 2017).

There are many consequences of this ageing population, including age-related diseases, rising healthcare costs, the shortage of healthcare professionals, increasing inability to live independently, and limited facilities to handle the ageing population (Rashidi & Mihailidis, 2013). Countries all over the world are facing two main challenges due the ageing population: the first is to provide the elderly with an independent life in their familiar environment, while the second is the shortage of caretaking personnel to support the elderly during their daily activities and the cost of caring for them. In the US alone, more than 19 million people give primary assistance to their dependent relatives and the cost of caring for people with dementia will increase from 203 billion in 2013 to a projected 1.2 trillion per year by 2050 (Jacobsen et al., 2011).

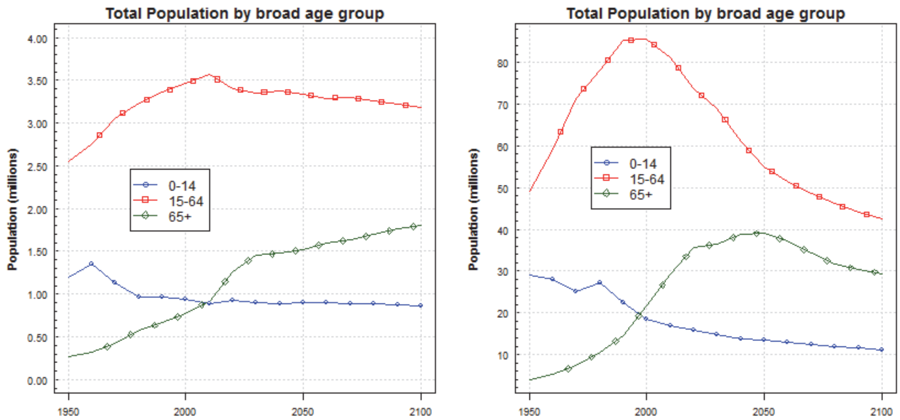


Fig. 1. Population by broad age group in Finland (Left) and the population by broad age group in Japan (Right) (United Nations, 2017).

ICT could play an important role provide solutions to enable the elderly to live independently, safely, and comfortably, namely ageing well-being (Li et al., 2015). Technology can provide "peace of mind" for caregivers who living at a distance, regarding the safety and daily activities of ageing loved ones (Huber et al., 2013). There are already many technological interventions available that provide services to elderly in various situations, such as assistive technologies, smart homes, Ambient Assisted Living (AAL), Augmented Reality (AR), wearable devices, the Internet of Things (IoT), cloud computing, assistive robots, tele-health, tele-monitoring, and tele-medicine (Li et al., 2015; Pigini et al., 2012). Among these solutions, AAL research has been adopted worldwide in recent years, and become an active area of research. The aim of AAL research is to investigate innovative technologies to assist elderly people with impairments and enable them to live independently and healthily (Li et al., 2015).

AR is a technology that allows users to view and interact in real-time with virtual images superimposed over the real world. Alongside AAL, AR is growing rapidly and becoming popular in different fields such as education, design, navigation and medicine (Liang, 2015). However, appropriate AR applications have placed limited focus upon the ageing population (Malik et al., 2013). Nonetheless, AR is becoming more mature and robust, and can provide innovative solutions to guide elderly users in various activities of daily living (Liang, 2015). Moreover, AR systems can be used to create a unique collaborative environment (Lukosch et al., 2015). With the help of remote collaborative environments, a caregiver can help many elderly people in their daily activities remotely and the elderly can ask for help during a task. Several studies have shown that AR systems can improve performance time, mental effort, efficiency, and satisfaction, on physical tasks (Lukosch et al., 2015). There are many techniques to display AR information, including head-mounted displays, smart phones and tablets, but this study chose projection-based AR technology because this method does not need users to carry any heavy hardware and does not require any technical knowledge to use the device properly. Many remote collaborative systems have used projection-based AR to help people in various tasks (Marner et al., 2014). However, few systems have been developed for the elderly to support them in daily activities. Additionally, in these developed systems, the supporter and the supported person are familiar with, or experts in, the target environment. The main goal of this study is to help the elderly to perform daily activities at home independently using projection-based AR technology and to allow caregivers to support them from a distance.

1.1 Purpose

The purpose of this study is to explore how remote collaborative environments can help caregivers support the elderly at a distance in their daily activities. The idea is to help the elderly age in their homes and reduce the burden on the community. The ageing population brings many challenges to the community and for the caregivers to support the elderly in their familiar environment. Key among these challenges is that the elderly prefers to live at home independently but need support in performing daily tasks due to cognitive and physical impairments. In parallel, caregivers live at a distance due to work or study and cannot support the elderly on a regular basis. Another challenge is that the age gap between the elderly and the young generation is increasing. Consequently, the caregiver needs to support and monitor the elderly on a regular basis. Remote collaborative environments can be a potential solution for caregivers to support and monitor the elderly from a distance. Moreover, these environments can help elderly people to participate and perform their daily activities. The use of AR in remote collaboration is a special case, where a person is remotely guided to complete a task with the help of the information that is digitally projected into that person's field of view. In this way, the problem can be solved collaboratively or with the help of added information over a distance despite physical absence of the supporting person (Fussell et al., 2004; Billinghurst et al., 2015).

1.2 Research questions

The following research question and sub-questions are used to structure the overall topic and focus on presenting the main findings. This thesis is not intended to supply a complete answer to all these questions. The study presented in this dissertation relies on remote collaborative systems as a way of improving the autonomy and quality of the elderly living at home independently. Scientific literature has indicated that remote collaborative environments are useful among experts and workers in completing a task together. Furthermore, we have explored that the elderly is adopting and accepting projection technology in their daily routine in the form of an assistive device. Elderly people with cognitive disabilities requires assistance to perform IADLs and their caregivers often live or work some distance away. As a result, the remote collaborative environment can play a significant role ensuring that the elderly remain at home independently and help caregivers to assist them from a distance.

The purpose of this study was to design and develop remote collaborative systems that can help elderly in various IADLs. There are various approaches to design an assistive system using the available technology, but we have developed an assistive system that can easily embed itself in the existing infrastructure and environments, given that the, elderly prefer to live in their accustomed environments and they are quite familiar with their existing assistive devices.

MQ: How elderly's daily activities can be guided remotely using projection technology?

From this main question, the sub-questions (SQ) were formalized to highlight different artefacts, design and develop for the elderly, to guide them in different activities as follows:

SQ 1.1: *How can we provide remote assistance to the elderly for outdoor activities?*

To answer this sub-question, we designed, developed and evaluated two constructs using modern ICT. These two constructs can help the elderly regarding mobility. More information about these constructs can be found in the publication I and II.

SQ 1.2: *How can we provide remote assistance to the elderly for indoor activities?*

To answer this sub-question, we designed, developed and evaluated four constructs using modern ICT. These four constructs can help the elderly with a cooking activity. More information about these constructs can be found in publication III, IV, V and VI.

SQ 1.3: *Is projection technology acceptable in remote assistive systems designed for the elderly?*

To answer this sub-question, we conducted a user study with 12 elderly participants in a laboratory environment. More information about this user study can be found in publication VI.

1.3 Main contribution

The main contribution of this study is to produce solutions that can assist the elderly in their daily activities, as depicted in Figure 2. These solutions are important because they can enable the elderly to perform their activities independently. This will improve their well-being and quality of life and reduce the burden on caregivers. Elderly people perform various activities in both outdoor and indoor environments. Outdoors, some important activities could include shopping, walking, and socializing. Indoors, this could include cooking, laundry, medication, bathing, walking, sleeping, etc. Among the activities, cooking and wayfinding require high levels of cognitive functioning and prerequisites of personal autonomy.

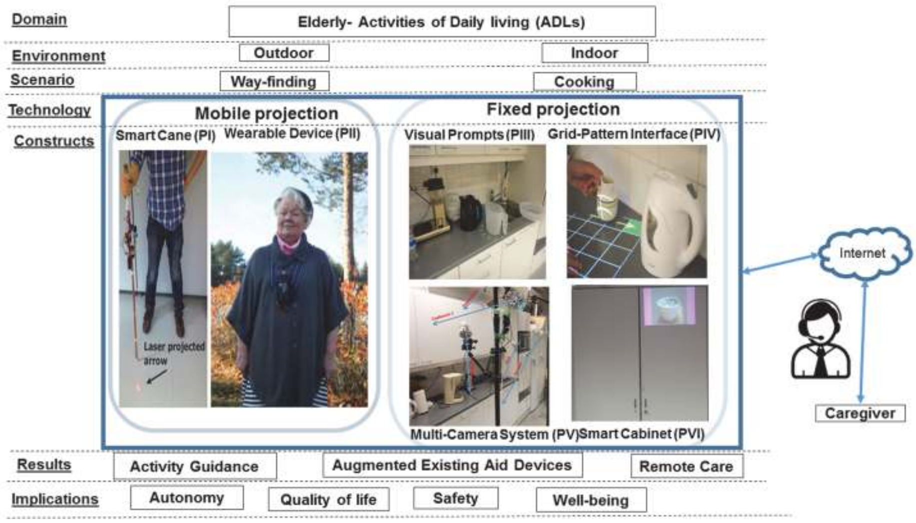


Fig. 2. Dissertation layout.

Elderly people with cognitive disabilities has trouble in successfully navigating from one place to another, an ability known as wayfinding (Passini et al., 2000). Successful wayfinding is crucial for the elderly because it is connected to many other activities, including shopping, socialising, walking, etc. Consequently, it is important for an elderly person to perform these activities safely and independently. Publications I and II focus on designing constructs that can help the elderly in wayfinding using laser projection technology. In Publication I, a smart cane was equipped with laser projection technology to display a projected arrow on the floor for navigation. Publication II presents a wearable device that an elderly person can hang around their neck to navigate outdoors and while the laser projection module displays a projected arrow on the ground.

Similarly, the elderly spends much of the time in a kitchen environment doing different activities. These activities such as cooking, preparing food and storing provisions, are vital for their autonomy (Blasco et al., 2014). However, these activities require strong cognitive functioning because they involve detailed instructions and different objects. Therefore, it is crucial for the elderly to perform these activities independently to maintain their autonomy and quality of life.

Publications III, IV, V, and VI focus on assisting the elderly for cooking activities in a kitchen environment using fixed projection technology. Publication III focuses on providing verbal and visual prompts that can assist the elderly in identifying and locating objects on a tabletop. In Publication IV, we designed and developed a grid pattern interface to help the remote caregiver to assist the elderly in an unknown environment. Publication V implemented a multiple camera system to provide a wider view of the kitchen environment. In Publications III and IV used, a single camera was used, which focuses on a small area. The wider view is useful for the remote caregiver to see all areas of a kitchen, given that, a user in a kitchen moves between different places during a cooking task. Publication VI explains a system that is implemented to identify and locate objects in hidden places that are not visible to the naked eye, such as cabinets and drawers.

All the artefacts were evaluated through trials with elderly people, some with some form of dementia. The results have determined that projection-based AR technology in relation to the elderly has the following advantages.

- Technology can easily be equipped with the existing aid devices and can easily augment the surface in the environment
- It can guide the elderly to perform ADLs independently and projected information around the elderly can assist them during tasks
- Allows remote caregivers to monitor and assist elderly in a daily task whenever required

1.4 Thesis structure

The remainder of the dissertation is structured as follows: The purpose of Chapter 2 is to introduce the conceptual background, which is crucial for the understanding of presented concepts, which are briefly explained. Chapter 3 explains the earlier systems and environments developed to help the elderly in their daily routines. Chapter 4 provides an overview of the research method used in the dissertation. Chapter 5 explains the original contribution of the publications included in the dissertation. The summary of each publication explains the purpose of the research, implementation and the main results for each system. Chapter 6 explores the research questions and provides a basis for the implications of the results. Finally, Chapter 7 concludes the overall study with limitations and future work, explaining the use cases based on projection-based technology for other ADLs.

2 Theoretical foundations

This chapter introduces the terminologies used later in this dissertation. Firstly, it is important to know elderly as a user and their cognitive impairments due to aging. Additionally, it is important to know about the daily activities' elderly performs at home and outside and problems they faced during those activities. Finally, caregivers and role of the caregivers in the lives of the elderly is presented.

2.1 Elderly ageing population

The number of people aged 65 or older is projected to grow between 2015 and 2030 from an estimated 901 million to 1.4 billion, with a dramatic increase to 2 billion by 2050. Similarly, the number of people aged 80 or over in the world population will grow from 125 million in 2015, to 434 million by 2050 (United Nations, 2015). Most elderly people prefer to live in their familiar living environment and to live independently for as long as possible. The elderly experience higher rates of cognitive decline, chronic age-related disease, as well as limitations in physical activity. These cognitive and physical impairments force them to move into nursing homes that can cause a loss of autonomy and quality of life. Practitioners face many challenges in providing care to the elderly, such as increases in rates of diseases, health care costs, a shortage of caregivers, and the elderly's dependency on others (Rashidi & Mihailidis, 2013). As a result, it is important to find solutions to improve the living conditions of the elderly and reduce their burden to society. A positive aspect, however, is that the elderly is more willing to adopt and use new technology that helps them to age in their homes.

2.2 Elderly people with MCIs

Mild cognitive impairment (MCI) is a condition defined by cognitive deficits exceeding that are expected in normal ageing yet are of insufficient severity to warrant a diagnosis of dementia (Avila et al., 2015). It is often considered as an early transition between normal cognitive ageing and dementia (Winblad et al., 2004). It is crucial to assist individuals with MCI to perform IADLs independently because they exhibit impairments in IADL abilities that increase in severity over time. Impairment in ADL is a major risk factor that leads to dementia and early IADL impairments presents a risk for more rapid decline (Avila et al., 2015). One of the defining features that distinguish normal ageing from MCIs and dementia is ADL independence (Gold, 2012).

ICT-based solutions can help people with MCIs with planning and managing everyday activities because they have a stronger potential to learn and adopt new technologies compared to people with dementia (Sixsmith, 2013). It has been examined whether technological solutions such as assistive technologies may be more effective if directed at a person those MCIs rather than those with dementia. It would give them time to learn and adopt the use of the assistive technology product that might persist into the early and moderate stages of dementia.

2.3 Elderly with dementia

Dementia is a very debilitating condition in the ageing population leading to severe cognitive decline that causes difficulties carrying out daily activities such as shopping, banking, preparing food, taking medication, using transport and managing personal finances (Federici et al., 2014; Sixsmith, 2013). As dementia progresses, the elderly become increasingly dependent upon family and formal caregivers for support in their daily activities. Technology may play a potential role in helping and supporting elderly people with dementia to manage their daily activities. Moreover, technology becomes extremely important for filling the gap between caregivers and the elderly. Fewer caregivers are available to meet the needs of the increasing number of elderly people due to the falling birth rate and the consequent lack of care available. It is important to identify the needs and wishes of elderly people with dementia while developing technological devices and systems for them. These devices must be easy to use, reliable, affordable and robust.

2.4 Taxonomy of ADL

According to the medical community (MedicineNet, 2015), ADLs are “the things we normally do in daily living, including any daily activity we perform for self-care, such as feeding ourselves, bathing, dressing, grooming, work, homemaking and leisure.” ADLs can be classified into basic activities of daily living (BADL) and instrumental activities of daily living (IADL). BADLs consisting of self-care activities such as ambulating, bathing, and dressing, eating and drinking. Katz and Lawton define a scale of ADLS and Instrumental ADLs (IADLs) (Katz & Lawton, 1976). ADLs are activities that need interaction with objects and people and allow an individual to live independently to in a community, for instance shopping, using the phone, preparing food, taking medication, housekeeping, managing money, and transportation (Fleury et al., 2010). Deficits and changes in these activities are considered precursors to more serious cognitive problems such as MCIs and dementia. Successful execution of ADLs is an integral part of an autonomous and self-determined life of people with cognitive disabilities (Peters et al., 2014). Some examples of ADLs are given in table 1.

Table 1. Domain of ADLs.

Domain	Activities
BADL	Ambulating, bathing, dressing, eating and drinking, shopping
IADL	Using the phone, preparing food, taking medication, housekeeping, managing money and transportation
EADL	Leisure activities, learning new technologies, communicating with family and friends

2.5 Problems during the activities of daily living

Most elderly people prefer to live in their familiar living environment and wish to perform their daily activities independently to increase self-esteem and self-determination. The elderly performs many different types of activities at home, including basic ADLs (clothing, feeding and toileting) and instrumental activities of daily living (IADLs). Activities included in this include managing finances, cooking, shopping and transportation (Giebel & Challis, 2015). Arguably, these activities require high-level cognitive functioning because these activities consist of many steps and require different objects. The elderly faced various kinds of difficulties during these activities such as task sequencing, finding things, operation of appliances, spatial orientation and navigation (Bosco & Lancioni, 2015; Wherton & Monk, 2010).

The focus of this study is to aid in wayfinding and cooking activities. Wayfinding, the ability of navigating from one place to another without becoming lost, is difficult for elderly people with dementia (Passini et al., 2000). Moreover, knowing one's location, remembering the location and navigating from one place to another is dependent on many cognitive and sensory abilities (Davis et al., 2008). Similarly, cooking also requires strong cognitive functioning because it consists of many steps and requires different objects. Task sequencing is one of the major problems the elderly face during a cooking task. Task sequencing refers to the ability to decompose tasks into sub-steps. For a successful execution of the overall task, the sub-steps need to be combined in an appropriate order (Peters et al., 2014).

2.6 Consequences of not performing daily activities

Inability to perform ADLs leads to a decrease or even a loss of independence and makes individuals with cognitive disabilities highly dependent on a human caregiver (Peters et al., 2014). To perform the ADLS successfully, these people are reliant upon on the assistance of human caregivers or relocation to residential care settings. Lancioni et al. (2009) suggests that people with a moderate level of AD were physically able to perform daily activities, but they progressively required step-by-step verbal instructions from the caregivers to complete a daily task. This leads to a decrease of independence for care recipients and imposes a high burden on caregivers.

2.7 Ageing in place

Ageing in place has been defined as "remaining living at home in the community, with some level of independence" (Davey et al., 2004). There are two main goals behind ageing in place: First, from the point of view of elderly and their caregivers, most of the elderly prefer to stay in their homes as long as possible. The main reason behind this that most of them fear losing their independence, leading to emotional stress, depression and reduced well-being. Second, from the perspective of policy makers, as care homes are much more expensive than provision home (Iecovich, 2014). Assistive technology has the potential to help elderly people to age in place and reduce the expenditure for policy makers (Robinson et al., 2013). Various assistive technologies have been developed to provide ageing in place for the elderly, including tele-monitoring (Czaja et al., 2013), tele-care, tele-medicine, tele-health and other (Armas et al., 2009). These technological systems keep the elderly and elderly with cognitive impairment in their homes and delay the entry in nursing care homes for as long as possible (Robinson et al., 2013). Nevertheless, none of these systems encourages the elderly to perform their daily tasks by themselves.

2.8 Caregivers

Family caregivers and informal caregivers refer to an unpaid family member, friend, or neighbour that supports elderly people with cognitive impairment and assists them with ADLs and IADLs (Reinhard et al., 2008). Our ageing population means the prevalence of cognitive impairments such as dementia will increase (McHugh et al., 2012). Due to this progression, caregiver assistance for the elderly in ADLs becomes increasingly important, allowing them to complete daily tasks (Reinhard et al., 2008). Informal caregivers can effectively decrease their care time and responsibility if assistive technology is used. Formal or paid caregivers may also benefit from assistive technology to keep care hours within the authorised amount of care and make the job of formal caregivers easier if its modesty increases formal care hours (Anderson & Wiener, 2015). Smart home technologies can help family caregivers to assist the elderly in their daily activities, especially as they live at a distance and/or have competing demands for work (Huber et al., 2013). At home, technologies can provide "peace of mind" concerning the safety and daily activities of elderly people who are ageing in place (Huber et al., 2013).

Recently, some of our colleagues from our research group (Hautala et al., 2017) conducted an online survey with 53 caregivers to examine the use of ICT in the caregiving of the elderly. During this survey, they found out that the elderly need assistance in various activities such as moving, both outdoors and indoors. Moreover, the results of the study show that 15 participants used ICT equipment to help care recipients from a distance and 12 had used ICT equipment when assisting on-site. In another study, a set of assistive technologies was experimentally tested with elderly people with memory disorders (Nauha et al., 2016). Additionally, these technologies were tested to support and facilitate the work of nurses and family caregivers. These technologies consisted of a smart flower stand to detect falls, a GPS safety bracelet to monitor location, a reminder with motion sensors to prompt about the daily activities, etc. Because of this study, they researchers revealed that assistive technologies can support and facilitate the work of care staff and family caregivers if the devices have sufficient utility, usability, and personalization to the user's specific usability needs (Nauha et al., 2016).

3 Related research

The aim of this chapter is to present the related research used in elderly assistance from technical devices for homes equipped with technology. Additionally, AAL focusing on assisting the elderly to live in their familiar environment are discussed with examples. Prompting technologies are clarified that plays an important role in smart homes in guiding the elderly for activity initiation and completion. Next, projection-based AR and remote collaborative environment descriptions and available solutions are discussed, as they are the focus point in this thesis. At the end, the importance of technology acceptance by the elderly is explained.

3.1 Assistive technology for the elderly

Assistive technologies provide one of the possible solutions to promote autonomy for the elderly and reduce caregivers' burdens. The general definition of assistive technologies is, for most cases, "Any device or system which assists a person to perform tasks they would otherwise unable to do or improving their independence, safety, security and dignity." (Stowe & Harding, 2010; Bonner & Idris, 2012). A useful assistive technology for the care recipient and for his or her caregivers must be autonomous, non-invasive, and must not require explicit input, as this can increase the burden on care recipients and overworked caregivers. Researchers have developed various assistive technologies to support the elderly in their daily routines such as prompts and reminders, communication devices, memory aids, safety devices, devices supporting everyday tasks, and leisure activities (Evans et al., 2015; Robinson et al., 2013). Additionally, there were many remote-care systems developed to support the elderly in daily routines, such as tele-care, tele-health, tele-medicine, and tele-monitoring (Robinson et al., 2013; Stowe & Harding, 2010). Remote care systems have many advantages, such as saving the elderly's time and cost of hospital visits and can delay entry into nursing homes. Table 2 illustrates the assistive technologies and their use. However, these systems lack the functionality of involving and encouraging elderly to perform their daily activities independently, which is important for their physical and cognitive enhancement.

Table 2. Assistive technologies and their use.

No	Assistive technologies	Usage
1	Tele-care: Robinson et al. 2013	Providing care using community alarms, sensors to monitor movement, reminders about tasks, surveillance outside the home
2	Tele-health: Robinson et al. 2013	Vital signs monitoring, assistance with medication management
3	Tele-monitoring: Gokalp & Clarke, 2013	Remotely monitoring the activities of daily living using various sensors such as pressure sensors, motion sensors, video sensors and optical sensors
4	Tele-medicine: Stowe & Harding, 2010	Providing remote consultation and treatment to patients, health, education and transfer of medical data
5	Ambient assisted living: Rashidi & Mihailidis 2013	Assistance in daily activity, mobility assistance, social inclusion and communication

3.2 Smart homes

A smart home is a living environment augmented with various types of sensors, actuators, smart appliances, and networks (Rashidi & Mihailidis, 2013) (Memon et al., 2014). Its facilities ageing in place by assisting the elderly in recognizing and monitoring daily activities, with fall detection/prevention, and providing a reminder system (Cheek et al., 2005) and assistance for those with hearing, visual or cognitive impairment, thus increasing their autonomy (Memon et al., 2014). Alam et al. (2012) further define smart homes as an application that can assist or automate users through various forms such as ambient intelligence, remote home control or home automation systems.

Smart home technologies may provide novel solutions to ageing in place and increasing the autonomy of elderly people with cognitive impairment and reduce caregivers' burdens (Seelye et al., 2012). Some smart home technologies have been developed to support the elderly and elderly people with dementia to live independently at home, as described in Table 3. The inclusion of augmented reality in the home environment makes it more immersive. Augmented reality techniques can enhance the user's view of the environment through additional computer-generated graphic information. That virtual information can be seamlessly added into the environment and would be projected at the right location and with the right orientation and be updated in real time. Moreover, projected augmented reality project data directly onto the user's surroundings.

Table 3. Example of smart home systems.

No	Title-Author	Applications
1	Aware Home: Kidd et al. 1999	Uses a combination of artificial intelligence, multimedia technology, mobile computing and robotics to predict the behaviour of a single inhabitant
2	CASAS: Rashidi & Cook, 2009	An adaptive smart home that utilizes machine learning techniques to discover patterns in residents daily activities
3	GatorTech: Helal et al. 2005	Automatically closes the blinds to reduce glare, provides medication reminders, and orders for soap and paper refills
4	Easy living: Brumitt et al. 2000	Migrating windows, contact anyone, anywhere, child care assistant, vision based home automation
5	UbiHome: Oh & Woo 2004	Entrance control service, finds lost objects, danger-preventing service, a gesture command controller
6	Ubiquitous home: Yamazaki, 2006	Track and identify multiple residents using active badge system. Active and passive RFID detects and recognizes inhabitants, plasma panels, liquid crystal displays and microphone enable user interaction
7	SELF: Nishida et al. 2000	An intelligent environment which observes a person's behaviour using distributed sensors invisibly embedded in the daily environment, and extracts physiological parameters from them
8	Vainio et al. 2008	Assist the elderly to live at home indepently, it can provide residents information to caregivers with respect to daily rhythms, sleeping orders, and medicine taking.
9	SOPRANO: Sixsmith et al. 2009	A cognitive orthotics system for people with AD, which monitors the performance of routine tasks and provide prompts using ubiquitous sensors-.

3.3 Ambient Assisted Living (AAL)

Ambient assisted living (AAL) is focused on assisting the elderly to live independently in their preferred environment. It refers to ICT systems and services that integrate sensors, actuators, smart interfaces, artificial intelligence, and communication networks into the homes and lives of the elderly, improving the quality of the lives of the elderly and their caregivers. AAL technology requires a series of objectives (Calvaresi et al., 2016; Blackman et al., 2016) as guidelines to design or develop any new system

- Extends the time the elderly can live in their preferred environment by increasing their autonomy and independence
- Operates automatically and unobtrusively in the background
- Facilitates and enables continued participation and engagement in activities at home and outside
- Supports caregivers, families and care organizations

Based on different literature reviews, various AAL technologies provide support to the elderly (Calvaresi et al., 2016; Blackman et al., 2016):

- Identification of ADLs
- Indoor and outdoor position tracking
- Health-monitoring and emergency-alert devices
- Monitoring vital signs
- Social support and communication

Based on the guidelines and examples above, this study focuses on designing and developing systems that can support the elderly living an independent life in their natural environment with the help of ICT.

3.4 Prompting technologies

Prompting technologies can be described as any form of verbal and non-verbal interventions (Das et al., 2011), delivered to assist the elderly with cognitive impairment with activity initiation and completion. Various types of prompt are used in smart homes to help the elderly to complete IADLS, for example auditory, pictorial, video and light (Tassel et al., 2011). A prompt is a hint, reminder or suggestion that supports the elderly completing a task in a home environment (Tassel et al., 2011). Furthermore, researchers (Das et al., 2011) define prompts as any form of verbal and nonverbal intervention delivered to a user based on time, context or acquired intelligence that helps in the completion of an activity. Normally, a task, such as cooking, hand washing, tooth brushing or dressing are defined as a sequence of steps organized in a time-frame (Peters et al., 2014; Wherton & Monk, 2010).

To decompose the tasks into sub-steps called task sequencing, and to complete the task successfully, the sub-steps need to be combined in an appropriate order (Peters et al., 2014; Wherton & Monk, 2010). People with cognitive disabilities tend to forget or stuck in task execution, and external intervention by a caregiver is necessary for its completion (Peters et al., 2014). Caregiver reported that various difficulties associated with people with MCI during IADL initiation and completion (Seelye et al., 2012). The goal of current prompting technologies is to be unobtrusive, flexible, and deliver prompts during an activity when crucial based on complex contextual information indicating the appropriate time, and situation (Seelye et al., 2012; Peters et al., 2014).

The COACH prompting system assists older adults with dementia through hand washing (Mihalidis et al., 2008). Two main goals were described in this system: First, the amount of hardware should be minimized, and the system should function without explicit input from the user and the caregiver (Mihalidis et al., 2008). The TEBRA (Teeth Brushing Assistance) system assists people with moderate cognitive disabilities in the execution of brushing their teeth. The system provides audio, pictographic, and video prompts during the task (Peters et al., 2014). Ultimately, the most crucial issue regarding prompting technologies is that the level of prompting required for a given task will vary between individuals over time, possibly even on a day-to-day basis as the dementia progresses (Boyd et al., 2017). Boyd et al. (2017) conducted a study with nine pairs of participants to evaluate four different types of prompts. The participants were consisting of a person with dementia and a carer and they perform two simple tasks: “Card-and-envelope” and

"CD player task". Based on this study, text and audio prompts were a clear and effective means of enabling a person with dementia to carry out simple tasks as compared to picture and video prompts.

As mentioned earlier, prompting technologies are well-known technique to assist the elderly in their daily activities. However, the efficacy and feasibility of these technologies need to be evaluated with the population of interest. To develop an efficient prompting system the researchers should collaborate with geriatrics, medical experts and designers to design and develop smart prompting systems to help elderly in their daily activities. Therefore, the goal of the study is to use, flexible and unobtrusive prompts to help elderly and elderly with dementia in outdoor navigation activity and complex indoor cooking activity. We proposed various solutions using prompting technologies to increase the independence of the tlists some of the prompting systems developed for people with dementia.

Table 4. Description of prompting systems.

No	Title-Author	Stages of Dementia	Description	Activity
1	COACH: Mihalidis et al. 2008	Mild to moderate	Recognizes the hand washing activity and provides a step-by-step plan in the form of useful prompts	Hand washing
2	Autominder: Pollack et al. 2002	Mild to moderate	Provides context-aware reminders for unattended activities using environment sensors	Daily living activities
3	Boyd et al: 2017	Mild to moderate	Provides text, recorded voice prompts, picture prompts, and video prompts to a person with dementia through a multi-step task	General activities
4	Ambient kitchen: Olivier et al. 2009	Mild to moderate	Utilizes RFID readers, six cameras integrated into the walls of the kitchen, accelerometers attached to kitchen objects, cupboard doors and utensils	Kitchen activities
5	GUIDE: O'Neill et al. 2010	Cognitive impairment of vascular origin	Scaffolds task performance by providing verbal prompts and questions and guidance for putting on prosthetic limbs	Putting on a prosthetic limb

3.5 Projection-based Augmented Reality

The main goal of an AR system is to enhance reality with digital content in a non-immersive way. The most commonly accepted definition provided by Azuma is that AR is a technology that has three key requirements (Azuma, 1997; Azuma et al., 2001):

- Combines real and virtual content in a real environment
- It is interactive in real time
- It is registered in 3D

The three characteristics above defines the technical requirements of an AR system. It must have a display that can combine real and virtual images, a computer system that can generate interactive graphics that respond to user input in real time, and a tracking system that can find the position of the user's viewpoint and enable the virtual image to appear fixed in the real world (Billinghurst et al., 2015). According to Azuma's definition, some sort of display technology is needed to combine the real and virtual images so that both are seen simultaneously (Azuma et al., 2001). AR displays can be classified into three major categories: head-worn displays, see-through handheld displays, and projection-based displays for viewing the merged virtual and real environments (Billinghurst et al., 2015). In this study, we have used projection-based AR displays to develop all the artefacts. Normally, projection-based AR displays use a projector mounted on a ceiling or on a wall. A projection-based displays have the advantage that the user is not required to wear or carry anything, and they can cover large surfaces for a wide field of view (Billinghurst et al., 2015). Projection-based AR displays, however, require a physical surface onto which the image can be projected (Van Krevelen et al., 2010).

Introducing the cameras into the system and applying techniques from computer vision can be helpful in overlaying content onto a physical surface (Jones, 2010; Fuji et al., 2005). In order to overlay the content, the projector-camera system must be accurately calibrated, a three-dimensional scan of the surface must be made, and content must be formulated in a way that adapts to the underlying display surface (Jones, 2010).

According to the above discussion, the projection-based AR displays can be beneficial to the elderly in supporting their daily activities given that, the assisted information can be projected directly onto real objects and real surfaces. With the help of this projected information, the elderly can easily focus on a real task.

3.6 Remote collaborative systems

Remote guidance or remote collaboration is derived from an area of research known as Computer Supported Cooperative Work (CSCW). CSCW systems provide shared visual spaces in which two or more people work together with physical objects to perform a task (Adcock & Gunn, 2015). During these tasks, one party needs help in figuring out how to perform or continue with a task. In a remote collaborative task, a remote expert (the helper) provides instructions to a novice user (the worker) on how to complete a task using various physical objects (Gurevich et al., 2015). An example of such a task for instance, a remote operator guiding the user to fix a printer, or paramedic teams giving first aid (Kirk & Stanton, 2006; Gurevich et al., 2015). Many factors require the worker to ask for help from an expert, for instance, they may lack some knowledge about the object or the operation of task (Gurevich et al., 2015). In our case, the user is an older adult who has cognitive issue such as memory problems, which prevent them from initiating or performing a daily task. To overcome these issues, the use of technology can allow people to collaborate remotely on some daily tasks (Kirk & Stanton, 2006).

According to earlier research, a remote collaborative system should have the following characteristics (Gurevich et al., 2015; Adcock & Gunn, 2015)

- A remote person can easily provide help to the local user
- The local user should see the technology as part of his/her working environment with minimal cognitive overhead
- The local user does not need to wear or operate the device, as their hands must remain free to do the work
- Uses off-the-shelf equipment to keep the costs low

Several mechanisms such as a remote pointer, sketches, and images of workers' hands, have been suggested to enable a remote worker to assist or guide a worker during various tasks involving physical objects (Adcock & Gunn, 2015; Gurevich et al., 2015). AR has also been examined as a solution to demonstrate how to perform various physical tasks in a remote collaboration environment (Gurevich et al., 2015). AR technologies combine virtually represented gestures, and real-world objects that help remote experts to convey the gestures to workers. AR displays can be classified into three major categories for viewing the merged virtual and real environments: see-through handheld displays, head-worn displays and projection displays (Azuma et al., 2001). Gauglitz et al. (2012) used handheld displays to enable digital annotations in a remote collaboration scenario. The camera's view of smartphone or tablet display computer-augmented with digital information required that the worker hold the tablet device in one hand to see the helper's annotations.

Hands On Video (Alem et al., 2011) used a Head Worn Display (HWD) AR system for remote collaboration at a mining site. The video stream taken from a camera mounted on top of the HWD was shown to the helper on a large tabletop display. Several studies have used the third AR approach, namely the camera-projector systems in a remote collaborative environment. Kirk and colleagues (Kirk & Fraser, 2006; Kirk et al., 2007) used camera-projector system mounted on the ceiling to examine projection-based remote gestures. The Illumishare project (Junuzovic et al., 2012) used two stationary devices to create a symmetrical shared workspace to share and annotate physical or digital objects between each user. These projects have used stationary projectors that are limited to a prearranged work area, but also some systems that support workspace flexibility.

The Wearable Active Camera with Laser (WACL) system provides workspace flexibility and mobility afforded by an HWD device. It allows a remote expert to point to physical objects near the worker using a laser pointer (Sakata et al., 2003). The laser pointer was fixed to pan/tilt camera that was mounted on the worker's shoulder. The TeleAdvisor system (Gurevich et al., 2015) provides a hands-free mobile, low-cost solution that supports gesturing by the remote expert while minimizing the cognitive overheads of the local worker. Sakata et al. (2014) have developed a remote collaboration system using Spatial AR techniques that can prevent occlusion problems caused by the instructor's body self when he/she sends clear instructions by whole body gestures and allows instructors to use direct manipulation. Table 5 describes some examples of the projected base guidance system.

Overall, pervious work has explored how remote collaborative systems allow experts remotely to interact with local helpers in a collaborative task with the help of AR. However, the same collaborative environments can be used to help the elderly and the elderly with cognitive impairment in their daily activities. In this setting, the remote caregiver can remotely interact and support the elderly at home in their daily tasks.

Table 5. Examples of projection guidance system.

No	Title-Author	Description
1	WACL: Sakat et al. 2003	Consists of a camera and a laser pointer, the remote helper can see the surroundings of local site and guide the user with a laser pointer
2	GestureMan: Kuzuoka et al. 2004	Projector-camera system on a robot platform, the remote helper can control the robot's movements and pointer with laser pointer
3	TeleAdvisor: Gurevich et al. 2015	Consists of a Pico- projector and two cameras mounted on top of a tele-operated robotic arm to the worker's side and an interface to view and control the camera on the helper's side.
4	Sticky light: Adcock & Gunn, 2015	Experts draw annotations directly onto the worker's workplace using a piece-projector, system can be worn by the worker and projected annotations may move with the demands of the worker's environment
5	Projector camera system: Kown et al. 2016	A projection-based AR system for elderly users, remote helpers' annotations are projected on the real object and the elderly can easily check the annotations during a daily task.

3.7 Technology acceptance by the elderly

As mentioned, the elderly prefers to live independently in their familiar environment. However, at the same time, they tend to be very "skeptical" toward supportive technologies in their home environment. During research by Ziefle et al. (2011), they found that elderly people have a lower degree of acceptance toward medical home monitoring systems than younger groups. Researchers have explained the various reasons that the influence elderly regarding ownership and level of use of technology (Peek et al., 2016).

For example, the elderly may be unaware of technological solutions could benefit them. Trust towards the use of technology is another important reason that must be considered when developing assistive technologies (Montague et al., 2009). For instance, technology that the elderly did not trust was more likely to be rejected (Lee & See, 2004). To gain the trust of an elderly person and acceptance towards a, technology is highly dependent on their specific personal, social and physical context (Peek et al., 2016). Other qualitative studies suggest that the acceptance of technology by the elderly is influenced by the perception of the properties of technology, perceived consequences of using the technology, perceived personal proficiency in using the technology, the perceived need for the technology, and the willingness to invest effort in using the technology (Peek et al., 2016).

Conversely, researchers have also asserted that the technology is the key enabler for the elderly to live independently in various domains, such as the ability to perform daily tasks, communicate with others and stay physically active (Smarr et al., 2012). The acceptability of technology among the elderly is dependent on the interaction between the perceived need for assistance, the efficiency, reliability, simplicity and safety of the technology, and its availability and cost (Czaja et al., 2013). Two models often employed in technology acceptance studies are the Technology Acceptance Model (TAM) (Davis, 1989) and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003). These models provide a questionnaire for measuring target user perceptions of the technological system, with the goal of predicting actual system use and other factors.

Therefore, it is crucial for researchers to consider the acceptance of technology by the elderly and some of these models while designing technological interventions for them.

4 Research method

The Design Science research framework by Hevner et al. (2004) has guided the research implementation of this study. According to Hevner, design science addresses important unsolved problems in unique or innovate ways or solved problems in more effective and efficient ways. Design science explains the models and guidelines that support researchers in how the new idea becomes embedded in purposeful artefacts and when those artefacts are field-tested in real-world environments. Hevner provides researchers with seven guidelines and three inherent research cycles to produce valid artefacts. All these guidelines are briefly explained here, a detailed discussion of each of the seven guidelines is presented in the subsections. The first and most important of these guidelines is the research must produce an artefact that is created to address an organizational problem. Furthermore, the artefact should be relevant to the solution of an important business problem. The artefact must be rigorously evaluated for its utility, quality and efficacy. The research should provide a clean and verifiable contribution and rigorous methods should be used for the development of the artefact and its evaluation. The development of the artefact should be a research process which based on the available tools and methods, reveals the solution to a given problem. Finally, the research must be effectively communicated to both technologies-oriented and management-oriented audiences.

The following subsections describe the design science process of this dissertation in detail, following the categorization introduced in Peffers et al. (2007) while an overview can be seen in Figure 3. Additionally, the research cycles are discussed in detail in section 4.7.

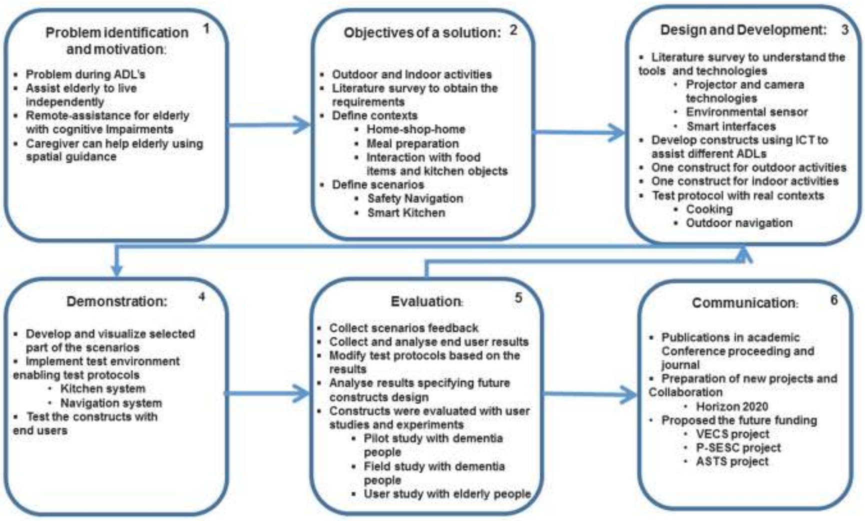


Fig. 3. The research process according to Peffers et al. (2007).

4.1 Problem identification and motivation

As described in the related work section of this thesis, the elderly wanted to perform ADLs independently. The deterioration of health hinders the elderly to perform the ADLs independently, technology can provide solutions to guide the elderly towards completing an activity. To understand the problems the elderly faces during ADLs, a background literature study was conducted. Based on the literature survey all the requirements were gathered and transformed into scenario videos. The idea behind these scenario videos was to visualize how the elderly could be assisted using technology in various ADLs, including going to a shop from home, visiting a friend or doctor, and cooking at home independently. These scenario videos were presented to scientific forums and to a multidisciplinary team. This team comprised information processing scientists, geriatrics, and experts from the gerontology field. Based on rigorous discussions with them, the final requirements were collected for this research work. Before designing the constructs, a literature survey was performed to reveal the more up-to-date and suitable tools and technologies. The main idea behind the selection of these tools and technologies was to see how the elderly would adapt and adopt the constructs. Again, we rigorously discussed the selected tools and technologies with information processing scientists, geriatrics, and expert from the gerontology field.

Modern state-of-the-art information and communication technologies render it possible for remotely located people to break barriers of distance in space and assist others in similar ways to those they can perform when they are co-located. The past two decades have seen the development of many remote collaborative systems where experts from a remote site to assist/guide workers in a local environment. Relatively less attention has, however, been given to remote assistance to elderly people in which a remotely located caregiver can assist elderly in his/her familiar environment. As technology becomes simple and easy to use, the elderly would be able to adapt the new technology in their homes and other places. There are various situations in which the elderly would require assistance from someone, such as family or friends, yet the unavailability of formal and informal caregivers makes the situation difficult.

In this thesis, we propose solutions to assist the elderly in their daily outdoor and indoor activities. For outdoor activities, we propose two constructs that assist the elderly in their navigation activities. For indoor activities, we primarily focused on cooking activities and proposed four constructs. These constructs were designed based on the use cases originating from the local research infrastructure and research projects to which the original publications of this work contributed. Each construct provides a solution to remotely assist the elderly in ADLs.

4.2 Objectives for a solution

The constructs can assist the elderly in different activities using various modern ICTs. The constructs can help the elderly live independently in their familiar environment for as long as possible and can assist them whenever they require help. Through examining the features of the constructs assisting the elderly in cooking and navigation activities using various modern ICTs, new constructs can be developed to help the elderly in other daily activities such as bathing, medication, shopping, etc.

4.3 Design and development

Four constructs instantiations, more specifically, two mobile projection systems (Constructs 1 and 2) and two fixed projection systems (Constructs 3, 4, 5 and 6), each were developed to assist the elderly in outdoor and indoor activities, see Table 7.

Construct 1 is a tele-guidance prototype system using laser projection to assist the elderly in outdoor navigation. This entails novel user interface on a cane that presents visual information on the floor during walking and connects the elderly to a remote caregiver via the Internet. In Construct 2, a wearable safety navigation and identification prototype was developed for the elderly. A device with a laser pointer assists the elderly in identifying real objects and laser projection arrows assist them in outdoor navigation. The fixed projection was used in Construct 3 and 4 to design smart kitchen interfaces that provide the elderly with step-by-step instructions on how to complete a cooking task. Both interfaces project visual prompts onto the tabletop to identify the objects used in a cooking task.

In Construct 5, we developed an information system that can help a remote caregiver in assisting elderly people with cognitive impairment in a kitchen environment. Additionally, we set up a multiple camera system in a kitchen environment to obtain the full view of the kitchen. The reason for the development of this construct was twofold: Firstly, the idea was to develop an information system that can help the caregiver by automatising the cooking activities based on the real cooking date. Secondly, we used a single camera in Construct 3 and 4 that covers a small kitchen area that. In Construct 6, we designed, developed and evaluated a remote assistive system that helps the elderly to find and locate objects from hidden places.

4.4 Demonstration

The smart cane prototype of Construct 1 was demonstrated in a user study to evaluate the visibility of the projected arrow and usability of the system. The wearable navigation and identification, prototype of Construct 2 was tested with a user group to investigate the potential of the proposed system. The smart kitchen prototype of Constructs 3 was analysed by a small group of elderly participants. A grid-pattern interface of Construct 4 was developed for the remote caregiver to send detail instructions to the elderly during a cooking task. An information system to assist the remote caregiver and a multi-camera system of Construct 5 was developed for a kitchen environment. The prototype of Construct 6 developed for the kitchen to find and identify objects in hidden places was thoroughly analysed with twelve elderly participants. Table 6 depicts the publications responding to each research question:

Table 6. Publications responding to each research question.

Artefact	Publication	R.Q
Constructs 1 and 2: Outdoor Activities	I, II,	1.1
Construct 3: Indoor Activities	III, IV, V	1.2
Construct 4: Indoor activities and technology acceptance	VI	1.3

4.5 Evaluation

Each construct was originally developed to assist elderly people in their daily activities, but it was hard to find elderly people to participate in testing the developed artefacts. However, we managed to evaluate the feasibility and usability of each construct with a small number of participants. This evaluation gave us future ideas for the improvement of each construct. The original evaluations were as follows: In Construct 1, we equipped a cane with laser projection to assist the elderly in outdoor navigation. During the evaluation of Construct 1, we established that laser projection is feasible for elderly people those who used a cane frequently as a mobility aid but not for those who has some physical problems such as shaking hands. For Construct 2, we developed a wearable device for identifying real objects and assistance in outdoor navigation. We evaluated this construct with six participants in an indoor environment, which confirmed the feasibility of the system. Nevertheless, this device needs to be tested in real situations and in harsh conditions.

For the smart kitchen prototype of Constructs 3, we observed two elderly participants in a kitchen environment. As a result, we examined where we can use indirect projection and when direct projection is needed. In Construct 4, we designed a grid-pattern interface to help caregivers to provide instructions to the elderly remotely. After observing the interfaces of Construct 3 and Construct 4, we discovered that we need a system that covers the entire kitchen site. Consequently, Construct 5 covered the entire kitchen using multiple cameras and a pilot study was performed to conduct the feasibility of the system. After implementing three smart kitchen prototypes, systems for open places, i.e. tabletops, we designed, implemented and evaluated a projection-based system to help elderly to find items from hidden places such as a cabinet during a task.

4.6 Communication

All the design artefacts were published in recognized and established conference and journals. Furthermore, the design artefacts helped us to write research proposals for funding and guide us to collaborate with others.

4.7 Research cycles

The design science research cycle in Figure 4 is a combination of an information system's research framework and three inherent research cycles: relevance, design and rigour cycle (Henver, 2007). In an example work, Zahedi et al. (2016) adopted a design science approach to design, develop and evaluate the augmented virtual doctor office (AVDO). The author designed a virtual world, namely an online place to provide group medical visits in cyber space (Cyber GMV). This work was intended to address two major shortcomings in telemedicine and GMV: lack of naturalness and patients' privacy concerns. In another work, Barjis et al. (2013) designed and developed a tele-monitoring system for inhabitants living in the rural areas of South Africa. This study was driven by a real-world problem and was based on a design science approach. The developed system can contribute better and more efficient healthcare for the inhabitants of rural areas.

The relevance cycle initiates design science research with an application domain that provides the requirements for the research as input along with the acceptance criteria. An application domain consists of people, organizational systems, and technological system that interact to work toward a solution. In this study, the domain consists of the elderly users and the activities of daily living they performed independently at home. Additionally, the research focused on gathering the problems the elderly face during ADLs and providing solutions for research purposes. In this study, the opportunity and the research question in general become, specifically, how to develop solutions that can benefit the elderly in performing their ADLs using projection technology.

This study forms of various multidisciplinary research projects. Consequently, various artefacts were designed and developed during these research projects. Various stakeholders such as information processing scientists, medical technology experts, experts from gerontology, and geriatrics, provided requirements and feedback for each construct. To design and develop these artefacts various technologies were used such as laser projection(Publication I and II), fixed projection(Publication III, IV, V, and VI) , sensor/actuators (Publication I, II, III and IV), remote assistive technology (Publication I, II, III, IV, V, and VI), smartphones (Publication I and II), and WI-FI technology (Publication I, II, III, IV, V, and VI). The relevance cycle not only focuses on providing the requirements as input, but also defines the criteria for the ultimate evaluation of the research results. The evaluations were conducted within both laboratory environments and in the care home. The evaluation in the laboratory environments was conducted by setting up the prototype systems. The participants were invited to the laboratory for feasibility and usability of the prototype systems. This study is presented in Publication V and VI. The evaluation performed in the care home is presented in Publication I, II, and III.

The next step of the process is to bring past knowledge to the research and to ensure the researchers thoroughly research and reference the knowledge base to guarantee that the design artefacts produced are research contributions. This study selected the theories of taxonomy of ADLs and the problems and contexts of ADLs for constructing and evaluating the artefact. New prototypes, test protocols and test plans were made that were an extension to the original theories and methods. As research contributions to the knowledge base, the researcher tried to address the visualization and occlusion issues users faced during assistance from the remote caregiver.

The internal design cycle iterates more rapidly between building, and developing artefacts, and their evaluation and subsequent feedback, to refine the design. Various artefacts were developed, as discussed in the following chapter, and each tested all various experimental situations with real users.

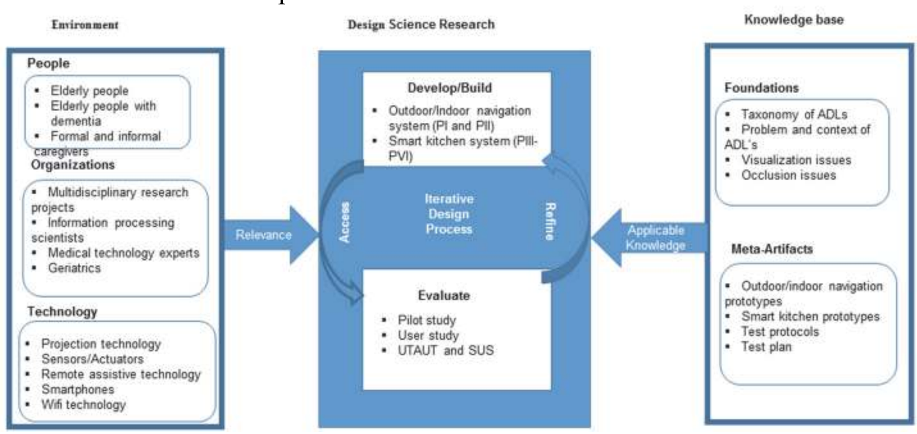


Fig. 4. Reproduced from Hevner's (2007) paper on design science research cycles.

5 Results

In this chapter, we present the summary of each study presented in the original publications included in the dissertation. The dissertation consists of six publications discussing two constructs developed for navigation activities and four constructs developed for cooking activities. Two constructs utilize the laser projection technology to solve the wayfinding problem and can be embedded to pre-existing assistive devices. Other four constructs utilize the fixed projection technology to solve the cooking activities problems and can be part of the existing infrastructure.

5.1 Construct 1: A Laser Projection-based Tele-guidance System Embedded on a Mobility Aid

Publication I describe the development of a tele-guidance system for elderly people that can assist them outdoors without an escort, while their caregivers can monitor them from a remote site when they need any help. The author specifically proposed the concept of this system and coordinated its design and implementation. The author planned and designed the user studies with the help of his supervisor. A visiting researcher Dr. Goshiro Yamamoto from NAIST, Japan, implemented the system. As the corresponding author, the author of this dissertation shared in the writing of the paper.

5.1.1 Purpose

The main purpose of this support system is to assist the increasing number of elderly people around the globe who have trouble in orientation, navigation and wayfinding. Simultaneously, the increase of older adults inevitably requires more caregivers. Therefore, there is an urgent need to realise safety-supporting systems that can offer elderly people with cognitive impairments a normal life and enhance the quality of life with the support of fewer caregivers.

The challenging aspect of this research was to find a suitable solution for the abovementioned problem using available information and communication technologies (ICTs). Figure 5 shows the overall concept of a safety navigation system. The main idea behind this system is to equip existing assistive devices such as canes, or rollators with the latest ICT technologies to provide visual cues during walking as shown in Figures 5b and 5c. Furthermore, a new wearable device was designed that provides key-code assistance that aids the elderly in opening the security code lock, as depicted in Figure 5a.

Frequently, older adults use canes, wheelchairs and walkers as assistive devices for mobility. Our aim is to develop a novel user interface on a cane that augments visual information on the floor to provide wayfinding assistance as shown in Figure 5b. This novel user interface connects the elderly to the remote caregiver via the Internet, allowing the remote caregivers to monitor the elderly during outdoor activities and guide those using visual cues whenever needed.

In earlier studies, the researcher designed a smart cane system for the elderly to reduce the risk of falls (Winston et al., 2008). For wayfinding, spatial light cues have been used for people with dementia (Stefaine et al., 2012). In this research, a cane is used as a mobility aid device that indicates the direction with an arrow, created by laser projected onto the ground for guiding the elderly outdoors. The purpose of this research is to free the older adults from interacting directly with the system. To test the visibility of the projected arrow and usability of the proposed system a user study was conducted with elderly participants at a healthcare centre. Preliminary results indicate that this kind of system is useful for specific users, but not however, for everyone.

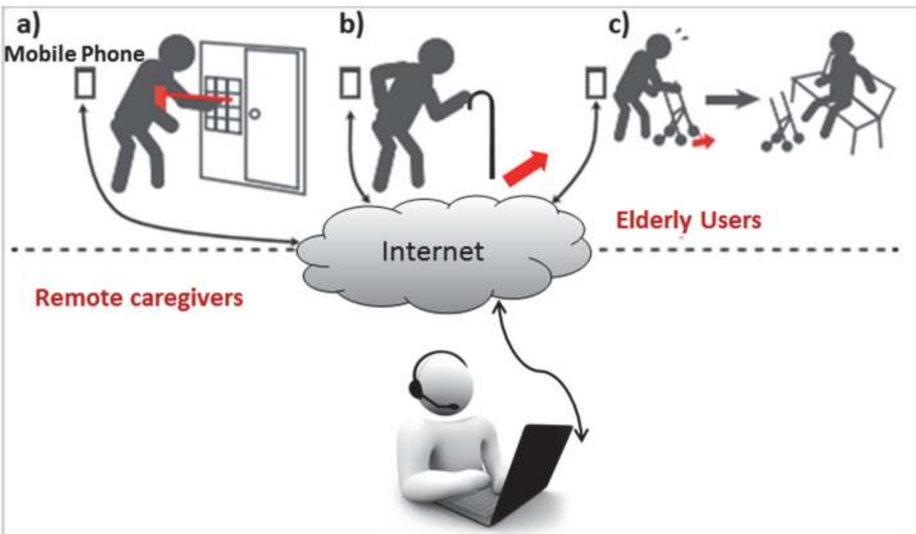


Fig. 5. Safety navigation conceptual overview.

5.1.2 System design

The purpose of this proposed system was to embed various actuators and sensors to a cane for guiding the elderly in wayfinding. Before the actual system design, we conducted a preliminary survey to find out what types of mobility aids are used by elderly people, consisting of a cane, followed by a walker and a wheelchair. Moreover, these mobility aids have, with the support of ICT, possibilities to connect elderly users with remote caregivers by ubiquitous networking. The system has a guidance interface that connects remote caregivers to elderly users via the Internet. For guidance in navigation and wayfinding, a laser projection module is attached to the cane that displays an arrow, indicating a direction that user should go directly on the ground by projection-based drawing. The reason for using laser projection to display the visual information is that the current projectors are not suitable for outdoor or bright spaces and they do not have strong enough light to show information to the user in these conditions. One of the drawbacks of using laser projection is that the laser light can be harmful to eyes. A safety mechanism is thus embedded in the proposed system to avoid this problem. Figure 6 shows the architecture of the proposed system.

The main components of this system are actuators with a laser module to display an arrow, sensors to acquire the orientation information and position of the device, a mobile device that can connect to the Internet, and a controller. The digital compass provides the orientation data, which is used to calculate the position of the actuators so that the arrow points in the direction defined by the remote caregivers. After calculating, actuators are moved to rotate the laser module toward the direction. A pressure sensor, a distance sensor, or a button can trigger the contact between the tip of the cane and the ground, to realise the safety mechanism.

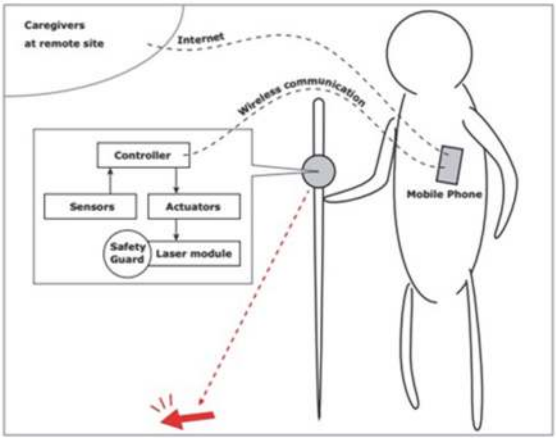


Fig. 6. Architecture of the proposed system.

5.1.3 System development

The purpose of the experimental study was to ascertain the usability of the proposed system and the visibility of the laser-projected arrow by through observations. The system consists of a cane made of bamboo and, a commercially available laser pointer containing the arrow drawing functionality. To cover the whole range of arrow rotation, two servomotors are combined in series, without any gear. To achieve the head direction of the cane a digital compass module HMC6352 was used. An Arduino UNO micro controller manages all these sensors and actuators. A laptop computer was used as a remote server to communicate interactively with the micro controller embedded on the cane using wireless communication. A remote user can provide one of eight directions to the elderly for guidance. The microcontroller received the selected direction and calculates the angles of servo motor rotation.

5.1.4 User test design

A user test was conducted to confirm the visibility of a projected arrow on the ground and the usability of the proposed system. To verify the visibility of the projected arrow, two parameters were set: that the user can recognize the shape of the projected arrow and to reveal which distances between the cane tip and projected arrow were easiest to see. Figure 7 demonstrates how system provides four positions for displaying the arrow.

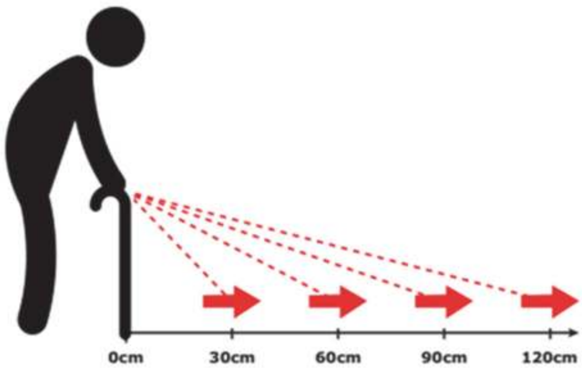


Fig. 7. The system provides four positions for displaying the arrow.

An actual user test was conducted with six participants in the age range of 89−94. All six participants lived in a healthcare centre and received assistance from the healthcare staff whenever needed. During the user tests one Finnish therapist supported the participants with answers to any questions and observed the entire test. Of the participants, three used multiple mobility aids, with five using canes, three using rollators and one using Nordic walking sticks.

A simple task was prepared for the test subjects, namely, to walk from a start point and follow the projected arrow and reach the destination. This path had two corners along the route. Four trials with the various positions (30cm, 60m, 90cm, 120cm) for the projected arrow were carried out. The reason behind using these ranges was to check how far an elderly could see the projected arrow. The route in each trial was constant. Usability was measured with a questionnaire.

5.1.5 Results

There were different views regarding the distance between the cane tip and projected arrow. According to the results of the questionnaire data, one preferred the projection position of 30cm, one preferred 60cm, one preferred 120cm and one had no preference. The data for the other two participants were excluded because they could not complete their tasks. The therapist also commented that it was not good for the subject to have the arrow's position located at 30cm because the participants' heads were in a downward position and shoulder hunched. In contrast, if the projected position were longer, the subjects would straighten up their backs. Based on the three participants' opinions, it was not clear which position would be the best.

Based on observational results some problems can be seen to have occurred during the guiding function. Sometimes, test participants lost the projected arrow when the distance between the cane tip and the arrow was too great. Moreover, we found that the laser was always on despite the safety mechanism. Therefore, the researcher had to stop the experiment for safety reasons. However, the results combined with our observations seem promising and the study should be continued further with more participants.

5.1.6 Discussion

The present study evaluated the visibility of the projected arrow and usability of the proposed system. Regarding the distance between the cane tip and the projected arrow, different opinions were given. The reason for the differing views is that this kind of assisted device was a novelty for test subjects and they have never previously experienced using such a device, leading to occasional confusion. For example, user was concentrating on how to use or follow the arrow rather than paying attention to the position. In our opinion, the results would improve once when the test subjects had become accustomed to using the device. To achieve more focused results in the future, we should test the device with ideal subjects in an ideal environment and should consider the characteristics of the users.

Regarding the guiding assistance provided by the prototype system, we observed the following three problems:

- The device shakes
- A cane with a laser pointer might not be suitable for every user
- The system is not sufficiently robust

The problem consists of two parts. The first related to the handling of the cane: to make sure that the cane does not slip from their hands, the participants tried to use more force on the cane, which caused the projected arrow to swing wildly. This handling problem was a result of age-related physical impairment. The second part of the problem is related to shaking hands being a common feature of being elderly. The position of the projected arrows is sensitive to the cane's movement, and, in the case of trembling, it is difficult for older adults hold the cane on the ground. To mitigate the shaking problem, an accelerometer or some other sensor may be used to ascertain the cane's movement and direction. These observations indicated that canes with laser pointers are not suitable for every elderly person, even if they use assistive aid in their daily life. Some test subjects became confused while the system was rotating the arrow to the correct direction because the arrows were moving continuously. As a solution, it is important to add a mechanism to turn the laser light off while adjusting to the correct angle and back on once the correct angle is reached.

There were other comments regarding the size and shape of the arrow. Some subjects said that the tail of the arrow should be longer, or the size might be too small for a short-sighted person. A final observed aspect was that these kinds of assistive device were not feasible for people who are living in the care homes because they have helpers all the time to support them. The results might be different if user studies were conducted with older adults living at home independently.

This research work used a popular assistive device, i.e. a cane, used by the elderly and equipped it with a tele-guidance system to remotely assist in outdoor activities. A prototype system was developed using laser projection and carried a user test with real elderly participants. As a result, there were some issues such as the device shaking and the visibility of the arrow that must be solved for an improved system. According to our observations, it is important to consider the properties of users before developing this kind of system because this system is useful for specific users, yet not for everyone. Lastly, to make an ideal system for a special user group it should be tested with them in an ideal environment. This said, a popular assistive device such as a cane used by the elderly in their daily lives could be equipped with laser projection, if it has strong light and can display a figure on the ground. Moreover, the elderly can be given guiding information from a remote site whenever needed.

5.2 Construct 2: A Navigation Aid for People Suffering from Dementia using a Body-Worn Laser Device

The author of this dissertation contributed to the research, design and implementation of the proposed system. The idea was to design and develop a wearable device for navigation using laser projection, for users who do not require a cane for walking. The author was responsible for arranging the user study with the end users. Jari Tervonen was responsible for implementing the actual device. The author mainly contributed to the writing of the paper. Professor Petri Pulli and Goshiro Yamamoto contributed to the paper writing process and user studies, respectively.

5.2.1 Purpose

Publication II describes the design, implementation and evaluation of a wearable safety navigation and identification device presented in the conceptual overview (Figure 5a) in Publication I. The main purpose of the system is to transmit the video stream from a camera embedded in a chest-worn device. In cases where assistance is needed, the caregiver can remotely access the view of the user wearing the camera. An elderly person connected to a remote caregiver via the Internet that navigates him or her using laser-projected arrows carries this device. Furthermore, this device helps older adults to identify a real object by directly pointing at it using the laser pointer.

Previous research (Mann et al., 2000; Sakata et al., 2003; Kurata et al., 2004) has shown that the laser pointer as a pointing tool enables smooth remote collaboration for simple tasks, such as selecting and specifying real world objects. Our idea is to use a laser pointer as a pointing tool for the elderly to assist them in daily tasks such as for entering the correct number of a security door lock, as shown in Figure 8a, or helping them at the grocery store kiosk to enter the correct product number, as shown in Figure 8b.

Additionally, this intervention helps the elderly with cognitive impairment with both out of home and indoor mobility, independence, and a better quality of life as depicted in Figure 8c. When the elderly cannot navigate safely and freely, the burden on caregivers, community services increases, and the opportunities to act independently and participate fully decrease. Moreover, ageing affects older adults' ability to carry out cognitively demanding processes. For example, their ability to store and retrieve new information declines, such as knowing and remembering several items in a grocery shop or remembering door locks. This system provides a remote view for the caregivers to watch the demented person's view on a smartphone as well as on the Internet. This view helps the caregivers to guide the user with the help of a chest-worn device equipped with a microcontroller and a smart phone. The smartphone camera shows the walking path of the demented person. The laser pointer helps the remote caregiver to guide the elderly person more easily, because it is difficult to rely on verbal instruction alone while giving the instruction through the Internet, especially in a noisy environment.

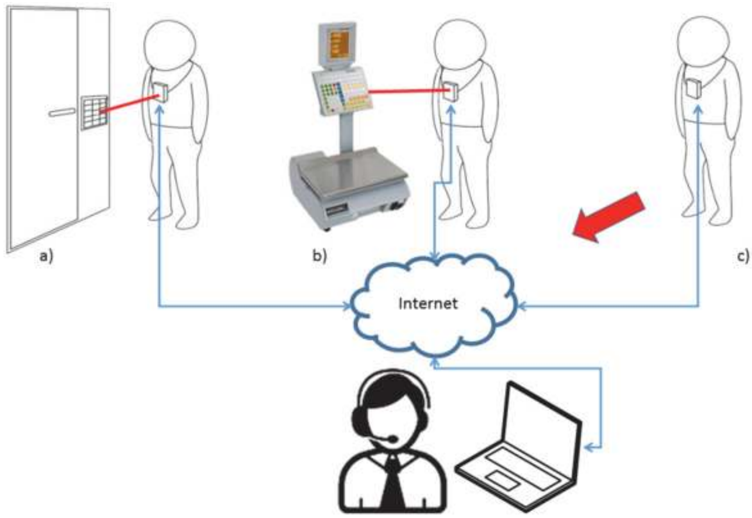


Fig. 8. Conceptual chest based navigation and identification device.

5.2.2 System design

The design of the system was divided into two logical domains

- Hardware domain

The laser-pointing device has an impact on the hardware implementation, as the physical safety of the device must be considered. The weight of the laser and its mount has a significant impact on the design as the user must bear the weight and consequences. The sensors and cameras must align perfectly in order to provide usable information.

- Software domain

On the software side, factors such as communication and availability are closely related. The communication between the remote assistance node and the aid device worn by the elderly person has a direct connection. Issues with the delay in communication and processing power of the device are also addressed in the design of the software.

Moreover, the device must operate in any indoor/outdoor environment, at any time of day or night. The source for the visual cue must be of high contrast. Therefore, a laser is the preferred technology for this system. During the design, it is important to consider safety issues related to the lasers because of the high intensity of energy they create in a small area. To solve this issue, we designed the system in such a way that it is not possible to point the laser upwards and potentially cause accidents.

The laser navigation module consists of 1) the main controller, 2) the battery, 3) lasers and 4) servos. The main controller unit handles the operation logic task and communication with the smartphone. A simple Android application runs on a smart phone that connects with the microcontroller using TCP/IP. Two laser modules are connected to general-purpose input/output pins on the microcontroller: one for pointing the laser at the real objects and the other for projecting the arrow. The lasers can be switched on and off and are moved with four servos, of which two are used the laser beam on the X and Y-axis and other two are used for rotating the projection.

5.2.3 Implementation

The implementation of the prototype system consists of various hardware components, an interface between these components, and four modes of operation

Main components

The main hardware components of the system are shown in Figure 9. An Android smartphone was used as the primary processing and communication device. An Arduino mega 2560 prototyping platform handles the task of providing users with visual cues by directing the laser pointer device with the servo motors. The microcontroller is powered by a battery pack consisting of six batteries.

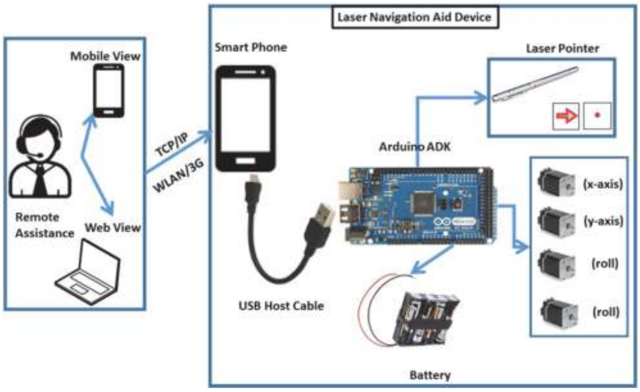


Fig. 9. Implementation of the system.

Interface between components

The interfaces between the various components in the prototype have been kept as simple as possible. The prototype device uses two different methods for communication between components

- Universal- Serial-Bus (USB)

The USB consists of two different device types: hosts and devices. The important distinction between these two is the host supplies the operating power to the bus, enumerates the devices, assigns the address and controls the data traffic (Tervonen, 2014). However, the device reports its communication end points and accepts the address assigned by the host.

- Communication over the internet

The device uses basic TCP sockets to communicate with the network client. A simple client-server model has been implemented in the system in which the navigation aid device acts as a server and remote assistance as a client.

Modes of Operation

We stated four different modes of operation for the device at the time of the design.

- Remote Assistance

The remote assistance application is used by a remote assistant or a caregiver using a personal computer or a mobile device. The user interface provides a live real image feed from the navigation aid device along with data from the sensors attached to the device.

– Pointing

In order to point at the real object accurately, the distance to the target must be ascertained. Figure 10 demonstrates a situation when using separate modules for the camera and laser. The offset between the camera and the laser pointer leads to a problem when trying to point accurately at something that is visible to the camera in the middle of the frame.

– Navigation cues

The laser-projected arrows are used to guide the user to their destination. The laser projects the arrow onto the ground in front of the user, where it is easily seen and recognized. The laser can project the arrow in four directions: left, right, forwards and backwards.

– Laser control and safety measures

The laser-projected arrows are used to guide the user to their destination. The laser projects the arrow onto the ground in front of the user, where it is easily seen and recognized. The laser can project the arrow in four directions: left, right, forwards and backwards.

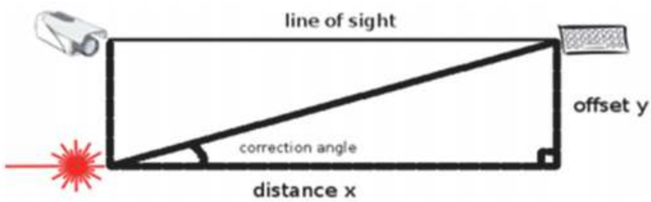


Fig. 10. The angle of correction when the laser and the camera have offset between them.

5.2.4 User study

To investigate if the system has the potential to assist older adults in both indoor and outdoor environments, it was evaluated with the help of senior citizens at a rehabilitation centre. The goal was to test the system in a real-world situation, with the main goal of uncovering errors in both software and design. The user study includes arrow guidance, laser pointing to objects, and the remote user's ability to control the device and visibility of the laser. The user tests consisted of tasks, questionnaires and interviews. All the sessions were videotaped and transcribed. Four males and one female, ranging 81−93 years participated in the user study at ODL, Oulu. Their severity of dementia ranged from between mild to moderate, while walking abilities were normal

5.2.5 Route setup (indoor)

For the turn cue and remote-control tests, two different routes were set up each including two turns. One route was 12 metres, as shown in Figure 11a, and second was 13.5 metres, depicted in Figure 11b. We used short, simple routes to test that the system had a satisfactory level of usefulness, i.e. could the elderly receive navigation cues correctly from the device with no training.

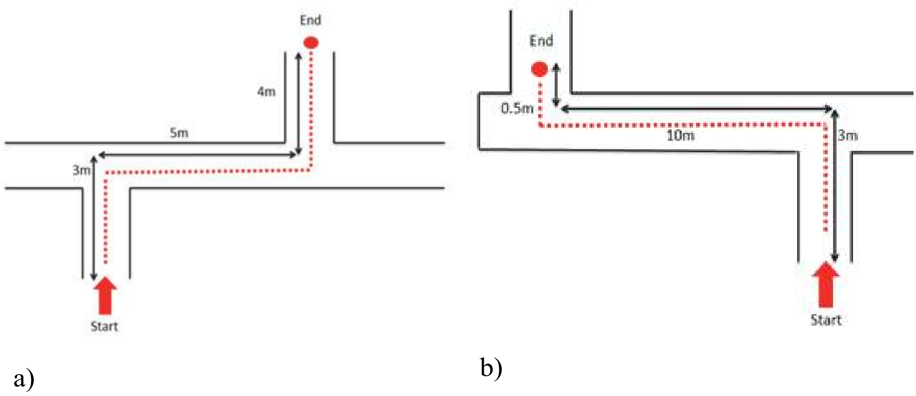


Fig. 11. Route 1 (a) and Route 2 (b).

5.2.6 Pointing test setup

For the pointing test, the idea was to test the viability of the laser pointer when pointing at real objects to steer the attention of the participants. Three real objects with different surfaces (a black mug, a black TV-remote and a reddish-brown book), were chosen and placed on a table at approximately 1.5 meters from the participants. The goal of this test was to examine if the elderly can follow a laser pointer pointing to any object. In earlier work, laser pointers were used for many purposes in remote collaboration systems, but never by elderly people. Figure 12 shows the arrangement of pointing test.

Fig. 12. The arrangement of pointing test.

5.2.7 Results

Based on the questionnaire data, the device can be used for guidance purposes. Participants were willing to use and adopt the new technology. The weight of the device (around 300 grams) was not burdensome when worn for the durations in our tests, which averaged about 2 minutes each. During the route tests, four out of the five participants completed the defined route with a few deviations. Table 7 shows the results of the route tests. Participant 5 informed that the lights in the hallway were too bright to see the laser clearly and therefore he was not able to complete the test. Figure 13 shows the four different arrow directions (left, backward, forward and right) projected during the user test using the wearable device.

The pointing test gave the preliminary results for using a laser pointer to direct the attention of an elderly person. All the participants felt that the laser

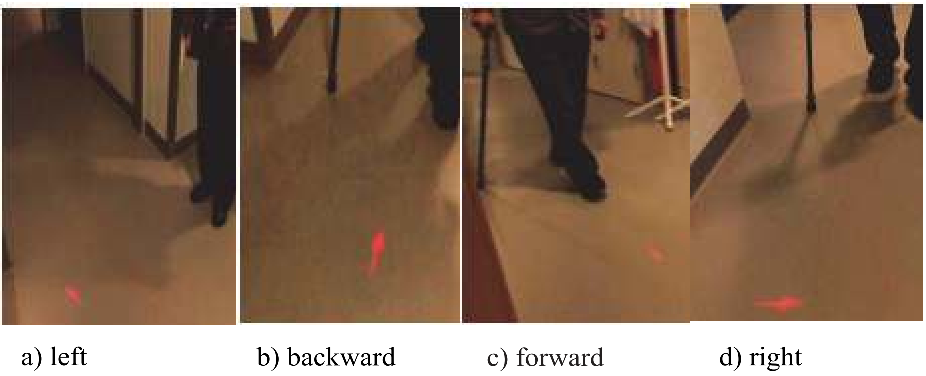


Fig. 13. Arrows shows the direction on the ground (left, backward, forward and right). Reprinted from publication II.

pointer seemed to be an effective way of showing the objects as none of the participants gave a wrong answer during this test. Furthermore, we observed during the test that the black mug was difficult to see because the material of the mug was too reflective, and it affected the visibility of the laser spot. Table 8 clearly shows that the black mug has the highest average time.

Table 7. Route completion details.

No.	Age	Gender	Medical condition	Route	Completed
1	88	M	No problem with memory	1	Yes
2	93	M	Slight problem with memory	1	Yes
3	99	M	Mid-stage Alzheimer's	2	Yes
4	81	F	Mid-stage Alzheimer's	2	Yes
5	90	M	Mid-stage Alzheimer's	1	No

Table 8. Time measured during the pointing test.

Participants	Book	TV-Remote	Mug
1	3,5s	3s	3.5s
2	1s	1s	2s
3	1s	1s	2.5s
4	0.5s	1s	1.5s
5	2s	1.5s	6.5s

5.2.8 Discussion and conclusion

The result of this preliminary testing shows that the device is well suited for navigation and identification purposes. The goal of the system was to evaluate the feasibility of using the laser pointer as a tool to present visual cues for navigation. Additionally, the laser pointer can be used for pointing at real objects for identification. During the pointing test, the elderly was able to follow the laser pointer to real objects, but this needs to be tested in real situations such as opening door locks and entering numbers at a kiosk. Moreover, five participants out of six elderly participants successfully followed the navigation cues projected by the laser to complete a defined path in an indoor environment. One participant did not complete the defined path because the light was too bright in the hallway and he could not see the projected arrow.

Overall, the design of the prototype system was acceptable and adaptable, but some shortcomings were discovered during the user study. Firstly, the latency between the chest device and the remote controller was around 2 seconds, which caused delays during the route guidance. Secondly, the laser needs to be more stable, contrasting the user's body movements. Thirdly, there should be an efficient way to provide power to the chest device as it drains batteries quickly. Lastly, we performed the experiment with relatively few subjects in an indoor environment. In the future, we plan to perform more experiments in outdoor environments, especially in harsh conditions such as snow, slippery and bright conditions.

5.3 Construct 3: Remote Assistance using Visual Prompts for Demented Elderly in Cooking

The author of this dissertation contributed by defining the conceptual idea of the system. The idea was to design and develop a projection-based system that can provide step-by-step information during a cooking task. The author contributed to research, design, and implementation of the system along with Sei Ikeda, a visiting researcher from NAIST. The author of this dissertation served as the corresponding author and contributed to the writing of the publication.

5.3.1 Purpose

This study presents a smart kitchen system for supporting demented elderly cooking in a kitchen environment. Cooking is one of the most important activities that elderly people can perform at home. Consequently, for many people with mild to moderate dementia, these multistep tasks are difficult without support. Wherton and Monk (2010) classified nine types of problems people with dementia faced in a kitchen environment. This study needs to recognize some of these types, such as sequencing problems, finding and identifying objects based on verbal and visual prompts. Earlier studies used various projection methods for pointing to objects in a real environment such as direct projection (Sakat et al., 2003; Kuzuoka et al., 1992), indirect projection, embedded monitors, projected windows and illumination devices. We have used the terms direct and indirection projection in this research work as shown in Figure 13. Direct projection provides visual assistance when objects are being moved in the air, while in contrast. Information that is projected on a nearby surface is considered as indirect projection.

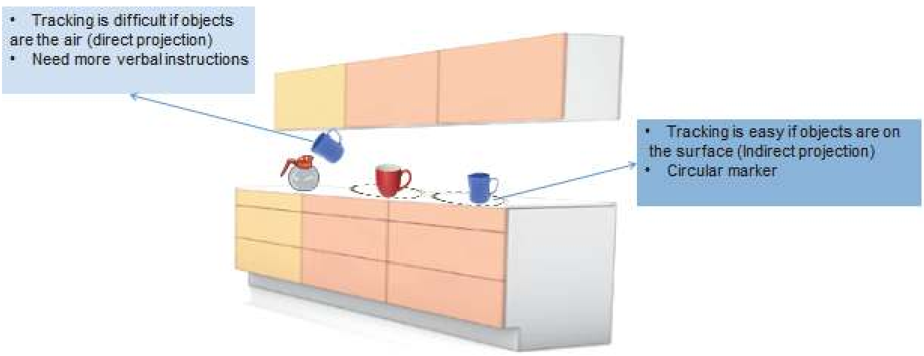


Fig. 14. Illustration of direct and indirect projection.

A typical kitchen environment consists of various objects with glossy and transparent surfaces. Moreover, various objects with different characteristics are used to complete a cooking task. During cooking, some objects are placed on a surface such as a tabletop and some objects are operated in the air such as a coffee pot when filling a cup. Indirect projection better provides visual information if the objects are on the surface because the tracking of objects is easier. Direct projection is used when objects are in the air, making them difficult to track. In the case of a kitchen environment, both direct and indirect projections are required to assist the elderly in cooking tasks. We observed two elderly participants making coffee in a typical Finish kitchen environment. As a result, we examined where we can use indirect projection and where direct projection is needed. A remote caregiver provides verbal and visual prompts to users whenever they require any help. Using projection technology, this system is designed to solve three practical problems:

– Objects with glossy or transparent surfaces are difficult to project with a projector or laser pointer
– A single projecting method is not enough to display visual prompts in a complex kitchen environment
– Remote caregivers are not sufficiently familiar with the kitchen environment

We therefore propose a novel system for overcoming the above problems using the following:

– Indirect projection of circular markers around the target objects
– Use of the proper method is automatically selected using a projector, embedded monitor and illumination devices, based on environmental information
– A remote assistance system developed to support remote caregivers

The system automatically selects flat surfaces to project onto and their reflective properties. Furthermore, the system switches between multiple modes for displaying visual prompts.

5.3.2 System development

The main purpose of the proposed system is to display visual prompts on the glossy and transparent surfaces of a kitchen environment. It is difficult to use direct projection methods, such as projectors or a laser pointer, to project images on these surfaces. Our idea is to focus on a projection method that highlights target objects residing on a surface with the indirect projection of a circular marker around the object. Additionally, visual prompts are presented on a wall by fixed projectors or an embedded monitor, in a like SharedView (Kuzuoka et al., 1992), using a fixed camera instead of an HMC (Head Mounted Camera). With the help of fixed projection, the user does not need to carry or wear any devices. Consequently, they can focus completely on the task. The primary contribution of this research is the proposal of a method that automatically switches between these display modes based on an analysis of images acquired with the camera and projector. Figure 14 provides an example of the implemented system.

Fig. 15. An example of the implemented system using indirect projection to highlight a jug. Reprinted from publication III.

5.3.3 Direct observations

Two Finnish elderly people participated in a coffee making activity with an electric drip coffee maker. The basic information of each participant including Global Deterioration Scale (GDS) and Mini-Mental State Examination (MMSE) is described in Table 9. We set up the proposed system in a kitchen at a senior centre and location was unknown to both participants. They made two cups of coffee and could ask the senior centre staff for support. They followed the step-by-step instructions to make a cup of coffee shown in Table 10.

Table 9. Information of each participant.

Participant	Gender	Age	Name	MMSE	GDS
1	Male	85	JO	18/30	3/15
2	Female	86	MI	24/30	8/15

Table 10. Details of all steps.

Step no	Step detail
1	Take a coffee filter from the cabinet
2	Open and take a dripper
3	Put the filter in the dripper
4	Take a coffee can from the cabinet
5	Take a tablespoon from the can
6	Put two spoons of coffee powder in the filter
7	Insert and close the dripper
8	Take a pitcher from the counter
9	Put water into the pitcher
10	Pour the water into a reservoir
11	Turn power to switch on

5.3.4 Results

Both participants successfully completed the coffee-making task. JO followed the step-by-step instructions and completed the task in five minutes, receiving support from the staff five times to find and operate the objects. While MI completed the task, using the same steps in seven minutes, and received assistance from staff on four occasions. Support staff indicated the positions of each object using visual and verbal prompts. We performed step-by-step analysis to determine where we could use indirect and direct projection in our system, see Table 11. In steps 4, 5, 9 and 11 of JO's performances and steps 1 and 11 for MI's performance, indirect projection of visual markers seems plausible, as the target item in each situation touches or is close to the projectable surface.

In step 10 of JO's performance, the instruction was to fill the pot, indicated by pointing at a part of the coffee maker. However, it was difficult to apply indirect projection because the coffee maker did not contact any projectable surface at that time. In step 7 of MI's performance, she tried to set the dripper and a carafe pot on the coffee maker but did not understand the process. Furthermore, she touched those items with both hands, peered down and leaned forward onto them. Her body thus covered both hands and the objects. In this situation, her hands cannot be observed easily, even if seen from any direction.

Table 11. Description of observational data.

Step no	Step detail	Indirect	Direct
1	Take a coffee filter from the cabinet	MI	
2	Open and take a dripper		
3	Put the filter in the dripper		
4	Take a coffee can from the cabinet	JO	
5	Take a tablespoon from the can	JO	
6	Put two spoons of coffee powder in the filter		
7	Insert and close the dripper		MI
8	Take a pitcher from the counter		
9	Put water into the pitcher	JO	
10	Pour the water into a reservoir		JO
11	Turn power to switch on	MI, JO	

5.3.5 Discussion

To confirm the feasibility of the proposed system, especially the application of indirect projection of visual prompts, we observed two elderly with dementia performing coffee making in an unknown environment. A set of 22 instructions was given to both participants. Based on the recorded video, they were given assistance eleven times. Ten times, visual prompts were used for identifying the required items, while indirect projection was used five times. This result is compatible with the idea that the indirect projection method can be used in various situations. Direct projection was available in two situations, i.e. less often than the indirect projection. However, in the future, we would evaluate the effectiveness of the proposed system with a user study.

We discussed a considerable number of solutions for the problems addressed in the previous section. Instead of marker projection at step 10 of JO's performance, a still or a video image showing the target object can be captured and displayed in an embedded monitor or a projectable area away from the target. By doing so, any markers can be drawn in the displayed image. However, this solution may not be applicable to the problem that occurred in step 7 of MI's performance, because it may not be possible to capture any viable images of the target objects as fixed cameras are easily blocked by users and other objects. In this case, the only remaining approach is to display pre-made instructional videos. Previously, the Ambient Kitchen (Olivier et al., 2009) integrated projectors, cameras, RFID readers and accelerometer to construct an environment to prompt people through some task in the kitchen.

According to these observations, switching between multiple modes of displaying visual prompts is inevitable. We thus inferred that measuring the environment with the camera and projector provides supporters with important information. In future work, we also speculate on how to switch display modes for intuitive prompting.

5.4 Construct 4: Grid Pattern indicating Interface for Ambient Assisted Living

The author of this dissertation was responsible for constructing the idea and designing of the system. The idea was to build a grid interface that can help caregivers to locate objects on a tabletop from a remote location. Yuki Uranishi, a visiting researcher from NAIST, implemented the system. The author of this dissertation served as a corresponding author and contributed to the writing of the publication along with Goshiro Yamamoto.

5.4.1 Introduction

This research presents a grid pattern interface designed and developed to improve the assistance method discussed in Publication III. In Publication III, we discussed how a smart kitchen could improve the cooking abilities of people with cognitive impairments. Cognitively impaired people lose autonomy due to memory deficits that could lead to difficulties in remembering the tasks required to perform, the steps in the activity or the locations of the objects involved in the activity. As a solution, a smart kitchen embedded with sensors and actuators should sense the progress of work and provide step-by-step instruction appropriate to the current situation. Additionally, a remote interface in a smart kitchen could help the caregiver assist the elderly in an unknown environment. The remote caregiver needs to express positions of various objects during a task. A well-designed remote interface as illustrated in Figure 15 can guide the remote caregiver to observe the local environment freely and can locate the objects easily. It can also reduce the burden to them when they need to send detailed instructions for searching and picking items.

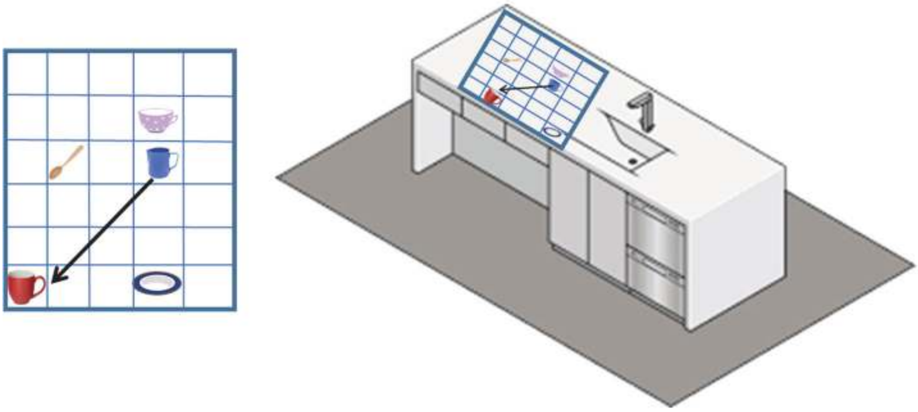


Fig. 16. Illustration of grid pattern interface.

5.4.2 Aim

Grid pattern interface aims to:

- Provide step-by-step instructions to avoid the sequencing problems mentioned by Wherton and Monk (2010)
- Solve the problem of presenting visual instruction on a monitor or difficult to interpret speech-based instruction with objects around the people, given that elderly people with cognitive impairment may not be to focus on multiple instructions.
- Reduce burden on remote caregivers when they need to send detailed instructions
- Provide remote instructions or gestures occluded by the real objects themselves

To achieve these objectives, the grid interface:

- Monitors the movement of the objects to reduce the chances of sequencing problems
- Recognizes the existence of objects at a specific location on the kitchen counter
- Helps remote caregivers to assist the elderly without knowing the location of objects and without knowledge of the kitchen environment
- Improves the visibility of remote gestures

While constructing a prompting method for elderly people with cognitive impairment, it should be considered how to indicate smooth step-by-step instructions, adjusted to their memory function and the knowledge of information technology. Wherton and Monk (2010) analysed the difficulties people with cognitive impairment face while performing ADLs. Problems, such as sequencing, occur when the elderly choose incorrect objects or actions for a given step. Each step is connected to others in a cooking task and, if a single goes wrong, it affects the entire task.

The grid interface system recognises the existence of objects at a specific location on the kitchen counter to determine whether the user is following the instructions. The system monitors the movement of the objects that reducing the chance of sequencing problems. Moreover, the system keeps track of the next step and a directional arrow is drawn between the previous and next steps. The directional arrow reduces the occlusion problem occurring due to the objects themselves. The system allows the remote caregiver to assist the elderly person without knowing the location of objects and requires no knowledge of the kitchen environment. On the local side, the grid interface projecting the visual assistance onto surfaces and objects provides better situational awareness to local users.

5.4.3 Grid pattern indication

Previous research has used monitors to present visual prompts and speech-based instructions to assist the elderly in daily tasks. Nevertheless, there is a trade-off between the flexibility and understandability of instruction. We assume a situation where a remote caregiver gives some instructions to an elderly person during a cooking task. Normally, the remote caregiver monitors the elderly person via a video stream and indicates locations by speaking or clicking on the monitoring view. Speech-based instruction is easy to understand but is difficult to express spatial information. On the other hand, monitor-based instruction is good for presenting spatial information, but the occlusion of the hand and body of the elderly may cause the remote caregiver to make mistakes. Depth perception, along with occlusion, also causes problems in a remote caregiver's judgement. A grid pattern indicating the view for a remote caregiver is one possible solution that can avoid occlusion and depth perception problems.

5.4.4 Proposed method

We proposed a work step indication method for supporting daily work with a grid-pattern projection. A range image sensor, a camera and a projector are utilized to develop this proposed method. The range image sensor measures the 3D geometry of the target scene, and the grid pattern is projected onto the screen directly. Direct projection of the work step can more easily be associated with the target objects around the assisted person. Additionally, the interface will draw arrows between the previous and next objects required during the cooking process. This system provides two interfaces, one for the local user and one for the remote caregiver as shown in Figure 16.

The grid interface at the remote site will display all the objects available on the tabletop. When using this interface, the remote caregiver does not need to worry about the size, colour or placement of objects on the tabletops during the cooking process - the remote caregiver has only to focus on the given instruction. Along with the grid interface, the remote caregiver can see the real scene of the local site. This will help the remote caregiver if the user at the local site is unable to follow the visual prompts. At the local site, a camera, a range image sensor (Kinect), and a projector is installed at a kitchen workspace. Kinect can explore the surface and interactions across a wall and table top surface. Kinect, along with the projector will guide the assisted person at the local site to complete a kitchen task. Additionally, a directional arrow will guide the local user to pick up one object and move it to another place, such as picking up the milk and putting it into the coffee. This process makes the task flexible and smooth.

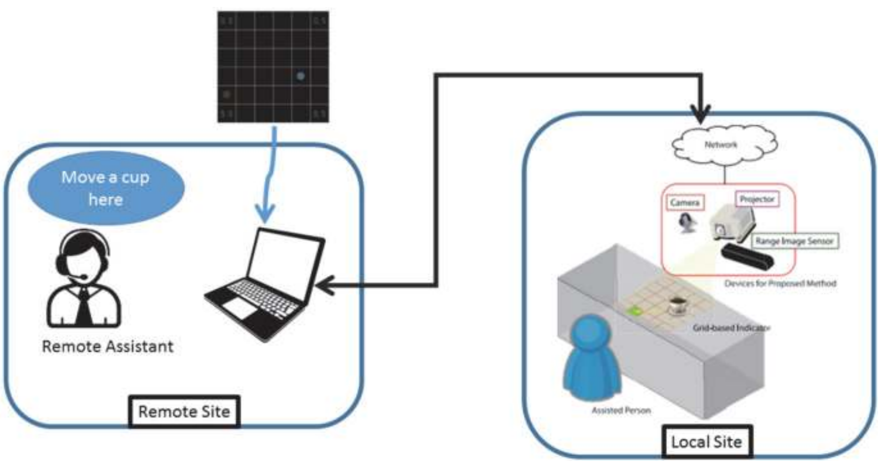


Fig. 17. Our conceptual system.

5.4.5 Implementation

A prototype of the proposed method was implemented. A Logitech C910 camera was used to capture images in 640*480 pixels. Microsoft Kinect for Windows was used as the image range sensor to obtain the range images in 320*240 pixels. The projector was an Optoma EP1691i DLP that projects a 1280*768-pixel image onto a physical surface. The Figure 17 shows an example of a work step indication developed from the prototype. The example work step was to move a pot to the designated position according to the directional arrow and projected on the surface. The target plane was correctly estimated even if there were the user's hands and the target objects obscuring the range sensor.

5.4.6 Discussion and conclusion

Supporting step-by-step instructions in a cooking task is a challenging task for those who are assisting the elderly from remote locations. We have thus designed and implemented a grid-pattern interface to help remote caregivers to assist elderly people in a cooking task. The prototype of the proposed system allowed us to observe its performance. Because of our observation, the prototype works as intended, and most of the users who acted as remote caregivers were able to indicate what they wanted within the space of the local site. Based on our feedback, the current interface can reduce the workload of remote caregivers when they need to send detailed instructions, such as the location, shape, and movement of the objects. Moreover, through this interface, any caregiver can provide help to any elderly person without having knowledge of the kitchen environment.

The outcome of the proposed system, along the results presented in Publication III, revealed various aspects of projection camera technology in a kitchen environment. They revealed aspects and improvements in the interfaces could provide detailed step-by-step instructions to the elderly to complete a complex cooking task. The identified technologies and preliminary results were considered as a starting point for creating a complete Projection-based AR kitchen for the elderly that could satisfy the identified design requirements. As a future study, we would like to set this system up in a real kitchen environment and test it with real elderly people and caregivers.

Fig. 18. A result of work step indication by the prototype. Reprinted from publication IV.

5.5 Construct 5: Visually-aided Smart Kitchen Environment for Senior Citizens Suffering from Dementia

The author of this dissertation planned the overall approach for the study described in this paper. The author was responsible for supervising and setting up the whole system. Yahui Li and Tomi Sarni were responsible for designing and implementing the actual system. When writing this paper, the author of this dissertation scrutinised the observational data in accordance with the aim of the study. The author of this dissertation served as the corresponding author and was responsible for the writing process.

5.5.1 Purpose

In Publication III and IV, we proposed two prototypes for a smart kitchen environment for elderly people with cognitive impairments. During the user studies, we asked each elderly participant to perform a cooking task based on the defined set of instructions. After developing and implementing these solutions, we realized that we should observe a real cooking process conducted by an elderly person. The purpose of this observation is to find out the real instructions followed by an elderly person with a cognitive impairment during a cooking task in a kitchen environment. For this purpose, we videotaped a coffee-making process in a real kitchen environment with an elderly person with cognitive impairment. This video provided us with detailed information about the coffee-making activity. Using the video data, we extracted step-by-step instructions. The data consisted of a total number of steps used in the cooking process, the name of each step, objects used in these steps, the location of objects, and how to operate these objects.

This data was further used to develop an information system that could help a remote caregiver assist the elderly with cognitive impairments in a kitchen environment. Furthermore, we set up a multiple camera system in a kitchen environment to obtain a full view of the kitchen. Earlier, in Publication III and IV, we used one camera for object recognition and detection focusing only on a single area of kitchen. It is difficult for a remote caregiver to instruct the local user efficiently using only a single camera as the remote caregivers cannot monitor the other areas of the kitchen. Normally, a user moves to different places in a kitchen during the cooking process, such as tabletops, cabinets, fridges, stoves, etc. To capture the entire kitchen environment, we set up a multiple camera system to cover different areas of the kitchen. This setup helped the remote caregiver to monitor and assist elderly during daily tasks. Finally, we conducted a pilot study with two participants to evaluate the feasibility of new information system and effectiveness of multiple cameras.

5.5.2 Design and implementation

Data extraction of coffee making process

We used a cooking activity, video-recorded by another researcher in our research group, as a data source. This video consists of a coffee-making process independently performed by an elderly person with mild dementia at a care centre. The elderly took 10 minutes and 26 seconds to brew a Finnish coffee. This video was used for three purposes: Firstly, this video gave us information about the brewing process, including the number of steps involved in brewing a Finnish coffee, how much time is required, objects used during the process, the location of objects, where and how elderly need assistance, and how we could aid. Secondly, this video was used as a data source for implementing the workflow system. Thirdly, we used this video to design a multi-camera system that can capture the whole kitchen environment.

Process of extracting data of coffee making process

We extracted the video data frame by frame and each frame represents a significant scene of the coffee making process. From these frames, we extracted all the steps information, along with the utensils and ingredients used in the coffee-making process. Moreover, we figured out the movement and location information of each object. We observed some exceptions while analysing this video. Sometimes the elderly person repeated the same step multiple times. For example, when he tried to get water from the tap with the coffee pot, he repeated the movement of putting the pot under tap and taking away several times. Wherton and Monk (2010) mention this problem with repetition. Figure 18 shows part of key frames and their sequenced data on the timeline.

Data content for workflow system

The extracted data were used to design an information system, named Smartflow for remote caregivers. This system uses workflow technology that enables remote caregivers to remotely monitor and assist the elderly in a kitchen environment. A workflow is an instance of a workflow model that consists of activities in a specific order. The main purpose of this Smartflow system is to automatise all the activities for remote caregivers, namely, ADLs that the elderly perform in their daily routines. We started to model a simple cooking activity in this research work based on the data extracted from the video. An industry-standard workflow language (XPDL) was used to assist in modelling and executing cooking activities. The workflow system consists of a server and a client component. The workflow server contains all the information about the cooking activities and its related data. A connection between the workflow system and the multiple camera system was established during the pilot study.

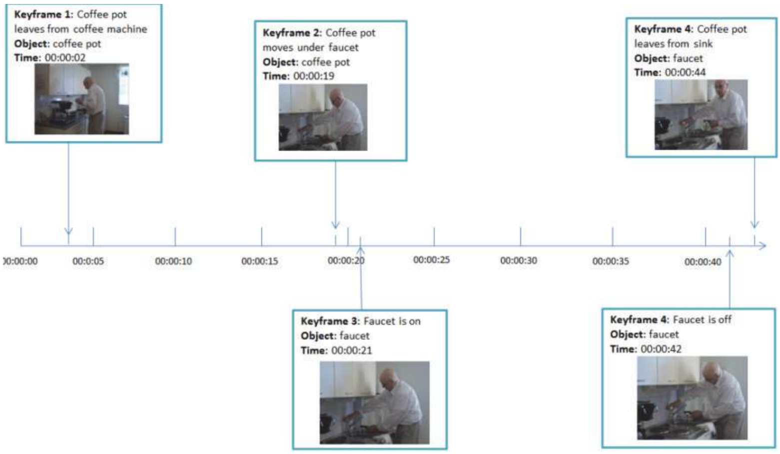


Fig. 19. Example of key frames and their sequenced data on the timeline. Reprinted from publication V.

Smartflow client

A Smartflow client was designed by Sarni (2013) to assist remote caregivers. This client interface displays all the activities and related data to a remote caregiver. Three control functions were available for the caretaker: start the activity, stop the activity, and move in-between the activity as shown in Figure 19. This interface contains details of ongoing activities in the kitchen environment such as the name of the current activity, and information about the utensils used in the current activity. This client interface is connected directly to the local smart kitchen application via the Internet. Multiple cameras were placed in the kitchen environment to provide a live view to the remote caregiver, providing them with the camera ID and the name of the camera showing the current area of the kitchen where a user is working.

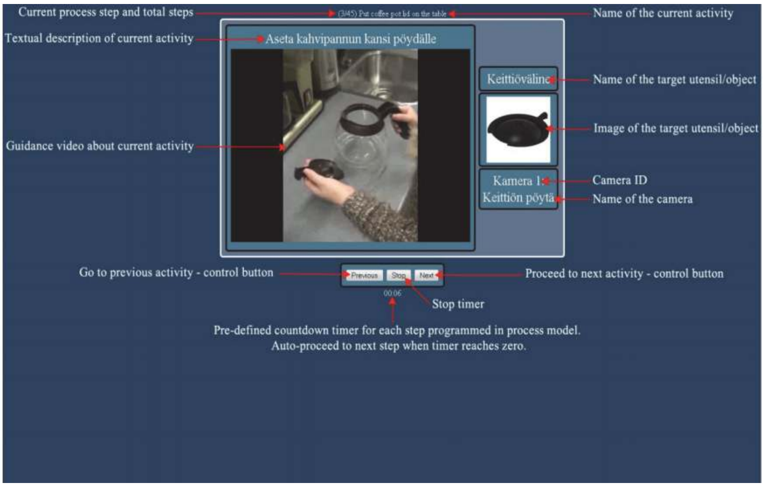


Fig. 20. User interface of smart client Sarni (2013).

Multiple camera placements

The aim of using multiple cameras was to capture the entire kitchen environment. We placed five cameras at five different locations in the kitchen. These cameras were wirelessly linked to a router and were connected to the remote caregiver's monitoring device. The camera was placed in such a way that they could cover the multiple locations the elderly used during the coffee-making activity, such as the countertop, sink, stove, etc. Figure 20 provides a diagram about the conceptual (left) and actual (right) placement of the cameras in a kitchen environment.

There are many reasons for the use of multiple cameras. First, it is hard for remote caregivers to assist with a single camera view due to occlusion problems. Along with mitigating the occlusion problem, it helps remote caregivers to monitor every area closely. This setup may improve the efficiency of the remote caregiver to monitor and assist elderly. The Figure 20(left) shows the placement of the camera in a typical Finnish kitchen. The C1 camera is focused on the countertop, C2 captures the sink area, C3 and C4 focus on the wall-hung cupboards 1 and 2, respectively, and C5 covers the drawers below.

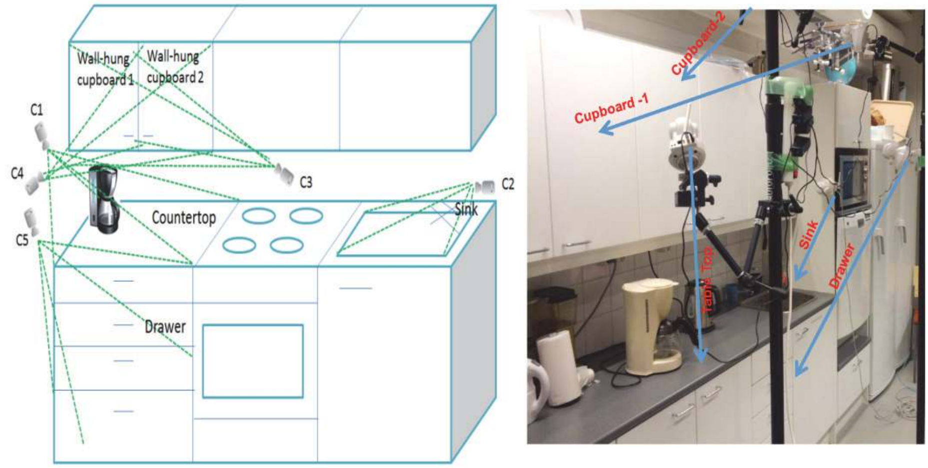


Fig. 21. Left: Design of cameras' placement in the kitchen. Right: Actual placement in the laboratory kitchen. Reprinted from publication V.

5.5.3 Pilot study

To confirm the feasibility of multiple cameras and the usability of the Smart flow system, we performed a pilot study with two participants: one participant acting as a remote caregiver, the other a user in the kitchen. Both participants had no prior knowledge of the kitchen environment and had never previously used the Smartflow system. We set up the cameras at the kitchen site and installed the camera application on the remote caregiver's computer. The remote caregiver could view the kitchen environment live through the cameras on their computer using the Smartflow client. After setting up the environment, we explained their roles in the pilot study to the participants. First, we explained the system at the remote site to the caregiver. The remote caregiver was told to provide step-by-step audio instructions to the local participant regarding the coffee-making process.

The Smart flow client application helps caregivers during the assistance process. The application shows each step of the activity, objects used in each activity, the location of those objects, and a live view of the kitchen. Local users at the kitchen site received instructions from the speakers and followed them sequentially. We then asked each participant questions regarding the use and improvement of the system:

- Did you experience any problems during the test?
- Did you find any problem regarding the verbal and audio instructions?
- Can you suggest any improvements?

5.5.4 Results

We asked for some feedback from both participants to reveal the level of feasibility and the shortcomings, and requested suggestions for the improvement of the proposed system. Based on the results of the caregiver questionnaire, feedback regarding the overall system was positive. This system can be useful for assisting people during daily tasks. The Smart-flow client interface provided useful information for the guidance. The content and steps of the coffee-making process extracted from the video were well prepared. The caregiver read each instruction from the interface clearly and followed the movement of the local user using live video streaming. Moreover, multiple cameras provided a full view of the kitchen. The video signal delay was minimal during the whole process and the image quality of each camera was good. The local user received the instructions clearly from the remote caregiver and completed the coffee-making task in 10 minutes and 55 seconds.

Both participants provided positive feedback on the entire system, explained the limitations of the system, and gave suggestions to improve the system. First, the caregiver focused on two interfaces: one for giving instructions and other to view the live situation of the local user. The caregivers spent additional time in moving between these two interfaces because we combined the two independent systems (Smartflow and multiple camera systems) to set up the prototype kitchen environment. We should integrate both the interfaces into a single interface in the future to make the process more efficient. Second, we cannot generalize the steps of the coffee making process based on one person's data alone. The steps of any cooking process should be adapted based on different user data. We should record more scenarios with different users in different kitchen environment. Third, the audio and textual instruction needs to be simple and easy to understand, as it might be difficult for elderly people with cognitive impairments to process lengthy instructions.

5.5.5 Discussion and conclusion

In this study, we improved the concept of a remote caretaker interface by designing an information system based on the data collected from real cooking tasks. Furthermore, we tested a multiple camera system in a kitchen environment to provide visual information to the remote caregiver. With the help of this system, a remote caregiver can effectively monitor and guide the elderly. Both participants provided positive feedback regarding the entire setup in the post-test questionnaire. We will improve the current system based on the suggestions provided by both participants. The system will need to be tested in the future with real users to verify its impact on elderly people with cognitive impairments and their caregivers. We will combine this setup with the other smart kitchen systems discussed in Publication III, Publication IV and Publication VI and will test the long-term use with real elderly people. We will record videos of more cooking scenarios and other daily activities, such as personal care, bathroom activities, taking medicine, and doing housework. The data of these processes will be included in the Smartflow application.

5.6 Construct 6: Remote Assistance for the Elderly to find Hidden Objects in a Kitchen

The author of this dissertation was responsible for constructing the idea, design, implementation and evaluation the entire system. The author was responsible for conducting the overall user study and analysing the dataset. Niina Keränen supported us in designing the study protocol and helped throughout the user study. The study was conducted with Finnish elderly people and Niina Keränen helped us with the language translation. The author was responsible for writing the paper in cooperation with the co-author, contributing most of the text.

5.6.1 Purpose

In earlier work such as Publication III and IV, we proposed systems to support kitchen activities that detect and identify objects placed in open locations such as a tabletop. To develop a complete kitchen prototype there was a need to design a system that can detect and identify objects placed in hidden locations such as in cabinets or drawers. Normally, a kitchen is a combination of open and closed locations. A user interacts with both types of location during any kind of cooking activity. For an impaired person, it is easy to remember the locations and shapes of every object available in a kitchen. However, in the case of elderly people with memory impairments, it is hard to remember the location and shape of each object.

As Wherton and Monk (2010) highlight, people with memory impairment require assistance in finding both items that are outside of view and those in plain sight. Therefore, in this work, we proposed a system that adds location support by projecting the object's image to the required location for hidden places such as drawers and cabinets. Twelve elderly participants were asked to perform a short find-and-locate items task from an unknown cabinet using our system. The task consisted of picking up items from cabinet shelves and placing them into a box location indicated by the remote caregiver. The participant found and recognized the required objects using the images projected at the desired location in the cabinet. After the tasks were completed, the user was asked to complete SUS and UTAUT questionnaires using a five-point Likert scale, noting their experiences relating to system usability and acceptability of projection technology.
The aim of designing this prototype was to provide two essential features

- Location: where the objects are and
- Appearance: what they resemble.

5.6.2 Design

Several technologies were available to keep track of a person or object's location indoors, for example an ultrasound positioning system or Received Signal Strength Information (RSSI). We used Radio Frequency Identification (RFID) that locates objects in an atmosphere, more accurately than ultrasound and infrared-based tracking. Battery-free passive tags can be embedded and hidden with no need for line-of-sight and can be read through various materials such as wood, plastic, or cardboard (Surie et al., 2013). These offer cheap tagging options for everyday objects such as cups, plates and bowls in a kitchen. In addition to RFID technology, we used image projection technology to display the image of the required object at the exact location. Using the projection technology, a user does not need to wear or carry any devices, in contrast to smartphones, tablets or smart glasses. We have used projection technology in earlier studies and received good feedback from the elderly people involved. In this research work, we proposed a remote assistive system by combining RFID and projection technology to assist the elderly and remote caregivers in daily cooking activities

This remote assistive system consists of a local site and a remote site as shown in Figure 21. The local site consists of a projector, a camera, a speaker, a microphone and an RFID reader system. The projector displays the visual information on the cabinet door surface and a camera provides the live view to the remote caregiver. Each shelf in the cabinet has a reader that continuously updates the tag information. The remote site application is designed to assist the remote caregiver. It shows all the required objects required in any task to the caregiver for assistive purposes. The live view from the camera helps the remote caregiver to see the real environment and elderly person's task progress.

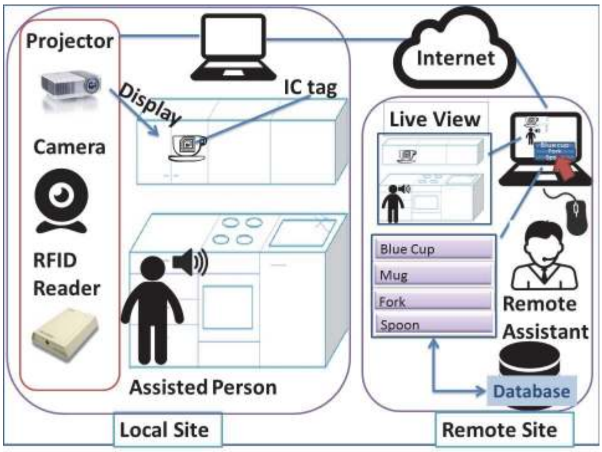


Fig. 22. Overview of the whole system. Reprinted from publication VI.

5.6.3 Implementation

The implementation of this system has two processes: offline process and online process. During the offline process, an RFID tag attached to each object, registers each object to the database and their relevant locations. For registration, an image of each item was taken and saved to the database along with the tag information using local application. After registration, the geometry between the camera, the projector and the door surface were calibrated. The online process has a remote application developed using OpenCV and MySQL database. The remote application was connected to the local application via the internet.

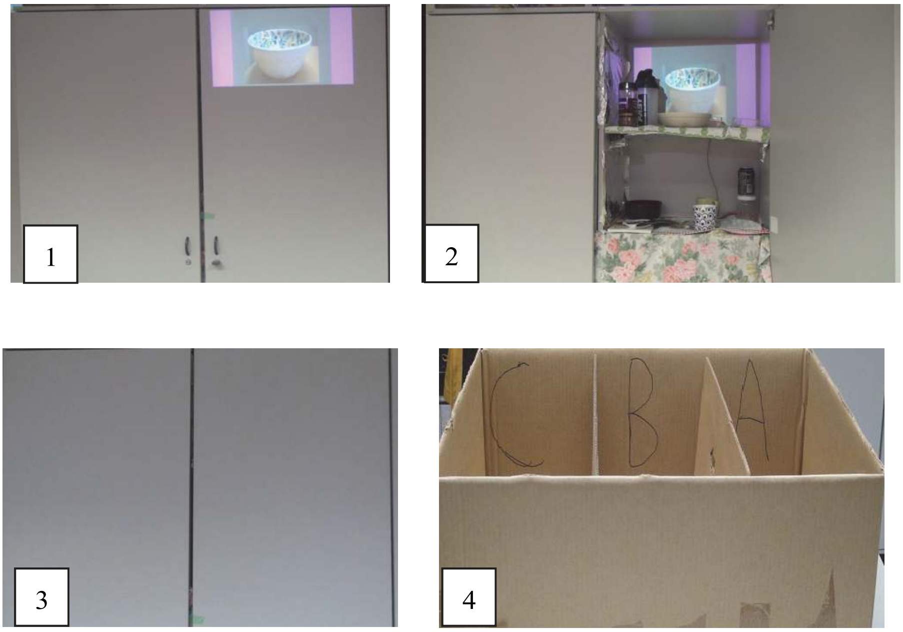
5.6.4 User study

Twelve elderly participants participated in a user study to evaluate the usability of the system. Additionally, we investigated the acceptance of the proposed system among the senior citizens. The subjects were eight women and four men aged between 64 and 84. All the participants lived at home independently or with a spouse and could independently perform all regular daily activities. Before meeting at the experimental location, we asked each participant to bring five kitchen items or other household items to use in the test. The study took place in two separate rooms in the University of Oulu. Both applications (local and remote) were connected via Wi-Fi.

Before the actual task, we explained the purpose of the system to each participant, namely to assist them in finding and locating items from the cabinet available at the test place. We used four shelves of the cabinet and placed the items on each shelf of the cabinet at random. We explained the task to each participant, i.e. to "Find and locate an object from the cabinet and put that object into the box behind". We further explained that there would be a caregiver remotely assisting them and will be giving them step-by-step instructions over the headphones. The step-by-step instructions used during the task are presented in Table 12.

1. Open the cabinet door.
2. Pick up the object from the shelf.
3. Close the cabinet door.
4. Put the object in the correct location of the box.

Table 12. Step-by-step instruction used during the task.



After the study, we asked each participant to fill out a post-test questionnaire to measure the usability of the system. The questionnaire consisted of the P-SUS scale and a modified version of UTAUT scale. SUS and P-SUS use a standardised form with ten questions to access the product's usability. SUS provides reliable results with a small sample size and it can differentiate between usable and unusable systems. In contrast, the UTAUT model predicts the use of the system. This system investigates the user's Performance Expectancy/Perceived Usefulness (PE/PU), Social Influence (SI) and Facilitating Conditions (FAC) as well as constructs for Attitude (ATT), Anxiety (ANX), Trust (TU) and Social Presence (SP). The questions were customized to account for the demonstration environment and this situation. The seven revised UTAUT constructs assessed with a questionnaire of 22, five-point Likert scales, ranging from 1 (completely agree) to 5 (completely disagree).

5.6.5 Results

The system usability evaluation was positive. The SUS scores ranged from 52.5 to 95 with a median of 77.5. In particular, low scores were attained in response to statements "I think that I could use the system without the support of a technical person" and "I could use the system without having to learn anything new"; whereas "I found the system to be simple" and "I thought the system was easy to use" were evaluated very positively. The modified UTAUT questionnaire performed effectively. The Cronbach's alpha values determined for all the constructs are presented in Table 13. The ATT, ANX, TU, FAC and SP constructs had acceptable values of 0.6 or greater. In Table 14, we document the results for the PU in more detail. Figure 22 shows the results of perceived usefulness.

Table 13. Results of the modified UTAUT questionnaire. Responses scored on a scale of 1−5, where 1 is most positive (Original ANX scale reversed).

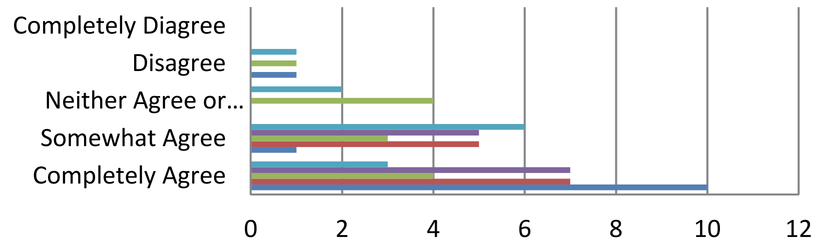
UTAUT construct	Number of questions	Mean scores	Cronbach's alpha
PU	1[a]	1,67	--
SI	2[b]	2,44[b]	0,93[b]
FAC	2	2,29	0,70
ATT	3	1,88	0,59
ANX	4	2,22	0,67
TU	2	1,75	0,93
SP	2	1,79	0,83

Only including the general questions [a] (13).

Question 6 removed. With question 6 included [b], α=0. 48

Table 14. Perceived usefulness in different aspects. Responses scored on a scale of 1−5, where 1 is most positive (completely agree).

Potential use	Mean scores	Completely agree	Somewhat agree	Neither agree or disagree	Disagree	Completely disagree	Agree or completely agree
Locating items	1,33	10	1		1		11/12
Guide and help in kitchen	1,42	7	5				12/12
Keeping in touch with family	2,17	4	3	4	1		7/12
Memory refreshment	1,42	7	5				12/12
Caring for remote family member	2,08	3	6	2	1		9/12



	Completely Agree	Somewhat Agree	Neither Agree or Disagree	Disagree	Completely Diagree
Caring for remote family member	3	6	2	1	
Memory refreshment	7	5			
Keeping in touch with family	4	3	4	1	
Guide and help in kitchen	7	5			
Locating items	10	1		1	

Fig. 23. Results of perceived usefulness.

5.6.6 Discussion and conclusion

The user feedback and usability ratings indicated the remote assistive kitchen could be useful and easy to use for real world use. The perceived usefulness in household assistance or as a memory reminder surpassed the expected value in social activity, but both was primarily evaluated positively. Participants also showed a positive attitude towards the technology. This shows they can readily adapt to a new technology in their home environment. It seemed that the participants were comfortable with the system. Most of the participants did not perceive any difficulties using the system. Results from Facilitating Conditions and Trust constructs illustrated that the elderly could follow the guidance from the projection system and it would fit into their homes. Results from perceived usefulness show that the projection guidance helps the elderly to locate and find items from hidden places during a task. The participants also rated the memory refreshment construct at the highest level. This data shows that the visual prompts assist the elderly in recalling the appearance of each object.

This may encourage others to adopt this technology in their homes with or without any technological experience. Some participants did not an answer for the question "Keeping in Touch with Family" construct. However, in our opinion, the question is not relevant to this kind of scenario. The test's focus was on the step-by-step execution of the given task. Aside from the positive feedback, we also observed some limitations. As we used one projector that could only cover only a small area of the kitchen, we need to expand the projection area with multiple projectors to cover the wide area of the kitchen. Another limitation was related to the registration of each object. Currently, we attach a tag to each object, take its picture, and save the information in the database before starting the actual system. To make the system more efficient in the future, it needs to scan all the tags and register new tags automatically. The camera can take pictures of new objects, and the pictures, along with the new tags, can then be saved to the database. We plan to integrate this system with our previous designs, Publication III and Publication IV, to form a complete smart kitchen environment. We would like to test this system with cognitively impaired elderly people in their familiar environment for an extended period.

6 Discussion

In this study, we have designed and developed various prototypes based on remote collaborative environments to assist the elderly in their daily activities. This thesis explored how remote collaborative systems can be used to support the elderly to perform daily activities independently. To investigate this, we followed the design science research approach, in which the objective is to iteratively create artefacts from the design, prototype and implementation steps in the process. In so doing, we first collected the requirements from two scenario videos, presented and discussed with various stakeholders. Following this, we built two prototype systems for outdoor activities and four prototypes for indoor activities.

6.1 Answer to RQ1: How can we provide remote assistance to the elderly for outdoor activities?

To answer this question, we designed two constructs based on laser projection technology to help the elderly in indoor and outdoor navigation activities. The aim of the first two prototypes was to propose projection-based solutions for the elderly to assist them in navigation in outdoor environment using laser projection technology. Laser projection technology has been used earlier in various remote collaborative tasks in indoor environments, while, we used this technology in an outdoor environment for mobility. Another important function of these prototypes is to establish a remote connection with the remote caregivers through mobile phones and through the Internet. This enabled a small group of remote caregivers to support many elderly people whenever needed.

The first construct was built on a walking cane like those used by many of the elderly in their daily routines for walking indoors and outdoors. The cane was equipped with laser projection technology to display a projected arrow on the floor for navigation. This solution does not require any wearable module or constant interaction from the elderly user. Moreover, this construct revealed that the normal walking cane could be equipped with multiple sensors to solve the mobility problem.

A second construct was a lightweight wearable device that an elderly person could hang around their neck to navigate outdoors and identify objects in an indoor environment. A camera is attached to a device that provides a real-time view to the remote caregiver, so that the remote caregiver can see the elderly person’s environment and easily guide them using a chest-based laser pointer. The laser pointer was valuable in two regards: for projecting arrows into the ground for navigation and for operating a shopping kiosk. This proposed solution was beneficial for elderly people who do not use any assistive device for walking. Moreover, their hands are free to operate any external device while using this device. The projected arrow worked well in an indoor and dark environment. However, it did not work so well in outdoor bright environments and snowy conditions.

Practical implications: The useful features of these two constructs suggested that the researchers should design and develop assistive systems using ICT for the elderly that can easily integrate with pre-existing aids and infrastructure. Table 15 documents the strengths and weakness of Construct 1 and Construct 2.

Table 15. Structure of the original publications with respect to outdoor activities, strengths, and weaknesses.

No	Description	Strengths	Weakness
I	Laser projection technology equipped to a cane for navigation	Works well indoors, Installed with pre-existing devices, non-wearable, no constant interaction	Naturally occurring tremors make the device unstable
II	Wearable device for navigation and identification of objects using laser projection	Lightweight, minimal interaction	No visibility of arrow in bright light conditions

6.2 Answer to RQ 2: How can we provide remote assistance to the elderly for indoor activities?

To answer this question, we designed four constructs based on fixed projection technology to help the elderly with indoor cooking activities. For indoor activities, we chose a kitchen environment where the elderly spent most of the time doing different activities such as cooking, food preparation, cleaning, etc. We selected a cooking activity for all the constructs because cooking is a complex activity and consists of many steps that are difficult for elderly people with dementia to perform without support. Moreover, a cooking task consists of complex surfaces and requires various objects from different places. We utilised projection-based augmented reality to provide visual information as guidance onto the physical surfaces and overlay information on the required objects.

Based on these considerations, we proposed four different constructs that can assist elderly people with dementia and their remote caregivers in a cooking task. The first construct (Publication III) was built to provide visual and verbal prompts to support the elderly in a cooking task. The proposed system was designed to solve three problems: to display visual information on glossy and reflective areas; to create a single method for displaying visual prompts was not enough in complex kitchen environment; and that assistance was required for remote caregivers in an unknown kitchen environment. The indirect projection of a circular marker under the objects was implemented. The indirect projection solves the problem of glossy or transparent surfaces restricting visibility. The proposed system worked as intended and an observational feedback from two elderly people with dementia was recorded. Based on the feedback, the integration of direct and indirect projection is required to cover different surfaces and different shape and colour of objects in a kitchen environment.

The purpose of the second construct (Publication IV) was to implement a grid pattern interface to assist the remote caregiver and elderly person in a kitchen environment. This novel interface provides a solution for the sequencing problem by monitoring the movements of the objects. It recognises the existence of objects at a specific location in a kitchen counter. It improves the occlusion problem and increases the visibility of remote gestures. This interface helps the remote caregiver to assist the elderly in an unknown environment. The identified technologies and preliminary results from Publication III and Publication IV are considered a starting point for creating a complete projection-based AR kitchen for the elderly that could satisfy the identified design requirements.

The third construct (Publication V) implemented a multiple camera system to provide a wider view of the kitchen environment. This wider view is helpful for the remote caregiver to see all the areas of a kitchen, given that, a user in a kitchen moves between different places during a cooking task. Additionally, we designed an information system based on the data collected from a real cooking task. The main idea of this system is to automate different ADLs that can enhance the efficiency of caregivers. A pilot study with two participants was conducted to test the feasibility and usability of the system. Both participants provided positive feedback relating to the both systems and gave suggestions for future developments. After implementing these three constructs, we observed that these systems detect and identify objects in an open place such as tabletops. For a complete kitchen construct, there was a need to design a system that can detect and identify objects placed in hidden places such as cabinets and drawers. In Construct 6, we designed, developed and evaluated a smart cabinet system that can assist elderly and remote caregivers to find and locate items from hidden places such as cabinets and drawers. Table 16 shows the strengths and weakness of Constructs 3, 4, 5 and 6.

Table 16. Structure of the original constructs with respect to indoor activities, strengths, and weakness.

No	Description	Strengths	Weakness
III	A projector camera system provides step-by-step visual prompts for a cooking task	Assist the elderly to identifying objects with glossy or transparent surfaces, no need to carry or hold any device	Lack of functionality for remote caregivers or requires an interface for remote caregiver
IV	A grid pattern interface to improve the efficiency of the remote caregiver during a cooking task	Helps remote caregiver to locate objects remotely, reduce occlusion during remote gestures	Low visibility of kitchen area for remote caregiver
V	Set up a multiple camera system to provide a better visualisation of a kitchen environment and an information system to automate the cooking activities	Increase efficiency by improving the visibility of the kitchen area and autonomously guide the cooking activity	View of closed places such as the cabinet or drawers is required
VI	A smart cabinet system to assist the elderly in finding and locating items in the kitchen. Test and evaluate performance with actual elderly person	Increase efficiency of the elderly in finding and locating items in the kitchen, decreases cognitive burden to the elderly	Lacks runtime registration of objects.

6.3 Answer to RQ 3: Is projection technology acceptable in remote assistive systems designed for the elderly?

Projection technology was used to develop and design all the constructs used in this study. Therefore, it was important to study the perspectives of the elderly regarding the projection technology in their familiar environment, given that the elderly have the right to decide for themselves what they allow into their homes. We conducted a usability study during the evaluation of construct VI in a laboratory environment, although conducting studies in real homes might provide different results and might have unique challenges. The analysis of the evaluation data suggests that the elderly in the kitchen environment accept the projection technology. Particularly, users showed a positive attitude toward the projection technology and were ready to adapt it in their home environment, as backed by the data. Moreover, the results of the perceived usefulness showed the usefulness of the projection guidance in finding and locating items from a cabinet during a task.

In parallel, the acceptability of projection-camera technology in other places of the home encompasses many challenges. Moreover, projection-camera technology is being intrusive in people's everyday lives like other technologies such as camera-based monitoring, positioning systems and microphones at home (Ziefle et al., 2011). The user's privacy must be respected in a privacy-sensitive area in the home environment and control over individual sensors must be granted to the user in order to overcome the privacy problem.

6.4 Summary of research contributions

The empirical research offers an insight into how to design, develop and evaluate remote assistive systems when the target users are the elderly people. The developed artefacts can guide them to perform and participate in daily activities using the projection-based technology. The projection-based AR offered the opportunity to create a remote collaborative environment that can be used to guide many elderly people in their daily activities from a distance by a caregiver. In addition, it allows the augmentation of digital information into a real environment to guide the elderly to complete the actual task. All the artefacts were evaluated with actual elderly people, many of them with some form of dementia. The results have ascertained that projection-based AR technology can augment with existing devices and infrastructure and the elderly are willing to use it.

The evaluation of each artefact, based on small sample sizes with elderly participants, many with some form of dementia, shows the results are encouraging. For quantitative analysis, each artefact requires long-term evaluation with a large user base.

6.5 Theoretical implications

The results of this dissertation support the idea of using remote collaboration for the elderly in their daily tasks. A remote collaborative system can allow a remote caregiver to guide elderly people in need of assistance to perform daily activities independently, as they elderly may lack knowledge regarding a task or may have some cognitive impairment that obstructs the completion or initiation of a task.

Moreover, through using a remote collaborative environment technique the dependency gap between the elderly and the caregiver can be reduced. The results of this dissertation will be useful for other researcher from the viewpoint of understanding how projection-based AR remote collaboration can support the elderly to perform daily activities independently.

The study proposes six solutions using projection-based AR to assist the elderly in their daily activities and feedback from these solutions supports the idea of a remote collaborative system in the elderly's daily routine. First two solutions (Publication I and Publication II) showed the use of laser projection technology for outdoor and indoor navigation. These solutions assist the elderly in getting from one place to another by drawing the projection arrows on the ground. Moreover, these solutions were simple to use and augmented with existing aid devices that are familiar to elderly people. This technology works well in an indoor environment but did not work in outdoor environment due to the bright sunny conditions.

The other four solutions (Publication III, Publication IV, Publication V, and Publication VI) demonstrated the use of fixed projection technology in a kitchen environment. The first solution displayed visual prompts on a counter top to identify the objects with a glossy and transparent surface. The second solution proposed a novel interface to solve the occlusion problem occurring during the remote assistance, due to the objects in the real environments and user's body. The third solution provided a wider view of the local environment to improve the performance of remote caregiver. The fourth solution provided information on a cabinet to solve the problem of finding and locating items from hidden places. The acceptability of projection technology in a kitchen environment was tested on a small scale, but further empirical studies in other places of a home environment are required.

Overall, this dissertation showed the use of projection-based AR technology to develop remote collaborative systems to help the elderly in their daily activities. All these solutions shared a view of the elderly's environment with the remote caregiver via a camera that can improve the performance of a collaborative task. However, the camera needs to be replaced with other sensors because it creates privacy problems in different areas of a home environment, such as the bedroom and toilet. Thorough investigation showed how existing aid devices and infrastructure could be equipped with the latest tools and technologies, as elderly people would feel comfortable using these devices in their familiar environments.

6.6 Methodological implications

The experience of applying a design science method as described by Hevner (Hevner et al., 2004) was positive, and the explicit focus was on utilising all the guidelines described in the design-science research paradigm for producing technology-oriented artefacts.

This DSR approach however, was not fully employed in this work because all the artefacts require rigorous and long-term evaluation of the intended population in a realistic environment. For rigorous evaluation, the work highlighted some important challenges that affect the evaluation of assistive solutions for the elderly. First, the availability of elderly participants during the development and evaluation of a construct is crucial. The recruitment of elderly participants and their availability is a long-term process that needs time, significant resources and extensive permission from the healthcare committees. We managed to recruit the elderly and elderly with dementia participants because we had contacts with the healthcare organisations and we had experienced people to help in arranging the user studies. Second, elderly's physical and cognitive abilities during the development of a construct are a major issue, as both decline with time, which also affects the long-term evaluation. Our solutions should be able to dynamically adapt to the changing context setting. The changes in contextual settings and users need to be observed on a regular basis and can be captured using video-recorded data. A camera should be placed in the home environment with the consent of elderly and should record all the activities of daily living performed by elderly while using our systems. Later, these videos can be used to analyse each construct. Lastly, the elderly user's skill level changes over time and their health deteriorates with time.

To apply design science research for this work, we would install the system in the elderly's home and video record all the activities. The system does not need any human interaction; the elderly should perform their daily tasks normally. The video- recorded data will help the researchers to improve the system or to add new functionalities. The idea of employing design science alone for this work was not enough. As the artefacts were designed and developed for a specialised group such as the elderly, it needs to be combined with user-centred design(UCD), given that, the UCD process outlines the phases through the designing and developing a tool or a system from the perspective of how it will be understood and used by a human user (Lee, 2014).

From the experience in this dissertation, the recommendations for other researchers based on our user studies is to thoroughly design the study protocol and involve all the stakeholders (medical experts, geriatrics, the elderly, caregivers and researchers) as much as possible. The major advantage of the user integration is that of a deeper understanding of the psychological, social, organisational, environmental, and ergonomic factors that can affect the adoption and effective use of an assistive technology by end users in their real context of daily life. Moreover, it is important to conduct the first pilot study and modify the prototype based on the feedback, explain the test scenarios to real users clearly, and video-record all the sessions.

The system should first be tested in a laboratory environment with real users and later in a realistic environment. The pre and, post-test questionnaire forms should be comprehensively designed, and the questionnaire should be based on existing well-known feedback models such as TAM, UTAUT and SUS. Following this, the researcher should modify the existing aid devices using modern tools and technology and embed the technology into the existing infrastructure. Then, we should test the modified devices with real people in a real environment to create a practical device. Specific people require specific devices; it is difficult to build devices for general audiences. Finally, we should design and develop a system in such a way the cognitive and physical decline would not limit its use.

6.7 Practical implications

According to the findings of this work, some practical implications are discussed here that need to be addressed in the future. Construct 1 and Construct 2 used laser projection to display a guided arrow on the ground for outdoor navigation. The laser pointer was not visible in the bright sunny conditions that needs to be replaced with better intensity laser projection. The occlusion problem occurred in Construct 3 and Construct 4, was then improved using multiple cameras in the local environment, as tested in Construct 5. Nevertheless, as cameras create privacy problems in sensitive home areas, these cameras should be replaced with some other sensor such as proximity sensors or motion sensors. Latency and quality of network play a significant role in remote collaborative systems. Therefore, for smooth communication, the latency and quality of the network should be improved. The 5G network can be a solution for improving the latency and quality of the network in the future. The lack of caregivers will increase in the future, and remote collaborative environments offer a solution. Some of other solutions for this problem may be to embed more sensors in the environment and to make the environment more intelligent.

7 Conclusion

This thesis explored the concept of remote collaborative environments to support the elderly in their daily activities by the caregiver at a distance. The idea was to help the elderly age in place and reduce the burden on the community. We examined various solutions using the projection-based AR technologies in the remote collaboration that can aid elderly in their daily activities. Each solution related to a single caregiver via internet who can monitor several elderly people remotely and can give support when needed. Each solution includes a way for the caregiver to see and augment the projected information on real objects and surfaces and an audio connection for the elderly to ask for the caregiver's assistance. In this way, human-human assistance is always available, and one caregiver can be available to assist several elderly people.

We used the projection-based AR technology to design and develop six constructs. Through a process of design science, we discovered that there are many advantages to using the projection-based AR in relation to the elderly. First, they do not need to carry any devices with them. Second, it can easily be equipped with the existing aid devices and can be augmented in the existing environment. Lastly, it can help the elderly to focus on the actual task and projected information around them can help them during the task whenever needed. The use cases presented in this work support indoor and outdoor activities, and the elderly performed these activities in their daily routine. These primarily encompassed mainly two activities: cooking and navigation. The use of laser projection technology helped the elderly to navigate freely and safely in an indoor and outdoor environment, while the fixed projection in the kitchen environment helped the elderly during the cooking activities. The projected information on the counter top and on the cabinets helped the elderly to find and identify objects used during a cooking activity. We tested all these constructs with the elderly and the elderly with dementia in care homes and in a laboratory environment. However, long-term evaluation of these constructs in realistic environments is required in the future.

This dissertation provides valuable input for future research relating to remote collaboration for the elderly and caregivers and highlights several useful features for researchers of projection-based AR technology. At the same time, the researchers can utilise the benefits of augmented reality by designing and developing more systems for other IADLs to support the ageing population.

7.1 Future work

Based on the observational and experimental findings of this work, the other researchers should design and develop systems for other ADLs based on the modern tools and technologies. They should encourage and involve the elderly to perform the activities and the elderly should adopt the technology into their daily routines. It is necessary to research how systems can be augmented in the environment, which require minimal interaction from the elderly users. Moreover, the researchers should also design and develop systems to support caregivers. There should be technological interventions that can help the caregivers to support the elderly. Alex Mihailidis and colleagues, discussing findings from their own research and the experiences of others related to designing AAL technologies for older adults with dementia, highlight that “devices designed to support people with dementia must also support their caregivers” (Mihailidis, et al. 2012).

One potential topic for future research is to encourage the elderly to communicate with the remote caregiver during a daily task. This idea emerged from the findings of the current work, as we have experienced during the research work that a formal caregiver using remote assistive systems can assist elderly with cognitive impairment in their daily activities and exchange task-related information with them such as picking up a cup from the shelf, putting coffee in it, and drinking it. They were given fewer chances to undertake informal conversations, mainly from the elderly side, because they do not know very much about the caregiver at the remote site and they have fewer topics of discussion. Based on this idea the research question could be “How can we enhance communication between the elderly and caregiver during a daily task?”

7.2 Other use cases

The use cases presented in this work are based on two activities. However, many other activities can be designed and developed using projection-based AR technology. In this section, some of the future use cases are discussed. Dressing up for harsh and wet conditions is a significant concern for the elderly and elderly people with memory problems. A projection system could be used to display weather information on a wall or on a cabinet, and, based on this information; the system can suggest clothes to wear. Furthermore, the system can display the clothes at the exact location with the help of projectors and RFID systems. Any large-sized display can assist the user with the daily appointments, daily reminders, etc. A projection system can display a reminder to a user relating to an appointment and display location information or a map giving direction to destinations. The bus timetable can be displayed along with the route information. For a home appointment, a system can display information on the person who is coming to meet the elderly person, information including a picture of the person, relation to the user, and the purpose of the meeting etc. Activities in the kitchen are time-consuming and complex, such as the cleaning of the utensils after cooking, which requires a great deal of effort. A system can be developed to display a cleaning method to the elderly and can guide the location of the utensils after the cleaning task. Another important activity for the elderly is to write a shopping list. A system can be developed to display the shopping list based on finishing food items and the same system can be helpful to return the items to the exact location after the shopping. Another important and crucial aspect of elderly life is to socialise with people, such as the caregivers who are helping them in their daily activities. If the caregivers are unknown, then it is difficult to socialise with them. However, a system can be developed that can provide prompts to elderly based on the relevant data.

List of references

Akatsu, H., Miki, H., & Hosono, N. (2007). Design principles based on cognitive aging. Human-Computer Interaction.Interaction Design and Usability, 3-10.

Avila, J., Flowers, A., Scott, T. M., Quilici, J., Apostolova, L. G., Woo, E., ... & Razani, J. (2015). Daily activity abilities in MCI, Alzheimer's disease, and healthy controls. GeroPsych: The Journal of Gerontopsychology and Geriatric Psychiatry, 28(4), 191.

Acampora, G., Cook, D. J., Rashidi, P., & Vasilakos, A. V. (2013). A survey on ambient intelligence in healthcare. Proceedings of the IEEE, 101(12), 2470-2494.

Alam, M. R., Reaz, M. B. I., & Ali, M. A. M. (2012). A review of smart homes—past, present, and future. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 42(6), 1190-1203.

Anderson, W. L., & Wiener, J. M. (2013). The impact of assistive technologies on formal and informal home care. The Gerontologist, 55(3), 422-433.

Armas, J., Berger, J., Broderick, A., Coye, M., DeMello, S., Harvath, B., ... & Steinmetz, V. (2009). Technologies to help older adults maintain independence: Advancing technology adoption. Retrieved from Center for Technology and Aging. Retrieved from http://www. techandaging. org/briefingpaper. pdf.

Azuma, R. T. (1997). A survey of augmented reality. Presence: Teleoperators and Virtual Environments, 6(4), 355-385.

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001). Recent advances in augmented reality. IEEE Computer Graphics and Applications, 21(6), 34-47.

Alem, L., Tecchia, F., & Huang, W. (2011). HandsOnVideo: Towards a gesture based mobile AR system for remote collaboration. In Recent trends of mobile collaborative augmented reality systems (pp. 135-148) NY: Springer.

Bosco, A., & Lancioni, G. (2015). Assistive Technologies Promoting the Experience of Self for People with Alzheimer's disease. Rivista internazionale di Filosofia e Psicologia, *6*(2), 406-416.

Boyd, H. C., Evans, N. M., Orpwood, R. D., & Harris, N. D. (2017). Using simple technology to prompt multistep tasks in the home for people with dementia: An exploratory study comparing prompting formats. Dementia, 16(4), 424-442.

Beard, J., Biggs, S., Bloom, D., Fried, L., Hogan, P., Kalache, R., & Olshansky, J. (2012). Global population ageing: Peril or promise?

Blasco, R., Marco, Á., Casas, R., Cirujano, D., & Picking, R. (2014) A smart kitchen for ambient assisted living. Sensors 14(1): 1629-1653.

Barjis, J., Kolfschoten, G., & Maritz, J. (2013). A sustainable and affordable support system for rural healthcare delivery. Decision Support Systems, 56, 223-233.

Brumitt, B., Meyers, B., Krumm, J., Kern, A., & Shafer, S. (2000). Easyliving: Technologies for intelligent environments. In Handheld and ubiquitous computing (pp. 97-119). Berlin/Heidelberg: Springer.

Billinghurst, M., Clark, A., & Lee, G. (2015). A survey of augmented reality. Foundations and Trends® Human–Computer Interaction, 8(2-3), 73-272.

Bonner, S., & Idris, T. (2012). Assistive technology as a means of supporting people with dementia: A review. Housing Learning and Improvement Network.

Blackman, S., Matlo, C., Bobrovitskiy, C., Waldoch, A., Fang, M. L., Jackson, P., Mihailidis, A., Nygård, L., Astell, A. and Sixsmith. (2016). Ambient assisted living technologies for aging well: A scoping review. Journal of Intelligent Systems, 25(1), 55-69.

Czaja, S., Beach, S., Charness, N., & Schulz, R. (2013). Older adults and the adoption of healthcare technology: Opportunities and challenges. In Technologies for active aging (pp. 27-46).NY: Springer.

Calvaresi, D., Cesarini, D., Sernani, P., Marinoni, M., Dragoni, A. F., & Sturm, A. (2016). Exploring the ambient assisted living domain: A systematic review. Journal of Ambient Intelligence and Humanized Computing, 1-19.

Cheek, P., Nikpour, L., & Nowlin, H. D. (2005). Aging well with smart technology. Nursing Administration Quarterly, 29(4), 329-338.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Quarterly, 319-340.

Davis, R. L., Therrien, B. A., & West, B. T. (2008). Cue conditions and wayfinding in older and younger women. Research in gerontological nursing, 1(4), 252-263.

Davey, J. A., de Joux, V., Nana, G., & Arcus, M. (2004). Accommodation options for older people in Aotearoa/New Zealand. Christchurch: Centre for Housing Research.

Debes, C., Merentitis, A., Sukhanov, S., Niessen, M., Frangiadakis, N., & Bauer, A. (2016). Monitoring activities of daily living in smart homes: Understanding human behavior. IEEE Signal Processing Magazine, 33(2), 81-94.

Ding, D., Cooper, R. A., Pasquina, P. F., & Fici-Pasquina, L. (2011). Sensor technology for smart homes. Maturitas, 69(2), 131-136.

Evans, J., Brown, M., Coughlan, T., Lawson, G., & Craven, M. P. (2015). A systematic review of dementia focused assistive technology. International Conference on Human-Computer Interaction, 406-417.

Federici, S., Tiberio, L., & Scherer, M. J. (2014). Ambient assistive technology for people with dementia: An answer to the epidemiologic transition. New Research on Assistive Technologies: Uses and Limitations. New York, NY: Nova Publishers, 1-30

Finland S (2015). Population Projection 2015-2065. Retrieved from: http://www.stat.fi/til/vaenn/2015/vaenn_2015_2015-10-30_tie_001_en.html

Fleury, A., Vacher, M., & Noury, N. (2010). SVM-based multimodal classification of activities of daily living in health smart homes: Sensors, algorithms, and first experimental results. IEEE Transactions on Information Technology in Biomedicine, 14(2), 274-283.

Fozard, L., Rietsema H., Bouma, H., Graafmans, J. (2000) Gerontechnology: Creating enabling environments for the challenges and opportunities of ageing. Educational Gerontology 26(4): 331-344.

Fujii, K., Grossberg, M. D., & Nayar, S. K. (2005). A projector-camera system with real-time photometric adaptation for dynamic environments. IEEE Computer Society Conference on Computer Vision and Pattern Recognition (Vol. 1, pp. 814-821). IEEE.

Fussell, S. R., Setlock, L. D., Yang, J., Ou, J., Mauer, E., & Kramer, A. D. (2004). Gestures over video streams to support remote collaboration on physical tasks. Human-Computer Interaction, 19(3), 273-309.

Gauglitz, S., Lee, C., Turk, M., & Höllerer, T. (2012). Integrating the physical environment into mobile remote collaboration. In Proceedings of the 14th international conference on Human-computer interaction with mobile devices and services, pp. 241-250. ACM.

Giebel, C., & Challis, D. (2015). Translating cognitive and everyday activity deficits into cognitive interventions in mild dementia and mild cognitive impairment. International journal of geriatric psychiatry, 30(1), 21-31.

Gokalp, H., & Clarke, M. (2013). Monitoring activities of daily living of the elderly and the potential for its use in telecare and telehealth: A review. Telemedicine and E-health, 19(12), 910-923.

Gold, D. A. (2012). An examination of instrumental activities of daily living assessment in older adults and mild cognitive impairment. Journal of Clinical and Experimental Neuropsychology, 34(1), 11-34.

Gurevich, P., Lanir, J., & Cohen, B. (2015). Design and implementation of teleadvisor: A projection-based augmented reality system for remote collaboration. Computer Supported Cooperative Work (CSCW), 24(6), 527-562.

Hautala, M., Keränen, N. S., Leinonen, E., Kangas, M., & Jämsä, T. (2017). ICT use in family caregiving of elderly and disabled subjects. E-Health 360° (pp. 42-48) NY: Springer.

Helal, S., Mann, W., El-Zabadani, H., King, J., Kaddoura, Y., & Jansen, E. (2005). The gator tech smart house: A programmable pervasive space. Computer, 38(3), 50-60.

Hevner, A. R. (2007). A three cycle view of design science research. Scandinavian Journal of Information Systems, 19(2), 4.

Hevner A. R., March S. T., Park, J. & Ram, S. (2004) Design science in information systems research. MIS quarterly 28(1): 75-105.

Huber, L. L., Shankar, K., Caine, K., Connelly, K., Camp, L. J., Walker, B. A., & Borrero, L. (2013). How in-home technologies mediate caregiving relationships in later life. International Journal of Human-Computer Interaction, 29(7), 441-455.

Iecovich E (2014) Ageing in place: From theory to practice. Anthropological notebooks 20(1): 21-33.

Jacobsen, L. A., Kent, M., Lee, M., & Mather, M. (2011). America’s ageing population. Population Bulletin, 66(1), 1-20.

Jones, B. R. (2010). *Augmenting complex surfaces with projector-camera systems*. (Master's thesis, University of Illinois). Retrieved from https://www.ideals.illinois.edu/handle/2142/18407

Junuzovic, S., Inkpen, K., Blank, T., & Gupta, A. (2012). IllumiShare: Sharing any surface. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, (pp 1919-1928). ACM

Katz, S., & Akpom, C. A. (1976). A measure of primary sociobiological functions. International Journal of Health Services, 6(3), 493-508.

Kidd, C. D., Orr, R., Abowd, G. D., Atkeson, C. G., Essa, I. A., MacIntyre, B., ... & Newstetter, W. (1999). The aware home: A living laboratory for ubiquitous computing research. International Workshop on Cooperative Buildings, (pp 191-198)

Kimura, M., Mochimaru, M., & Kanade, T. (2007). Projector calibration using arbitrary planes and calibrated camera. In IEEE Conference on Computer Vision and Pattern Recognition (pp. 1-2). IEEE.

Kirk, D., Rodden, T., & Fraser, D. S. (2007). Turn it this way: Grounding collaborative action with remote gestures. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, (pp. 1039-1048)

Kirk, D., & Stanton Fraser, D. (2006). Comparing remote gesture technologies for supporting collaborative physical tasks. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, (pp 1191-1200).

Künemund, H., & Tanschus, N. (2013). Gero-technology: Old age in the electronic jungle. Old Age In Europe (pp. 97-112) NY, Springer.

Kuzuoka, H. (1992*)*. Spatial workspace collaboration: A SharedView video support system for remote collaboration capability. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 533-540.

Kuzuoka, H., Kosaka, J., Yamazaki, K., Suga, Y., Yamazaki, A., Luff, P., & Heath, C. (2004). *Mediating dual ecologies*. Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work, 477-486.

Kwon, J. U., Lee, E. S., & Ahn, S. C. (2016). Projector-camera based remote assistance system for the elderly: Design issues and implementation. In IEEE/SICE International Symposium on System Integration (SII)*,* (pp. 230-235). IEEE.

Källström, M., Berdal, S., & Joshi, S. G. (2015). Designing an Indoor Navigation System for Elderly People’s Capabilities. In International Conference on Human Aspects of IT for the Aged Population (pp. 435-445). Cham: Springer.

Lancioni, G. E., La Martire, M. L., Singh, N. N., O'Reilly, M. F., Sigafoos, J., Pinto, K., & Minervini, M. G. (2009). Persons with mild or moderate Alzheimer's disease managing daily activities via verbal instruction technology. American Journal of Alzheimer's Disease & Other Dementias®, 23(6), 552-562.

Lee, C. (2014). *User-centered system design in an aging society: an integrated study on technology adoption* (Doctoral dissertation, Massachusetts Institute of Technology). Retrieved from https://dspace.mit.edu/handle/1721.1/89872

Lee, J. D., & See, K. A. (2004b). Trust in automation: Designing for appropriate reliance. Human Factors, 46(1), 50-80.

Li, R., Lu, B., & McDonald-Maier, K. D. (2015). Cognitive assisted living ambient system: A survey. Digital Communications and Networks, 1(4), 229-252.

Liang, S. (2015). Research proposal on reviewing augmented reality applications for supporting ageing population. Procedia Manufacturing, 3, 219-226.

Lukosch, S., Billinghurst, M., Alem, L., & Kiyokawa, K. (2015). Collaboration in augmented reality. Computer Supported Cooperative Work (CSCW), 24(6), 515-525.

Ly, N. T., Hurtienne, J., Tscharn, R., Aknine, S., & Serna, A. (2015). Towards Intelligent and Implicit Assistance for People with Dementia: Support for Orientation and Navigation. In Proceedings of the XVI International Conference on Human Computer Interaction (p. 31). ACM.

Malik, S. A., Abdullah, L. M., Mahmud, M., & Azuddin, M. (2013). Mobile applications using augmented reality to support older people. In International Conference on Research and Innovation in Information Systems (ICRIIS), (pp. 374-379). IEEE.

McHugh, J. E., Wherton, J. P., Prendergast, D. K., & Lawlor, B. A. (2012). Identifying opportunities for supporting caregivers of persons with dementia through information and communication technology. Gerontechnology, 10(4), 220-230.

MedicineNet. (2015) Retrieved from http://www.medicinenet.com

Memon, M., Wagner, S. R., Pedersen, C. F., Beevi, F. H. A., & Hansen, F. O. (2014). Ambient assisted living healthcare frameworks, platforms, standards, and quality attributes. Sensors, 14(3), 4312-4341

Marner, M. R., Smith, R. T., Walsh, J. A., & Thomas, B. H. (2014). Spatial user interfaces for large-scale projector-based augmented reality. IEEE computer graphics and applications, 34(6), 74-82.

Mihailidis, A., Boger, J. N., Craig, T., & Hoey, J. (2008). The COACH prompting system to assist older adults with dementia through handwashing: An efficacy study. BMC Geriatrics, 8(1), 28.

Mihailidis, A., Boger, J., Czarnuch, S., Jiancaro, T., & Hoey, J. (2012). Ambient assisted living technology to support older adults with dementia with activities of daily living. In J. Augusto et al. (Eds.), Handbook of ambient assisted living (pp. 304–330). Amsterdam: IOS Press.

Montague, E. N., Kleiner, B. M., & Winchester, W. W. (2009). Empirically understanding trust in medical technology. International Journal of Industrial Ergonomics, 39(4), 628-634.

Muszynska, M. M., & Rau, R. (2012). The old-age healthy dependency ratio in europe. Journal of Population Ageing, 5(3), 151-162.

Nauha, L., Keränen, N. S., Kangas, M., Jämsä, T., & Reponen, J. (2016). Assistive technologies at home for people with a memory disorder. Dementia, 1471301216674816.

Nishida, Y., Hori, T., Suehiro, T., & Hirai, S. (2000). Sensorized environment for self-communication based on observation of daily human behavior. International Conference on Intelligent Robots and Systems (IROS 2000) (Vol. 2, pp. 1364-1372). IEEE

Oh, Y., & Woo, W. (2004). A unified application service model for ubihome by exploiting intelligent context-awareness. In International Symposium on Ubiquitious Computing Systems (pp. 192-202). Berlin/Heidelberg: Springer.

O'Grady, M. J., Muldoon, C., Dragone, M., Tynan, R., & O'Hare, G. M. (2010). Towards evolutionary ambient assisted living systems. Journal of Ambient Intelligence and Humanized Computing, 1(1), 15-29.

Olivier, P., Xu, G., Monk, A., & Hoey, J. (2009). Ambient kitchen: Designing situated services using a high fidelity prototyping environment. In Proceedings of the 2nd International Conference on Pervasive Technologies Related to Assistive Environments (p. 47). ACM.

Passini, R., Pigot, H., Rainville, C., & Tétreault, M. H. (2000). Wayfinding in a nursing home for advanced dementia of the Alzheimer's type. Environment and Behavior, 32(5), 684-710.

Peek, S. T., Luijkx, K. G., Rijnaard, M. D., Nieboer, M. E., van der Voort, Claire S., Aarts, S., . . . Wouters, E. J. (2016b). Older adults' reasons for using technology while ageing in place. Gerontology, 62(2), 226-237.

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. Journal of Management Information Systems, 24(3), 45-77.

Peters, C., Hermann, T., Wachsmuth, S., & Hoey, J. (2014). Automatic task assistance for people with cognitive disabilities in brushing teeth-A user study with the tebra system. ACM Transactions on Accessible Computing (TACCESS), 5(4), 10.

Pigini, L., Facal, D., Blasi, L., & Andrich, R. (2012). Service robots in elderly care at home: Users' needs and perceptions as a basis for concept development. Technology and Disability, 24(4), 303-311.

Pol, M. C., Poerbodipoero, S., Robben, S., Daams, J., Hartingsveldt, M., Vos, R., ... & Buurman, B. M. (2013). Sensor monitoring to measure and support daily functioning for independently living older people: A systematic review and road map for further development. Journal of the American Geriatrics Society, 61(12), 2219-2227.

Pollack, M. E., McCarthy, C. E., Ramakrishnan, S., Tsamardinos, I., Brown, L., Carrion, S., ... & Peintner, B., (2002). Autominder: A planning, monitoring, and reminding assistive agent. In Proceedings of the 7th International Conference on Intelligent Autonomous Systems, 265-272.

Rashidi, P., & Cook, D. J. (2009). Keeping the resident in the loop: Adapting the smart home to the user. IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans, 39(5), 949-959.

Rashidi, P., & Mihailidis, A. (2013). A survey on ambient-assisted living tools for older adults. IEEE Journal of Biomedical and Health Informatics, 17(3), 579-590.

Reinhard, S.C., Given, B., Petlick, NH., Bemis, A. (2008) Supporting family caregivers in providing care. In: Hughes, RG., (Ed.). Patient safety and quality: an evidence-based handbook for nurses. Rockville: Agency for Healthcare Research and Quality; 2008. p. 1–64.

Robinson, L., Gibson, G., Kingston, A., Newton, L., Pritchard, G., Finch, T., & Brittain, K. (2013). Assistive technologies in caring for the oldest old: A review of current practice and future directions. Ageing Health, 9(4), 365-375.

Sakata, N., Kurata, T., Kato, T., Kourogi, M., & Kuzuoka, H. (2003). WACL: Supporting Telecommunications Using Wearable Active Camera with Laser Pointer. In ISWC (Vol. 2003, p. 7th).

Sakata, N., Takano, Y., & Nishida, S. (2014). Remote collaboration with spatial AR support. In International Conference on Human-Computer Interaction (pp. 148-157). Cham: Springer.

Sarni, T. (2013). Remote care for elderly people suffering from dementia: A novel information system design. IADIS International Journal on WWW/Internet, 11(3).

Seelye, A. M., Schmitter-Edgecombe, M., Das, B., & Cook, D. J. (2012). Application of cognitive rehabilitation theory to the development of smart prompting technologies. IEEE Reviews in Biomedical Engineering, 5, 29-44.

Sixsmith, A. (2013). Technologies for active aging (Vol. 9). G. M. Gutman (Ed.). NY: Springer.

Sixsmith, A., Meuller, S., Lull, F., Klein, M., Bierhoff, I., Delaney, S., & Savage, R. (2009). SOPRANO–an ambient assisted living system for supporting older people at home. In International Conference on Smart Homes and Health Telematics (pp. 233-236). Berlin/Heidelberg: Springer.

Smarr, C. A., Prakash, A., Beer, J. M., Mitzner, T. L., Kemp, C. C., & Rogers, W. A. (2012, September). Older adults' preferences for and acceptance of robot assistance for everyday living tasks. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 56, No. 1, pp. 153-157). CA: Sage.

Surie, D., Baydan, B., & Lindgren, H. (2013). Proxemics awareness in kitchen As-A-pal: Tracking objects and human in perspective. In Proceedings of the 9th International Conference on Intelligent Environments, (pp. 157-164). IEEE

Stowe, S., & Harding, S. (2010). Telecare, telehealth and telemedicine. European Geriatric Medicine, 1(3), 193-197.

Tervonen, J., (2014). *Wearable wayfinding aid for elderly demented persons*. (Master's thesis, University of Oulu). Retrieved from http://jultika.oulu.fi/Record/nbnfioulu-201402081073

United Nations (2017) Department of Economic and Social Affairs, Population Division. World Population Prospects: The 2017 Revision

United Nations (2015) Department of Economic and Social Affairs, Population Division. World Population Ageing 2015 (ST/ESA/SER.A/390).

United Nations (2013) World Population Ageing: Department of Economic and Social Affairs, Population Division.

Vainio, A., Valtonen, M., & Vanhala, J. (2008). Proactive fuzzy control and adaptation methods for smart homes. IEEE Intelligent Systems, 23(2)

Van Krevelen, D., & Poelman, R. (2010). A survey of augmented reality technologies, applications and limitations. International Journal of Virtual Reality, 9(2), 1-20.

Van Tassel, M., Bouchard, J., Bouchard, B., & Bouzouane, A. (2011). Guidelines for increasing prompt efficiency in smart homes according to the resident's profile and task characteristics. In Proceedings of the International Conference on Smart Homes and Health Telematics, 112-120.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. MIS Quarterly, 27(3), 425-478.

Yamazaki, T. (2006). Beyond the smart home. In International Conference on Hybrid Information Technology, 2006. ICHIT'06. (Vol. 2, pp. 350-355). IEEE.

Wherton, J. P., & Monk, A. F. (2010). Problems people with dementia have with kitchen tasks: The challenge for pervasive computing. Interacting with Computers, 22(4), 253-266.

Williams, G., Doughty, K., & Bradley, D. A. (1998). A systems approach to achieving CarerNet-an integrated and intelligent telecare system. IEEE Transactions on Information Technology in Biomedicine, 2(1), 1-9.

Winblad, B., Palmer, K., Kivipelto, M., Jelic, V., Fratiglioni, L., Wahlund, L., ... & Arai, H. (2004). Mild cognitive impairment–beyond controversies, towards a consensus: Report of the international working group on mild cognitive impairment. Journal of Internal Medicine, 256(3), 240-246.

Wu, W., Au, L., Jordan, B., Stathopoulos, T., Batalin, M., Kaiser, W., ... & Chodosh, J. (2008). The smartcane system: an assistive device for geriatrics. In Proceedings of the ICST 3rd international conference on Body area networks (p. 2).

Zahedi, F. M., Walia, N., & Jain, H. (2016). Augmented virtual doctor office: Theory-based design and assessment. Journal of Management Information Systems, 33(3), 776-808.

Ziefle, M., Himmel, S., & Wilkowska, W. (2011, November). When your living space knows what you do: Acceptance of medical home monitoring by different technologies. In Symposium of the Austrian HCI and Usability Engineering Group (pp. 607-624). Berlin/Heidelberg: Springer.

Original publications

This thesis includes the following six original publications, which are referred to throughout the text by their Roman numerals:

VII Yamamoto, G., Chen, A., Pulli, P., Hyry, J., Asghar, M.Z., Uranishi, Y., & Kato, H. (2013) A laser projection-based tele-guidance system embedded on a mobility aid. Proceedings of the 7th International Symposium on Medical Information and Communication Technology (ISMICT), IEEE: 139-143.

VIII T
ervonen, J., Asghar, M.Z., Yamamoto, G., & Pulli, P. (2013) A navigation aid for people suffering from dementia using a body worm laser device. Proceedings of the 7th International Symposium on Medical Information and Communication Technology (ISMICT), IEEE: 178-182.

IX Ikeda, S., Asghar, Z., Hyry, J., Pulli, P., Pitkänen, A., & Kato, H. (2011) Remote assistance using visual prompts for demented elderly in cooking. Proceedings of the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies (p. 46). ACM.

X Yamamoto, G., Asghar, Z., Uranishi, Y., Taketomi, T., Sandor, C., Kuroda, T., Pulli, P. & Kato, H. (2014) Grid-pattern indicating interface for ambient assisted living. Proceedings of the International Conference on Disability, Virtual Reality and Associated Technologies. pp. 405-408.

XI Yahui, L., Asghar, Z., & Pulli, P. (2013) Visually-aided smart kitchen environment for senior citizens suffering from dementia. International Joint Conference on Awareness Science and Technology & Ubi-Media Computing (iCAST 2013 & UMEDIA 2013) (pp. 584-590). IEEE.

XII Asghar, Z., Yamamoto, G., Taketomi, T., Sandor, C., Kato, H., & Pulli, P. (2017) Remote Assistance for Elderly to Find Hidden Objects in a Kitchen. EAI Endorsed Transactions on Pervasive Health and Technology, 17(12): e3. http://dx.doi.org/10.4108/eai.7-9-2017.153065.

Original publications are not included in the electronic version of the dissertation

705. Ventä-Olkkonen, Leena (2017) The characteristics and development of urban computing practices : utilizing practice toolkit approach to study public display network

706. Mononen, Jukka (2017) Korkeasti koulutettujen vammaisten integroituminen ICT-alalle heidän itsensä kokemana : ”Älä anna muille etumatkaa!”

707. Tolonen, Katri (2018) Taxonomic and functional organization of macroinvertebrate communities in subarctic streams

708. Turunen, Jarno (2018) Responses of biodiversity and ecosystem functions to land use disturbances and restoration in boreal stream ecosystems

709. Huusko, Riina (2018) Downstream migration of salmon smolts in regulated rivers : factors affecting survival and behaviour

710. Huusko, Karoliina (2018) Dynamics of root-associated fungal communities in relation to disturbance in boreal and subarctic forests

711. Lehosmaa, Kaisa (2018) Anthropogenic impacts and restoration of boreal spring ecosystems

712. Sarremejane, Romain (2018) Community assembly mechanisms in river networks : exploring the effect of connectivity and disturbances on the assembly of stream communities

713. Oduor, Michael (2018) Persuasive software design patterns and user perceptions of behaviour change support systems

714. Tolvanen, Jere (2018) Informed habitat choice in the heterogeneous world: ecological implications and evolutionary potential

715. Hämälä, Tuomas (2018) Ecological genomics in *Arabidopsis lyrata* : local adaptation, phenotypic differentiation and reproductive isolation

716. Edesi, Jaanika (2018) The effect of light spectral quality on cryopreservation success of potato (*Solanum tuberosum* L.) shoot tips *in vitro*

717. Seppänen, Pertti (2018) Balanced initial teams in early-stage software startups : building a team fitting to the problems and challenges

720. Maliniemi, Tuija (2018) Decadal time-scale vegetation changes at high latitudes : responses to climatic and non-climatic drivers

721. Giunti, Guido (2018) 3MD for Chronic Conditions : A Model for Motivational mHealth Design

Book orders:
Granum: Virtual book store
http://granum.uta.fi/granum/

UNIVERSITY OF OULU P.O. Box 8000 FI-90014 UNIVERSITY OF OULU FINLAND

ACTA UNIVERSITATIS OULUENSIS

UNIVERSITY of OULU
OULUN YLIOPISTO

ISBN 978-952-62-2048-2 (Paperback)
ISBN 978-952-62-2049-9 (PDF)
ISSN 0355-3191 (Print)
ISSN 1796-220X (Online)