NAIST-IS-DD1261022

## Doctoral Dissertation

# Designing Projected User Interfaces as Assistive Technology for the Elderly

Jaakko Hyry

16 June, 2017

Department of Information Science
Graduate School of Information Science
Nara Institute of Science and Technology

A Doctoral Dissertation
submitted to the Graduate School of Information Science,
Nara Institute of Science and Technology
in partial fulfillment of the requirements for the degree of
Doctor of ENGINEERING

Thesis Committee:

| | |
|---|---|
| Professor Hirokazu Kato | (Supervisor) |
| Professor Norihiro Hagita | (Co-supervisor) |
| Associate Professor Christian Sandor | (Co-supervisor) |
| Assistant Professor Goshiro Yamamoto | (Co-supervisor) |
| Professor Petri Pulli | (University of Oulu) |

# Designing Projected User Interfaces as Assistive Technology for the Elderly*

**Jaakko Hyry**

**Abstract**

Old age brings several physical and cognitive challenges for elderly people, which complicates the utilization of modern information and communication technology (ICT) for daily task assistance and for caretakers and family support. One factor hindering the adoption of ICT is that most existing user interfaces (UIs) require prior knowledge of use metaphors that many elderly people cannot learn to master. Research on developing assistive technology exists, such as phones for the elderly, but these often have UIs that require prior knowledge and use experience. Recent research has introduced Ambient Assisted Living (AAL) concepts for users' homes, for example projecting guidance into the environment. However, only a few empirical studies have attempted to define the type of projection-based UIs that would be intuitive for the elderly, and the system design processes that would help in developing such AAL have not been researched thoroughly.

This work presents three design iterations and their empirical evaluations. From these, a body of knowledge was produced for designing and developing AALs with projected Augmented Reality (AR) UIs. The first iteration had a sentence-building UI implemented for a wearable Projector-Camera (ProCam) system, which had limits in technical suitability for the elderly. The second iteration changed the use metaphor to a simple icon-based menu, and produced a requirement guideline for UIs in AAL. In the final iteration, the wearable was replaced with a fixed ProCam, allowing the elderly to make menu selections effectively. This iteration supported sequential tasks, such as taking medicine, with visual guides. The suitability of the new UI was tested with computer literate young adults and elderly users, many of the latter having memory and motor skill limitations. The comparison showed that the two groups performed similarly; however, the elderly needed a slower and more direct interaction technique adapted to their preferences in the UI. Assistance for the sequential tasks was found feasible.

This work produced a set of UI-related and technical factors that AAL designers should take into account when developing projector-based AR systems for the elderly with memory problems. In addition, this work offers suggestions on how to conduct UI testing sessions with this user group to reduce the amount of work and improve the success of the iterative development process.

**Keywords:**
assistive technology, augmented reality, design,  elderly, user interface

.*Doctoral Dissertation, Department of Information Science, Graduate School of Information Science, Nara Institute of Science and Technology, NAIST-IS-DD1261022, 16 June 2017.

***Dedicated to my family and friends who helped me achieve more than I thought I ever could 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 of these universities for the opportunity to participate in this collaboration.*

I would like to thank many individuals that made this thesis happen. First and foremost I would like to thank my excellent supervisors Dr. Hirokazu Kato and Dr. Petri Pulli. You two enabled my studies and double graduation both in Japan and Finland. Second, my heartfelt thank you to Dr. Goshiro Yamamoto for all these years of friendship and guidance; and Dr. Mikko Rissanen for being critical towards my work and having endured countless hours of listening to my repeated questions and outbursts and still continuing to guide my writing and research work. You are my dear friends who helped make most of this happen. I would also like to thank Dr. Norihiro Hagita; Dr. Haruo Noma and Dr. Petri Vuorimaa for reviewing my thesis; I offer a special bow to Mr. Max Krichenbauer for helping me create the vital system for this study. Also, Dr. Takafumi Taketomi and Dr. Christian Sandor, I appreciate all your help.

I would like to extend my gratitude towards several institutions for enabling me to do my research work in Finland and Japan: the Academy of Finland, the Japan Society for Promotion of Science (JSPS) and the Japan-Finland Research Cooperative Program of the Japan Science and Technology Agency and Ryhti-project. Several grants were approved and I would like to most humbly thank the Technology Industries Centennial Foundation, the Academy of Finland, the Tauno Tönning Research Foundation, the Scandinavia-Japan Sasakawa Foundation, Tekniikan edistämissäätiö (TES) and the University of Oulu grant foundations. To my friends at Videra for videoconferencing services of the doctoral public defense to Japan.

There are several people to whom I would like to give special thanks as they helped and opened up a lot of doors for me over the years. Dr. Kunihiro Chihara and everyone at the former Image Processing laboratory, you introduced Japan and its research environment to me for the first time and let me stumble around aimlessly but happy for my first year. Thank you to Dr. Petteri Viramo and the Oulun diakonissalaitos (ODL) staff for supporting my research; to Dr. Ilkka Winblad who passed away too soon, but taught me about health care and the difficulties of the elderly; and to Dr. Seamus Hickey, Dr. Peter Antoniac, Dr.

Jarkko Polvi and Dr. Martti Hyry for being very supportive all these years. I also give many thanks to Dr. Jorma Riihijärvi for helping with my statistical analysis and Dr. Raija Halonen for her support with the structure of my work. I would like to raise a glass to Dr. Ari Hautasaari for being my support in life. You made me improve physically so that I could endure mentally throughout this process, and as a friend, there is no substitute. You rock. I want to thank my closest friends, Janne Somervalli, Markus Rahm and everyone from Tornio, for offering me a sofa to sleep on and a sauna to relax in whenever I wanted to talk; and my mother, Sirkka Streller, for giving me the biggest help and love when I needed it the most. My sister and her family, my friends, I love you all. As always, I cannot thank everyone I would like to, so I give my deepest thanks to all of you who have ever been there for me.

Kiittäen,

16 June, 2017 Jaakko Hyry

## Abbreviations and definitions

| | |
|---|---|
| AAL | Ambient Assisted Living |
| AAMI | Age-Associated Memory Impairment |
| AD | Alzheimer's disease |
| ADL | Activities of Daily Living |
| AR | Augmented Reality |
| CLU | Computer Literate User |
| GUI | Graphical User Interface |
| HMD | Head-mounted display |
| IADL | Instrumental Activities of Daily Living |
| ICT | Information and Communication Technology |
| MCI | Mild Cognitive Impairment |
| MMSE | Mini-Mental State Examination |
| PECS | Picture Exchange Communication System |
| PiTaSu | Picture Tapping Surface |
| UI | User Interface |
| VR | Virtual Reality |

*Age-Associated Memory Impairment (AAMI):* Normal ageing-related decline in cognitive functions, resulting in mild forgetfulness.

*Gerontechnology:* Gerontechnology is a combination of the terms gerontology and technology. It refers to interdisciplinary research into technology for an ageing society. It aims to improve the quality of life of elderly individuals in an optimal way by using technology when applicable.

*Mild Cognitive Impairment (MCI):* MCI can be considered as a more-than-average cognitive decline of an elderly person, and it has a chance of developing into Alzheimer's disease (AD).

*Projector-Camera (ProCam) system:* As used in this dissertation, the term ProCam refers to a combination of a *projector* and a *camera,* calibrated to display computer-generated images correctly in a real-world environment. The projected image can be tracked in real time with the camera. As a result, the image can be computationally manipulated and displayed correctly regardless of the position of the projector. The camera can be used to track a scene, objects or markers. This projector-camera combination, also used in this study to realize a system, is often used in Augmented Reality (AR) solutions.

# Original publications

This thesis is based on the following publications, which are referred throughout the text by their Roman numerals:

I Hickey S, Yamamoto G, Pitkänen A, Hyry J & Yoshitake D (2009) Implementation of a Picture Based User Interface to Assist the Elderly Suffering from Memory Problems. Proceedings of the 8th International Conference on Virtual Reality Continuum and its Applications in Industry, Pages 351-356.

II Pulli, P, Hyry, J, Pouke, M, & Yamamoto, G (2012) User interaction in smart ambient environment targeted for senior citizen. Medical & biological engineering & computing, 50(11), 1119-1126.

III Hyry, J, Yamamoto, G, & Pulli, P (2011) Requirements guideline of assistive technology for people suffering from dementia. In Proceedings of the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies (p. 39). ACM.

IV Ikeda, S, Asghar, Z, Hyry, J, Pulli, P, Pitkänen, A, & Kato, H (2011) Remote assistance using visual prompts for demented elderly in cooking. In Proceedings of the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies (Article No. 46). ACM.

V Hyry J, Krichenbauer M, Yamamoto G, Taketomi T, Miyazaki J, Sandor C, Kato H & Pulli P (2017) Design of Assistive Tabletop Projector-Camera System for the Elderly with Cognitive and Motor Skill Impairments. ITE Transactions on Media Technology and Applications, 5(2), 57-66.

# Contents

# 1 Introduction

People's life expectancies are rising along with the average age increase, and the elderly demographic around the world will continue to grow larger in the future. The result will be a population structure consisting heavily of the elderly and less of a younger demographic. More elderly will be in need of assistance in the form of a professional caretaker or a family caregiver who may not be readily available to them due to the age demographic mismatch. The ageing problem is a global one, and the data and the proposed solutions presented in this thesis would be feasible in most countries. Regarding ageing problems, Japan is currently in the worst position, according to Statistics Bureau of Japan (2007). However, figures provided by Statistics Finland (2007) show that Finland is in nearly the same situation. As the population structures shift, studies have shown that countries will face two large problems in the future: the cost of supporting the elderly will rise, and the number of caretaking personnel will not be sufficient to support those in need of help (Niemelä & Salminen 2009). Solutions for reducing costs, easing the growing workload of caretakers and offering effective assistance for the elderly are needed.

The State of Aging and Health in America (Center for Disease Control [CDC] 2013) reports that 64% of American older adults surveyed want to stay in their own homes as long as possible, which is consistent with the preferences of the Finnish elderly population. The services provided to the elderly should support the independent execution of daily tasks (Vaarama et al. 2010) Based on these statistics and elder preferences, help should be provided on location at an elderly person's home whenever possible. Being able to stay at home longer costs less than being in an institution from the time that support is needed. However, among the aged, the number of elderly who live alone is increasing, and these people require more assistance in basic daily tasks from professional caretakers. In addition, the older a person gets, the more assistance they need (Parkkinen 2007). All degrees of memory impairment among the elderly population will more than double during the next 30 years (Ferri et al. 2006), and this population with memory impairment will need more assistance than the average elderly person, so the problem needs to be addressed.

This study is part of a multidisciplinary research project in which the proposed solutions to these financial and personnel problems could be achieved by improving caretaking personnel's productivity, as well as by postponing the decline in the cognitive and memory function of the elderly by a few years. As an example, an 80-year-old person could have the same functionality and capabilities as a 75-year-old person. In addition, if caretaking professionals' productivity could be increased annually by just 1%, the current number of workers would be sufficient. In these optimal cases, the need for more caretaking personnel plummets from nearly 25% to about 15% (Parkkinen 2007). A more functional elderly person could live in their own home longer and would not need a place in a nursing home where they would have less independence and would accumulate greater caretaking-related costs for society. Ageing in place would accumulate vast savings for society (Niemelä & Salminen 2009).

Research has been done to implement technology as an assistive and supportive tool for both caretakers and the elderly. Everywhere, technology surrounds our lives more and more every day in the form of ambient intelligence. It is being integrated into many aspects of our lives and has changed the ways we communicate. It could also change the way we deliver health care to individuals in need. It is crucial to think what kinds of technologies are available for the elderly who suffer from memory impairment and whether the design aspects are taking this growing population's needs into account. If the current solutions are not adequate, there is a need to create novel, easy-to-use devices to meet elderly user requirements. Human-computer interaction systems designed specifically for the elderly are required in many countries where elderly people feel alienated in the use of new technology.

This study proposes an assistive projection tabletop solution in the home of an elderly person and investigates how feasible such a system would be. Cognitive and physical limitations of the elderly make technology use more difficult, so this research seeks to establish whether this fairly unknown technology is appropriate for elderly people, offering types of assistance that are comfortable to users, with a user interface (UI) they can effectively and intuitively use. Often the use of new and state-of-the-art assistive technology requires skills that elderly users might not have, and the technology must be taught with a caretaker's assistance. The assistive technology offered also needs to be accepted into the elderly person's home through explanations of its usefulness to the end user. For this to happen, the design and use of an assistive system has to be as approachable as possible and be unobtrusive to the elderly person.

Bouma et al. (2004) discussed the improvements that technology could bring to the lives of the elderly. Augmenting the elderly's abilities to perform their routine tasks more effectively would make them more productive. In addition, the elderly could access information they often require but do not have easy access to and they could stay better connected with their family and caregivers. Bouma et al. also presented the challenges the elderly have with technology and stated that one should understand why the elderly have trouble adopting new technology. They also questioned why the focus of research is not on the elderly being active users. If this technology acceptance problem cannot be solved, the benefits of new technologies are out of reach for the elderly population. This dissertation sheds additional light on the problem points presented by Bouma et al. by discussing the experience of conducting user studies with the elderly. The work presented in this dissertation is a collaboration between a Japanese and a Finnish university through a double-degree program. Most of the technical solutions were developed in Japan, and the user studies for the prototype systems were conducted in Finland. The collaboration aims to offer solutions suitable for both countries, as both suffer from similar problems regarding ageing.

## 1.1 Purpose

The purpose of this study was to design, test and verify an assistive technological solution in the form of a projective tabletop system for the elderly in order to sustain independent living at home. The research focused on finding out whether using new projection-based systems and tailored user-interface methods in elderly users' home environments is feasible as an assistive alternative for the elderly. Newer technologies that use unproven or unverified methods of interaction have not been tested extensively with elderly users, and thus require proper design and testing. The home environment was chosen as the assistance area because enabling ageing in place is one of the ways to maintain an elderly person's quality of life and also to reduce the costs of placing a person in institutionalized care.
The research in this study employed a user-centred approach and Design Science methodology to iteratively create artefacts from the design, prototype and implementation steps in the process and to add to the knowledge base from the findings. First, the research focused on the elderly and how they interact with new technology. Second, the focus was on an actual task they had to follow using the proposed projection system. The process and the results are presented from the iterative format of the pilot and the user tests done for the system. The research focused on finding out how usable a projection-camera (ProCam) system would be for an elderly user by looking into the effectiveness and ease of use of the elements of the design.

## 1.2 Motivation

The motivation for this study was the large number of elderly who will not receive proper assistance in the future due to a lack of economic and human resources. The rising elderly population, many with varying levels of memory impairment, require assistance from caretakers. According to the World Population Prospects from a United Nations report (United Nations 2013), the median age of the world will rise from 29.2 years to 36.1 years in the next 35 years, and the life expectancy will rise from 68.7 years to 75.9 years in the same time period. As examples, Figure 1 shows the percentage rise for people aged over 60 and aged over 80 years of age for Japan, Finland and the world. Looking at Japan, the percentage of people over the age of 60 will grow from 32% of the population to nearly 43% of the population by the year 2050. Similarly, in Finland, the ageing population over the age of 60 can be seen growing from 26.3% to 31.5%. The percentage of elderly people over the age of 60 in the world population will rise dramatically from 11.7% to 21.2%, and the percentage of people over the age of 80 will grow from 1.7% to 4.1% in the next 35 years.

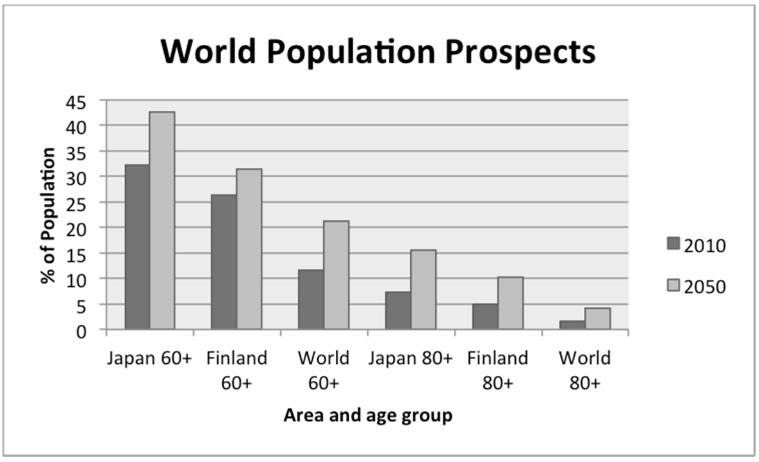
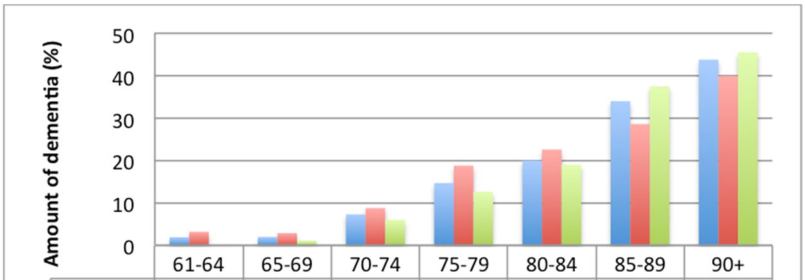



**Fig. 1. World ageing population prospects (United Nations 2013)**

The number of people with dementia will also rise in the world and among the elderly. Figure 2 shows the prevalence of dementia in age groups of 60 to over 90 which shows an increase from 1.9% to 43.8%. This representative example is for a single population in the Finnish town of Haapajärvi (Winblad et al. 2010).

Societies cannot afford to take care of the elderly in the future with the current number of caretakers and lack of funding. Many elderly p eople with memory impairment require either constant care in an institution or visits from caretaking staff in their homes. Often, these individuals would like to live in their own homes as long as possible, but they need to be institutionalized due to the daily problems resulting from the dangers presented by memory problems i.e. falling down at home, forgetting medication, getting lost. In Finland, the financial and personnel prospects cannot sustain the expected future ageing population and the predicted number of people with dementia. The world lives in an age of ubiquitous technology, used by people in the form of smartphones, tablets and personal computers, as well as existing inside everyday machines. Assistance could be provided using existing techno logy or newer technology that was not initially thought of as useful in elderly care. However, the attitudes of the elderly towards technology might often be negative. Learning how to use current technology is difficult, as it is not often designed with el derly users, especially users with memory impairment, in mind. This lack of skills in using unfamiliar devices presents problems for the introduction of technological assistance into a home environment.




| | 61-64 | 65-69 | 70-74 | 75-79 | 80-84 | 85-89 | 90+ |
|---|---|---|---|---|---|---|---|
| All | 1,9 | 2 | 7,3 | 14,7 | 20 | 34 | 43,8 |
| Men | 3,2 | 2,9 | 8,8 | 18,8 | 22,6 | 28,6 | 40 |
| Women | 0 | 1,1 | 6 | 12,6 | 19 | 37,5 | 45,5 |

**Fig. 2. The distribution of dementia by age and sex for 60+ population. Modified from (Winblad et al. 2010)**

Studies show that a person with dementia needs to feel safe and assisted, and also that an informal caretaker, such as a spouse, needs to know that the elderly person is taken care of if they are not present at home (Björneby et al. 1999). This is because there is a strong mental burden on the informal caretakers of a person with memory impairment. Family members taking care of the elderly often feel that the workload is so significant that they might end up with depression themselves. For this reason, reducing the workload is important as well as providing the information that caretakers require about the elderly person. Technology could offer improved ways to help the elderly and provide information about their situation to caretakers. This assisted work can be as simple as knowing that the elderly person has taken their medication on time and correctly.

AR has been a fairly well studied research field for many years, but it has been relatively untested for its possibilities in the field of elderly assistive technology. This thesis chose projected AR technology as a research focus for assistance because it provides information and a UI for the elderly user, which, overlaid on surfaces and objects, are visible to the user as well as to others around the projection. It is not bound by a screen and does not need to be carried or worn by the user and thus would be a more unobtrusive and less limiting solution.

When looking at how computer use has increased over the years and how human-computer interaction has been studied, there is still a gap between age groups, which should be taken into account (Charness & Boot 2009). The role of technology in everyday life situations is growing, and the share of the elderly in the population is increasing, especially in developed countries. Although the elderly are facing increasing technology in their everyday lives and other contexts (Mikkola & Halonen 2011), they are not yet accustomed to its use. Marcus stated that a future of connected and smart objects creating a ubiquitous network, combined with appropriate services for communities of regular people, is already among us, not only for people with special needs (Marcus 2003). Activities that promote independent living for the elderly in their own homes are acknowledged as information and communication technology (ICT) based activities (Curry et al. 2002), and Fuglsang saw efforts in empowering the elderly to become more active citizens as an important factor (Fuglsang 2005). However, there are difficulties with the use of current and new technologies among the elderly. Hawthorn pointed out that the acceptance and use of new technology are often difficult due to convoluted guides and structures (Hawthorn 2007). As such, designing technology that takes into account elderly users should be seen as one of the more important tasks, as pointed out in several studies. Rogers and Czaja stated that, in addition to designers' ability to make products more desirable for any given market, they can improve elderly people's quality of life with their design choices (Rogers & Czaja 2004). The study by Charness & Boot (2009) added that poorly designed technology is one of the things that incite fear of technology among the elderly. This makes it increasingly difficult to adopt newer technologies. The negative feelings and attitudes of elderly users make thought processes more difficult, and they cannot concentrate on new tasks or on the features of a given system. For this reason, Broady et al. suggested that technology designs should take into consideration the abilities of the elderly and the kind of physical or mental changes ageing causes for these individuals. For the growing elderly population, the acceptance and utilization of new technologies is becoming more and more important (Broady et al. 2010).

Not only is there a need to design technology suitable for the elderly, but it is also important that ethical aspects be taken into account when technology is increasingly implemented and used and when it starts to affect the elderly (Mordini et al. 2009). As an example, the technology presented in this study uses a camera that has infrared capabilities; however, it is not used to expose the user to possible privacy-limiting surveillance via a video feed. The infrared light emitted by the camera will only be able to see objects with special markers in the environment. The necessary data shared by the proposed system (e.g. scheduling and medication) would either be securely stored locally or be accessible over a secured connection only to authorized persons. However, as a limitation, this thesis does not extensively focus on information security, privacy or ethics, as the focus of this work is on the interaction with and feasibility of new technology. Still, the ethical and privacy points are presented as suggestions of how to address these important considerations in the discussion section of the thesis.

## 1.3 Elderly user, environment and ethical consideration

This study limits the scope of the research to a couple of factors. The proposed system would be installed in the home of an elderly user. This is considered a place where they need the most assistance due to being alone for long periods of time, and this installation would enable ageing in place. The intended users of the system are individuals ranging from those with normal ageing-related difficulties to individuals with mild dementia. Elderly people in more advanced stages of dementia require constant care in a nursing home and thus are not suitable for an assistive technological system, as learning the technology would be next to impossible and extensive human assistance is required for them. This study focuses on an average user who is an elderly person over the age of 65 and who may have the above-mentioned limited cognitive capabilities. For physical capabilities, the user must have adequate eyesight to read two -centimetre-sized text, at minimum, with or without the a ssistance of glasses. For motor skill problems, slight tremors are acceptable as well as similar restrictive hindrances to movement (e.g., gout), as long as the person can perform pointing actions and hold small items for short periods of time. As the test s were performed using an interface projected on a table, individuals using wheelchairs were accepted for the tests. However, the elderly users for this work were chosen from an available pool of participants mostly based on convenience samples. This was d ue to the fact that it was difficult to find available elderly participants for testing.

Ethical aspects were highlighted as concerns of telecare technology implementations by Eccles (2010). Eccles claimed that ass istive technology use will grow more significant in the near future. He stated that growing telecare technology necessitates a debate on how technology can be ethically implemented while considering that good care might be defined differently for different users. Thus, a certain level of ethical consideration has to be taken into account, considering the fragile nature of the elderly with memory impairment. Oftentimes, these people suffer from symptoms including unpredictable behaviour, thus needing to be t reated with care under professional supervision. In the case of Alzheimer's disease (AD), the elderly might have anxiety or anger towards new situations, so in testing a new assistive system with new and unproven input methods, the design of the system has to be robust and the test situations, flexible. Ethical questions regarding system design have to be considered, so that an elderly person in a frail state of mind can enjoy sufficient privacy, regardless of the technology. Ethical permission for the research was applied for from the ethical committee, but it was deemed unnecessary by the committee due to the less strenuous usability and technological focus of the work.

Intuitiveness is often associated with UI and product design, but its exact nature is often left unspecified. To create a system design for the elderly that can be considered intuitive, and thus to understand what intuitiveness is and how it can be measured, the term itself has to be defined clearly. In this work, "intuitive use" is based on a study (Blackler et al. 2003) that defined the term as that which takes into account previous knowledge of a person regarding products, and that which is created from experience. Thus, a product that has intuitive use has to be based on some form of familiarity, so that the user can expect a certain result .

## 1.4 Prior research

In recent years, there has been an increasing amount of gerontechnological research, which focuses on studying elderly people's experiences with technology. The basic principle is to improve designs and technology solutions by incorporating elderly users as a central part of the design process, so that the end result better serves an ageing society. At present, the elderly use a multitude of devices ranging from simple one problem–one solutions to assistive devices that are more versatile in nature. The possibilities of smart homes with a wide variety of sensors and other automated or context-sensitive assistive technology devices are being studied to improve this situation. Ambient assisted living (AAL) systems focus on offering ubiquitous assistance to the elderly in their daily tasks, meeting context sensitivity, minimal interaction and unobtrusiveness requirements. Projection and AR systems research that takes elderly users into account is very limited, as most traditional systems research is studied from the perspective of offering solutions to younger users. However, even though the research is scarce, AR projection systems offer usability that could likely be harnessed for systems designed for the elderly. Taking advantage of the technologies and researching how the interaction method matches the needs must be a priority.

## 1.5 Research question

For this work, a projection system with a UI was created to be used by the elderly. As projection technologies are relatively untested with elderly participants in mind, the research focus was on gathering knowledge on the intuitive use problem. To address the presented use context, the main research question (MQ) was:

*MQ: What are the improved ways to construct and validate a UI for the elderly using an AR projection system?*

From this, the sub-questions (SQ) were formalized to address different parts of the projection-based system design factors as follows:

*SQ 1.1: What projection type would be suitable for the elderly at home?*

*SQ 1.2: What requirements are there for a projection system UI for the elderly, and, Are there different requirements for a projection system for the elderly compared to computer-literate users (CLUs)?*

*SQ 1.3: What factors do UI designers need to take into account when choosing the selection methods for a Projector-Camera (ProCam) system for elderly users?*

*SQ 1.4: Is a projection system suitable for supporting a correct execution of a sequenced task such as medication intake?*

*SQ 1.5: What physical assistive devices useful for the elderly, such as medication dispensers, would be appropriate to virtualize using projection technology?*

AAL systems are mainly designed for elderly people with basic ageing-related problems. To create a design specifically for those with memory impairment, the available knowledge on these systems needs to be assessed. These research questions are based on the data received from a background literature review on assistive technology devices that are meant for use by the general population or by the elderly. Based on the literature, there seems to be a lack of technology designed specifically for the elderly or for users with memory impairment, even though the research field is growing. Ageing presents physical and cognitive challenges in learning as well as, in some individuals, an unwillingness to learn new technology, so the goal of this study became a search for ways to help the elderly with technology by taking into account what the users already know, but also focusing on whether an unknown technology could offer assistance in a feasible way. The research question proposed a system with adequate ease of use for the elderly, while still offering new interaction methods not used by this population before.

## 1.6 Research method

This research work uses a Design Science (DS) method and elderly user-centric approaches in realizing the end system with iterating the requirements, technology and user interfaces.

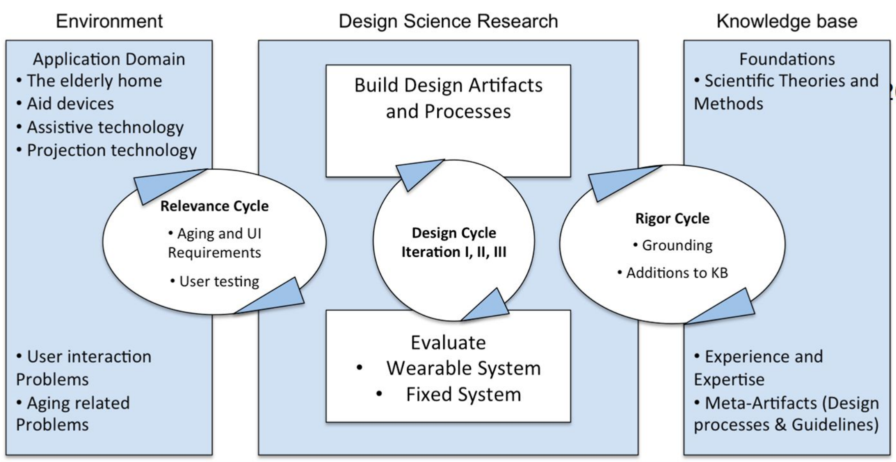


**Fig. 3. Design Science research cycle (Reproduced from Hevner 2004)**

Design Science method is used to create artifacts from different parts of the research process, which are used to expand the existing knowledge base of gerontechnology and technology research. To improve or change the design artefacts, iterations were measured for their rigour. Hevner et al. (2004) introduced seven Design Science research guidelines, which were followed in this research. A more detailed description can be found in Chapter 4, 'Research methodology'.

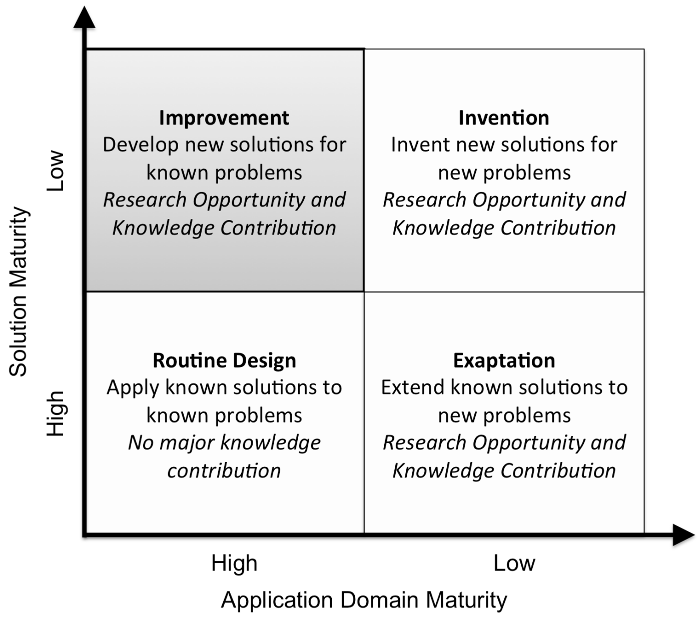



**Fig. 4. Knowledge contribution framework (Reproduced from Gregor & Hevner 2013)**

This thesis presents research that can be classified using the framework in Figure 4 as an *improvement,* where a new solution is developed for known problems, but it can also be considered an *invention*, a new solution for new problems. This is due to the elderly not having extensive experience with projection-based and AR technologies, and thus the interaction experiences with these technologies are new and might present problems. Research presented in this work used a fairly small convenience sample size, as elderly participants available for research purposes were limited. User studies were conducted using participation, observations and interviews to gather feedback .

### 1.7 Main contribution

The main addition of this study to the existing knowledge base for gerontechnology is to address whether (one type of) projection technology is suitable for assisting the elderly in a home environment. The overall design, conceptualization and implementati on of the systems were done through testing the user interaction methods extensively. Additional contributions to the Design Science knowledge base of experience and expertise were derived from the experience of designing and testing a technological system with elderly users and observing how they cope with technology and what kinds of measures should be taken into account for test situations. The research work used in this dissertation has been presented in five publications discussing two platforms and th ree UI concepts, as shown in Figure 5.

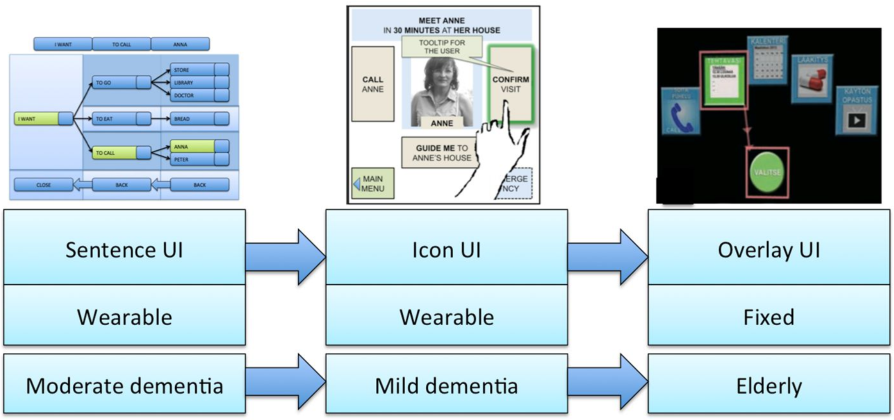



**Fig. 5. Evolution of the UI concepts, system prototypes and target users focus**

The initial concept presented in publication (I) is a UI design based on the picture exchange communication system (PECS). Based on the preliminary requirements of memory impairment, a sentence -based structure of UI was chosen to support cognitive impairment. Initially, a projective system could offer better interaction and display capabilities for the elderly due to real -world projections. Publication (II) built on the idea of using a wearable system in

combination with remote assistance and location sensors to offer context -sensitive support. Findings showed that a wearable system has technical projection issues that might not be suitable for the elderly, and the affordance of a sentence -based UI is low without context-sensitive triggers. Consequently, an additional gathering of elderly requirements was needed, and a new concept for a UI was proposed: publication (III) presents additional requirements for an assistive technology design. A reduction in the number of devices was needed, as well as the implementation of more functionality for the assistive technology devices. This reduction and combination of functions reduced the need for use rs to learn more new devices. The kitchen-assistance-related publication (IV) shows the possibilities of assisting an elderly person in a kitchen environment using visual prompts with a tabletop projection system. Additional qualitative data was gathered of elderly people preparing coffee by observing them in an actual, unfamiliar kitchen environment. Finally, publication (V) shows the development of a tabletop system (Figure 6), which
overcame the technical difficulties of a wearable system and presented a UI for the elderly in a home environment through pilot and user studies. The findings of publication (V) were as follows:

1. Direct interaction is useful when using AR for the elderly.
2. Overlaying on top of objects helps the user with sequential tasks.
3. The hover interaction method is the most suitable for the elderly.
4. A large projection helps the elderly with their interaction limitations.
5. A fixed solution is more suitable than a wearable one for the elderly.

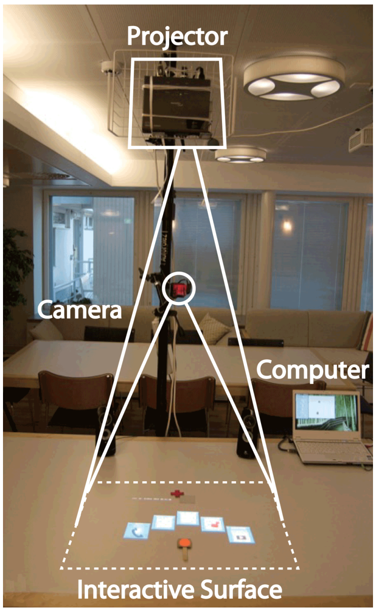



**Fig. 6. Fixed-installation tabletop system solution**

These findings suggest that AR technology with previously unused input methodologies is as suitable as touch-based systems for the elderly. Younger computer-literate and elderly users are fairly similar, with individual levels of skill. Designing a system with these individual traits in mind will result in a more acceptable system for each user. The addition of projection on top of real-world objects gives an additional benefit not available for touch-screen or portable devices. The user study showed that, in a medication task, users had no difficulties understanding the additional projections on top of objects, suggesting that projections would be beneficial to elderly users in other daily tasks. Some of the elderly participants showed problems recovering from mistakes and had self-confidence issues in dealing with technology. Boosting users' confidence with easy-to-use technology is essential. Also, it was difficult for users to distinguish system mistakes from their own mistakes. These publication approaches and findings are shown in more detail in Chapter 6.

Additionally, user testing with the elderly accumulated notions about how tests should be conducted. Subjective observations, interviews and test environments presented some problems that could be avoided with more planning. How to form questionnaires and handle elderly participants for better data by inducing willing participation is explained in the discussion and future work sections .

## 1.8 Structure of the thesis

In Chapter 2, the elderly are described as bein g prone to various physical and cognitive problems, including dementia, which affect their successful completion of daily tasks. In addition, their attitudes and skills in using technology are presented in more detail, including how these affect technology designs. The chapter also supports Chapter 3, where earlier systems designed to assist the elderly are discussed, from simple tools created for simple tasks to more complex assistive technologies that take advantage of sensors and other embedded technologies. The lack of research on elderly -oriented projection -based systems is described, and the need for more studies in this field is explained. Chapter 4 focuses on the overview of the Design Science research method used throughout this study, including how different parts of the research process reflect the method via artefact creation for design and how they are evaluated and refined in later stages of the research work. Chapter 5 presents the main contribution of the work from the initial system concept o f a wearable projection system to a home environment-installed fixed system. The overall arc of different designs and how they were constructed, improved and user tested is described in detail. The results and evaluation of iterations are presented in Chap ter 6 in relation to the research questions. Chapter 7 concludes the overall study with limitations and future work on the possibilities of projection technology for the elderly and describes the additional experience gathered from the user study interview s and observations.

# 2 The elderly as a user

This chapter is a prerequisite for the related works in Chapter 3, since understanding an elderly user, who often has cognitive issues, is important for the evaluation and discussion of the work presented later in this dissertation. To enable ageing in place, there has to be support for the elderly to cope with the changes that happen to them physically and mentally, as well as changes in the environment in which they live. As an example, physiological support might include housing designed according to the capabilities of the elderly as well as solutions, even technological solutions, to help them when their physical conditions are limited. Cognitive supports are to assist elderly people in activities for which they may not function as well mentally or learn as easily as they used to. The work presented in this study focuses on cognitive function support, but it takes into account some of the physical problems the elderly might have when they use technology. Bouma et al. define *gerontechnology* as "*a study of technology and aging for ensuring an optimal technical environment for older adults"* (Bouma et al. 2004).
To design a system for use by the elderly, this chapter will present a description of the elderly as technology users, so that the kind of problems they face every day and the physical and cognitive impairments they have on a general level might be understood. In addition, the problem points created by these impairments are discussed in relation to system requirement creation. The more severe forms of cognitive impairment are explained briefly to justify why technology assistance is not always possible and to limit the scope of the work presented.

## 2.1 Elderly-related requirements and environment

To understand how to assist elderly people, we first have to understand what kinds of problems they face in their daily activities and how technology might provide solutions to these problems. We also need to limit the scope of the research to an acceptable degree, as the elderly with severe memory impairment are currently outside the help of this advanced technology. This study defines the elderly user and the environment as follows:

1. An elderly person is an individual over the age of 65.
2. The users in this study are only those with mild to severe age-associated memory impairment (AAMI), mild cognitive impairment (MCI) or mild dementia affecting their cognitive abilities.
3. Based on the above, the user must have a Mini-Mental State Examination (MMSE) score in the 15–26 range, which suggests AAMI, MCI or dementia.
4. The user requires assistance from caretakers in their instrumental activities of daily living (IADL) such as cooking, cleaning or taking medication.

A technology-assisted person in this study is limited to having a maximum of mild dementia, due to the difficult impairments presented in later stages of dementia-based illnesses. In moderate cases of dementia, the learnability of new technology suffers greatly, and the assistive devices become less useful, as an actual caretaker might be required to help operate them. In severe cases of dementia, such as AD, the person's impairments are so severe that they require constant help in a controlled environment such as a care home. The MMSE is a test for measuring the level of cognitive impairment in an individual. A score of 30 is the starting point, which is then evaluated through a set of questions and tasks. Each question or task affects the overall score by either lowering it or keeping it at the current level. According to the original MMSE method used in Finland, scores between 30 and 27 are considered to be within the normal ageing level, the range 24–26 suggests that the individual has normal cognition or MCI, 18–23 suggests mild dementia, 12–17 for moderate dementia and 0–11 for severe dementia. Education might affect the MMSE score so that a score of 27 or even 30 for an educated individual might still reflect mild dementia. A non-educated person might have a score of 23 but be free of any cognitive impairment (Folstein et al. 1983).

People age at different rates, so elderly users' skills with technology vary greatly, and this variation increases the older people get (Mynatt et al. 2000). In addition, the learning of new things is slower for an older than a younger population (Kelley & Charness 1995), and the acceptance of new technology by the elderly must be considered when designing new systems (Björneby et al. 1999). Also, people with memory problems, especially dementia, present a much more challenging environment for designing usable UIs. For people with different stages of dementia, technology can offer assistance in the form of reminders, stimulation to prevent boredom, responses in case of danger, surveillance and the creation of an environment where social networking is easily possible (Björneby et al. 1999). Hawthorn (2000) referenced Jagacinski et al. (1995), saying that physical changes can be seen when the elderly user is told, for example, to follow a target using a mouse. The movements are slower, and they have a tendency to be unable to control the movement and its power/strength (Hawthorn 2000). An ageing person's eyesight becomes worse, especially their ability to see up close, which is required when working with computers, smartphones and tablets. Hearing and speech recognition should also be taken into account when designing products for elderly users (Hawthorn 1998b).

Cognitive changes affect memory, attention, reaction to triggered events and learning capabilities (Asano et al. 2007, Hawthorn 2000). Short-term memory and working memory are required for managing details in an application and controlling and interacting with a UI. Long-term memory is used for more complex tasks spanning longer time periods, such as creating documents and using more complex applications. Learning and ease-of-use over time requires long-term memory (Hawthorn 1998a). More time is required to complete tasks and to react to changes. Over time, ageing can also present a decline in motivation and understanding (Asano et al. 2007). However, skills learned when younger will help the person in the use of IT applications, so if a person used applications extensively in their working lives, learning new ones when older is easier (Hawthorn 1998a). According to Akatsu et al. (2007), elderly users, in addition to their cognitive skills, have knowledge and social factors that affect technology use. A person might have different assumptions on how something should work. If there is a mismatch between the assumed use metaphor and how the user thinks the technology should work, the end result can be confusing. Akatsu et al. also argued that the elderly often do not want to use products that are not familiar to them.

Broady et al. stated that the biggest factor that makes the elderly avoid technology is their lack of knowledge of the capabilities of the technology and how to utilize it (Broady et al. 2010). However, if new technology is perceived with positive attitudes by elderly users, there is a curiosity to test technical equipment (Eisma et al. 2004). Despite the hampering factors caused by cognitive or physical limitations, the elderly tend to believe that there is a need for them to accept ICT, rather than a need to avoid it (Broady et al. 2010). Many aspects of life now have more technology integrated into them, changing the nature of work, the scope and form of communication and how health care is delivered (Bouma et al. 2004). However, an understanding of why older adults have difficulty adapting to new technologies, as well as perceiving themselves as active users of technology, is important. Otherwise, the benefits of the new technologies may not be realized for older populations (Bouma et al. 2004).

## 2.2 Daily activities and related problems

The elderly living at home face a multitude of problems when there is a decline in their basic skills, and they often struggle to complete simple tasks that they were previously capable of handling successfully. The problems can be roughly divided into two categories: physical and mental. For the system design, this study takes into account the basic physical problems related to ageing and focuses on the cognitive capabilities and limitations of the elderly, including dementia -related illnesses.

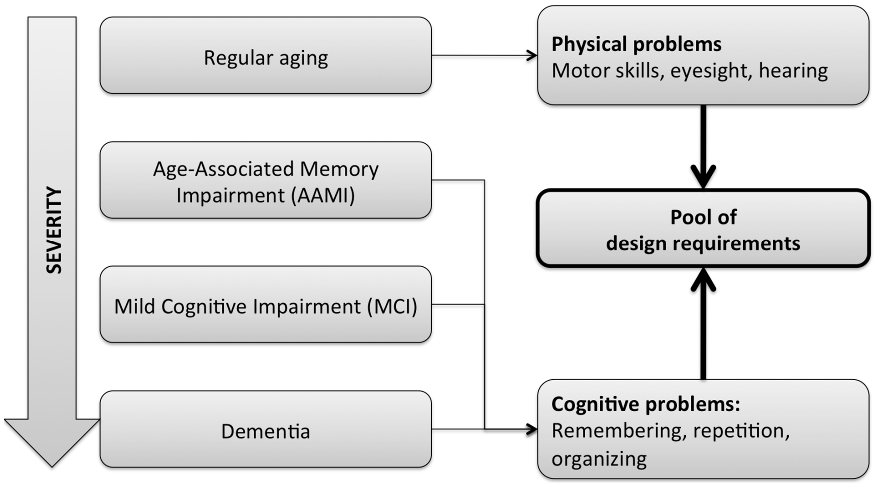



**Fig. 7. Design requirements gathering, from physical and cognitive problems**

As presented in Figure 7, when designing a system for elder use, one needs to take into account basic ageing-related problems, as well as possible memory impairment, to form the underlying basic requirements. The requirements for the design can also be applied from the ISO/IEC Guide (Gulliksen & Harker 2004). An elderly person faces varying degrees of physical problems due to ageing, the most common related to motor skill functionality. As people age, movements become more imprecise, and eyesight and hearing weaken. In terms of UI considerations, small fonts become harder to read and assistive audio, harder to hear. Smaller buttons, icons and displays, for example, on mobile phones, become harder to manipulate, as precision can be a problem. The current elderly population also has a low degree of knowledge related to techno logy use. They are not traditionally accustomed to modern devices such as tablets and smartphones in the same way as younger generations have become CLUs. As technology is offered more in everyday situations, the difficulties in learning each new system are a burden for the elderly. The daily use of systems such as banking, the internet, television and computers might require outside assistance, as design aspects are not uniform.

## 2.3 Different levels of cognitive decline in an elderly person

An elderly person might suffer from varying degrees of decline in their cognitive skills. These present as problems in short- and long-term memory functions, problem solving and thought processing. All of these problems influence their use of technology and form a cognitive requirements artefact for the system design. People age differently, so some individuals might not present any cognitive decline at all, while others might experience mild to more severe types of cognitive decline problems. Ageing-related cognitive decline can be divided into three general groups, from mild to severe: AAMI, MCI and dementia-related illnesses. In the case of normal ageing, no easily perceivable difference in cognitive skills or the mood of a person can be observed, so this study details the three cognitive impairments briefly presented below.

**Age-Associated Memory Impairment (AAMI)**

The regular ageing process manifests as a cognitive decline in half of the population over the age of 65 (Lobo et al. 2000). This can be considered a part of the normal ageing process and results in symptoms such as mild forgetfulness, the misplacing of items and difficulties in recalling names or the proper words to use in a sentence. As such, it does not present a need for the individuals to seek help or assistance from caretakers.

**Mild Cognitive Impairment (MCI)**

An individual with a more serious decline of cognitive functions compared to the average in their age group and education level can be classified as having MCI. The estimated number of people with MCI ranges from 3% to 19% for people over the age of 65 (Gauthier et al. 2006). Individuals diagnosed with MCI can remain stable, but over half of them develop some form of dementia within five years. As such, this can be regarded as a risk for developing dementia and possibly AD.

**Dementia and related diseases**

Dementia is an all-encompassing term for many different memory impairments. It is not a disease itself, but instead, it describes different kinds of symptoms related to a decline in memory or thinking that affects people in their daily activities. According to Pirttilä et al. (2006), the most common form of dementia is AD, constituting 80% of dementia cases. The symptoms of AD take the form of memory loss, particularly of short-term memory, and a decline in intellectual capabilities. As there is no known cure for AD, the symptoms become worse over time, and a person with AD will eventually require constant care in a hospital or a nursing home in the later stages of the disease. AD has three general stages: mild, moderate and severe. It can also be divided into seven more specific stages of severity, including early-onset symptoms. The symptoms and the closely related decline in skills vary from person to person, so the stages are generally an estimate and should be defined individually for each person. Mandell & Green (2011) have described dementia as impairment in at least three of the following five areas: language, memory, visuo-spatial skills, personality, behaviour and capabilities in acquired knowledge manipulation.

According to Pirttilä et al. (2006), typical symptoms of mild or moderate AD include the following:

1. Difficulty in *remembering* names or items
2. *Disorientation* of time and place
3. *Forgetting* location of items or events
4. Difficulty in *organizing and planning*
5. Difficulty in *complex task execution*

Dementia-based diseases also sometimes manifest as follows (Cahill et al. 2007, Pirttilä et al. 2006):

1. *Apathy*, *passiveness* and *social isolation* due to lack of initiative
2. *Mood changes* such as frustration, agitation or irritability
3. *Suspiciousness* due to personality changes

The basic AD phases are presented below, so that the inclusion and exclusion of the users for this work can be understood.

**Mild AD**

Mild AD is often characterized by MCI symptoms such as mild forgetfulness, getting lost, having trouble with cash and paying bills, repetition of tasks and questions and requiring more time to complete tasks. It can also slowly lead to difficulties in planning, organizing and following instructions. At this stage, some personality changes are possible due to frustration with one's own ability to remember.

**Moderate AD**

Individuals with moderate AD require more assistance with their daily activities, as forgetfulness becomes more apparent. Getting lost is a more constant problem, and task repetition is continuous. Tasks such as choosing the proper clothing for the time of the year and remembering to carry needed items become difficult.
People with moderate AD need more specific and suitable designs, and they would benefit from testing for a more appropriate solution. Our current solution is not suitable for those with mild dementia.

**Severe AD**

In the severe stages of AD, the person's mental abilities have declined so drastically that they need constant care and help in most tasks. Dressing, showering and eating become difficult, and short-term memory functions are limited. Thought processing is affected and often results in wrong interpretations. As an example, a person might misunderstand a sign for a "wet floor" as "urinate on the floor". Paranoia and not recognizing oneself in the mirror might be additional symptoms. Often, aggressive behaviour increases. As such, these individuals need caretaker support in a proper institution that can provide constant comfort and personal care.

Problems with daily activities for people with dementia are related to regular activities. A person might have trouble preparing meals, remembering events and people or coping correctly with tasks that have multiple steps. In particular, interrupted tasks present difficulties, for example, during cooking or traveling to a location, as the next step is forgotten. Keeping individuals with these problems active and involved has been shown to help slow their degrading cognitive and physical skills. Due to memory problems, a person might not remember to eat, exercise or sleep properly, which leads to even poorer physical and mental health. Thus, having a routine and a schedule that supports the activities is recommended. Keeping a person socially active also helps with depression related to loneliness. Enabling communication via video, phone or visits is considered advantageous when preventing social isolation.

AD sometimes presents additional symptoms: *visual agnosia* affects a person's ability to recognize things such as food or drinks, and with *apraxia*, a person has difficulties performing intended actions due to a motor skills disorder (Cunningham & Archibald 2006). These symptoms should be taken into account in system design, if necessary. Medical and caretaking staff's general recommendations for activating and easing the life of a person with memory impairment are as follows:

- *Give choice***.** Let the person make choices and stay involved in decision-making.
- *Encourage communication* by two-way conversations.
- *Offer simple instructions.* Use simple step-by-step instructions to reduce confusion.
- *Repeat instructions* and allow more time to respond; try not to interrupt.
- *Limit the number of choices,* for example, "Would you like a hamburger or chicken?" instead of "What would you like to eat?"
- *Do one task at a time*. Keep things simple by asking or saying one thing at a time.
- *Keep a daily routine*, so the person knows when certain things will happen.
- *Ask for help from the person.* For example, "Let's set the table", "It's time to go for our walk" or "I need help folding clothes".

## 2.4 Elderly technology acceptance and usability issues

Hawthorn (2007) pointed out how the elderly try to avoid errors when using a computer by not using all of the functions available. By doing this, they inadvertently minimize the potential of the computer. Hawthorn also mentioned that there is a lack of well-developed design vocabulary and that it is possible to adjust interfaces to elderly requirements; however, most elderly users do not know this. As a result, the elderly user is often unable to explain what they would like from the computer regarding functionality and features. Morris & Venkatesh (2000) argued that age is a limiting factor only at the very beginning of technology experiences, but there is a stronger emphasis on the adoption of new technology based on age; that is, whether the technology should be taken into use or not is a more common problem when technology is seen as an unnecessary tool. Goodman & Eisma (2003) pointed out that this negativity towards technology and the underestimation of one's own skills is a problem among the elderly. This view is also shared by Lehtinen et al. (2009). However, the elderly interviewed by Mikkola & Halonen (2011) generally had positive attitudes towards technology, contradicting the previous statement. This might suggest that there is some technology resistance but that it varies from person to person. For elderly users, a lack of confidence in their own abilities and problems remembering how technology is used result in less technology adaptation. This might also result in the elderly users' skills not progressing in tandem with those of younger users who adopt and learn new technology at a more frequent pace. Comparisons to younger CLUs were made by Morris & Venkatesh (2000), who stated that when it comes to technology, younger users are more affected by attitudinal factors and that the elderly are more affected by social and process factors. An elderly user might take a device into use if others show its usefulness.

Hanson (2009) and Charness & Boot (2009) both discussed existing problems regarding technology adaptation that will likely exist 20 years in the future. They stated that the advances of technology in the future will result in similar problems as today for the elderly in the learning and adoption of new technology. According to Charness & Boot (2009), this continuous lag in adoption could be decreased by designing technology for the capabilities of the elderly and using better guidelines for the design process. Rogers & Czaja (2004) argued that even though the elderly of the future might be more experienced in technology use and new devices specifically, ageing still happens regardless, and the changes caused by ageing will continue to affect people's ability to use those devices. As technology has a dynamic nature, there will always be a need for the elderly to learn new technologies. Akatsu et al. (2007) stated that in addition to the cognitive factors that affect the use of technology, the lack of knowledge and the thought processes involved in the use also result in difficulties in adoption. The thought processes of an elderly person might differ from those of an average technology user who already knows what the affordance of the system is. This should be better conveyed to elderly users who often use only familiar devices they know well and who do not want to learn newer, yet possibly more suitable, devices.

# 3 Related research

This chapter presents related research used in elderly assistance from earlier non-technical devices to newer technological approaches. Additional discussion describes general user interaction design needs and how they affect elderly users. UI design definitions are clarified, when needed, in relation to the research presented in this thesis. AR and projection technology descriptions relevant to the work are presented. First, the wearable AR solutions are presented through examples, then the fixed AR installations are discussed and, finally, some AAL and tabletop examples available for the elderly are presented.

## 3.1 Prior assistive devices and technology for the elderly

Assistive devices are used to compensate for physical or cognitive impairments to enable activities of daily living and to reduce isolation (Kylberg et al. 2013). The older a person gets, the more assistance they may require. As women live longer than men on average, older individuals are often female and live alone, suggesting single-user systems. A study conducted in the Nordic countries (Månsson et al. 2008) discussed in detail the aid devices the elderly with dementia have and how suitable they are for them and their caretakers. Experience of and improvements in the aid devices used during a time span of two years were gathered from interviews with informal and formal caretakers. Results of the study showed that the aid devices improved daily task management, helped to maintain the users' skills and activated the users to socialize more. This reduced loneliness, which is often associated with dementia as loneliness causes people to become apathetic. There was a desire for the device to match a problem specifically and effectively for a longer period of time, as a constant need to replace and learn new devices occurred due to memory impairment symptoms becoming worse. Caretakers can learn the use of new devices, but the users with dementia will later on be unable to do the same, so the use of a device has to be learned early on by the elderly, to solve this problem.
Many users in the study also had unique preferences regarding the devices, which manifested as different ways of using them in different situations. Compiled in Table 2 are examples of aid devices used in the home of a person with dementia. In many of the cases, the task of the device was very straightforward and simple: one device for one job, often acting as a reminder for the user to do a task with the help of that particular device. Some devices were meant to support the

caretakers, such as the GPS locator and the time management website. Table 2 also shows how several devices can be divided into wearable, fixed or movable installations. The general classification is meant to convey which type of devices the user has to carry or wear (e.g. a watch), which ones are put into the environment in a certain location but are movable (e.g. talking photo frame) and which ones are fixed in place (e.g. stove safety switch).

**Table 2. Examples of cognition support systems**

| Assisted task | Type of assist | Installation |
|---|---|---|
| Webpage for time management | Caretaker and elderly support | Movable |
| Electronic bed alarm to inform of user getting up | Caretaker support | Fixed |
| GPS-locator worn on waist | Caretaker support – Safety | Wearable |
| Phone with quick dial, big icons or pictures of people | Communication assistance | Movable/Wear |
| Simpler mobile phone | Communication assistance | Wearable |
| Key holder worn around the neck | General assistance | Wearable |
| Large size display wristwatch | General assistance | Wearable |
| Safety camera at front door | General assistance – Safety | Fixed |
| Safety switches in kitchen equipment | General assistance – Safety | Fixed |
| Audio instructor device near exit | General reminder | Fixed |
| Electronic calendar | General reminder | Fixed |
| Guiding lights indoors | Navigation assistance – Safety | Fixed |
| Talking photo frame | Person or situation memory reminder | Movable |
| Alarm in multiple locations for calling family members | Remote support device | Movable |
| Guide implemented coffee maker | Task assistance | Fixed |
| Dishwasher reminder magnets | Task reminder | Movable |
| Electronic medication dispenser | Task reminder | Fixed |
| Medication dispenser with calendar near | Task reminder | Fixed |
| Notebook for memory | Task reminder | Wearable |
| Paper calendar and post-it notes | Task reminder | Movable |
| Reminder clock | Task reminder | Movable |
| Wristwatch with medication alarm | Task reminder | Wearable |

Well-being technologies like the ones displayed above enhance users' feelings of empowerment, and the ability to cope with problematic situations with the help of aid devices has been shown to increase social contact, increase safety, help in daily tasks and offer quicker help, as well as to reduce the workload and stress of the caretakers (Månsson et al. 2008). Many of the current assistive solutions for the elderly can be divided roughly into simple or complex ones; the former offers solutions usually to a single problem, the latter to multiple problems. For example, a medication dispenser can remind a user what medication to take at the correct time. Another simple solution would be a wrist-worn alarm bracelet for emergencies (see Figure 8). More complex solutions aim at creating a smart-home environment where various sensors, embedded or wearable, are used in unison to detect what the user is doing and to offer assistance based on the situational or use context. These technological systems do not focus only on a single problem and offer a more extensive approach to enhance a person's daily living activities. Systems that use ubiquitous technology in a smart-home environment are called *Ambient Assisted Living* (AAL) systems.

**Fig. 8. Wrist alarm with an emergency button**

### 3.2 Ambient Assisted Living (AAL)

Rashidi and Mihailidis (2013) discussed a fairly new paradigm called ambient intelligence. Its aim is to offer information technology to build people's capabilities through digitalized environments that adapt and respond to the needs of the user. The main elements of ambient intelligence are unobtrusiveness, pervasiveness and anticipatory communication for human-computer interactions (Rashidi & Mihailidis 2013). AAL can be considered as an extension, as well as a sub-category, of ambient intelligence, exclusively describing the elderly. The goals for this paradigm are more related to the problems that the elderly face in their daily lives, for example, taking care of medical activities. Usual examples of AAL are related to medication reminders (Khan et al. 2010), safety and emergency services (Eklund et al. 2005) and surveillance solutions (Fleck & Strasser 2008). AAL is a common research area that is gaining ground rapidly as a framework for assistive technology design for the elderly. It focuses on creating guidelines on how technology should be designed and created for the elderly.

Kleinberger et al. (2007) argued that ambient assistance technology will only be successful if three requirements are met:

1. The system has to be ubiquitous and should not be obtrusive to the user to achieve a high acceptance rate.
2. Users have individual needs, so the system should adapt itself to these requirements.
3. The assistance the system provides should be accessible by means of improved usability.

These three requirements are desirable requirements for all assistive devices, not only for AAL solutions, as discussed in Chapter 2. The main theme of AAL is the focus on relying on automation and mostly passive assistance and offering limited and simple UI functionality based on context or situational awareness if the user needs to interact with the system at any point (Newell & Gregor 2002). Rashidi and Mihailidis pointed out that usability and user experience are both vital for creating good AAL systems. With extensive training and information provided to the elderly user, systems often perceived as complex can become more desirable to the users (Rashidi & Mihailidis 2013).

However, there are problematic points in using these AAL guidelines. The first is the common reliance on sensors to capture the context of assistance if the user does not want to wear them. Second, if the system requires extensive training, elderly users who have cognitive difficulties might not be able to use them. Fully automated systems are not yet possible to create a fully functional and optimal AAL system, so there is a need for research into systems that offer UIs for the users as a stepping stone before achieving the higher goals of ubiquitous technology set for AAL.

### 3.3 Direct and indirect UIs

The UI is at the centre of human-computer interaction, as it controls how people experience technical systems. Interfaces can require different approaches in how they are used, from tangible, object-manipulating methods and gesture controlling to traditional ones. Methods can be divided into two types: *indirect* and *direct*. A graphical user interface (GUI) in computer systems is commonly controlled with an indirect input device such as a mouse or a keyboard. Indirect manipulation refers to the action on the screen being performed with a separate device, for example, a mouse, while direct manipulation would involve directly touching an icon on a touch-screen device such as a tablet. The action on-screen from an indirect input device, for example, moving a mouse (see Figure 9, left) to move the cursor to a desired icon, has to be understood by the user when learning the use of the input device; they must learn the correlation of the movement on-screen and the real-world movement of the mouse. In comparison, the actions of direct input require less or no learning when the user wants to select an icon, as the icon is pressed directly. Charness et al. stated that the directness of the operation can result in faster operation, accuracy and acquisition interaction with the interface (Charness et al. 2004), and while menu selection by users who were experienced was faster with indirect devices, a much earlier study stated that users who were novices had better results with direct devices (English et al. 1967). Murata and Iwase (2005) found that when the input device matched the task (e.g., a touch screen with big buttons for task selection), it showed faster performance compared to a mouse. In addition, age-related differences between the elderly and younger users were minimized (Murata & Iwase 2005). This notion supports the findings of Rogers et al., that a mismatch of the device and input requirements is affected by age (Rogers & Czaja 2004), and that indirect manipulation devices are cognitively challenging for the elderly (Charness et al. 2004). Such difficulties could be minimized by a proper matching of the task, device and input.

**Fig. 9. Left: Indirect input tool, a mouse vs. Right: a direct input tool, a touch screen**

Touch-screen interfaces that use direct input are most commonly used on mobile phones and tablet devices (see Figure 9, on right). A study by McLaughlin et al. stated that there was a higher demand for concentration by the elderly when the task and the device were mismatched, compared to the experience of younger users in the same study (McLaughlin et al. 2009). This suggests that the elderly need a device matching their input requirements. A single -purpose system like an ATM focuses on offering simple bank services to the user, and as such, the UI is designed to take into account only the features and functionality necessary to successfully carry out these specific transactions. The available buttons and the screen are limited in scope to allow the user to focus only on the task at hand. On the other hand, a smartphone with a touch screen takes into account multiple ways of user interaction, for example, making a phone call or texting, reading web pages or listening to music, limited only by the possibilities of a touch interface. The design of these functions has to be unified within the system that offers them, so that the user does not get confused by constantly changing methods of interaction. Based on previous research, the problems of the elderly with technology and related UI interaction te chniques and the reasons for these problems can be generalized as follows:

1. *Lack of knowledge*: The use metaphors of new UIs are less known among the elderly, making learning new systems difficult (compared to the experience of younger generations).
2. *Difficulty in learning*: Indirect manipulation is cognitively challenging, as it requires more processing.
3. *Motor skill limitations*: Movements become less precise with old age.
4. *Eyesight limitations*: As eyesight worsens, smaller screens become difficult to read, so in turn, smaller screens become harder to manipulate.

Discussion of interaction methods presents possible solutions for these problems, which are generalized from the works discussed above, as follows :

5. *Direct manipulation* requires less learning for the elderly.
6. *Direct manipulation* results in faster and more accurate target acquisition.
7. *Input devices* need to match the task to reduce performance differences between younger and older users.
8. *Screen size* is important, as larger screens and icons reduce in put errors and enhance readability.

Generally, direct interaction methods are seen as more suitable for novice users as well as for elderly users, as both groups need simple approaches in system design.

## 3.4 Augmented Reality (AR)

AR is a well-known area of research where the real world is augmented or, in other words, overlaid with virtual objects or elements using computer graphics. The principle definition of AR is that the real world must be tracked in real time so that the virtual elements can be displayed reliably and correctly on top of it (Azuma 1997). Many AR solutions use a camera to track the real world, while the devices used to display the virtual objects can vary from handheld mobile phones and tablets to head-mounted displays (HMD) and projectors that are wearable or fixed in a location. Each device offers different advantages with respect to immersion or interaction capabilities. Using the real world as the prominent background element makes AR different from virtual reality (VR), where the user is totally immersed in a fully computer-generated world. Milgram and Kishino (1994) presented a framework to define the areas between real and virtual worlds as a graph, shown in Figure 10.


**Fig. 10. Virtual reality (VR) continuum**

This definition shows the real environment as the one we live in, which can then be enhanced by overlaying it with computer graphics, thus creating AR. Augmented Virtuality (AV) reverses this by incorporating real-world elements into a virtual world. A virtual world where everything is computer-generated is VR. The solution presented in this work can be labelled as AR due to its mixing of computer graphics with the real world, calculated in real time using a projector and a camera.

### *3.4.1 Projection and camera systems*

To realize an AR system, ProCam systems are a common approach as they are readily available. A projector can be a fixed installation or can be wearable, depending on the mobility requirements of the intended solution. Many of the wearable types of solutions use a pico-projector, a tiny projector comparable in size to a small mobile phone. Compared to HMDs or mobile devices, projection has the advantage of producing a larger screen space for the user to view and manipulate. Offering a projected-onto solution instead of a see-through solution, a display associates the projection clearly with the environment and its objects. It also does not block the user's view, as the projection is displayed into the environment; compare this to HMDs, where the view is in front of the eyes and needs to take into account that the real-world elements are not accidentally blocked. Table 3 presents studies intended for CLUs, where the technology is wearable or handheld in nature. The focus is more on general interaction research on AR and how the UIs can be manipulated using a ProCam type of approach.

**Table 3. Studies on wearable AR systems for computer literate users**

| No. | Year-Title | Generic/App | Platform | Interaction |
|---|---|---|---|---|
| 1 | Choi & Kim (2013): Usability of one-handed interaction methods for handheld projection-based AR | General: Menu selection and interaction | ProCam, mobile phone | Indirect and Direct |
| 2 | Beardsley et al.(2005): Interaction Using a Handheld Projector | General: Augment real world | ProCam | Indirect |
| 3 | Harrison et al. (2011): OmniTouch: Wearable Multitouch Interaction Everywhere | General: Interaction and display research | ProCam | Direct |
| 4 | Mistry et al. (2009): WUW - wear Ur world: a wearable gestural interface | General: Interaction research | ProCam | Indirect and Direct |
| 5 | Tomitsch et al. (2012): Designing for Mobile Interaction with Augmented Objects | General: Interaction research | ProCam | Indirect |

Paper 1 in Table 3 (Choi & Kim 2013) aimed to go beyond the assumption that ProCam AR does not have mature usability or interaction methods. The study incorporated four different methods usable with a single hand that also take advantage of a mobile phone touch screen. The proposed method used a pico-projector image on the wall as seen in Figure 11. Pressing the touch screen on the phone enables the selection of an icon in the first method. The second method uses a virtual cursor, shown on the projected surface, which is used to select an icon and which can be classified as indirect action.

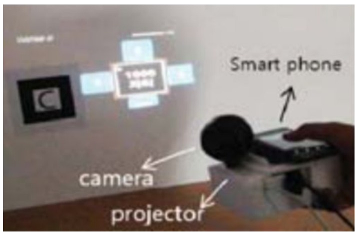



**Fig. 11. Choi & Kim (2013) proposed method for interacting from afar. Used with permission from © 2013 IEEE**

The first method forces the user to look at the mobile phone in his or her hand when making a selection, which takes the focus away from the projected screen, a disadvantage of the method. Even though the user interacts with the phone in a direct interaction method, the advantage of a big projection is minimized when the user has to look at the phone and cannot manipulate the larger icons made possible by the projection. Thus, this method is a sort of hybrid direct-indirect method. Using the cursor manipulation approach on the projection lets the user focus on the projected image, but it relies on a mouse-like approach to interaction, which is not desirable for the elderly. The advantage, however, is that the system can offer haptic vibration feedback from the phone when performing a selection, which a projection does not offer. Both methods also have the advantage of enabling the user to do a selection no matter how far they are from the projected screen, as the input control is in their hands.

Paper 2 in Table 3 (Beardsley et al. 2005) also focused on solving the interaction problem by using handheld projectors. The smaller size of such a device allows users to move away from fixed installations, but the moving projection presents limitations for manipulation. A solution like a mouse-cursor was presented, which is usable with a single hand. The selection is made by pressing the handheld device. Interaction is reversed, in that the cursor is static in the centre of the screen, and the user moves the projected screen around. The solution has not been quantitatively tested, and one clear disadvantage is the approach of trying to implement a mouse-like manipulation into an AR environment, which demands more suitable and novel options. As well, the solution is an indirect manipulation method, which has been shown to be difficult for novice and elderly users.

Paper 3 in Table 3 (Harrison et al. 2011) presented OmniTouch, a shoulder-worn and depth-sensing projection system that can display images on the user's hands and legs or on different surfaces like a wall or a hand-held paper. The system tracks the user's hand and tries to stabilize the projection. This system seems fairly robust, but it is not yet prefect. The interaction method gains an advantage from the depth-sensing camera, which enables more versatile interaction as the user can use a hover-over or physical "click" on the projection surface. It also has finger tracking for multi-touch capability and can distinguish a planar surface, such as a wall, from an organic hand surface as seen in Figure 12. This can be used to offer the needed UI design for proper surface detection. However, the surface recognition is not robust yet and needs more research.

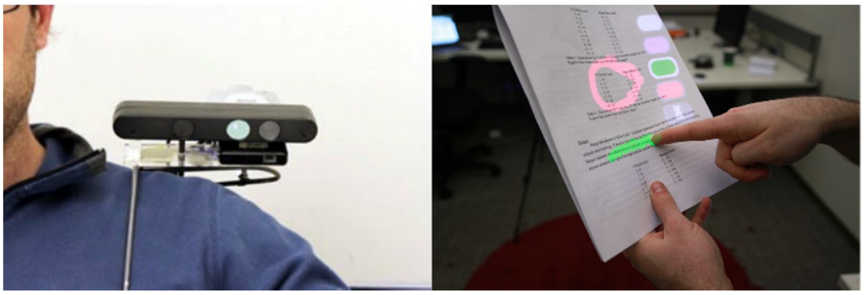


**Fig. 12. Left: shoulder-worn ProCam with depth sensor; right: finger and paper tracking with OmniTouch (Harrison et al. 2011). Used with permission from © 2011 ACM.**

The system offers an interesting approach to wearable technology, but may not be suitable for elderly use, as the tests thus far have been done with CLUs experienced with touch-screen devices. Future work is aimed at creating more complex interaction implementation, and a large system worn on a shoulder is not currently feasible for the elderly.

Paper 4 in Table 3 (Mistry et al. 2009) proposed an implementation of earlier research work similar to that done by OmniTouch. This work differs in that it uses markers on fingers to track the user's hand movements. The research also focused on gestures in the air that the user must learn to be able to use the system, but the system can also offer direct manipulation possibilities. The air-drawn gestures complicate usage for new users, especially the elderly, and thus far, the use of markers for detection is not a feasible solution for an elderly user at home. However, like OmniTouch, the system has the advantage of overlaying information on objects such as a newspaper, a wall or other physical objects, which would be beneficial for pointing out items of interest to the user.

Paper 5 in Table 3 (Tomitsch et al. 2012) presented AR work that augments information related to physical objects in the environment using a handheld pico-projector. However, for testing purposes, the handheld device was simulated, and the actual installation was a fixed solution. This allowed the researchers to test features without the need to create an often-needed stable projection when using a handheld device. Four user interaction methods were presented in the work: a physical tap of the device to execute a function, a slide to execute a different function, a gesture rotation to move forward in the menu and an alteration of the proximity of the device to the projection trigger to move back and forth in the menu. All of these methods rely on a single-hand interaction method, but some suffer from the same kinds of problems that Paper 1 presented, that is, a disconnection between using buttons on the device and focusing on the displayed screen. In addition, the rotation and proximity methods do not offer any cause and effect to the user of the system, so the controls have to be explained to the user. The users were also taught the use of each method beforehand, yet still experienced problems in the interaction. Interestingly, the tests produced opinions from the users describing some of the methods as fun to use, a feature not often tested in elderly interface design methods.

**Table 4. Examples of fixed AR and tabletop system for computer literate users**

| No | Author-Year-Title | Generic/App | Platform | Interaction |
|---|---|---|---|---|
| 1 | Ju et al. (2001): CounterActive: An Interactive Cookbook for the Kitchen Counter | Application: Cooking aid | AAL, multimodal | Direct interaction with step-specific touch area |
| 2 | (Heidrich et al. (2013): Device-Free Interaction in Smart Domestic Environments | Generic: Smart-home management | ProCam | Direct interaction |
| 3 | Lin & Lin (2013): Projection-based User Interface for Smart-home Environments | Generic: Home control | ProCam | Direct interaction |
| 4 | Pinhanez (2001): The Everywhere Displays Projector: A Device to Create Ubiquitous Graphical Interfaces | Generic: Display on surfaces | Projector | No interaction |
| 5 | Benko et al. (2012): MirageTable: Freehand Interaction on a Projected Augmented Reality Tabletop | General: Interface | ProCam | Direct interaction |

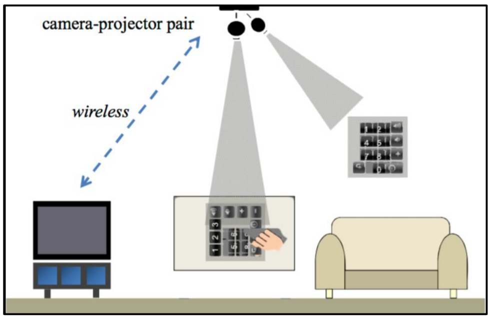
| | | | | |
|---|---|---|---|---|
| 6 | Molyneaux & Gellersen (2009): Projected Interfaces: Enabling Serendipitous Interaction with Smart Tangible Objects | General: Interaction research | ProCam, tangible objects | Direct interaction with a camera; indirect interaction with the objects |

Table 4 presents work, both tabletop systems and systems based on fixed projection types, either used in AR, in AAL or in extending the projection range for a fixed installation. Table 4 explains how the approaches differ from wearable solutions and how using a direct interaction method could increase the ease of use.

Table 4, Paper 1 (Ju et al. 2001) presented a system intended as an aid in a kitchen environment. The system tracks the used objects and ingredients with RFID tags and a sensor field while giving feedback through audio and visual projections. The preliminary results drawn from following the users cooking found that the visual cues were effective. However, the instructions used for cooking had multiple steps, which proved problematic, as the users could skip whole steps. Inserting a single instruction per guiding page might lead to a reduction in errors. Though untested, this might be a feasible system for the elderly.

Table 4, Paper 2 (Heidrich et al. 2013) presented a ProCam system that controls smart-home features through gesture controls for a menu displayed on the table. Gestures are explained as a trade-off between learnability and robust recognition of the hand. This suggests that technology limitations affect the design of a more suitable interaction method. The findings also showed that users tried to press the icons instinctively instead of using the "pull-down an icon to select it" method proposed by the users. The system was also deemed "fun" by the test users, which increased its desirability. One factor of note from the research was the flexibility of the tabletop UI system. It should work on any surface of the home, so users can use it anytime and anywhere. Otherwise, the system is too limited for elderly users.

Fig. 13. Projection-Camera proposed by Lin & Lin (2013). Used with permission from ©




2013 IEEE

Table 4, Paper 3 (Lin & Lin 2013) presented a similar kind of solution to that of Heidrich et al. (2013) for creating a ProCam-based smart home without the need for carried or worn equipment. The paper also recognized that regular mouse- and keyboard-type methods are not adequate for a ProCam system and, instead, it presented a method where the camera tracks the user's hand and fingertips to enable a more natural touch-based method. In addition, Lin & Lin (2013) wirelessly connected separate devices to the system, so that the ProCam system could control these devices. Selecting a menu icon in the system is based on fingertip hover time on top of the icon, as there is no depth information available due to the use of a regular camera. The proposed system uses a numeric keypad-style interface much like a television remote control for testing purposes. This UI might present an accidental selection issue, as the icon layout is not changed to suit the hover-based method (see Figure 13).

Table 4, Paper 4 (Pinhanez 2001) talked about the widely known fixed-installation issue related to projectors. Since the displayed image generally cannot be moved once installed, the paper proposes an *everywhere display* that takes advantage of a rotating mirror to enable projection to other surfaces from a fixed-installation projector. The solution is simple and cheap to produce, and it enhances the current methods of fixed projectors. An additional camera would enable device-free and touch-based interaction using the system.

Table 4, Paper 5 (Benko et al. 2012) presented an AR system using 3D projection with the help of special glasses and a depth sensor to track the user as well as the objects on the table. The objects can also be 3D captured into the system and used as virtual representations. The system uses freehand interaction and head tracking to know where the user is looking. The interaction is meant to offer the user a chance to manipulate virtual objects, but it does not have a UI yet.

The thing of note in this research is the ability of the system to scan objects and create a virtual representation of them for later use. This feature could be usable for the elderly, as it could track personal possessions or ne eded items related to a task such as cooking.

Table 4, Paper 6 (Molyneaux & Gellersen 2009) discussed how to create the architecture of a system that has a tangible UI, using a ProCam approach. A tangible UI extends a normal ProCam approach with detected smart objects, which are used to control or manipulate the system. In the paper, the method uses direct interaction, where the user has an interface directly created on the smart objects. As an alternative, the paper discusses indirect interaction created from the proximity of two smart objects affecting each other, which would enable more features for the used objects. Projections on top of the objects can change depending on the detec ted shape of the object, such as a book being open or closed; this was demonstrated with a photo album in the research. The system shows potential for elderly use, as the object manipulation and recognition would enable precise assistance based on the obje cts on the user's table. The paper argued that projection next to the object would be confusing to the user and would break the association between the projection and the objects, so the authors focused only on using projections on the objects.

### *3.4.2 AR for the elderly*

Studies on AR systems designed for the elderly are very rare; most studies focus on systems designed for a computer -literate population. Similarly, systems using projectors in combination with a camera have not been extensively studied as technology for the elderly. However, AR, with its ability to display additional information in an environment and detect inputs, could offer novel ways to assist an elderly user.

**Table 5. Examples of dementia- and elderly-focused AR solutions**

| No | Title | Generic/App | Fixed/Wear | Platform | Interaction | User |
|---|---|---|---|---|---|---|
| 1 | Olivier et al. (2009): Ambient Kitchen: designing situated services using a high fidelity prototyping environment | Application: Kitchen assistance | Fixed | AAL: Sensors, projectors and cameras | No. Prompting and sensing | Dementi a |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | Hoey et al. (2010): Automated handwashing assistance for persons with dementia using video and a partially observable Markov decision process | Application: Hand washing aid | Fixed | AAL: Camera, LCD display for prompting, audio | No. Prompting or automated audio guide | Dementia |
| 3 | Ceccacci et al. (2012): User Centered Approach for Home Environment Designing | Application: Home design tool | Wearable | AR: IR-Camera, AR glasses | Direct interaction | Elderly |
| 4 | Kurz et al. (2014): Towards Mobile Augmented Reality for the elderly | General: AR handling test | Wearable | AR: Tablet, HMD | Prompting only | Elderly |
| 5 | Piper et al. (2010): Exploring the Accessibility and Appeal of Surface Computing for Older Adult Health Care Support | General: Touch interaction tests | Fixed | AAL: Tabletop device | Direct interaction | Elderly |

Table 5 presents two types of systems for the elderly, fixed and wearable installations, some with AR. Two use a fixed-installation type to assist people with dementia, and two use wearable and handheld systems designed for or tested with elderly people without dementia. Notably, the dementia systems and one of the elderly-focused systems only prompt the users with instructions, with no interaction capabilities. The home design system and the tabletop touch-screen system for the elderly both have direct interaction capabilities.

Findings and discussion in Paper 1 in Table 5 (Olivier et al. 2009) presented a general smart-home environment test bed for elderly use incorporating various sensors and cameras, and the paper talked about the positive effects of ubiquitous computing for dementia in the near future. However, the current level of automation and technology is not yet sufficient. Prompting systems are considered valuable as well as the customization of features to each user's needs. The weakness of the smart-home idea is that it has not been tested and is only proposed for future work so far.

Paper 2 in Table 5 (Hoey et al. 2010) presented work aimed at assisting users with dementia to wash their hands using automated assistance. Tests showed that guiding the users with visual and audio prompts was a successful approach, but as an improvement point for future work, the researchers agreed that adapting to the situation and user needs is required to offer proper assistance when dementia symptoms progress, and the assistance needs to change. An additional point was the need for less invasive sensors for collecting the data to create the automated aid steps. The issues of privacy and adaptability are also reflected in Chapter 2, as elderly technology design requirements.

Paper 3 in Table 5 (Ceccacci et al. 2012) studied the use of AR and VR as tools in designing and prototyping a home environment from an elderly user-centred design point of view. Tangible AR, where objects can be touched and manipulated, was used in combination with AR glasses. Preliminary analysis showed that while AR glasses seemed comfortable to the users, the elderly had some physical and AR vision difficulties that affected their use. Additionally, the UI interaction was problematic due to hand tremors, and manipulating real-world objects for AR viewpoint registration seemed problematic. The virtual objects and the real world did not correlate, so the elderly had difficulty placing the objects.

Paper 4 in Table 5 (Kurz et al. 2014) evaluated the comfort of AR on a tablet device and HMD. The results showed that tablet devices were difficult to handle for long periods of time due to weight and grip issues, while HMDs seemed more suitable for the elderly. As these kinds of assistive systems are scarce, research on more elderly-focused AR systems is clearly needed.

Paper 5 in Table 5 (Piper et al. 2010) examined the possibilities of using surface computing in health-care support for the elderly and used a device with multi-touch gestures. The research took into account that many elderly people have motor skill and cognitive limitations due to MCI in their system design. Thus, the system was required to be comfortable and quick to learn. Vision-related issues were also covered as part of the colour, contrast and size element discussion. Results in the paper showed that the elderly managed to independently learn to perform with the touch-based device. The elderly were slower in performance than the young adults were, and they needed hints to perform some functions such as resizing an image. Younger adults also experimented with the UI features and gestures to reach their end goals, while the elderly did not experiment unless told to try something new. Touch interaction was deemed a manageable and preferred method for the elderly and was also described as fun. Recommendations from the findings are to provide cues on how to interact, slow down the interaction and take into account motor skill problems by avoiding the fine detection of hand movement. In motor skill cases, multi-touch interaction should be avoided, and instead, using physical devices is recommended. The disadvantage of a fixed-screen device is obvious, as the screen cannot dynamically adapt to changing situations. The current system cannot detect anything around the environment, as there is no camera, but even if there were one, the output is still tied to a single location. However, the interaction points presented could be used in a projection-based system design if they were slightly adjusted. These kinds of approaches can be applied to AAL research to support elderly-focused designs by taking advantage of the existing research and implementing the approaches to new system designs that do not have an existing robust approach. As such, they would add to the existing knowledge base. Thus, there is a possibility to create knowledge in which new methods can reuse the existing approaches with limitations.

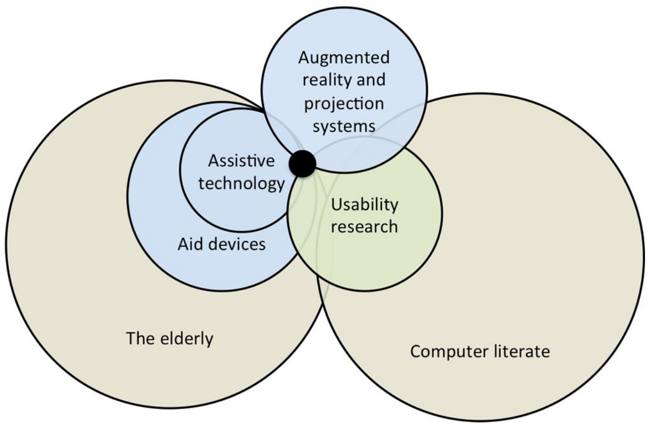



**Fig. 14. Illustration of the research gap on usability between the elderly and computer-literate users (CLUs)**

Figure 14 shows the current gap in elderly and technology research. Among existing elderly users, some can be considered CLUs, but that group is still fairly small, as a move to technology happens slowly over time. There are existing aid devices designed for the elderly, and within that area, there are assistive devices that take advantage of technology as one approach to support. Usability research in the figure shows that often the focus is on CLUs, the digital natives of today, and is less on the elderly, even though assistive devices require more research, as they are meant to support health care. AR and projection systems are fairly new, and thus far, the solutions are general purpose but are sometimes used in AAL research for the elderly. However, the usability and suitability of AR and projection systems for the elderly are, thus far, not well researched; this is represented by the black dot in the figure. Taking advantage of what AR could bring to an elderly person's daily life, in the form of enhancing communication and supporting life management should be a target for more usability researchers.

# 4 Research methodology

Starting research on this topic requires a definition of the methodologies used to answer the research questions identified in Chapter 1. The work presented in this paper is based on the main research question and the sub -questions. Several information science methodologies were considered. Due to the nature of the technology being presented for elderly use, which involves the be havioural inspection of the users as well as the need to create information system solutions, Design Science was chosen as a suitable research method. Design Science offers guidelines and research cycles, which this study is based on to create an instantiation in the form of a system. In addition to the Design Science method, thorough definitions of ageing and dementia -related illnesses are presented and discussed in detail.

## 4.1 Design Science

Design Science research is a methodology designed for the informati on systems discipline with the purpose of creating new and novel artefacts from an engineering point of view. It differs from basic behavioural science by adding a novel information system artefact layer on top. This is the differentiating characterization presented by Hevner et al. (2004), where research in information science is divided into two paradigms: behavioural science and Design Science.

**Table 6. Design-Science Research guidelines (Hevner et al. 2004)**

| Guidelines 1–7 | Description |
|---|---|
| 1. Design as an artefact | The research has to produce an artefact in the form of a construct, a model, a method or an instantiation. |
| 2. Problem relevance | The goal of Design Science is to create a technological solution relevant to important business problems. |
| 3. Design evaluation | The artefact has to be rigorously tested for its utility, quality and efficacy attributes with properly designed and executed evaluation methods. |
| 4. Research contributions | The contributions provided should be clean and verifiable in the areas of the design's artefact, foundations and/or methodologies. |
| 5. Research rigour | Design Science research uses rigorous methods when constructing and evaluating the design artefact. |
| 6. Design as a search process | All available tools and methods have to be used to find the solution to a given problem. |
| 7. Communication of research | The results of the research should be communicated well to both |

technology-oriented as well as management-oriented audiences.

Behavioural science produces and verifies principal laws and theories based on human and organizational behaviour. Design Science focuses more on the technical aspects of creating a solution as an artefact for a particular problem. To support this creation process in a study, guidelines are presented to produce valid artefacts for the Design Science research methodology. These seven basic guidelines by Hevner et al. (2004) can be seen in Table 6. Additionally, these seven guidelines can be explained in more detail by joining them with the research cycles of Design Science. Section 4.2 explains the relation of the different parts and cycles by using a checklist format presented by Hevner et al. (2014)

## 4.2 Research cycles

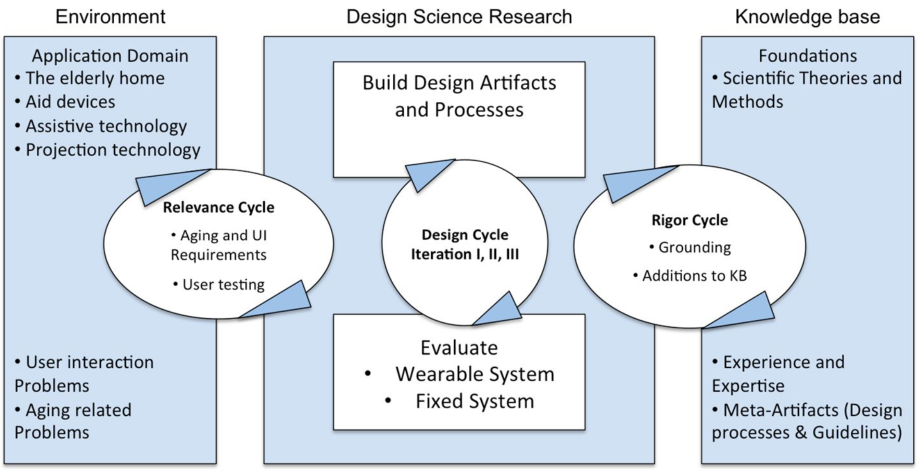



**Fig. 15. Reproduced from Hevner's (2007) paper on Design Science research cycles**

The design research cycle in Figure 15 is based on Hevner 's (2007) illustration; it is a combination of an information system 's (IS) research framework and three overlying research cycles. The starting point of the research in the diagram is the relevance cycle, where the application domain defines the initial research area, participants, problem points and research questions. In this study, the domain consists of the elderly users and the related assistive devices they use in a home environment. In addition, the environment on which the research is focused gathers the problems and opportunities relevant to the application environment and creates the requirements for the research. In this study, the opportunity and the research question in general become about researching, specifically, how the elderly can benefit from the use of projective technology in their home environment.

The relevance cycle focuses on the research environment from which the requirements produced are designed and constructed as design artefacts and processes in the Design Science research main design cycle. The build design artefacts answer what the actual artefact is and how the artefact is presented, and the process part answers what design process is used to build them.

The next step of the process is to test the rigour by comparing the design to the existing knowledge base and by finding relevant theories that support the work. When the rigour has been checked, the design artefacts and processes themselves are evaluated by looking into iterations of the design and how they are improved. Artefact iterations are then applied to the application domain and are tested with proper metrics that aim to explain the improvements made. From the testing, new additions to the knowledge base are created in research articles, new theories or method formats. The Design Science cycle's final step is to evaluate whether the research question has been sufficiently answered. Artefacts created in this research are done in an iterative fashion to improve and implement the changes necessary. As the system design focus changed during the process, Chapters 5 and 6 will discuss in detail how the process of creating a wearable system design changed it into a fixed system design, with similar changes to the UI. The evaluation of the system involves observation as well as evaluation, based on the use of the system tests and controlled experiments.

## 4.3 Addressing the research problem

As described in the related works section of this thesis, AAL systems aim to assist the elderly with automatic and ubiquitous technologies not requiring any human-computer interaction capabilities. As the need to communicate and manage daily activities with the use of technology increases, there is a certain need to assist the elderly in coping with this change in society. Automatic and context-sensitive systems can offer assistance, but when there is a need to use a device for a specific task such as calling a specific person, interaction is required. Thus, the research in this work focuses on helping the elderly to access technology and assisting in their using new and changing interfaces efficiently. Figure 16 shows how the research iterations are connected to the Design Science method, as an example of the first iteration. Numerated circles in the figure are explained as follows:

1. In phase 1, a look at the existing research was conducted to identify the theories in elderly-focused research.
2. During phase 2, the environment of the elderly (where the technology should be situated) was scrutinized to create the knowledge base for the requirements and to find out which situations needed assistance. Dementia presents very specific needs, so an initial gathering of those requirements was done.
3. Phase 3 focused on building the artefacts used in the research, which were initially for a wearable ProCam system.
4. Phase 4 implemented the system in user tests, which were conducted with the elderly in a care home setting.
5. After testing, the artefact (in this case, a wearable system for assisting the elderly with a tapping interface) was evaluated in phase 5.
6. The evaluation presented findings from the research, which could be added to the knowledge base. In this work, there were also some problems that could be added to the experience pool, and the ProCam experiences were additions to the knowledge pool of elderly design theories in phase 6.

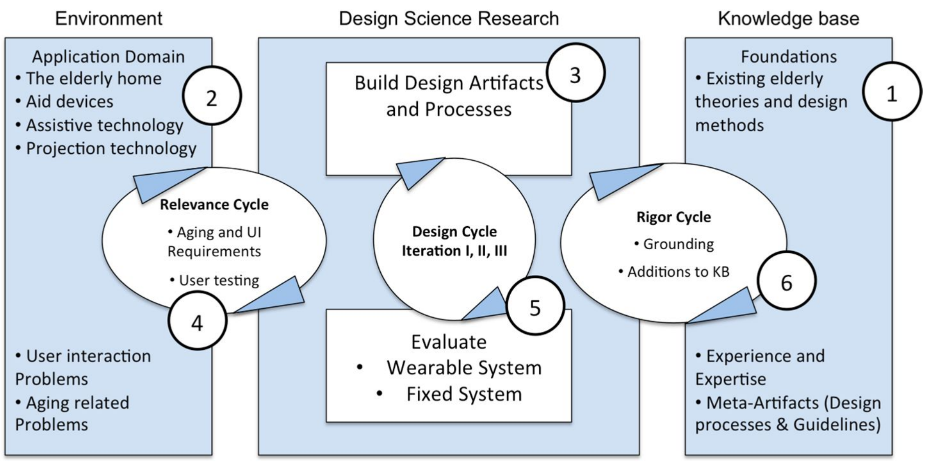



**Fig. 16. Our research in relation to Design Science research cycles**

This first iteration round, in papers I and II, focused on creating a wearable system ProCam system, which was evaluated for its practical uses for the elderly. At the evaluation phase 5, we noticed that the technical design of the system might not be enough for proper UI testing, so an additional iteration round was used to create new design concepts. The findings from the evaluation were added to the existing knowledge base as guidelines for creating wearable devices for the elderly as well as additional guidelines for designing elderly technologies, which we presented in paper III. We re-evaluated the existing problems of the elderly and re-evaluated their environment when creating a fixed ProCam system in papers IV and V. This iteration round focused more on the usability and UI creation for tabletop projection purposes. Motor skill and readability problems found in the wearable iteration round were taken into account in this round. During user testing and evaluation of the system, a third iteration occurred to improve the interaction methods, as the proposed methods were not suitable, discussed in paper V.

### 4.3.1 Problem relevance and user requirements

Chapter 3 discussed the physical or cognitive problems ageing presents and the difficulties faced by the elderly of today in using technology. These areas offer general and specific requirements for the design of assistive system artefacts based on Design Science research guidelines.

The elderly are often reluctant to carry or wear assistive devices; this presents a problem in designing suitable devices for them. As non-wearable is a requirement for the design of an elderly-preferred device, the research proposes a home-environment-implemented system. Additionally, both projection- and camera-based systems are little researched methods for use in an elderly setting, and thus, the user interaction methods and requirements are not clearly known. So general font, colour and other general requirements are used as a basis, and other requirements for a projection system were gathered through the research work done for the system via user studies.

To understand the problems the elderly have in their daily activities, a background literature study was conducted. In addition, a multidisciplinary group of researchers including architects and medical field experts shed light on some of the findings the elderly face at home and when using technology.

### *4.3.2 Constructing the main artefact and sub-artefacts*

To realize the main system concept, the work had to be divided into differ ent components required for the design. The components were defined as follows:

1. Create a projection system to display information using a single projector or multiple projectors.
2. Create a UI that tracks user inputs and objects using a camera.
3. One sub-artefact is to create a simple object and interaction definition database for easy UI modification.
4. Another sub-artefact is to create a data-logging module to track user inputs. This artefact is for the purpose of evaluating the user interactions in more detail.

### *4.3.3 Evaluation of the construct and discussion*

This work presents two different systems as the main targets of the UI designs: a wearable and a fixed system. As the proposed projection methods have not been evaluated with actual elderly users thus far, the knowledge base for them is not extensive. Therefore, the comparison to existing systems from the knowledge base is done with respect to elderly assistive devices, existing guidelines and projection technologies. The evaluation of the construct is done in e ach step of the iteration, so the findings from the user tests can be evaluated against and added to the knowledge base. The implementation, results and evaluation are discussed in more detail in Chapters 5, 6 and 7, respectively .

# 5 Research design and implementation

This chapter presents the two main assistive systems, a wearable and a fixed projection system, for which the different UIs are designed. The work has been done in an iterative way, so this chapter explains the whole process from the first conception to the final system. Iterations shown here explain the system design, the evaluation of the design and how it affected the next iteration process and implementation of the design, in a hierarchical format. The difficult part of creating a touch-focused system that could be described as easy for the elderly to use is that such a system often requires previous knowledge of this type of interaction. As the elderly do not often have extensive experience with smartphones, tablets or even computers, the paradigm is complex to construct.

## 5.1 Summary of the iterative design process

The original publications I–V presented as part of this dissertation show the evolution of the UI, the system changes related to it and the existing research knowledge that is used as the basis for the designs and new iterations. The UI has evolved from the initial design in iteration I (shown in papers I and II), to the second iteration, where the UI changes more into an icon-based concept (paper III) and, lastly, is transformed into a tabletop UI with a focus on interaction and selection methods (papers IV and V). The tabletop system was used in most of the UI studies. This study will briefly present the related systems that were created by other researchers in the same research group as the author of this work, to explain the purpose of the intended UI designs. A wearable system called a Picture Tapping Surface (PiTaSu; papers I, II and III) is the target platform for the first UI designs. A kitchen assistance system (paper IV) is a demonstration of a task assistance scenario and the problem points of a system that visually assists people. The core of the work in this dissertation is meant to show in detail the whole process from the first designs to the final projective tabletop system and the UI (paper V). This is done by dissecting the work in detail, from the design aspects, to the implementation and testing with end users, to the analysis of the collected research data.

## 5.2 Iteration I - First conceptual system design

As a first step, the initial concept of the system started from a literature review of assistive devices and from studying the needs of the elderly in their application domain, using the Design Science approach. The needs of the elderly in a home environment were used as system design goals. Second, existing assistive technologies were used to create the design artefacts. A requirement often conveyed by the elderly is that an assistive device should not have to be carried around. In the case of memory impairment, there is the possibility of misplacing the device. Research suggests that the use of projection technology would be beneficial to elderly users, as it can offer larger projected guidance information compared to smaller devices such as mobile phones. From this starting point, a suitable UI was needed for the system to enable interaction functionalities and to support communication. Additional requirements for the design included unobtrusiveness, adequate performance and acceptable usability for elderly users. A detailed description of the system can be found in paper I. A design-for-all philosophy was used to encompass all of the elderly users within the use of a single and effective system.

### *5.2.1 Conceptual UI design I: Sentence-based UI*

The aim of the first meta-artefact design was to offer a UI that would take into account more serious cognitive impairments such as moderate AD, where individuals cannot easily learn existing or new UIs anymore. The first conceptual design of the UI was based on a path-like structure design of common written language using a subject-verb-object format. This design relied on the existing knowledge of individuals and their ability to understand written language even with more severe cognitive impairment. Speaking, reading and writing are learned at an early age and will remain usable by individuals for a long time, even if more recently learned skills start to deteriorate. The path-structured sentence UI was designed for a wearable projection system, as shown in Figure 17, and was divided into two parts: first, providing information to the users via reminders and guides, and second, offering interaction capabilities to the users to accomplish simple functions such as calling or finding lost items. The path-structured UI was designed for the interaction part of the UI, while the reminder part would use a more traditional step-by-step instruction layout. A UI description language was used in development to create more abstract UI models that could be modified for different UI layouts.

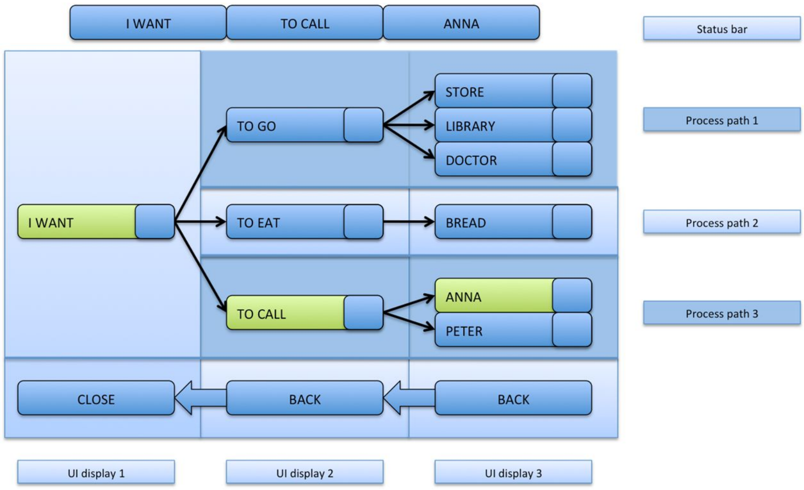



**Fig. 17. Sentence-based UI layout concept. Reprinted from paper II**

In summary, the path structure was seen as having the following advantages for people with memory impairment:

1. *Language support*. A descriptive full sentence of the UI action would be easier for the user to understand.
2. *Feedback support*. The user creating the desired UI function, using sentence creation by selecting the words from a premade list, would understand at which point they were situated in the menu, based on the visual completeness of the sentence. Thus, the user would not get confused.
3. *Heuristic support*. A general UI design guideline of using text and icons would offer a more understandable UI structure.
4. *Contextual and grouping support*. Offering contextual information and grouping relevant actions together would reduce the information on -screen, requiring less cognitive processing.

The research used the knowledge of how languages are understood as the basic principle guiding the initial UI design work. The second approach to the design was created from the understanding that the elderly have problems in following sequential tasks. Due to cognitive impairment, a process or a task that is interrupted often results in the user forgetting the next step in a task they are performing. To support the successful continuation of an interrupted task, the UI needs a feedback mechanism to tell the user where they are in the menu structure at any given moment. The language structure used in the UI would show each step as a feedback item in order to create a full sentence as the final step. By looking at the sentence formed from the menu interactions, the user could follow where they were at any given moment. The third approach to the design supports visual feedback to the user. Studies about UI heuristics st ate that providing only textual information to the user is not enough to create a reasonable affordance for a UI. The suggested solution, also added to the UI design of this work, is a combination of text and icons. A well-designed icon in combination with descriptive textual information offers a better cause and effect correlation than using only text or icons.

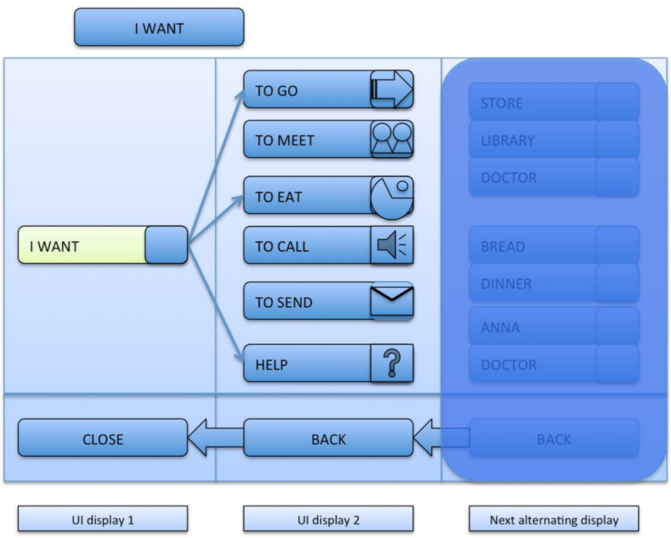



**Fig. 18. Calling a person with the UI; amount of information shown to the user is limited**

A language-based UI would need to be effective for the end user, because it creates something that has a huge number of accessible functions in the form of sentences. For this reason, the functions in the interface needed to be grouped so that a minimum amount of information was offered to the user. Guidelines also show that a minimal number of icons should be offered to elderly users. Figure 18 shows how the concept UI is divided into separate processes related to each other. In addition, the information would be provided based on situational context, to keep the user from having too much information on the screen at one time and showing only the relevant information. As an example of using the user interaction part for calling, a typical sentence would be "I want to call Anna". This sentence can be divided into three parts; "I want", "to call" and "Anna". The "I want" part indicates system initialization, as the user wants to do something. "To call" indicates the action they want to perform, and "Anna" is the intended target of the action. The advancement in the UI is displayed on top as a status bar.

For designing understandable icons and text for a UI in relation to cognitive impairment, the initial designs were informed by augmentative and alternative communication (AAC). However, as the concept UI ended up using an existing language structure, a mix of text and icon methods was needed. Among different AAC methods, PECS (Bondy & Frost 1994) offers pictures designed for non-textual communication. They are designed in such a way that the actions the system user wants to perform are effectively expressed with pictures. The PECS method also takes advantage of pictures to create sentences to convey the user's message. Because of the similarity of creating sentences, PECS was used as a design reference in creating useful icons in addition to using ISO guidelines for UI design for the elderly for basic contrast, colour and icon size recommendations (Gulliksen & Harker 2004).

A common problem for cognitively impaired users is the need to have reminders of daily tasks, as their memory degrades over time. In addition to offering user interaction, a reminder and a guiding system have to be offered to a user. In our system, these reminders were designed to work based on AAL solutions, where the system works in the background and offers the relevant information based on the context. Reminders are either simple to-do lists or guided tasks. To-do reminders do not require additional interactions, as they are designed to simply propose that the user do a task such as going to a doctor's appointment or watching a television program or to remind the user to carry needed items when leaving the house. Guided tasks or reminders are special events that require the user to follow step-by-step instructions to complete a task, for example, taking medication or cooking.

Figure 19 demonstrates how a guided task would be presented in a kitchen environment or when a user is leaving the apartment, in the form of guiding arrows and informative text shown to the user. The guided task could assist the user in the cooking process by helping the user to find items and to add ingredients in the correct order. The projection shown in Figure 19, right, could remind the user to take necessary items along when leaving home. Task guidance and reminders for the elderly would be updated by the family members, trusted persons and medical staff to create special events with appropriate details and guidance instead of being automatically created. However, this requirement of information sharing and updating is not presented in detail in this work and will only be discussed briefly in the future work chapter.


**Fig. 19. Projected guiding information on different flat surfaces in a home environment**

These additional concepts were created for the system to offer access for caretakers and family members using a separate UI, which would enable remote assistance features. A UI that can be used by CLUs could disregard the more complex requirements of the elderly and offer more powerful tools for the assistive people; one example would be a medical doctor being able to add appointments for and check the health status of an elderly person. Family members could track medication usage, add calendar activities and check the consistency of daily schedules. Additionally, a remote connection offers remote communication for problematic situations that might arise when automation cannot function. A contextual approach for the user's tasks is considered in the design. Any tasks the user can do at home should be divided into blocks that have connecting steps or overarching and related tasks. For example, a room in which the user is situated or the time of day and the daily schedule can affect what the

UI offers to the user. The conceptual system design with the contextual information is aimed at reducing the workload of caretakers and family members. The additions are divided into separate modules, as shown in Table 7.

**Table 7. UI modularity**

| Module: | Task: |
|---|---|
| Communication | Tools for audio, video and text messaging between external contacts and the senior citizen |
| Outdoor guidance | Provides information to the elderly user of known and unknown routes to locations via safe paths |
| Home guidance | For home-specific tasks, such as cooking, cleaning or other personalized tasks that require system intervention or are triggered by the user |
| Scheduling | Reminders and scheduling of upcoming tasks for the elderly user or external members; split between multiple users for data acquisition and entry |
| Emergency | Handles direct requests from the elderly user, via automation or manual trigger; forwards alerts to the appropriate assistive members. |

Dividing the UI into modules supports the assisted tasks found in Table 2 (Chapter 3.1), where many of the devices were related to communication assistance, caretaker support, alarms or scheduling.

### 5.2.2 Wearable assistive system: Picture tapping surface (PiTaSu)

The first concept of the UI was designed for a wearable assistive system that uses a pico-projector, a web camera and an accelerometer. The system was developed by researchers at the Nara Institute of Science and Technology and is the technical platform intended for the UI presented in this work. Pico-projectors are small in size, comparable to existing mobile phones, but they offer a larger projected screen compared, for example, to flat panel monitors or other mobile devices. HMDs could offer a large view for the users, but they have the disadvantage of possibly blocking relevant information from a user's field of view. The narrow field of view and floating virtual objects can also be disorienting for an elderly user. A projection displayed on a physical surface does not carry these risks, and the physical surfaces and objects can be touched. Interactive systems that use projection and a camera for tracking are divided into two types: wearable and environmental. The advantage of a wearable system is that because it is situated in front of the user, the user's own body cannot obscure the projection. The design presented in this work is a neck-worn type of system. Additional locations for the camera can be a wrist or a shoulder.

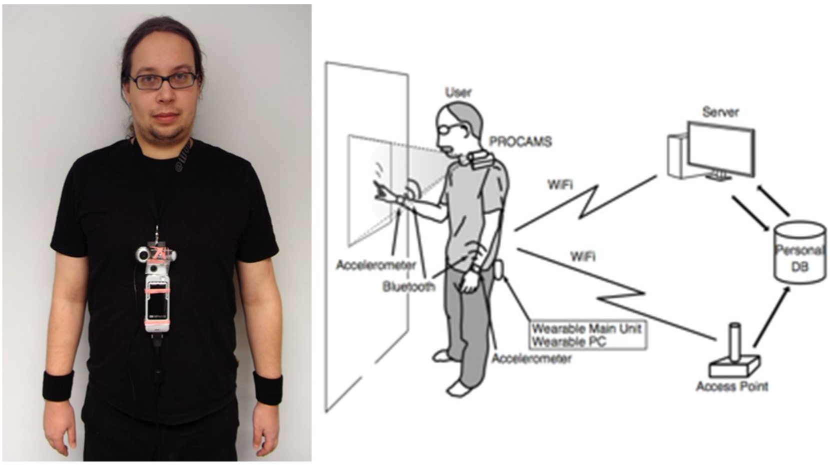



**Fig. 20. The wearable projection system PiTaSu prototype (left); illustration (right), of PiTaSu with a projector, web camera and an accelerometer worn on the wrist. Reprinted from papers II and III**

The prototype system shown in Figure 20 is called a *Picture Tapping Surface* (PiTaSu) due to the user being able to tap the computer graphics-based icons on a physical surface displayed by a projector and detected with a camera. The taps on the surface are tracked with an accelerometer worn on the wrist. The UI is displayed using a projection in front of the user, and the hand on top of the UI is tracked with the camera. In the future, small projectors and cameras will be embedded into clothing due to the smaller form factor, and the accelerometer will be embedded in a wristwatch because of its small size. The system used in the research consists of a mobile pico-projector (3M Micro Professional Projector MPro110, SVGA resolution), a web camera (Logitech QuickCam Vision Pro, in 1280 x 720 pixel mode), a small accelerometer (ATR-Promotions WAA-006, 3.5 mm x 4 mm) and a notebook-sized computer (Apple MacBook, Intel Core 2 Duo 2.4 GHz). The total weight of the prototype is about 300 grams, excluding the computer.

The projections are displayed on different surfaces by using and tracking separate markers in the user's home environment. The interaction with the UI is detected via a separate method. First, the projection of the image has three distinct steps: capturing, image processing and coordinate conversion.

1. *Capturing*: Due to the projector light being displayed on the surface and on top of the interaction hand, elimination of the light is accomplished by detecting the markers in a near-infrared domain.
2. *Image processing*: The markers are analysed and the 3D position is detected using ARToolKit algorithms.
3. *Coordinate conversion*: Coordinate conversion is used to calculate the position and skew of the projection.

As a final result, the computer graphics image is projected near the desired marker location.

Second, the input action is detected using three steps: tapping classification, finger position detection and action validation (from tap and finger position data).

1. *Tap classification*: A Fourier transform analysis is done to the accelerometer sensor data to determine whether a user action is a tap. A tapping action has a high spectrum for detection determined by a certain threshold.
2. *Finger position detection*: Using the marker location in combination with a hand model, the 2D position of the index fingerti p is calculated on top of the displayed surface.
3. *Action Validation*: The fingertip location on top of the displayed surface icon is checked against the accelerometer data that exceeds the set threshold, to verify the UI selection.

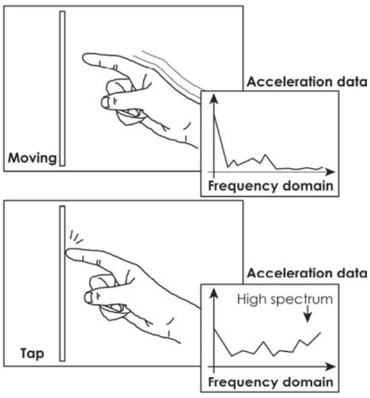



**Fig. 21. Illustration of the acceleration data from a tap causing a detectable high spectrum spike. Reprinted from paper II**

Figure 21 shows an example of how tapping on a wall surface affects the acceleration data as a spike. Figure 22 shows the way in which the camera image is processed to extract the hand outlier image and to determine the tip of the finger as the user's desired icon position, demonstrated as a line ending in a tiny circle.

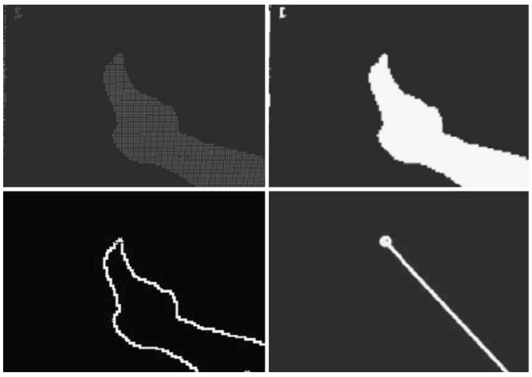


**Fig. 22. Processed camera images to extract the hand outlier and to determine fingertip position. Reprinted from paper II (Original Publications).**

Figure 22 (upper left) is one of the outlier images. This image has noise from the shadow and from defocusing. The latter effect is caused when the projector is out of focus. The shadow noise is caused from the us er hand shadow and environmental shadows. To recognize the hand area, the outlier image is processed with a labelling operation. Figure 22 (upper right) shows the result of this labelling operation. When it is assumed that an input action must enter the projection area, we can define that the hand area has a captured -image edge. Therefore, an area that does not have that edge can be considered as noise. In addition, the largest area that has the captured -image edge is recognized as the hand area. To detect the fingertip, the recognized hand area is processed with edge detection. The distance from the image screen edge is calculated along the hand area outline, as shown in Figure 22 (lower left). The furthest point on the outline is estimated as the fingertip direction, as shown in Figure 22 (lower right). Finally, that same point is defined as the fingertip position.

The PiTaSu system was then tested with the elderly in a nursing home in Finland and was evaluated for its usefulness in that environment. The first test focused on technical aspects such as projection quality, size, tapping algorithm and the usability of the prototype. In this case , the users were elderly residents of a care home who did not have dementia -related diseases. Test systems with users who have AD need to be robust and reliable enough that the user does not get anxiety attacks or get frustrated with the test situation. Fo r this reason, the testing of the initial technical aspects of a new and novel system first needs to be done with normal users. In addition to testing PiTaSu, some additional test information was gathered with the accelerometers on both wrists of an elderl y person to determine whether they could be used to automatically detect what the user was doing, based on location sensor data showing where the user was situated in the nursing home. These preliminary results showed that reliably is low when tracking a task in problematic situations only using accelerometers, so a remote assistance scenario seemed a more suitable approach for future research. A more detailed description of the PiTaSu system tests can be found in paper I, and of the accelerometer and locat ion sensor test, a description can be found in paper II. As a summary of the tests, our findings showed the following:

1. Remote assistance might be more helpful than automated process recognition.
2. A wearable projector has limited use for the elderly becaus e of the small projection size on surfaces within hands ' reach.
3. A tapping interaction with the current solution is inconvenient and may have significant trade-offs regarding recognition reliability and comfort of use.
4. Low brightness and image stabilization issues limit the use of current pico-projectors.

In summary, we designed a UI as a sentence -based structure for a wearable system based on requirements gathered with respect to problems the elderly have in daily activities at home. A wearable system was c hosen due to its light weight and its ability to project large images compared to other portable devices such as a mobile phone or a tablet device. We assume that the technology will become more suitable in the future to better suit portability and elderly users' strict requirements. The UI design approach focused on taking advantage of the fact that elderly with dementia are still able to understand written language; therefore, it was if the system used a similar language -based UI. A minimal amount of UI information would be shown, based on the contextual situation determined by environmental sensors. The system and the ability to automatically offer contextual information were tested in a nursing home in Finland, which produced data showing that the rigour of the system was not sufficient. Chapter 5.3 will discuss the changes made to the design as iteration II.

## 5.3 Iteration II - Conceptual UI design II: Icon-based UI

The proposed sentence-based UI was evaluated for its rigour and its fit with the user requirements. The user tests showed that a portable device had difficulties in UI interaction that were related to the technical limitations. The small-scale conducted test limited the amount of gathered knowledge, so as an additional step, the research moved to a greater focus on creating a more extensive requirements guideline for the elderly system design. This was done by returning to the relevance and rigour cycles of Design Science and looking at the environments in which the elderly live, gathering knowledge on the problems they have in their homes due to memory impairment and discerning the challenges posed for an assistive system design. More detailed information for this iteration can be found in paper III.

First, the amount of memory impairment allowed f or the included users was reduced to a range between MMSE scores of 30 to 18, so that the assistive technology would be more usable. The literature survey on dementia and the use of aid devices was also extended. The additional review findings were as foll ows:

1. *Scheduling*: Daily activities should be given reminders and be scheduled for the user. The goal is to activate people with dementia. Additional remote assistant capabilities for informal and formal caretakers would enable updates of the data for the u ser and updates for caretakers

regarding the status of the task. Furthermore, the user should be part of the process so that they feel involved and competent.

2. *Simplicity*: As the disease progresses, learning becomes difficult, so the assistive system offered to the user should be as simple as possible. A UI should not be too complex to use or learn. Instructions and guides should be offered.
3. *Tailoring*: Individual users approach and use devices in different ways. Tailoring devices or their functions to the user is necessary. A tailored device instils trust in the user towards the device. A single device should be able to multitask so that there is less need to learn new devices for new tasks.
4. *Reliability*: An unreliable device, which does not do as intended or which stops working, provokes mistrust from its user. Often in these cases, the device will not be used again, and thus cannot offer any assistance. It goes without saying that it is essential that the device work. In cases when it fails to do so, it should be replaced as soon as possible. Essential data and specifications should be backed up so that the process is smooth.
5. *Support*: When the device is taken into use for the first time, the support should last from that point until it is removed from use. Necessary maintenance should be available and effective for the total duration of use.
6. *Passive*: Passive devices are effective, because they require less learning and interaction. Because of this advantage, they are easier to use. Implementing as much passive functionality as possible should be considered.
7. *Durability or perceived durability*: Often, technologies seem as if they might be easy to break, which leaves them unused by the user. If it is demonstrated that the device is durable for everyday use, it can create trust towards the device. In any case, a device durable enough for misuse should be considered. AD can manifest as frustration and agitation, so it should be expected that a user may mishandle a device when they are frustrated.
8. *Being like the rest*: The experience of wearing an assistive device is often perceived as uncomfortable when the device is clearly visible, making users feel that they are not like the rest of the population. A device that clearly presents to others as an assistive device creates mistrust or a sense

of unwanted attention. Therefore, technology design should make the device look like any normal device or be as hidden as possible. New wearable devices are often designed to look like jewellery, which makes it is easier for users to accept them.

Additionally, a fully automated system that can help people with dementia, and yet carries no risk that it will function incorrectly, is currently too complex to create. So as an alternative solution, a remote assistance feature was considered to be more effective and less error-prone. Formal caretakers have more experience in the different problems the elderly have, so taking advantage of their existing knowledge would be beneficial with a system that can assist at anytime, anywhere.

As a summary, the review showed that devices should have several tailored and updateable features as well as features that match the exact needs of memory-impaired users. An approach where information and communication is shared between assistive external users and home users was considered. The goal was to figure out how data sharing, updating and communications could be handled between the two parties when regular aid functions such as medication intake, labels on objects, handwritten reminders and appointments were digitized. Instrumental for any digital assistive device that would be taken into use by inexperienced users would be the ability to back up and restore functionality, so any problem situations could be handled effectively and quickly without long interruptions in the device use scenarios.

The approach for the UI was changed to be more feature-rich, compared to only having a sentence structure. This was done because people with moderate dementia have symptoms that are very difficult to take into account in system design to ensure that the end product is suitable. The approach for dementia was thus scaled back. First, a system should have usability that is sufficient enough for an elderly user; then the memory impairment requirements can be extended into the design. If the system is robust enough, the research can be extended to cover more impairment in the design. The UI, as it was, was deemed to have low affordance in its current state with the dementia scale focused more on mild dementia users, so the layout of the interface and the usability were reconceptualised. Figure 23 shows the alternative UI with the icons spread out on a touch interface. The number of icons presented is based on general guidelines proposing that elderly users should have few icons so the UI is easier to use.

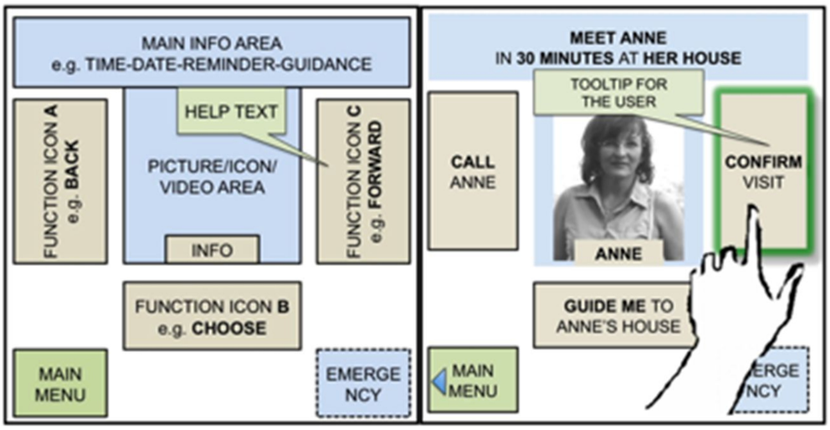



**Fig. 23. The conceptual UI II for a wearable assistive system. Reprinted from paper III**

Tooltips were added, so that if the user does not know what a specific icon does, they receive additional information about the icon by hovering over it. The functions are laid around the target in the centre, so the user does not have to reach too far to make a selection and so the icons are associated with the centre of focus target. The icons have data that is relevant to the centre icon, so they can be customized based on the information provided. Informal and formal caretakers requested an emergency feature so an icon for that feature was added. Figure 24 shows a possible scenario of a reminding system in a bedroom environment that does not need interaction functions but which can instruct the user on their daily activities and how to accomplish them and scheduling.

As a summary, the requirements of assistive technology design were re-examined as a new interface was proposed to incorporate more complex elements and as the target group was extended to include users with mild dementia. A change in the user focus was made, so the end system would be more robust and usable for all elderly users. Focusing on moderate dementia presents difficulties in designing for users with normal cognition or mild dementia.

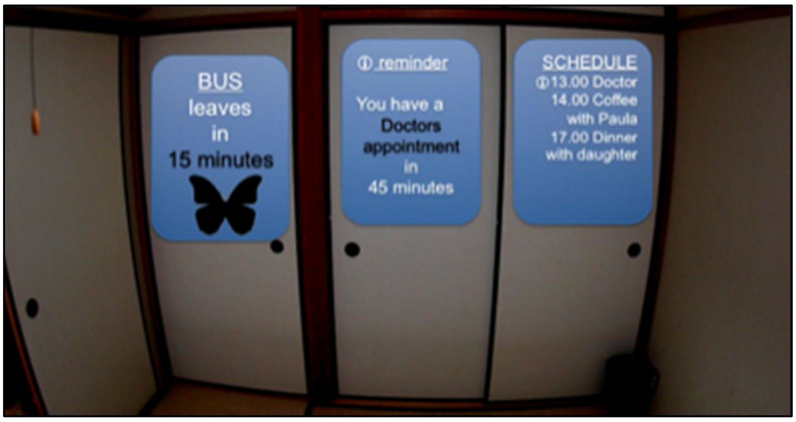



**Fig. 24. Reminder and guidance concept in a bedroom environment, displayed on the closet surfaces. Reprinted from paper III**

### *5.3.1 Kitchen remote assistance with a fixed installation*

This section describes a system designed for a specific assistive task for the elderly and the benefits a projection system with remote assistance could bring to an elderly user. This part is descriptive to show why remote assistance is an important feature of the proposed system for this work. Additional work was conducted to find out what kinds of advantages and problems projection systems have when remotely assisting in a task with the elderly. Paper VI presented the kitchen assistance system developed by researchers at the Nara Institute of Science and Technology in more detail. The goal was to test how projections could be done on kitchen environment surfaces to enable effective remote assistance and how visual prompting could be used to emphasize objects. This approach is meant for people with mild dementia, who often have difficulties in following sequential task steps. Thus, a supportive system for these tasks is needed. Cooking is one instrumental daily activity that involves several steps to be followed, and many elderly users are forced to rely on food delivery when their skills deteriorate. For this reason, a system that encourages and activates a user to continue living a normal life would be beneficial. Related assistive systems for a kitchen often rely on automated assistance, for example, with sensors and situational detection methods, but a fully automatic system is problematic because of difficulties in computer vision and pattern recognition.

Due to this, the kitchen assistive system presented here relies more on remote assistance from an actual person instead of on an automated system. Systems that offer remote assistance have been typically designed for activities other than cooking, and they are also commonly designed for computer-literate, not elderly, users (Fussell et al. 2003, Hestnes et al. 2001, Kraut et al. 1996, Kurata et al. 2004, Kuzuoka et al. 1994).

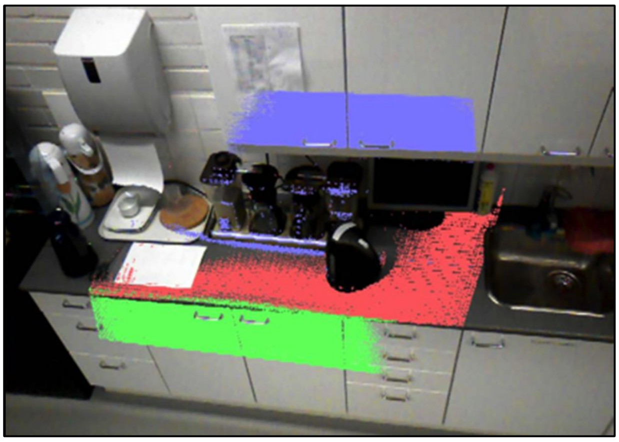


**Fig. 25. Camera image for the remote assistive user with coloured visual areas marked as usable for visual prompts. Reprinted from paper IV**

The kitchen assistance system uses a projector (EPSON EMP-73, 1500 Lumens, 1024 x 768), a camera (Buffalo Kokuyo Supply Inc. BSW13K05HBK, 640 x 480, 30 fps) and a laptop PC (Intel Core2, 2.66 GHz, 2.94 GB). In order to display visual prompts on kitchen surfaces, it is necessary to compute how the prompts are distorted in the projected image, and which surfaces are suitable for projections. Hence, the system projects a calibration pattern into the kitchen area, after which the surfaces are recognized. A more detailed technical description of how the process is calculated and displayed can be read in paper IV. Figure 25 shows the sample kitchen after a calibration process has detected the suitable surfaces. The coloured surfaces in the photo are meant to show suitable visual guiding prompt areas for remote users assisting the elderly in their task. The image also shows the full usable size of the projection for the projector used here when it is attached to the ceiling. Either a larger area is needed to cover the whole kitchen, or the projector position should be movable in the ceiling. For a proof of concept, a static position was used. Figure 26 shows how a water jug is highlighted with an animated visual prompt to assist the user in a coffee -making process. Using visual prompts enables remote pointing to objects, which is better than an over -reliance on audio cues.

**Fig. 26. An example of an animated visual prompt around a water jug. Reprinted from paper IV**

A small-scale observation was conducted and recorded on video of two elderly people with mild dementia (MMSE score 18/30 and 24/30) living in an elderly care home in Finland. The goal was to observe how they performed a coffee -making process in an unknown environment. An unknown environment mimics the experience of having problems with memory, where the location of items needed for the task is also not known. Additionally, in this observation, the coffee process had 11 steps from start to finish. The care home staff assisted the elderly people in the process, and the number of times that assistance was given was counted. One user needed guidance five times, and the other user, four.

Results of the small-scale observation showed that both users needed both pointing and verbal guides from the caretakers, which supports the re commended use of both visual and audio prompts. Some guides cannot be shown with direct prompting by a projector, due to location or object reflection issues, but an indirect prompt showing the process, for example, an animation of the process, is feasible. As a result, a mixed method with static displays for indirect prompting and a projector for direct prompting was proposed.

## 5.4 Iteration III - Fixed ProCam system design

This section explains how the design was changed from a wearable solution to a fixed one. In addition, the user studies starting with CLUs as a basis and moving on to elderly users are explained through the pilot test and user group comparison, using the example of a sequential task test. The structure first presents the tabletop system in detail. Next, the user studies are split into several sections: pilot tests, selection method, group comparison test and sequential task test. Each section explains the aim of the test, the methods used and the results, with an additional summary of how they lead up to the next section. A full summary of the interconnected structures can be read at the end of the chapter, and additional information found for the tests can be read in paper V (Original Publications).

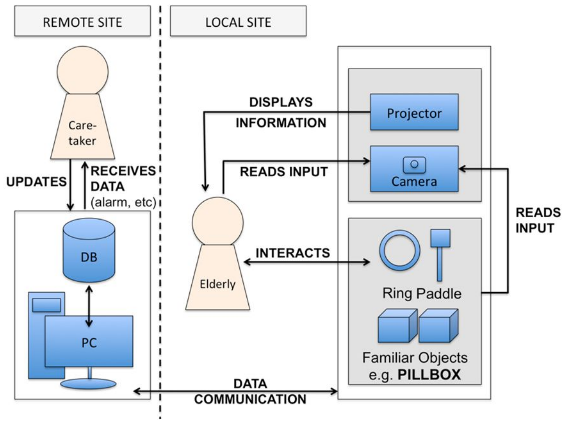



**Fig. 27. Data communication of the tabletop system**

The PiTaSu wearable projection system had stability and projection issues, which affected how interaction functions could be tested. To eliminate the technical issues and to focus on how the elderly manipulate a projected UI, the system design was changed to a fixed installation. In a fixed projection, the image is stable at all times on different flat surfaces, and the projected image can be larger compared to that from a wearable device. The tabletop system is limited to the home environment of an elderly user due to its fixed indoor nature, but in the future, we expect portability to be a feasible option. A fixed projection also has the advantage of not needing the user to carry additional devices. Figure 27 shows the overall design of the system: the formal caretakers manage and update the data remotely for the elderly, who in turn interact with the system using the tools provided. The managed data can, for example, be related to appointments or medication. Items are tagged with markers that the camera can recognize, and the projector displays information to the user in the form of a UI or related information for the objects in the environment based on the markers. If necessary, the formal caretaker can communicate and guide the user with the system via a remote connection if the user needs help in their task. The system does not, and is not meant to, track users constantly by invading their privacy. The system is meant to offer the services of a caretaker to the elderly remotely if necessary, and on location assistance is offered whenever possible. However, this feature is not implemented, so the remote connection discussion is limited to the future work chapter.

### *5.4.1 Tabletop projection system*

This section describes the final tabletop projection system designed based on previous observations and technical experiments. Subsequently, this section describes several GUI designs for elderly use and how they have evolved over the user test results. The tabletop system consists of a camera, a projector and a laptop computer, which is a standard implementation for a ProCam system, as shown in Figure 28 left. Audio speakers are used to give audio cues as feedback to the user when the person interacts with the icons. The tests for the system assume the interaction is performed at a dining table, a place used daily. The camera and the projector are installed on an upper location close to the ceiling and point downwards onto the table surface. The projector creates the graphical information on the surface, and the camera detects the location of the target objects. These act as triggers to launch system features (for example, a menu card is used for showing a graphical menu), and input tools are then used in the form of a ring on the user's finger, or as an alternative, a paddle detected by the camera, as shown in Figure 27 right. The tools are meant to enable two interaction concepts, respectively, a finger-operated method (similar to touch-panel-equipped devices such as tablets) and a tool-based operation, such as a stylus pen. The system uses an Optitrack FLEX:V100 R2 camera (640 x 480, 100 Hz) with a filter switch for two alternate modes: an RGB colour mode for calibrating the system output correctly with a checkerboard pattern on the table and an infrared (IR) mode used for tracking the retro reflective markers. The projector was an Epson H431B LCD model (1920 x 1080), and the computer was a Fujitsu-Siemens 13.3-inch laptop (i3-M380M 2.53 GHz dual core). Additionally, the projection method has an advantage when compared to large installed displays. With a projection, we can provide easier-to-associate visual information related to real-world physical objects located on the table by using AR technology.

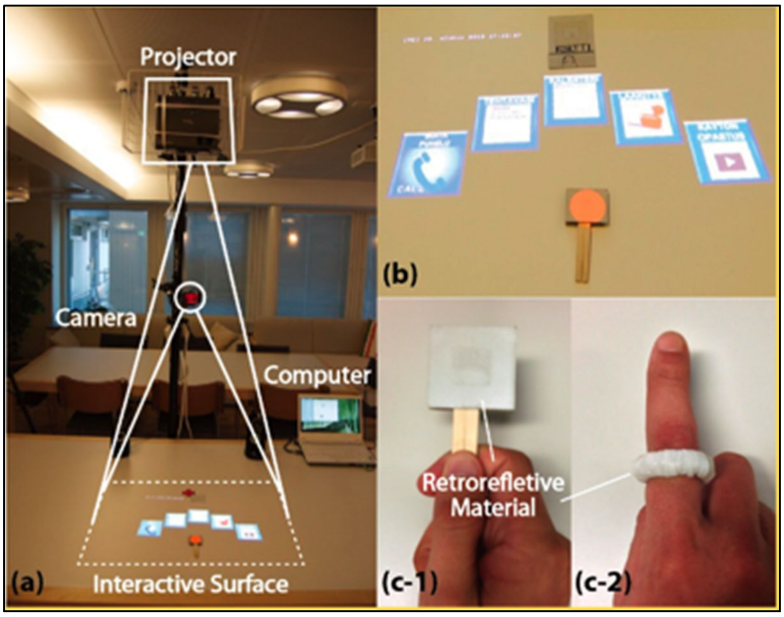



**Fig. 28. a) Tabletop projection set up in a care home of the elderly; b) An arc-shaped UI shown below the trigger card; c-1, -2) interaction tools with retro-reflective material for camera detection**

This added information is not only for the elderly but also for other people around the projection. In contrast, a user with an HMD sees information only visible to them. However, it is not certain whether current UI designs and methods are acceptable because of the new technology used for the elderly. Hence, we devised several types of GUI designs for projection methods. Then, we obtained the key elements through user studies with elderly participants interacting with the system.

The projector-camera system shows projected information at the location where the corresponding markers are on a tabletop surface, based on geometrical calibration between the camera and projector screens on the table. A demonstration of this is the menu card (Figure 28b) that changes the orientation of the menu in real time. This is advantageous in a home environment, as the elderly user can display the menu in any direction they want. The homography is calculated between two-dimensional coordinate systems on the camera and the projector screen by limiting the interaction on the tabletop (Figure 28a). The calibration can be done instantly by displaying a checkerboard pattern on the table surface with the projector and instantly capturing it with the camera in colour mode upon program start-up. After calibration, the camera automatically switches to infrared mode, and to estimate the coordinates of the trigger card or the input paddle, we use an AR marker, a standard marker for ARToolKit, with retro-reflective material for detection purposes. Using the homography, a graphical menu corresponding to the trigger card can be projected onto the exact location where the card is in real space and can be updated in real time (Figure 28b). Since the paddle location can also be estimated in each frame, the system can also handle pointing events with a paddle (Figure 29: a1 and a2).

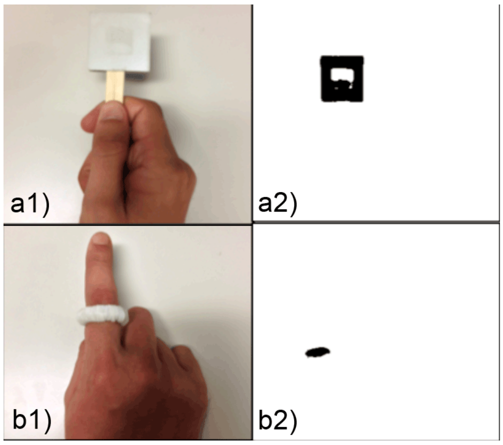



**Fig. 29. Binarised images extracted from the IR-camera**

In order to detect a control ring, we used a different approach, because applying a sufficiently sized AR marker to a tiny ring was not feasible. To overcome the problem, the ring had retro-reflective material on its surface, which was then captured and extracted clearly in the infrared region (Figure 29: b1 and b2). The extracted shape of the ring was measured in its eccentricity and ratio between width and height of a bounding rectangle along the axis of the orientation. Thus, finger tracking can be done when these parameters are decided through several experiments. The fingertip position is different from the detected ring, so the tip is an estimation that can be adjusted for different users if the finger length varies greatly.

### *5.4.2 Two pilot studies for the designs*

Layout is one of the important elements when developing a useful interface. Since a projection system does not have a clear border, various designs with different sizes or shapes for the icons were considered. Shown in Figure 30 are some of the earlier designs, such as a) straight alignment and b) arc alignment, which evolved after a few iterations. The initial prototype of the system and the related UI design were first pilot tested with 20 CLUs with a median age of 25.5 to choose the initial UI layout and test the selection method, before trying a more robust design with elderly users.

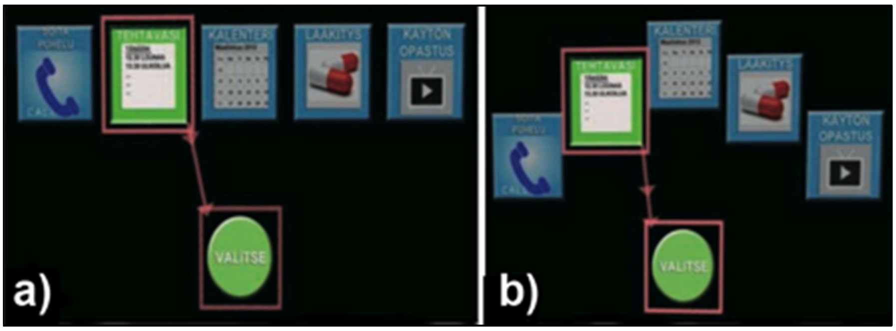



**Fig. 30. Initial menu layouts: a) line and b) arc, both with a “select and move to activation icon” method. (in Finnish)**

The selection method in the prototype works by first choosing an icon and then confirming it by an additional SELECT (VALITSE) icon in the cent re of the UI (Figure 31). This two-step feature is meant to reduce accidental selections when using the UI. The SELECT icon is kept in the centre of the user ’s field of view to help the user understand the confirmation functionality. Second, the removal of tapping detection requires a different approach in designing the selection method. To allow the user to hover over the icons without triggering a selection, a confirmation requirement was created. The users did two simple tasks without any guidance to the use of the system. Not giving guidance was intended to roughly simulate a user having memory impairment, as they might not remember instructions given to them about the system. The first task was to call an imaginary person, and the second task was to use an imaginary “Find keys” function of the system.

The two tasks consisted of 4–6 steps in total. The "making a phone call" task included the following steps:

1. Select Phone
2. Verify selection
3. Select the right person
4. Verify selection
5. Return to main menu
6. Verify selection

The error count, speed, accuracy, questionnaires and interviews regarding layout and selection preferences were gathered. The line layout was fastest, but it produced more accidental selections, because the icons were situated closer together; due to this disadvantage, users preferred the arc layout. When we considered the natural movement of the arm on a table surface, the layout of fanned-out icons that were easily reachable was chosen as the basic layout for the initial projection system.

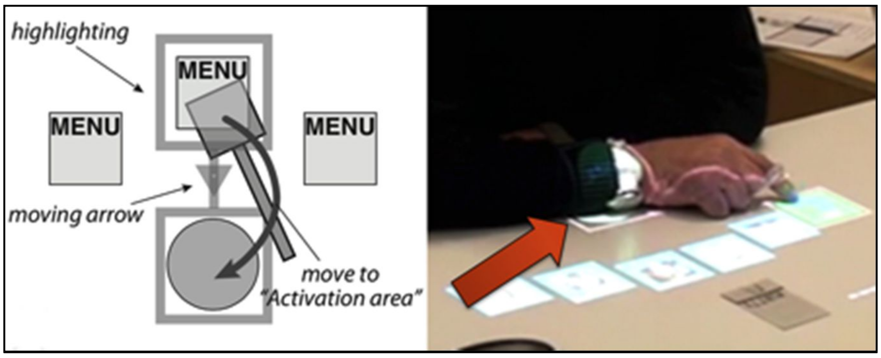



**Fig. 31. Left: Two-step activation method. Right: An elderly user blocks the activation icon with their hand**

A second pilot test was conducted with six elderly participants with a median age of 90. The additional test was to find any age -related problems related to the system design, which the designs might have overlooked, for example, readability or interaction method usability. Questionnaires (Appendix 1) measuring user interaction satisfaction and post -experiment interviews for overall experience were conducted. This study focused on two tasks. The first was to make a simulated video call to a caretaker using the provided interaction tools, a ring and a paddle. Second, the user repeated the same calling task but was interrupted by another task; the user was requested to take their medication. This task was meant to produce data on how the elderly person responds if the main task is interrupted and whether they are able to recover from the interruption. An interruption often leads to the user forgetting the initial task, a common problem for people who have memory impairment. In addition to observing the recovery, the test measured the usability of an instructed step-by-step medication task. In the test, no initial guidance for the UI was given to participants, and the calling task was relatively the same as that in the previous pilot test. To interact with the icons, an activation button sat at the bottom centre of the UI, as seen in Figure 31. When the user selected one of the desired functions from the arc menu, an activation button appeared. The desired icon and the activation button were highlighted and connected with an animated arrow between the two to indicate to the user where to move to complete their selection. There was a red circle indicating the position of the fingertip when using the ring as an input tool. This was used to help the user realize where the system thinks their input finger is.

Testing a UI when the users are elderly usually requires a unique approach as the difficulty of a UI is typically measured using Fitts' Law (Fitts 1954). The basic assumption in Fitts' Law is that the tested users have equivalent cognitive and motor skill capabilities. However, in our tests, the elderly users often had varying degrees of motor skills limitations and changes in their cognitive functions, including memory impairments such as dementia. For this reason the basic Fitts' Law approach could not be used and this was reflected in the test analysis. Using only a statistical method is not representative of the target population so additional qualitative analysis was described to accommodate the elderly approach. A paper by Bakaev (2008) applied Fitts' Law by taking into account the advanced age of the users. In these tests, the elderly performed twice as slowly as the younger population, but performed slightly better in accuracy measurements than the younger population when the target icon sizes where increased. This result is reflected in this dissertation; however, the tests done by Bakaev did not take into account the AAMI or MCI difficulties of an elderly user so the results are not totally applicable to our system. As a solution, qualitative analysis of the user test was done, focusing on individual users, their characteristics and problem points and how they affected the use of the UI.

*Observations of individual users*

The following is a summary of the six participants and their experiences with the system. Afterwards, we describe the findings based on the users ’ experiences.

1. User 1 was a male with mild to moderate AD with no previous experience on smartphones or touch-screen devices. He had a computer at home for writing. He had some mild hearing issues and slight arthritis in his hands.

*Analysis:* Looking at how he performed with the UI, we noticed that the user hovered 5cm over the UI when using the paddle; however, when using the ring, he touched the icons. He said that the ring “felt more natural” and that “…a separate paddle might get lost”. When presented with a guiding video in the main menu, he had problems with it, as he did not understand it was a video. The user ended up touching the icons in the video to try to manipulate them. The same kind of confusion was experienced with the pop-up tooltips where the user thought he could make a call from a tooltip that stated, “with this you can make a call”, as seen in Figure 32.

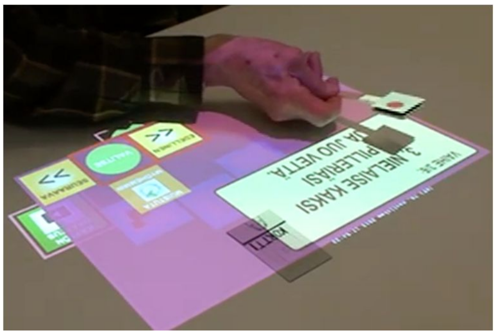


**Fig. 32. User confuses instructional text as a selectable icon.**

This might be a wording or design element problem, or it may be due to the user’s inexperience with newer interfaces that have tooltips. When he understood the meaning of the tooltips, he read them by pointing at the text line by line. During the phone call task, the user assumed calling would still involve inputting a number somewhere in the system: he asked, “So how do I input the number here? ” This is clearly a learned habit from traditional phone call methods. While the method in our UI was different from what he was used to, he said that choosing numbers might be difficult. He said our system of only choosing a person was easier, due to his arthritis problems. The selection method with an additional confirmation step was confusing for him, but he used his finger to point at the icons instinctively. When the system interrupted the phone call task with an alarm to take medication, he still wanted to continue the initial calling task and rejected taking medication.

2. User 2 was an elderly male with mild to moderate AD and no experience with smartphones, computers or touch-screen devices. He had had corrective eye surgery on his left eye, which resulted in poor eyesight. He had no motor skill problems.

*Analysis:* The user was initially afraid to move his hand to interact with the menu and had to be encouraged to start the test. He was clearly anxious and needed encouragement to use the new UI. While his hand with the ring stayed put on the table, he used his free hand to check the icons before pressing anything. During the test the user had problems with the two-step selection method and got confused with the use context. He clearly wanted a single press of an icon to be enough to select a function and kept tapping the same icon repeatedly. The red circle indicating the tip of his finger also confused him while he was manipulating the menu. First he wondered why it followed his finger. Later, when he understood it was a control point, he often hovered over the UI and focused on moving the red circle on the table instead of tapping an icon. The user did not always have time to read the tooltips properly. This happened when the tooltips disappeared just as the user wanted to point at them and read them out loud with his input finger. Additionally, the user was more negative towards computers and technology in general, but expressed the opinion that family members searching online for information and news for him was useful. He preferred the ring, as it was "easier to use".

3. User 3 was a female with mild to moderate AD. She had no experience with smartphones or touch screens. Previous experiences with computers were from work with no other personal use cases. She had corrected eyesight with glasses and no hearing or motor skill problems. She was missing one index finger from her right hand.

*Analysis:* The user had confidence issues and disparaged her skills before and during the test. This was evident from her saying, "I did this in a stupid way, didn 't I?" and "Stupid, idiot, I do not get it." Despite her self-reproach, observations showed that she did not have clear problems interacting with the menu. In her case, the calling task was fairly quickly finished compared to other users. She seemed to learn the method quickly, challenging her opinion that "others are smart, so they learn the use faster ". The confidence issues were themselves the main hindrances in her case. She read each icon aloud, including the tooltips, so she could understand the functions before selection. The missing index finger did not affect the selection. Initially she wanted to use her off hand because she was embarrassed to show her hand without the index finger. After relaxing and performing the test with the ring in her middle finger, she preferred the ring as she felt "it was more natural".

4. User 4 was a male using a wheelchair. He had no experience with smartphones, computers or touch screens and no memory impairment. He had corrected eyesight with glasses and no motor skill problems.

*Analysis:* The user immediately knew to touch the icons with his index finger and was not confused by the red circle. The initial method of interaction he chose was a single tap to select icons, and when this did not work, he quickly learned the two-step selection method. He referred to this learning by saying, "This is easy but I need to understand how to play (use) this". The menu structure seemed logical to him as he stated, "We go forward and backwards in the menu by pressing the icons like so ". He also demonstrated this to the researcher by going back and forth in the menu outside of the given task. His confidence to use the UI resulted in him stating that he could teach other elderly people how to use it. He also deemed the text sizes proper: "[the icons and texts] are good sized. I can see them clearly … if you can't read this text, then you have a problem with your eyes". The interrupted call task with a medication reminder was understandable to him, but the icons in that menu were too close together and too small to manipulate so he could not finish it properly. Both the paddle and the ring were easy tools for him, but he preferred the ring as it was easy, "felt better", was more practical and would not get lost.

5. User 5 was a male with mild AD. He had no experience with smartphones, touch screens or computers. He had some trouble hearing but did not wear glasses. He had some stiffness in his hands, but no severe motor skill problems.

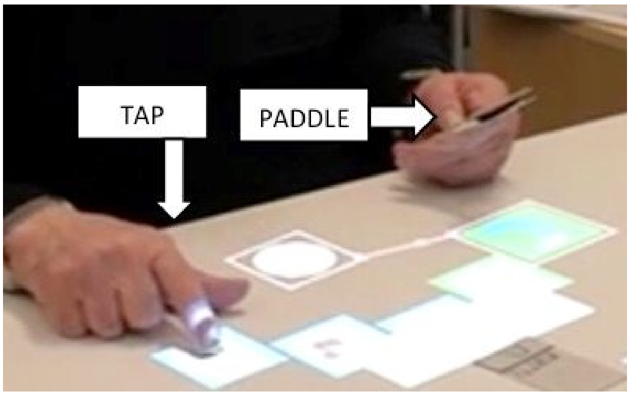



**Fig. 33. The user naturally wanted to use a finger to select the icons instead of the paddle**

*Analysis:* The two-step selection method was clear to the user initially, but after watching the user guide video in the menu, this user also thought the video had elements that could be selected. This confused the user, as he could not use the selection method inside the video. Then he assumed the earlier learned two-step method did not work at all, and he started to try other ways of selecting. Eventually, exiting the video led the user to try the selection method again successfully. While using the paddle, the user sometimes wanted to interact with the menu by using his finger, which indicated the natural desire to tap icons as seen in Figure 33. The user hovered over the icons with the paddle and did not touch the icons unless he wanted to select one. Hovering seemed to be only for checking the icon functions, and the same occurred when the user had a ring.

6. User 6 was a male with moderate AD. He had no experience with smartphones or computers. He had some trouble hearing and had had corrective eye surgery limiting his left eyesight and thus the field of view. Otherwise, his eyesight was very good.

*Analysis:* This user had initial trouble selecting with the ring as he assumed he had to touch the table with the ring. The user tried at first to knock on the table using an upside down fist with the ring, but eventually, tapping with a single tap was the natural assumption for him. However, when he used the paddle, the two-step selection method was easier for him to understand. Like others, the user read the menu functions aloud while occasionally pointing at the text. He also had difficulty understanding the selection method and struggled with the use context. He needed to be reminded of the task fairly often so that he did not get lost in the menus. Frequently, he ignored the paddle and tried to use his finger to select; for him, the finger seemed instinctively to be the interaction tool. The user would recommend the system for other users with bad eyesight, as he reported that he could see the elements and text well. When trying the make a call the user inquired, “Where can I input the number?” in the exact same way as user 1. He preferred the ring, saying, “[it fits] freely in the finger and does not need adjusting ”.

### *Overall analysis of the findings based on the experiments*

Out of the six users, three had mild to moderate AD, one had moderate AD and two had normal cognition for their age. When we look at the effects of AD on the tests, the learning ability of a simple interaction method was limited and produced problems. The users with moderate AD had significant problems using the interface and understanding the test in general. The users with normal cognition performed better with the system and could understand and learn the proposed selection method quickly. As a summary, we can say that the users required an easier selection method; the tested one was hard to use and produced too many mistakes in the selection. Age alone clearly was not an issue, but the method itself was not clear enough. The medication task icons were insufficient for all users, as even the skilled ones could not perform well with them. The elderly users requested more guidance than what we offered in the use of the system, but successful interaction varied from person to person. One accommodation would be the system reacting more slowly in response to the users’ demonstrated skills. Usually, the elderly need a bit more time to perform. Compared to younger users, they would more often read the text aloud and point at what they were reading. The traditional method of calling with a number input misled some users initially, but all understood the new method later on. AD affected the learnability of the UI by slowing down the interactions, but tapping as a gesture was natural for all users instinctively. Lack of self-confidence or negative attitudes towards technology were only issues within the test situation experience, and did not affect the performance of the users. Gender also did not seem to play a role in the test performance. All users except one, regardless of their physical limitations, deemed icon and text sizes sufficient. This was also evident as even people with motor skill problems manipulated the menu well. Some graphic elements affected use, for example the red circle often made users hover over the table instead of sliding over it.

Through these user tests, we identified several problems, as seen in Figures 32 and 33. Figure 31 (right) shows how an elderly user blocked vital projection information with their arm. This problem was not present for CLUs who observed the table and the UI before and during the UI manipulation. Observations also showed that the UI's input method produced a high number of errors for all participants. The selection method concept seemed more difficult for the elderly compared to the younger CLUs. The appearance of the activation icon was also timed, so a slower elderly user often could not reach it before it disappeared from view. This clearly indicated that times should be tweaked for individual users. The se quence of selecting and confirming with a separate icon was also unclear for some of the users.

In the second task, where the user was interrupted during menu manipulation, the UI was also prone to accidental selections. Only two users managed to navigate to the end of the task successfully. Due to constant selection problems, the test did not produce enough reliable data regarding the interruption recovery. For this reason, the focus was on observing what the problem points were in that particular task. The various difficulties were related to the icon sizes and locations, leading to the accidental selection of unintended icons. The interactive icons were located in the lower right corner of the screen, which took users ' attention away from the instruction screen located in the top centre position, as seen in Figure 35. The resulting problem was that the users, while manipulating the icons, did not always notice that the instructions had changed for them, and they failed to follow the proper steps of the me dication task.

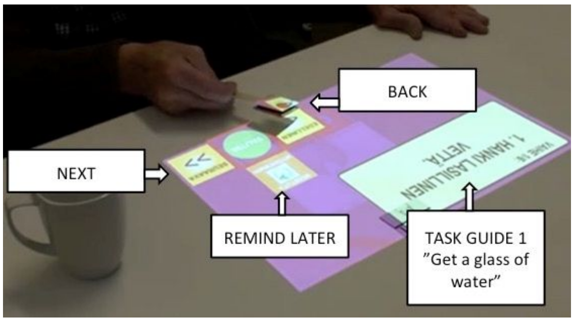



**Fig. 34. The problematic medication task icon placement and size issues**

Looking at the questionnaire results (Appendix 4), there was a slight tendency towards ease of use for the system, as direct interaction was easy to perform. The overall icon d esign was also logical. Learning was deemed difficult, as the selection problems experienced by the users hindered their experience, so users did not recommend the system to others for the most part. As a result, the system design was re-evaluated to find more suitable input methods for the user interaction. The selection method of the overall interface also affected the medication task, so an improved layout of its icons and a different selection method for this particular task was needed.

There are many implications of these observations on the use of projection technology to assist elderly people. We need to take into account that a borderless projection space can be difficult to understand as the elderly might block some icons if they do not understand where the projection starts or ends. However, the projection itself was not confusing as a concept, as the elderly users treated the table surface mostly like a touch-screen device. Using a two-step selection method is not easy for most elderly people, as they cannot easily grasp this use metaphor. It was evident that most of the elderly users assumed a tap would execute an action. As the current implementation did not detect a tap, the selection method should be reconsidered. The screen size of the UI was adequate for all of the users, so a big projection clearly is helpful for the elderly. A short summary is as follows:

- Simple and straightforward methods are effective.
- Tapping was natural for the users even when they were asked to use other input tools.
- Interaction methods previously learned by the users should be considered; however, new interaction methods were not too complex for users, e.g. calling with a number pad vs. calling with icons.
- Elderly users without memory impairment can use more complex approaches.
- Guidance is always needed, especially when users make a mistake or have memory impairment.
- The speed of the system should be adapted to the users' skill levels.
- Elderly users need more time to perform tasks than usually expected by a designer.
- Self-confidence does not seem to influence test performance.
- The use of a large UI overcame motor skill deficiencies.
- A borderless UI has the potential to confuse the user in terms of where the interaction area starts or ends.

### 5.4.3 Interaction method and user group comparison test

As the previous design created difficulties with icon selection, a new selection artefact was created. Figure 35 shows a) the existing two-step method, b) a time-triggered hover method and c) a slide method. The two-step method affordance and icon placement difficulties led to the introduction of two alternative selection methods for comparison and testing purposes. In the hover-based method (Figure 35b), the user hovers over or touches an icon for a predefined length of time, for example, 0.5 seconds, to activate a selection. A progress bar above the icon also indicates to the user the selection time length. In the slide method (Figure 35c), the verification icon "SELECT" appears over the menu icon. When the finger or paddle is moved over the "SELECT" icon, the activation is immediate.

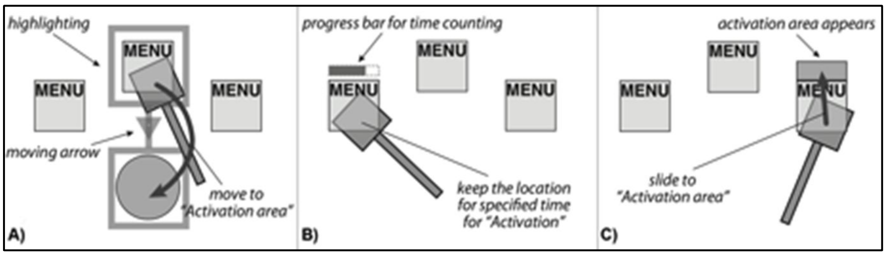



**Fig. 35. Three methods used in the comparison tests: a) two-step, b) hover and c) slide**

We chose a commonly used hover method as a good candidate for comparison studies. The slide method was chosen to reduce the distance users need to move their hands. We assumed that this would reduce the number of mistakes. Additionally, as field of focus often narrows with old age, placing selectable icons where the user is looking was deemed logical. If the important icons are inserted at the edge of a user's field of vision, they must be indicated clearly. Lastly, pop-up tooltips were added to the system to help the elderly understand what each icon means and is used for. However, the hover-based selection method can only offer limited tooltip functionality, so the test did not measure the effects of offering tooltips to the user. Overall changes demonstrated with the two-step method can be seen in Figure 36.

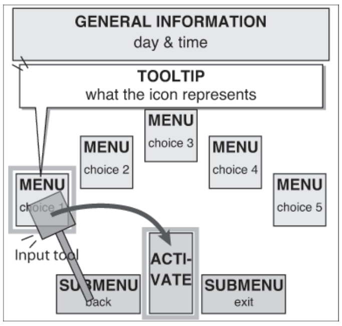
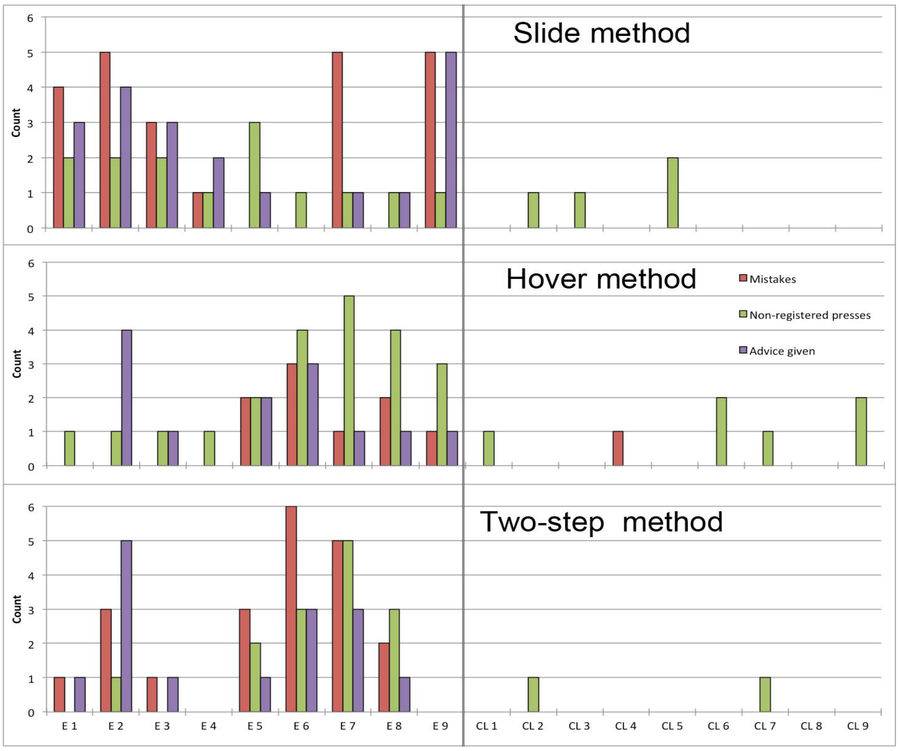



**Fig. 36. Two-step method as an example of the changes to the UI functionality.**

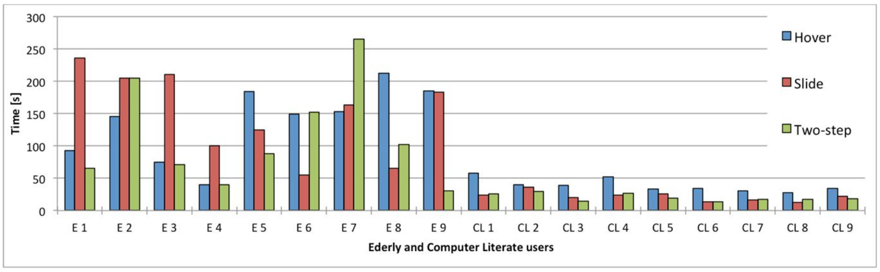
The study focused on testing the UI selection methods as well as comparing computer-literate and elderly users. As a test setup, CLUs were selected randomly from university students, with a median age of 26.6. All of them had experience with smartphones and computers. The elderly participants were selected based on their need for assistance, their MMSE score and their permanent residence in a care home (or a minimum stay of six months in care). The median age of the elderly users was 89.1. None of the elderly participants had used smartphones with a touch screen or any type of tablet device. Only two elderly users had some experience with computers, one for work and one for writing at home. Five additional elderly participants willing to be tested had to be excluded due to significantly deteriorated physical (eyesight) or cognitive abilities (moderate dementia). Before the tests, the system's main purpose as an assistive tool for the elderly was explained, and the large projection area on the table was identified as the usable interaction area. Finger pointing and the paddle were explained as the input interaction tools. No other guidance was given to the users, in order to gather as much data as possible on their initial learning experiences with the UI.

**Fig. 37. Elderly (E1–9, left) and computer-literate (CL1–9, right) user comparison**




Two calling tasks to two different receivers were given to all participants. Each task was tested once with each of the three interaction methods, as shown in Figure 35a–c. The methods were counterbalanced within subjects to avoid interaction-learning bias. A comparison between the computer -literate and elderly users was done to evaluate the performance, speed, satisfaction and preferred interaction method between and am ong the groups. All of the test sessions in these user studies were recorded on video, and the interaction data (time, error count and icons touched) was logged automatically by the system for analysis. Questionnaires (Appendix 2) measuring the user intera ction satisfaction and post-experiment interviews for overall experience were conducted and analysed (Appendix 5). The 7-point Likert scale was changed to a 5-point version because in the post-test questionnaire, the elderly showed problems with too many choices.

**Fig. 38. Total time spent completing methods between elderly (E1–9) and computer-literate**




**(CL1–9) users**

The three graphs, as shown in Figure 37, show the number of mistakes, non - registered presses and pieces of advice given to the users for all three meth ods, comparing the elderly (E1 –9) and the CLUs (CL1 –9). The hover method produced the fewest mistakes (9), less than half the number of mistakes (22) made with each of the other methods, the slide and the two -step method. Regarding completion time, Figure 38 shows that, on average, the elderly users took longer to perform the test, mainly due to more errors performed. The elderly users who had no or few mistakes, however, could perform at the same speed as some of the CLUs**.** When using the hover method, none of the elderly users consistently hovered on top of the icon long enough to register a selection. Each elderly user made this mistake at least once. CLUs appeared to notice and understand the time progress bar, so only a single CLU made this mistake and i mmediately corrected it without instructions. This observation suggests that the current progress bar design was not understandable for the elderly users. In addition to being slower and making more mistakes, elderly users were somewhat uncertain of their own abilities. If they made a mistake, they paused or stopped performing the selection or the whole task, and they got easily confused about how to proceed. Low confidence in their abilities to solve simple problems or to recover from a mistake was apparent. The CLUs, on the other hand, tried to recover from errors by experimenting with how the UI worked. The interface use metaphor was familiar to the CLUs due to its being close to existing touch -screen device methods. The CLUs understood the use after thei r first attempt with the system, which led to good performance with other methods. Elderly users, on the other hand, showed difficulties in understanding the similarity of the tasks, and their performance did not improve significantly when a new selection method, with the same interface use metaphor, was presented to them.

There was a great difference in the total time spent on tasks by the elderly users compared to the time spent by the CLUs. This can be explained by looking at the number of mistakes made. For the elderly users, recovering from mistakes took a lot of time, in the form of backtracking in the menus. Mistakes often led to verbal self-doubt, for example, saying, "Am I doing this wrong?" Statements like this seemed to further worsen the self-confidence issues of the elderly users. As observed in our tests, lack of confidence is a common problem, and this is discussed in several related works. The elderly users in our tests had very little experience with technology use in general, due to their advanced age, which might explain some of the results. When compared to the CLUs, who learned the use metaphor of the system quickly after using the system a few times, the elderly users had difficulties with the use metaphor. The CLUs were likely taking advantage of their existing knowledge base from the use of smartphones and tablets. This knowledge is not common for the elderly of today. The calling task used people's faces and names as call target icons, and this approach was somewhat unfamiliar to the elderly people. This could explain why they had learning difficulties even when the calling task remained the same during the whole test. The elderly clearly need reassurance that they can use technology, and support while using it. Overall, the elderly users could manipulate the UI well if they did not make any mistakes or encounter an error from the system side, as recovering from mistakes took time and confused them. Thus, the number of mistakes and errors should be minimized, and additional support should be provided when needed. If we look at how moderate AD affected the tests, again it resulted in the users having trouble understanding the task at hand. Many of them needed reminders about the task as they would forget where they were and what they were doing. This indicated that personal assistance from a caretaker is needed for these individuals. As such, technology presented in this paper is not yet suitable for them. Regarding users with mild to moderate AD, the tests were much more suitable. They could perform adequately, as long as they had time to react to the UI and to understand the given tasks.

In summary, a fixed projection system seems feasible as an assistive system for the elderly, as these elderly users could successfully navigate the UI even with the mistakes they made while using it. The hover selection method showed promise as the preferred method for the elderly, as the non-instantaneous nature of the method was seen as an advantage. This enabled the users to take their time with the interface before a selection was made, producing fewer mistakes than when using the other two methods. We could also see that various ageing-related motor skill problems were not a factor when using the projection system. The projection was large enough to offer easy-to-manipulate icons even for users with severe arthritis or hand tremors.

### *5.4.4 Medication reminder test*

Chapter 5.3.1 discussed kitchen assistance that aimed to help elderly people remotely in a cooking task. To test how a similar sequential task could work with a projection system, the medication task first presented in Chapter 5.4.2 was re-designed and tested. This section explains the reasoning and approach for the test, how it was conducted and how the evaluation was done.

Testing a common task with steps that the elderly need to follow through is needed in a supportive system. The initial medication reminder had an unintuitive UI and was prone to accidental selections. For this iteration, the UI was changed to incorporate more space, and all of the information was displayed in the user's field of focus. The number of interactive icons was reduced for each step so that the user's focus would be solely on the step at hand. Additional guiding elements for placing items on the table were added. As the hover method was the most reliable and had the fewest number of errors in the previous test, it was chosen as the selection method for this test. The test involved 10 elderly participants, six female and four male, with the average age being 84.5. Most of the participants lived permanently in the two care homes, and two participants were on a six-month care interval. Three of the elderly people initially chosen for the tests were excluded due to physical (eyesight) or mental (severe AD) problems. Two of the participants had mild AD, and one had both moderate AD and early Parkinson's disease. These two diseases present problems in cognitive and fine motor skills. There were also an additional four cases with slight motor skill problems due to old age, presented in tremors of the hand from or arthritis. Two participants had AAMI that slightly affected their cognitive skills. All participants took medication from at least twice to at most seven times per day, and four used a medication dosette with time and weekday markings to help remind him which medication to take and when. From a technology point of view, two participants had some experience on tablets, smartphones and computers, and an additional four users had some experience with desktop computers. During the test, the participants were recorded and interviewed, and a questionnaire (Appendix 3) on the experiments was conducted.As a test setup, the users were told to use the finger with the ring as the only input tool and to follow the on-table displayed instruction to take their medication. Additional items used were a glass of water and a medication dosette, both having markers on them to enable additional assistive projection related to them. In total, the system tracked four objects simultaneously and in real time: the ring, the glass, the pillbox and the menu initialization card. The medication task consisted of six instructional steps the user had to follow. The user verified each step with a confirmation press.

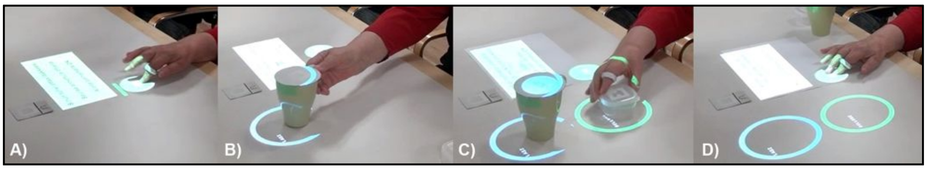



**Fig. 39. Demonstration of four steps in the medication task.**

The steps shown to the user are shown below with the corresponding references to the figures:

1. You should take your medication. Follow the on -screen instructions. Start by pressing OK. (Fig. 39A)
2. Set a glass of water on the area marked by a blue circle, and press OK. (Fig. 39B)
3. Set the pillbox on the area marked by a green circle, and press OK. (Fig. 39C)
4. Take two pills from the pillbox and drink a glass of water, then press OK.
5. Put the glass of water and the pillbox away, and press OK. (Fig. 39D)
6. Your medication task is complete. Finish by pressing OK.

The total number of concrete actions needed to complete the task was 11, and the users were not given any time limit for the task. Time reserved for the test for each person was limited to one hour, including the pre - and post-test interviews.

Based on the number of mistakes, the fluency results of the UI were *non-intuitive* (4 users), *semi-intuitive* (3 users) and *fluent* (3 users). The system had three users who showed the system to be intuitive for them from start to finish and who also had the fastest times for manipulating the system. Three users who had initial problems with the system presses could be classified as semi -intuitive. Both assumed that the selection of an icon would be immediate, and they had to learn that the selection took a second to be registered. After learning this, the users had no problems with the system. This is a different result compared to the previous calling test, where the users had little confidence in their skills and often had trouble with interaction and the use metaphor. There was an outlier user who took a total of ten minutes to complete the test, which was more than double compared to other participants. The explanation was that the user had difficulties in concentrating on the task at hand. As the user's concentration was low, he had to be advised more than the others, but he made no mistakes while using the UI. Of the computer-experienced users, the one with mild AD (MMSE 26/30) was one of the fluent users, while another user with mild AD (MMSE 22/30) was slower. The differences between them in the data involved non-registered presses. Subjectively, I observed that the difference was in their attitudes towards using technology; while one wanted to use it, the other did not want to use an assistive device and often gave up trying during the task. This indicates how important technology acceptance is and how it should be emphasized more, but as a subjective result, it is only a suggestion for future work. The users made an average of 1.25 mistakes, among which there were many non-registered presses for OK (31). The single-second-long selection time explains the non-registered counts, and these confused users when they could not advance as expected. However, this single-second selection time reduced the number of accidental presses. One solution would be to have a depth-sensor-based tapping method, which could differentiate between intended and unintended taps on the table.

Eight participants were able to complete the medication task from start to finish, and two users failed. Between these two, one managed to finish the task when retested but was counted as a failure, due to an excessive need for guidance. The other failed participant had an MMSE score of 15/30, which indicates moderate dementia, and also had Parkinson's disease, which affects thinking and motor functions. This exceeded our restrictions for the intended target user, but the person was still tested as a preliminary analysis of a more severe dementia user using the interface. They had great difficulties in understanding what they were doing and made five times more errors than the average user, even when instructed at every step. A recurring problem in the test for some of the users was that they did not read the instructions fully and proceeded to continue in their task regardless of what the system asked them to do. Video observations revealed that the users did not focus on the full information when it was split with a photo in between (Fig. 40). The text reads as follows "Place a pillbox on the table marked with a green circle. (PICTURE) When you are finished, press OK to continue". The upper sentence guides the user to place the pillbox on the table, and the lower sentence guides the user to press OK when finished. Some users ignored either the upper or the lower sentence.


**Fig. 40. A pillbox task guidance, with a photo, to set the pillbox down on the marked spot.**

The improved ring-detection method resulted in less user frustration towards the interface interaction, but a slightly longer selection time, in turn resulting in some frustration with use. Overlaying information on the table and onto objects helped the users to understand item handling more clearly, but for some elderly users, the step-by-step instructions for every move were described as condescending. Customizing the selection time with only the needed steps for each user could be a better solution. Some users recommended the use of this system for users with more severe memory impairment, considering the detailed guidance, but as the system was difficult for a user with moderate dementia, additional design is needed. The use of the system was also recommended in cases where the user is alone and would otherwise need some form of help from the caretakers.

### 5.5 User studies results summary

The material gathered from the user studies is mostly qualitative due to the relatively small sample population, so the results are mainly implications based on the analysis. The initial wearable ProCam system was first designed to be used with a language-based UI. This design was changed due to low affordance issues from paper prototyping, even with CLUs, but mostly due to other notable difficulties of a technical nature. Reliably detecting the user's tapping for interaction purposes proved to be difficult when using a wearable projector and accelerometer. There were also projected image stability issues while using low-contrast projection. Thus, presenting a wearable ProCam solution for people with moderate dementia was not feasible. This led to changes in the system and UI designs, and memory impairment requirements were refined to accommodate the needs of the elderly more precisely. A fixed projection system was introduced as a more robust test environment for UI design elements. The system menu layout was iterated through several designs into an arched layout with a simple two-step selection system. Additionally, a medication task was tested to see if the system was feasible for a concrete task needing assistance. The medication task proved to be difficult with the first iteration of the system UI. In the pilot tests, the CLUs had no problems with the selection method, but it proved to be unreliable and error-prone for the elderly users. Thus, the system interaction methods were redesigned and tested. The new and old methods were compared for preference between elderly and CLUs. The most promising one was a hover method, as the elderly users felt more comfortable with it. This was due to the simplicity of the method. Lastly, the medication task was re-tested with the hover method and proved reliable for elderly use. It showed that assisting in a concrete task with AR projection is advantageous. More testing is needed before quantitative conclusions can be made.

# 6 Discussion

This chapter discusses the findings of the research and what they mean in general for projection systems and the elderly. The research questions presented in the beginning of this work are answered and evaluated for how well they match the research work done. The implications that this work has on theoretical and methodological levels are discussed in their own sub-chapters.

## 6.1 Purpose of the study

This work explored the possibilities of using a projection system and its UI solution as a suitable system for providing assistance to the elderly living at home. Extending the solution into a home environment where aid devices can be replaced or enhanced with technology could provide updateable features and in turn would better correspond to the changing needs of the elderly. Despite the limited research in this particular area, the results show that AR and projections in the environment are usable for assistance if several points are taken into account in the design and implementation of the system and its features.

## 6.2 Research results

Chapter 1.7 collected the original publications (papers I-V) used in this work from the viewpoint of their purpose and findings. In Table 8, the papers were presented from the point of view of the summary of their findings. How the findings of each paper relate to the research questions is answered individually below. Notable for the papers is the change in target users from those with moderate dementia to a more elderly-focused situation. During the research for this work, it became clear that to create a system suitable for users who have dementia, extensive research would need to be conducted, combined with observations and interviews with caretakers, family members and the elderly users themselves. This is the only way to understand the specific usability issues of the elderly, and must be done before any such systems can be tested and offered to elderly people with dementia.

**Table 8. Structure of the original publications with respect to purpose, findings, UIs and target users**

| No | Purpose | Findings | Platform | Target user |
|---|---|---|---|---|
| I | Offer a UI for a wearable device | Initial design of an elderly-focused UI interface showed promise as an assistive tool for dementia | Sentence-based UI, Wearable | Moderate dementia |
| II | Test feasibility of user input method of the wearable assistive device. Automated process recognition. | Tests showed that remote assistance would be more helpful than totally automated process assistance. Additionally, wearable projector showed technical limitations that might hinder user testing. | Sentence-based UI, Wearable | Moderate dementia |
| III | Search for assistive technology requirements | UI design guidelines were extended to provide a more accurate technical solution. Lowering the level of dementia of the target user allowed for a more complex UI design. | Icon UI, Wearable | Mild, moderate dementia |
| IV | Observe elderly executing a sequential task (making coffee) in a real environment. Design a visual prompting system. | Sequential tasks were observed for problem points that showed promise for remote assistance with a projection system for finding items or guiding tasks. A fixed projection system was discovered as a more stable system for testing UI interaction techniques. | Prompt visual icons for task guidance, Fixed tabletop | Mild dementia |
| V | Design a tabletop system and a UI for the elderly. Test and evaluate performance with actual elderly and compare with computer-literate users (CLUs) | A fixed projection system was shown as a stable test bed. The hover method was suitable due to slower selection speed and fewer errors. Recovery from errors is more difficult for the elderly and may stop the entire process. Implications of the system are suitable for sequential tasks. The need to adapt to different users' needs was implied based on user tests | Elderly guidance and interaction, Fixed tabletop | The elderly and mild dementia |

Before answering the main research question, the process will be reversed and the sub-questions will be answered to shed more light on the main question. The questions are presented as follows, and their answers are discussed below.

*SQ 1.1: What projection type would be suitable for the elderly at home?*

A wearable system is not yet feasible for elderly assistance, as the technology is not mature enough. This was indicated after the user test (II) showed some technical limitations regarding the stability of the projected image and the selection technique. The image that was displayed on the wall proved to be small, so the UI would be not significantly larger than that of a tablet device when the interaction had to be done within a hands reach of the UI. As the elderly of today are novice users of technology, the system should be designed to be as robust as possible. It must be unobtrusive, reliable and easy to use. A system with a fixed installation removes the technical limitations presented by a wearable system, such as AR glasses or HMDs, and answers the request of the elderly not to have to carry anything (Ceccacci et al. 2012, Kurz et al. 2014). Wearable systems often aim very far into the future and employ UIs with unproven interaction methods for the elderly, such as the systems presented by Mistry (2009) and Tomitsch et al. (2012). A projection displayed onto an environment such as a table or wall enables the use of direct interaction methods, a more familiar approach for the elderly (V).

*SQ 1.2: What requirements are there for a projection system UI for the elderly? Are there different requirements for a projection system for the elderly compared to CLUs?*

Adapting to the user's needs is vital for a suitable system. When comparing computer-literate and elderly users, there are different existing knowledge bases between the two groups. Currently, the elderly population uses more conventional ways to interact (Akatsu et al. 2007), and thus their approach to the use of new devices is based on this metaphor. Research has shown that elderly people learn more slowly (Kelley & Charness 1995) and move more slowly (Hawthorn 2000) than their younger counterparts, so the designs created for them should reflect this knowledge. AR is a new way of offering technology for the elderly, but the use metaphor of the system can be designed in a way that is understandable for an elderly user, as discussed in (V) and supported by the touch-based interaction research done by Piper et al. (2010). As an example, pointing is a normal direct interaction in any use case, so using this familiar approach based on previous knowledge is easier to understand for a new user. Indirect manipulation is cognitively difficult for the elderly to understand (McLaughlin et al. 2009), a problem that younger users do not experience. Thus, a more straightforward and direct approach would produce better results than designing a complex but more versatile system that is usable for CLUs. However, as individual users have different preferences and skill levels, as pointed out in Mynatt et al. (2000), the system interaction should be customizable. Designers and researchers should take advantage of observation and interview opportunities before creating a system as a solution. Caretakers and family members have valuable information that can be used in the design process in the form of knowledge of problematic activities needing assistance. This is also confirmed in observations from previous studies (Månsson et al. 2008), which stated that interviewing and observing people with dementia is important. Physical changes present several needs that are also discussed extensively in the literature regarding eyesight, motor skills and hearing, but as a general rule, it is better for the iconography and manipulation elements of the UI to be large and represented with great contrast (Hawthorn 2007), as confirmed by Fisk et al. (2012). A hands-on approach helps in understanding the daily problems of a person with dementia, and it helps in gathering problems that might not be noticed if only informal caretakers collect the data. Also, a user-centred approach in human-computer interaction is crucial, because design requirements might otherwise be inaccurate. The systems built for this work also confirm the previous statements that direct interaction techniques are useful, and motor skill problems can be overcome with direct interaction and a larger interaction surface design. Memory can also be supported with direct interaction, as the projection system showed fewer learning requirements. In addition, the slower input method, slightly disliked by the CLUs, was confirmed to be more suitable for the elderly.

*SQ 1.3: What factors do UI designers need to take into account when choosing the selection methods for a ProCam system for elderly users?*

From a technical point of view, the elderly need to be shown what the actual projection area is. The projection should always be provided in such a way that the user does not block it accidentally. An adaptive approach would be a suitable solution. It is essential to reduce mistakes made due to a change in interaction, as the elderly have a slight tendency to get further confused by any errors. Intuitiveness, stability and recovery should always be a priority. As briefly discussed in sub-questions 1.1 and 1.2, the direct interaction method is more suitable for new users; thus, a recommendation would be to use that as the first approach for any implementation. As vision and motor skills decline with old age (Ketcham et al. 2001, LaLomia & Sidowski 1993), direct methods that incorporate larger interfaces with bigger icons should be used, and the user should be given time to use the interface, since motor skills also affect their use. A direct method also requires less learning of a new use metaphor. As memory functions decline with old age, the use of associative memory for learning is affected (Birren & Schaie 2001), which in turn affects how inputs are associated with outputs (Umemuro & Shirokane 2003). Similar results were also found by Piper et al. (2010), although from a surface computing point of view. However, for a person with dementia, this study cannot offer clear answers, as the results are not sufficient and are relatively untested. A more detailed study focusing only on users with dementia is required. As interaction methods are related to existing knowledge, future elderly users are more likely to be able to use different methods compared to the less technology-oriented elderly of today, as technology skills adapt over time (Akatsu et al. 2007).

*SQ 1.4: Is a projection system suitable for supporting a correct execution of a sequenced task such as medication intake?*

The user tests done for this work show partial success in offering sequential support in a medication task, but they cannot be clearly verified (V). Note that the medication intake task itself was notably uninteresting for the elderly participants, as it is something they have to perform many times per day. As a suggestion, instead of testing a system with a task that is common and uneventful, the task chosen should be of some interest. Using this approach and masking the use of the system and the features with a desirable task should be met with test subjects with less technology- or task-resistance, and it might even result in intermittently getting more elderly people to participate through recommendations. This argument is supported by Eisma et al. (2004) and is also found in the study by Umemuro & Shirokane (2003), where Japanese elderly computer users' positive attitudes towards technology affected their will to use it in the long term. The tests for this work showed that the given instructions posed some problems in that the users skipped some steps without reading them fully. Similar problems were encountered by Ju et al (2001). A detailed review revealed that this situation occurred when the instructions were broken up by a photo of the object to be used. The object in the photo cut the guiding sentence in two, so the elderly users skipped reading either the lower or upper part of the text and moved forward. As a suggestion, any text elements and pictures used should be separate, so that they do not affect the reading of any sentences. Contrary to Molyneaux & Gellersen (2009), who suggested that projecting computer images next to a tracked object instead of on top might confuse the user, the user test done for this work showed no correlation in this respect. The elderly people tested could understand the difference between the guiding informa tion and the related object.

*SQ 1.5: What physical assistive devices useful for the elderly, such as medication dispensers, would be appropriate to virtualize using projection technology?*

Table 9 presents a selection of currently used aid devices, divi ded according to the type of assistance offered. Comparisons can be made to existing projection systems so that the suitable tasks for assistance can be collected. Many if not all of the reminder functions could be used in the system developed for this wor k. A projection can help in phone dialling by displaying the photo of the caller, as was also done in the user tests of the system. Any large -sized display can also be supported, such as a calendar, reminder notes or a photo frame. Table 9 also tabulates devices that assist the user in a task, such as guides implemented on a coffee machine, a dishwasher having guiding magnets with instructions for the user to either empty, wash or fill the machine or guides for when to take medication, such as an alarm in a wristwatch or a medication dispenser. These guides can be replaced or enhanced fairly easily with the UIs presented in this system and with most of the systems presented in the related works, the issue being how easy and reliable the systems are for the e lderly to use. Not all of the tasks presented in Table 9 are replaceable or feasible to replace, and most of these are related to the safety of the user. As examples, the key holder worn around the neck is not a device that should be replaced, but the user can be reminded to take it with them when they leave their house. A GPS locator that the user carries with them offers functionality that is not possible on a projection system. In addition, there is no need to replace safety switches on the kitchen stove with a projection system, as the physical timer 's goal is to ensure the safety of the user. Only connectivity from the switches to a general alarm system would be advisable. It is noteworthy that many of these can work with the system and be interoperable . A holistic and more homogenous AAL is clearly possible. Tasks and devices in Table 9 that could be replaced are marked with a (*). Often the tasks could be replaced with a simple projection, in such cases as a calendar, photo frame or guiding lights in a hallway. In other cases, the projection could add more features or guidance to the tasks, such as adding icons and input interaction for making a phone call with a regular phone. The user could be guided in the coffee -making process by overlaying informat ion onto the surrounding environment and objects, instead of attaching permanent guide stickers onto the machine itself.

**Table 9. Examples of cognition support systems. * = virtualizable**

| Assisted task | Type of assist | Installation |
|---|---|---|
| * Webpage for time management | Caretaker and elderly support | Movable |
| Electronic bed alarm to inform caretaker of user getting up | Caretaker support | Fixed |
| GPS-locator worn on waist | Caretaker support – Safety | Wearable |
| * Phone with quick dial, big icons or pictures of people | Communication assistance | Movable/Wear |
| * Simpler mobile phone | Communication assistance | Wearable |
| Key holder worn around the neck | General assistance | Wearable |
| Large size display wristwatch | General assistance | Wearable |
| Safety camera at front door | General assistance – Safety | Fixed |
| Safety switches on kitchen equipment | General assistance – Safety | Fixed |
| * Audio instructor device near exit | General reminder | Fixed |
| * Electronic calendar | General reminder | Fixed |
| * Guiding lights indoors | Navigation assistance – Safety | Fixed |
| * Talking photo frame | Person or situation memory reminder | Movable |
| * Alarm in multiple locations for calling family members | Remote support device | Movable |
| * Guide-implemented coffee maker | Task assistance | Fixed |
| * Dishwasher reminder magnets | Task reminder | Movable |
| * Electronic medication dispenser | Task reminder | Fixed |
| * Medication dispenser with calendar nearby | Task reminder | Fixed |
| * Notebook for memory | Task reminder | Wearable |
| * Paper calendar and reminder notes | Task reminder | Movable |
| * Reminder clock | Task reminder | Movable |
| * Wristwatch with medication alarm | Task reminder | Wearable |

Medication dispensers that take advantage of a wristwatch or an electronic calendar could be replaced by a single system that recognizes the time and the objects needed to do the task; any guiding steps could be added to the task, and family members could be informed. On a general level, any caretaker -supported task could benefit from sharing data related to the well -being of the elderly person on some level. To know that everything is OK is often enough for family members. Task reminders are the most logic al replacement or enhancement tasks, but most useful are the tasks that presently need assistance either with notes, guides or communication tools. Enlarging many of the features of a physical device could ease the use of existing devices. Lastly, many of the fixed devices such as photos or multi-located alarms could be made dynamic and movable by digitizing the same functionality, so the possibilities for virtualization are various.

The answered sub-questions form an overall picture of the research done, after which the main research question can be answered. The main question was presented as follows:

*MQ: What are the improved ways to construct and validate a UI for the elderly using an AR projection system?*

AR is new technology for the elderly, so to offer it as a system for the elderly, several viewpoints should be taken into account. As pointed out in the sub-questions, first, the methods of how to offer a UI must be decided. A simple and direct method is the most suitable for the elderly. Often new AR solutions rely on more complex approaches or try to implement old methods unsuitable for AR (Beardsley et al. 2005, Choi & Kim 2013). A simpler method would take into account novice and elderly users (Chin-Yang Lin & Yi-Bin Lin 2013, Harrison et al. 2011) while still being effective for CLUs. Creating a system for the elderly or for people with dementia requires extensive knowledge of system design, the elderly and dementia-related diseases. For this reason, a solution is needed where observations and interviews are conducted with the end users and with the individuals who take care of them. Relying on documentation and research done from afar does not create experts. Instead, real involvement with the elderly helps more when designing a new system, so observation is vital for creating a suitable system. Family members are often unknowingly the experts with respect to a family member with dementia and can offer insight into the life of that individual. During the study, each visit to the care homes in Finland proved fruitful for observations of the environments and the users. Preliminary observations from care homes situated in Tangoen, Japan, also showed several areas that could be improved with technology use. These observations underline the need for hands-on experiences.

Users' existing knowledge affects their use of devices, and taking advantage of this is the only logical approach in designing systems for future elderly users. It should be noted that as dementia symptoms progress and affect memory more deeply (Birren & Schaie 2001), designing and testing should not be done using traditional methods, as these users do not function like healthy individuals.

The errors and bugs in a system affect the desirability of the system, so it is imperative that a robust system is tested instead of a quick prototype when interacting with the elderly. The elderly have less tolerance for systems that have errors or are difficult to use. This might lead to cancelation of the test or to inaccurate research results affected by disinterest towards the test or the system. Additionally, no matter how precisely the tests or user interactions are designed, there will be cases when the user interacts with the system in an unpredictable way, or when the system has limitations that are not taken into account in the design. Thus, alternative interaction methods should be developed, as no two users are alike. Methods should take into account worst-case scenarios, so that an alternative solution for these users can be offered. Based on elderly and their caretaking personnel interviews, there is a need for a more thorough assessment of user needs validation. Studies suggest that activating the elderly and enabling easy communication for the user might create a feeling of security, both for the elderly and for their family members. Discussions with medical staff have brought out some views on ethical sensitivity regarding the use of systems that track users' every movement, so the information stored by the system has to be secure at all times and accessible only by those with sufficient privileges. Offering a system for testing with features that are interesting to the elderly would be more suitable, as making a call or taking medication are not very engaging tasks. Additionally, measuring the capabilities of a UI was done with questionnaires, and there were some limitations with this method. The questions should be formulated clearly to avoid any confusion, as, in the case of this study, the questions regarding usability often needed clarification. However, there are no clear ways of expressing what interface actions or elements mean, so it is recommended to use assistive photos and explain each point or to use alternative measures of inquiry. The number of questions has to be limited to the capability of the elderly user, because the asking of even a limited set of questions was considered stressful by some of the elderly participants.

Regarding the reproducibility of the research, it is possible to create a similar system based on the original publications and the implementations presented here, but the interaction methods need to be tweaked to each situation separately. However, the end results should be fairly close to the original system. But as a recommendation, additions to the interaction method should be made instead of following the system design and implementation exactly. Using a stereoscopic camera solution or using a depth camera for detecting interactions in three dimensions would be more suitable. Replacing the camera used with one of a higher resolution is already possible, which would enable the detection of markers from a much further distance while the rest of the system could remain the same. Repeatability of the results is possible based on the recurring issues that the elderly have with technology use and the innate and learned skills they possess.

The technical solution of this study can be considered as a proof-of-concept, as there are many AR systems that offer reliable interaction detection methods. One example is the input detection method, which relies on using an IR-camera tracking an input ring. This is in contrast to the elderly requesting a system where they do not need to wear or carry anything. However, the ring solution is used to demonstrate that tabletop interaction is a feasible method and that other ProCam methods can be used to replace the need for a ring in improved iterations. An example of this is the OmniTouch system by Harrison et al. (2011), which uses a depth camera to track the user's hands to accomplish device-free interaction. Although OmniTouch is a wearable device, the solution it uses can be implemented in a fixed-device solution. The end product of our work is thus an approximation of the wanted features and functionality created with usable methods available at the time. The tabletop solution is also intended for indoor use at home and would not work as an assistive technology outside, so all of the features were chosen with this approach in mind. The system itself is cost-effective, as it can implement many of the currently used aid device features. Additionally, implementing a form of context awareness for the system would reduce the need for UI elements, as not all of the functions are needed in each situation.

Even if the solution presented is a fixed installation and there are some negative attitudes towards wearing or carrying devices, we argue that people are becoming more willing to carry technology, so the use of a wearable assistive device in the future is not improbable. The elderly of today do not have the same skillset as will the elderly of the future, so adjustments for the device requirements have to be made regardless of the results presented in this work.

Privacy and ethics are an important part of any technology discussion, especially when using a camera capable of monitoring an elderly person at home. This study does not discuss such issues in detail, but our solution uses an IR-camera only to detect objects and would not see the user unless specifically switched to RGB mode. So any ethical issues regarding the use of a monitoring camera are not relevant. In case of user emergencies, the camera RGB mode could in theory be turned on, but this feature was not implemented. Secondly, the focus of the work is on offering assistance with a UI, and it was designed to find usability issues and not study ethical issues extensively. However , the privacy issue when using cameras in practical applications, such as smart care homes of the future, is a real problem and a practical application is needed. The existing and arguably better user interaction detection methods rely heavily on the use o f depth cameras or live camera feeds. While these might be better for interaction purposes, they are worse for privacy.

### 6.3 Research contributions

This empirical research offers insight into how design processes should be conducted when the target users are el derly people with cognitive and physical limitations. The projective system offered to the users brings out clear limitations to the features that an assistive device can offer, so the design should be limited and adapted to the users' needs and skill level. The exploratory research offers a quantitative analysis of the data based on small sample sizes, but the users of the system were actual elderly people, many with some form of dementia, so the results are promising. For quantitative purposes, a new stud y should be conducted with a larger user base. Currently, results and knowledge of the existing problems of the elderly have shown that fully automated systems are very difficult to create and use. The design requires a level of certainty that the user and the caretakers can trust the system to perform as expected because the repercussion of system failure are quite serious e.g when taking medication or in emergencies. The work has ascertained that while direct interaction techniques are currently effective , elderly users' skill levels will change over time, which in turn will enable more complex designs for a UI. However, some design limitations will still remain, for example, physical changes in the form of the decline of motor skills. Also, learning will continue to be a problem point, so designers of ICT for the elderly should always take into account the least skilled users in the design process. The limitations presented in this research also shed light on the issues of different interaction methods. As a proof-of-concept, the proposed system works, but to acquire extensive data, a more robust system with more features should be tested.

### 6.4 Theoretical implications

There are extensive studies that focus on existing technology use and designs for the elderly, but few studies discuss future technologies and even fewer focus on the elderly with dementia. This work supports many of the current research implications from a theoretical point of view regarding elderly design, and it brings new insight into how projections can add new elements into an elderly user's home environment. The use of direct interaction benefits is verified through testing and observation. More thorough investigation on how current aid devices could be replaced is suggested, as many of the features in present devices could be handled with a single smart device in the elderly user's home. The work does not offer a solution for people with dementia, but it has implications for a technological system capable of assisting users in sequential tasks. The existing research shows that designing assistive devices for people with dementia requires extensive knowledge for researchers, which should be gathered from experts in the field as well as from caretakers and family members close to the intended target users. These results have created knowledge base additions for the elderly design guidelines.

## 6.5 Methodological implications

The use of Design Science alone for this work was not fully suitable, as the research area required a more flexible approach. The problems might relate to trying to implement the method in a sensitive user environment. As a future methodological approach, adding a long ethnographic study to understand the Japanese elderly in more detail would offer ways to understand how the prototype system and its features should be adapted to Japanese needs. As a result, the artefacts for Design Science would be more accurate. The work at many points had to be re-evaluated, as the solutions were often trial-and-error approaches to unknown problems. AR is advanced technology, and the kind of technology that can assist with memory problems is an untested area. Many of the aspects could not be anticipated, resulting in difficulties and extensive changes in the process. The research topic was also a bit too large for the scope of the project. The focus has to be either on the elderly with normal cognition for their age or on those with dementia. Solutions for the former group can be larger and can focus on the user having more capabilities, while the latter group requires solutions that are more precise and limited. But in order to help people with dementia, the basics of the problems of all elderly people should be understood and tested. This approach of first helping the elderly with normal cognition and then the elderly with dementia would be more effective.

# 7 Conclusions

This work offered an extensive look at what problem points designers have to take into account when offering technology to the elderly. The use of AR and the requirements of using such technologies for the elderly are presented as recommendations for future system designs. Notably, the current system is not suitable for users with more severe forms of dementia, as these users need a more refined solution that is not possible with the current level of features. This study showed that currently, the design approach is more suitable for normal or slightly memory-impaired elderly users. As an overarching experience, results show that a good AAL interaction solution can be developed if the system can adapt to each user's needs and relies on direct and simple interaction experiences.

Regarding the interaction methods, wearable and fixed projection systems are used to manage the display size problem and to demonstrate the simplified UI interaction designs. For gerontechnology, this work verified many of the existing theories and views on how technology should be designed, but it extended to projected UIs. One suggestion for other researchers is to use direct interaction techniques as the preferred approach, as state-of-the-art technology often focuses on complex approaches unsuitable for novice users. The current limitation of technologies regarding wearable systems showed that they are not yet mature enough to offer reliable interaction solutions to the elderly, but as technology progresses, wearable solutions might become feasible. By following the suggested features and approaches for the design of this study, an AAL-focused researcher should most likely avoid the biggest pitfalls in their design. Researchers focusing on other fields but who are still human-computer interaction-focused should take advantage of this work to gather data on how UIs of the future should be designed as individual skills degrade over time. It is necessary to research how device manipulation can be improved and extended upon, but at the same, there should be a focus on finding out how a novice user sees these systems for the first time, as with the memory-impaired elderly, this might be their everyday experience for several years.

As such, the systems presented in this work are not innovations that completely change the way individuals look at interface design or devices for the elderly. Instead, the work offers insights into the process of UI design and demonstrates systems from a holistic viewpoint. Many of the theories for a touch-screen device can be used when designing a projection system, but the use of augmentation presents new areas not yet well researched. The use of real-time tracked objects, guidance and interaction brings new challenges and research theories on offering assistance for the elderly.

### 7.1 Limitations and future work

The system presented in this work is not fully realized and does not possess all of the features that were initially designed and wished for by the elderly. The system was originally meant for people with dementia, but during design and testing, the features proved not mature enough for this particular user group, so the focus on dementia was not feasible. However, the results thus far imply that in the future, this focus could be possible; the current system can be improved to match the needs of people with dementia, since the underlying feature set requirements are now better known. This adjustment of the target user population was done because prior to any implementation of a system designed for the elderly, the designs should be evaluated or discussed with informal and formal caretakers in more detail. Conducting observations for a long period of time would be especially desirable for the researchers to understand the end users as clearly as possible. The assisted tasks require more extensive testing and refinement but showed a lot of promise regarding direct interaction use in AR. Object detection and manipulation research in particular show promise for future work. Detecting the objects makes it possible to assist the elderly in more ways, already demonstrated in the medication intake task incorporating multi-object detection. Our recommendation is to research the advantages of object overlay and how it would change UI interaction needs. Getting additional information proved useful in the medication task, but the test scenario itself, even though vital, seemed boring for the test participants. More engaging tasks based on the users' interests would most likely produce more willing participants. In turn, we argue that the tests could be more complex and longer if the task were more interesting. Elderly participants were also not readily available, which was the most limiting factor in this study. This also limited the amount of statistical data gathered from the tests.

Regarding other future research possibilities, there are areas that need studying. The features of existing aid devices can be combined into a single system and should be tested using long-term ethnological or case study approaches. Our recommendation is to use a multi-disciplinary research collaboration that can realize a total smart-home environment with other technological assistive features. Such an environment for the elderly could assist in imperative tasks in an actual home environment and could also gather data for research and design. These problems might be possible to overcome using a projective system that virtualizes the information for the elderly and the caretakers. Helping both the elderly and the people who take care of them is imperative to reduce the workload and stress of both parties. If we can achieve this goal with the help of technology, the result may be that the elderly can be more independent and productive members of today's society.

# 8 List of references


Akatsu H, Miki H & Hosono N (2007) Design Principles Based on Cognitive Aging. Proceedings of the 12th International Conference on Human - computer Interaction: Interaction Design and Usability. Berlin, Heidelberg, Springer-Verlag: 3-10.

Asano Y, Saito H, Sato H, Wang L, Gao Q & Rau PP (2007) Tips for designing mobile phone web pages for the elderly. In: Human -Computer Interaction. Interaction Design and Usability. , Springer: 675 -680.

Azuma RT (1997) A survey of augmented reality. Pr esence 6(4): 355-385.

Bakaev, M. (2008). Fitts' law for older adults: considering a factor of age. In Proceedings of the VIII Brazilian Symposium on Human Factors in Computing Systems (pp. 260-263). Sociedade Brasileira de Computação.

Beardsley P, Van Baar J, Raskar R & Forlines C (2005) Interaction using a handheld projector. Computer Graphics and Applications, IEEE 25(1): 39 - 43.

Benko H, Jota R & Wilson A (2012) MirageTable: freehand interaction on a projected augmented reality tabletop. Proceedings of th e SIGCHI conference on human factors in computing systems. , ACM: 199 -208.

Birren JE & Schaie KW (2001) Handbook of the psychology of aging. Gulf Professional Publishing.

Björneby S, Topo P & Holthe T (1999) Technology, Ethics and Dementia : *A guidebook on how to apply technology in dementia care*. Norway, Sem : Norwegian Centre for Dementia Research, INFO -banken.

Blackler A, Popovic V & Mahar D (2003) The nature of intuitive use of products: an experimental approach. Des Stud 24(6): 491 -506.

Bondy AS & Frost LA (1994) The picture exchange communication system. Focus on Autism and Other Developmental Disabilities 9(3): 1 -19.

Bouma H, Czaja SJ, Umemuro H, Rogers WA, Schulz R & Kurniawan SH (2004) Technology: A Means for Enhancing the Independence and Connectiv ity of Older People. CHI '04 Extended Abstracts on Human Factors in Computing Systems. New York, NY, USA, ACM: 1580 -1581.

Broady T, Chan A & Caputi P (2010) Comparison of older and younger adults' attitudes towards and abilities with computers: Implication s for training and learning. British Journal of Educational Technology 41(3): 473 -485.

Cahill S, Macijauskiene J, Nygård A, Faulkner J & Hagen I (2007) Technology in dementia care. Technology and Disability 19(2): 55 -60.

Ceccacci S, Germani M & Mengoni M (2012) User centred approach for home environment designing. Proceedings of the 5th International Conference on PErvasive Technologies Related to Assistive Environments. , ACM: 31.

Centers for Disease Control (CDC) (2013) The state of aging and health i n America 2013. Atlanta, GA: Centers for Disease Control and Prevention, US Department of Health and Human Services.

Charness N, Holley P, Feddon J & Jastrzembski T (2004) Light pen use and practice minimize age and hand performance differences in pointing tasks. Hum Factors 46(3): 373-384.

Charness N & Boot WR (2009) Aging and Information Technology Use: Potential and Barriers. Current Directions in Psychological Science 18(5): 253 -258.

Chin-Yang Lin & Yi-Bin Lin (2013) Projection-Based User Interface for Smart Home Environments. Computer Software and Applications Conference Workshops (COMPSACW), 2013 IEEE 37th Annual. : 546 -549.

Choi J & Kim GJ (2013) Usability of one-handed interaction methods for handheld projection-based augmented reality. Personal and ubiquitous computing 17(2): 399-409.

Cunningham C & Archibald C (2006) Supporting people with dementia in acute hospital settings. Nursing Standard 20(43): 51 -55.

Curry R, Tinoco MT, Wardle D & Britain G (2002) The use of information and communication technology (ICT) to support independent living for older and disabled people. Department of Health.

Eccles A (2010) Ethical Considerations Around the Implementation of Telecare Technologies. Journal of Technology in Human Services 28(1 -2): 44-59.

Eisma R, Dickinson A, Goodman J, Syme A, Tiwari L & Newell AF (2004) Early user involvement in the development of information technology-related products for older people. Universal Access in the Information Society 3(2): 131-140.

Eklund JM, Hansen TR, Sprinkle J & Sastry S (2005) Information Technology for Assisted Living at Home: building a wireless infrastructure for assisted living. Engineering in Medicine and Biology Society, 2005. IEEE-EMBS 2005. 27th Annual International Conference of the. : 3931 -3934.

English WK, Engelbart DC & Berman ML (1967) Display-selection techniques for text manipulation. Human Factors in Electronics, IEEE Transactions on (1): 5-15.

Ferri CP, Prince M, Brayne C, Brodaty H, Fratiglioni L, Ganguli M, Hall K, Hasegawa K, Hendrie H & Huang Y (2006) Global prevalence of dementia: a Delphi consensus study. The Lancet 366(9503): 2112 -2117.

Finland S (2007) Published 31 May 2007, Väestöennuste 2007 -2040 (population projection 2007-2040) [Homepage of Statistics Finland] .

Fisk AD, Rogers WA, Charness N, Czaja SJ & Sharit J (2012) Designing for older adults: Principles and creative human factors approaches. CRC press.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of experimental psychology*, *47*(6), 381.

Fleck S & Strasser W (2008) Smart Camera Based Monitoring System and Its Application to Assisted Living. Proceedings of the IEEE 96(10): 1698 -1714.

Folstein MF, Robins LN & Helzer JE (1983) The mini -mental state examination. Arch Gen Psychiatry 40(7): 812.

Fuglsang L (2005) IT and senior citizens: Using the Internet for empowering active citizenship. Science, Technology & Human Values 30(4): 468 -495.

Fussell SR, Setlock LD & Kraut RE (2003) Effects of head -mounted and scene-oriented video systems on remote collaboration on physical tasks. Proceedings of the SIGCHI conference on Human factors in computing systems. ACM: 513-520.

Gauthier S, Reisberg B, Zaudig M, Petersen RC, Ritchie K, Broich K, Belleville S, Brodaty H, Bennett D, Chertkow H, Cummings JL, de Leon M, Feldman H, Ganguli M, Hampel H, Scheltens P, Tierney MC, Whitehouse P & Winblad B (2006) Mild cognitive impairment. Lancet 367(9518): 1262 - 1270.

Goodman J & Eisma ASR (2003) Age-old Question(naire)s. in Proceedings of Include 2003. : 7-278.

Gulliksen J & Harker S (2004) The software accessibility of human -computer interfaces—ISO Technical Specification 16071. Universal Access in the Information Society 3(1): 6-16.

Hanson VL (2009) Age and Web Access: The Next Generation. Proceedings of the 2009 International Cross-Disciplinary Conference on Web Accessibililty (W4A). New York, NY, USA, ACM: 7 -15.

Harrison C, Benko H & Wilson AD (2011) OmniTouch: wearable multitouch interaction everywhere. Proceedings of the 24th annual ACM symposium on User interface software and technology. ACM: 441 -450.

Hawthorn D (1998a) Cognitive aging and human computer interface design. Computer Human Interaction Conference Proceedings. 1998 Australasian. : 270-280.

Hawthorn D (1998b) Psychophysical aging and human computer interface design. Computer Human Interaction Conference Proceedings. 1998 Australasian. : 281-291.

Hawthorn D (2000) Possible implications of aging for interface designers. Interacting with Computers 12(5): 507-528.

Hawthorn D (2007) Interface Design and Engagement with Older People. Behavaviour & Information Technology 26(4): 333-341.

Heidrich F, Golod I, Russell P & Ziefle M (2013) Device-free interaction in smart domestic environments. Proceedings of the 4th Augmented Human International Conference. ACM: 65-68.

Hestnes B, Heiestad S, Brooks P & Drageset L (2001) Real situations of wearable computers used for video conferencing and for terminal and network design. Wearable Computers, 2001. Proceedings. Fifth International Symposium on. IEEE: 85-93.

Hevner AR (2007) A three cycle view of design science research. Scandinavian journal of information systems 19(2): 4.

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

Hirdes JP, Poss JW & Curtin-Telegdi N (2008) The Method for Assigning Priority Levels (MAPLe): a new decision-support system for allocating home care resources. BMC medicine 6: 9-9.

Hoey J, Poupart P, von Bertoldi A, Craig T, Boutilier C & Mihailidis A (2010) Automated handwashing assistance for persons with dementia using video and a partially observable markov decision process. Computer Vision and Image Understanding 114(5): 503-519.

Jagacinski RJ, Liao M & Fayyad EA (1995) Generalized slowing in sinusoidal tracking by older adults. Psychology and Aging 10(1): 8.

Ju W, Hurwitz R, Judd T & Lee B (2001) CounterActive: an interactive cookbook for the kitchen counter. CHI'01 extended abstracts on Human factors in computing systems. ACM: 269-270.

Kelley CL & Charness N (1995) Issues in training older adults to use computers. Behaviour & Information Technology 14(2): 107-120.

Ketcham CJ, Stelmach GE, Birren J & Schaie K (2001) Age-related declines in motor control. Handbook of the psychology of aging 5: 313-348.

Khan DU, Siek KA, Meyers J, Haverhals LM, Cali S & Ross SE (2010) Designing a Personal Health Application for Older Adults to Manage Medications. Proceedings of the 1st ACM International Health Informatics Symposium. New York, NY, USA, ACM: 849-858.

Kleinberger T, Becker M, Ras E, Holzinger A & Muller P (2007) Ambient Intelligence in Assisted Living: Enable Elderly People to Handle Future Interfaces. Universal Access in Human-Computer Interaction.Ambient Interaction : 103-112.

Kraut RE, Miller MD & Siegel J (1996) Collaboration in performance of physical tasks: Effects on outcomes and communication. Proceedings of the 1996 ACM conference on Computer supported cooperative work. , ACM: 57 -66.

Kurata T, Sakata N, Kourogi M, Kuzuoka H & Billinghurst M (2004) Remote collaboration using a shoulder-worn active camera/laser. Wearable Computers, 2004. ISWC 2004. Eight International Symposium on. IEEE 1: 62-69.

Kurz D, Fedosov A, Diewald S, Guttier J, Geilhof B & Heuberger M (2014) [Poster] Towards mobile augmented reality for the elderly. Mixed and Augmented Reality (ISMAR), 2014 IEEE International Symposium on. IEEE: 275-276.

Kuzuoka H, Kosuge T & Tanaka M (1994) GestureCam: a video communication system for sympathetic remote collaboration. Proceedings of the 1994 ACM conference on Computer supported cooperative work. ACM: 35 -43.

Kylberg M, Löfqvist C, Horstmann V & Iwarsson S (2013) The use of assistive devices and change in use during the ageing process among very old Swedish people. Disability and Rehabilitation: Assistive Technology 8(1): 58-66.

LaLomia MJ & Sidowski JB (1993) Measurements of computer anxiety: A review. International Journal of Human - Computer Interaction 5(3): 239-266.

Lehtinen V, Näsänen J & Sarvas R (2009) A Little Silly and Empty-headed: Older Adults' Understandings of Social Networking Sites. Proceedings of the 23rd British HCI Group Annual Conference on People and Computers: Celebrating People and Technology. Swinton, UK, UK, British Computer Society: 45-54.

Lin C & Lin Y (2013) Projection-Based User Interface for Smart Home Environments. Computer Software and Applications Conference Workshops (COMPSACW), 2013 IEEE 37th Annual. IEEE: 546 -549.

Lobo A, Launer LJ, Fratiglioni L, Andersen K, Di Carlo A, Breteler MM, Copeland JR, Dartigues JF, Jagger C, Martinez -Lage J, Soininen H & Hofman A (2000) Prevalence of dementia and major subtypes in Europe: A collaborative study of population -based cohorts. Neurologic Diseases in the Elderly Research Group. N eurology 54(11 Suppl 5): S4 -9.

Mandell AM & Green RC (2011) Alzheimer's Disease. In: Anonymous The Handbook of Alzheimer's Disease and Other Dementias. Wiley -Blackwell: 1-91.

Månsson I, Hurnasti T & Topo P (2008) Apuvälineet ja dementia Pohjoismaissa: Muistia ja muita kognitiivisia toimintoja tukevat apuvälineet dementoituvan ihmisen arjessa: haastattelututkimus Suomesta, Islannista, Norjasta, Ruotsista ja Tanskasta.

Marcus A (2003) Universal, ubiquitous, user -interface design for the disabled and elderly. interactions 10(2): 23-27.

McLaughlin AC, Rogers WA & Fisk AD (2009) Using direct and indirect input devices: Attention demands and age -related differences. ACM Transactions on Computer-Human Interaction (TOCHI) 16(1): 2.

Mikkola K & Halonen R (2011) Nons ense'ICT perceived by the elderly. The European, Mediterranean & Middle Eastern Conference on Information Systems.

Milgram P & Kishino F (1994) A taxonomy of mixed reality visual displays. IEICE Transactions on Information Systems. 77(12): 1321 -1329.

Mistry P, Maes P & Chang L (2009) WUW -wear Ur world: a wearable gestural interface. CHI'09 extended abstracts on Human factors in computing systems. ACM: 4111-4116.

Molyneaux D & Gellersen H (2009) Projected interfaces: enabling serendipitous interaction with smart tangible objects. Proceedings of the 3rd International Conference on Tangible and Embedded Interaction. ACM: 385 -392.

Mordini E, Wright D, Wadhwa K, Hert P, Mantovani E, Thestrup J, Steendam G, D'Amico A & Vater I (2009) Senior Citizens and the E thics of e-Inclusion. Ethics and Information Technology. 11(3): 203 -220.

Morris MG & Venkatesh V (2000) Age differences in technology adaptation decisions: Implications for a changing work force. Personnel Psychology 53(2): 375-403.

Murata A & Iwase H (200 5) Usability of touch -panel interfaces for older adults. Human Factors and Ergonomics Society. 47(4): 767 -776.

Mynatt ED, Essa I & Rogers W (2000) Increasing the Opportunities for Aging in Place. Proceedings on the 2000 Conference on Universal Usability. New York, NY, USA, ACM: 65-71.

Niemelä H & Salminen K (2009) Kansallisten eläkestrategioiden muotoutuminen ja Euroopan unionin avoin koordinaatiomenetelmä.

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

Parkkinen P (2007) Riittääkö työvoima sosiaali -ja terveyspalveluihin. In Finnish, English summary). VATT discussion papers 433.

Pinhanez C (2001) The everywhere displays projector: A device to create ubiquitous graphical interfaces. Ubicomp 2001: Ubiquitous Computing. Springer: 315-331.

Piper AM, Campbell R & Hollan JD (2010) Exploring the accessibility and appeal of surface computing for older adult health care support. Proceedings of the sigchi conference on human factors in computing systems. ACM: 907-916.

Pirttilä T, Alhainen K, Erkinjuntti T, Koponen H, Puurunen M, Raivio M, Rosenvall A, Suhonen J & Vataja R (2006) Alzheimerin taudin diagnostiikka ja lääkehoito. Käypä Hoito-suositus. Duodecim 122(12): 1532-1544.

Rashidi P & Mihailidis A (2013) A survey on ambient-assisted living tools for older adults. IEEE journal of biomedical and health informatics 17(3) : 579-90.

Rogers WA & Czaja SJ (2004) CREATE: center for research and education on aging and technology enhancement. CHI'04 Extended Abstracts on Human Factors in Computing Systems. ACM: 1071-1072.

Statistics Bureau J (2007) Statistical handbook of Japan .

Tomitsch M, Mitchell MC & Weng H (2012) Designing for mobile interaction with augmented objects. Proceedings of the 2012 International Symposium on Pervasive Displays. ACM: 5.

Umemuro H & Shirokane Y (2003) Elderly Japanese computer users: assessing changes in usage, attitude, and skill transfer over a one-year period. Universal Access in the Information Society. 2(4): 305-314.

United Nations (2013) World Population Prospects: The 2012 Revision. Comprehensive Dataset in Excel. United Nations Publications.

Vaarama M, Luoma M, Siljander E & Meriläinen S (2010) 80 vuotta täyttäneiden koettu elämänlaatu. Suomalaisten hyvinvointi 2010 : 150.

Winblad I, Viramo P, Remes A, Manninen M & Jokelainen J (2010) Prevalence of dementia–a rising challenge among ageing popu lations. European Geriatric Medicine 1(6): 330-333 .

# Appendix 1 User test 1 – Questionnaire

*Translated from Finnish to English*

**User interface questionnaire**

Sex (Circle the answer) : male / female

Age: _____

Have you used a smartphone?

No ____ Yes _____

Have you used a computer?

No_____ Yes _____

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|---|
| 1. The UI was easy to use | **Disagree** | O | O | O | O | O | O | O | **Agree** |
| 2. I could effectively do my tasks with the system | **Disagree** | O | O | O | O | O | O | O | **Agree** |
| 3. I learned the use quickly | **Disagree** | O | O | O | O | O | O | O | **Agree** |
| 4. I did not understand the use of the system | **Disagree** | O | O | O | O | O | O | O | **Agree** |
| 5. Icon and text placement was logical | **Disagree** | O | O | O | O | O | O | O | **Agree** |
| 6. I liked using the system | **Disagree** | O | O | O | O | O | O | O | **Agree** |
| 7. I would recommend the use for my friends | **Disagree** | O | O | O | O | O | O | O | **Agree** |
| 8. The system was cumbersome to use | **Disagree** | O | O | O | O | O | O | O | **Agree** |
| 9. I believe most learn the use quickly | **Disagree** | O | O | O | O | O | O | O | **Agree** |
| 10. The UI was nice/comfortable to use | **Disagree** | O | O | O | O | O | O | O | **Agree** |
| 11. Calling with the system was easier than with a phone | **Disagree** | O | O | O | O | O | O | O | **Agree** |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |

What didn’t you like about the system?

What did you like about the system?

Any other notes about the system or the test itself?

**Thank you for your participation in the test!**

**Task 1:**

Make a call using the system to the person called XYZ ZYX.

**Task 2:**

Make a call using the system to the person called YZX YXZ.

**Task 3:**

Check how to take your medication today using the system.

# Appendix 2 User test 2 – Questionnaire

*Translated from Finnish to English*

**Questionnaire Finland** **(Location:___________** **No:_______________)**
(Interviewer will fill this) (Interviewer will fill this)

Sex (*Circle*) : **male** / **female**,
Age: _____

Have you used smartphones or other?
**No** ____ **Yes** _____

Do you / Have you used computers?
**No**_____ **Yes** _____

**Instructions:**

1. **Answer all of the questions.**
2. There are no wrong answers. Everything is useful
3. If you do not understand the question, please ask the interviewer for clarification

Thanks for your answers and participation in this test

UI: _______________

Answer all of the questions. Choose suitable option.

| | | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|
| 1. UI icons were easy to understand | **Agree** | | | | | | **Disagree** |
| 2. UI text were easy to understand | **Agree** | | | | | | **Disagree** |
| 3. UI was easy to use | **Agree** | | | | | | **Disagree** |
| 4. It was easy to choose correct option | **Agree** | | | | | | **Disagree** |
| 5. It was annoying to perform a task | **Agree** | | | | | | **Disagree** |
| | | **1** | **2** | **3** | **4** | **5** | |

What didn't you like about the system? (Why?)

________________________________________

________________________________________

________________________________________

________________________________________

What did you like about the system? (Why?)

________________________________________

________________________________________

________________________________________

UI: _______________

Answer all of the questions. Choose suitable option.

| | | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|
| 1. UI icons were easy to understand | **Agree** | ✎ | ✎ | ✎ | ✎ | ✎ | **Disagree** |
| 2. UI text were easy to understand | **Agree** | ✎ | ✎ | ✎ | ✎ | ✎ | **Disagree** |
| 3. UI was easy to use | **Agree** | ✎ | ✎ | ✎ | ✎ | ✎ | **Disagree** |
| 4. It was easy to choose correct option | **Agree** | ✎ | ✎ | ✎ | ✎ | ✎ | **Disagree** |
| 5. It was annoying to perform a task | **Agree** | ✎ | ✎ | ✎ | ✎ | ✎ | **Disagree** |
| | | 1 | 2 | 3 | 4 | 5 | |

What didn't you like about the system? (Why?)

________________________________________

________________________________________

________________________________________

________________________________________

What did you like about the system? (Why?)

________________________________________

________________________________________

________________________________________

UI: _______________

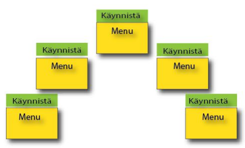
Answer all of the questions. Choose suitable option.

| | | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|
| 1. UI icons were easy to understand | **Agree** | ✎ | ✎ | ✎ | ✎ | ✎ | **Disagree** |
| 2. UI text were easy to understand | **Agree** | ✎ | ✎ | ✎ | ✎ | ✎ | **Disagree** |
| 3. UI was easy to use | **Agree** | ✎ | ✎ | ✎ | ✎ | ✎ | **Disagree** |
| 4. It was easy to choose correct option | **Agree** | ✎ | ✎ | ✎ | ✎ | ✎ | **Disagree** |
| 5. It was annoying to perform a task | **Agree** | ✎ | ✎ | ✎ | ✎ | ✎ | **Disagree** |
| | | 1 | 2 | 3 | 4 | 5 | |

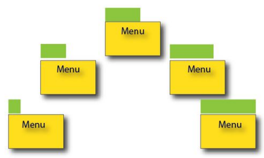
What didn't you like about the system? (Why?)

What did you like about the system? (Why?)

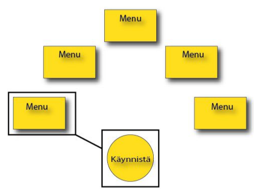
6. If you would use the system again, which method would you choose? (why)




Slide




Hover




2-step

Anything else to say or opinions about the tests or the system itself
(You can say these verbally to the interviewer too)

# Appendix 3 User test 3 – Questionnaire

*Translated from Finnish to English*

**Questionnaire Finland** **(Location: ___________** **No: _______________)**
((Interviewer will fill this) (Interviewer will fill this)

Sex (*Circle* : **Male** / **Female**,
Age: _____ Do you live in?: Own home _____ Care-home ______

Have you used / do you have a smartphone?
**No** ____ **Yes** _____

Have you used devices with a touch screen?
**No** ____ **Yes** _____

Have you used computers?
**No**_____ **Yes** _____

Do you take regular medication? **No** __ **Yes** ___ , If yes, do you use
**A reminder (Alarm / Notes )**_____, **Pillbox** _____(Kind?)____________________ **Other** ______

Do you have problems with any of the following?
**Eyesight** ____ **Hearing** _____ **Hand motor skills** _______ **Other** _______

(Interviewer will fill this)
1. **Answer all of the questions.**
2. There are no wrong answers. Everything is useful
3. If you do not understand the question, please ask the interviewer for clarification

Thanks for your answers and participation in this test

Choose the text sizes that are comfortable to read for you. Choose multiple.

- O This text is comfortable to read for me
- O This text is comfortable to read for me
- O This text is comfortable to read for me
- O This text is comfortable to read for me
- O This text is comfortable to read for me
- O This text is comfortable to read for me
- O This text is comfortable to read for me
- O This text is comfortable to read for me

Projection: _______________

**Answer each question by marking the appropriate circle.**

| | | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|
| 1. The system was easy to use | Agree | | | | | | Disagree |
| 2. Following the instructions was hard | Agree! | | | | | | Disagree! |
| 3. Text and icons were understandable | Agree! | | | | | | Disagree! |
| 4. Text size was difficult to read | Agree! | | | | | | Disagree! |
| 5. The system was useful for the task | Agree! | | | | | | Disagree! |
| 6. I would not recommend the system | Agree! | | | | | | Disagree! |
| 7. Selection was fast to perform | Agree! | | | | | | Disagree! |
| | | 1 | 2 | 3 | 4 | 5 | |

Projection: _______________

| | | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|
| 8. In general I felt the test was easy to perform | Agree! | | | | | | Disagree! |
| 9. I felt there were too many instructions | Agree! | | | | | | Disagree! |
| 10. I am satisfied in the total time it took me to perform the task | Agree! | | | | | | Disagree! |
| 11. I felt the system displayed too much information | Agree! | | | | | | Disagree! |
| 12. I am satisfied in the use of the system | Agree! | | | | | | Disagree! |
| 13. I felt that the system guided me adequelty in how to perform the task | Agree! | | | | | | Disagree! |
| 14. Overall, I am satisfied with the system | Agree! | | | | | | Disagree! |
| | | 1 | 2 | 3 | 4 | 5 | |

Projection: _______________

| | | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|
| 15. I felt the test situation uncomfortable | Agree | | | | | | Disagree |
| 16. I got enough instructions in the use of the system | Agree | | | | | | Disagree |
| | | 1 | 2 | 3 | 4 | 5 | |

What didn't you like? (Why?)

______________________________________________

______________________________________________

What did you like? (Why?)

______________________________________________

______________________________________________

Did you feel the system did what you wanted it to do? (Why?)

______________________________________________

______________________________________________

______________________________________________

**Thank you very much for participating in testing the system!**

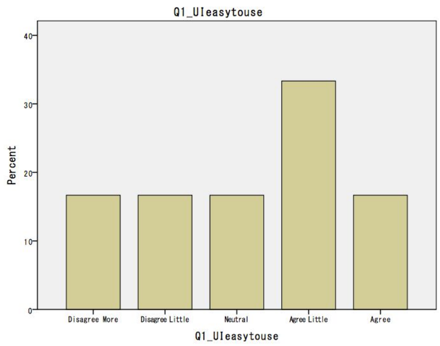
Checklist:
- Make sure video is always recorded
- Check Video Timestamps
- Log System Timestap check before each test user
- Number each user for paper analyzing papers
- Give the same instructions to all of the users
- Ask the same questions from all the users
- Check the UI setting are the same for all users
- Verify the possible extra disabilities the users might have even though the questionnaire asks them in the beginning

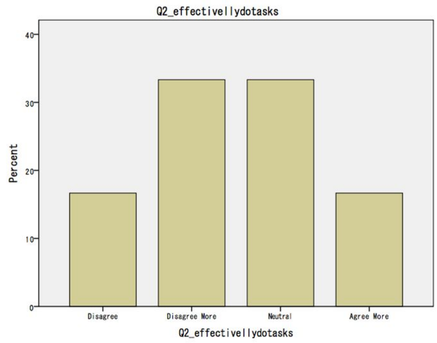
General questions:
- "How did it feel to use?"
- What would you use the system for?
- Did you feel in control?
- What would you change?
- Do you think extra projected information would be useful in daily tasks e.g…
- Did you feel the ring was uncomfortable?
- Did you feel the test was uncomfortable so that it affected how you performed?

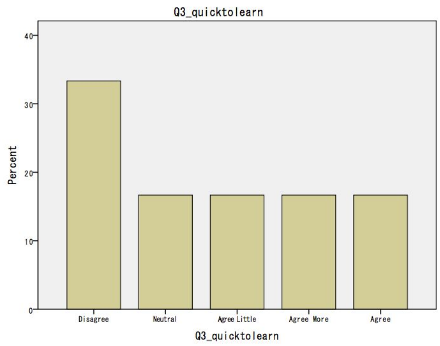
Specific questions
- If someone deviates from expected behaviour, ask why
- How did the users feel about the colours, contrast, sizes and icons?

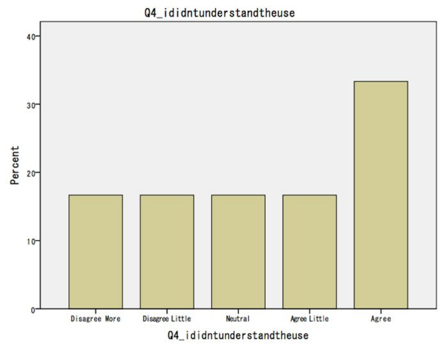
# Appendix 4 – Elderly Pilot study results

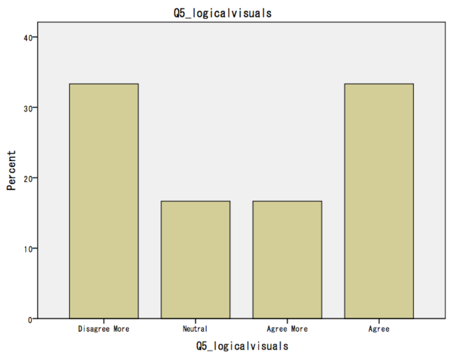
The following graphs show the questionnaire results created with SPSS (IBM SPSS Statistic for Windows, v.22).

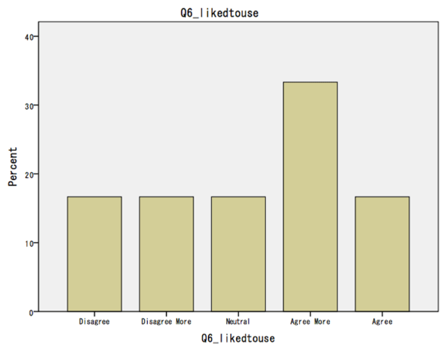


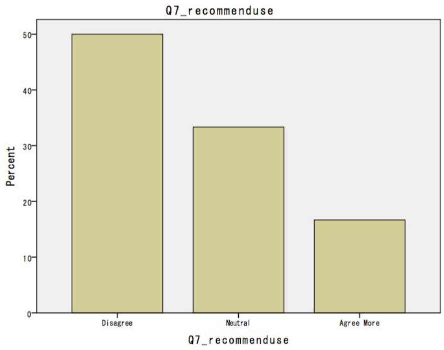



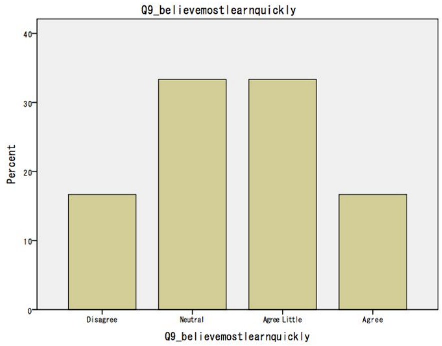



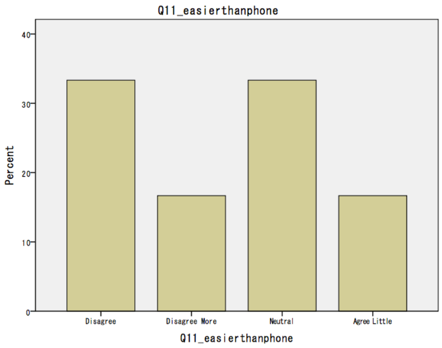




Q7_recommenduse
Percent
0
10
20
30
40
50
Disagree
Neutral
Agree More
Q7_recommenduse


Q9_believemostlearnquickly
Percent
0
10
20
30
40
Disagree
Neutral
Agree Little
Agree
Q9_believemostlearnquickly


Q11_easierthanphone
Percent
0
10
20
30
40
Disagree
Disagree More
Neutral
Agree Little
Q11_easierthanphone

# Appendix 5 – Statistical analysis SPSS for user tests 2 and 3

*Statistical analysis done by Dr. Jorma Riihijärvi, University of Oulu.*

## *1. Background*

The data inputted in an Excel graph was transferred to SPSS (IBM SPSS Statistic for Windows, v.22) and used in our statistical testing analysis. Statistical tests were done for both data sets (elderly test and elderly and CLU test) separately. The questionnaire items were different for both sets so the data could not be combined. All three tests for the elderly and CLU (three different tests) were analyzed by pooling the material.

In the elderly and CLU tests, both groups had nine participants. The latter elderly test had ten participants (n=10). Non-parametric tests were used for statistical analyses due to small number of participants and non-normal distribution of the data (Heikkilä 2001, Metsämuuronen 2002). Non-parametric tests are used when the data violates assumptions of normality, or if the variables are categorical or ordinal (Metsämuuronen 2004). Parametric tests are also used for well-fitted ordinal variables (Metsämuuronen 2002). However, parametric analysis of variance (ANOVA) tests were conducted for the pooled data of Test Group 1 (three experiments, two participant groups, n=54). Originally, the intention was to use regression analysis to examine the relationships between variables, but unfortunately the size of the data and violations of assumptions for these types of tests did not allow the use of regression analysis as part of the statistical testing.

## *2. Statistical analysis methods*

The central statistical analysis methods were correlation analysis, analysis of variance (ANOVA) and various non-parametric tests, such as Kruskall-Wallis test and Mann-Whitney U-test. The statistical significance was determined by p-value. Differences between groups were determined as statistically significant at a p-level of $p < .001$, and borderline significant at p-levels of $p < .01$ and $p < .05$. In this research, the p-value for rejecting the null hypothesis is set at $p < .05$.

### 2.1 Correlation Analysis

The simplest way to examine the relationship between variables is to examine the correlation between them. The results of a correlation analysis can be used as a basis for further analyses, such as factorial or regression analyses. In this research, Spearman's correlation coefficient was used for all correlation statistics. It is, however, important to note that correlation does not prove causation between variables (Heikkilä 2001).

### 2.2 Analysis of variance (ANOVA)

Analysis of variance examines whether there is a statistically significant difference between group means. In case there is only one categorical variable, the test is called one-way analysis of variance (one-way ANOVA). In this research, one-way ANOVA was used to test for differences between participants in addition to non-parametric tests. ANOVA requires additional post-hoc statistical tests in order to determine among which groups statistical differences exist. The assumptions of ANOVA include that the population is normally distributed (Heikkilä 2001, Metsämuuronen 2002). In this research, this assumption was violated, and all ANOVA results are considered descriptive and reported as a support for the non-parametric tests.

### 2.3 Non-parametric average tests

Non-parametric tests (Spearman's rank correlation coefficient) also examine whether there is a statistically significant difference between group means. In this research, Kruskall-Wallis and Mann-Whitney U tests were used. SPSS software selected the proper test based on the data. Non-parametric tests do not include assumptions regarding, for example, population distribution or size (Metsämuuronen 2002).

## *3. Results*

The next section includes the results of the statistical tests. First, the results for Test Group 1 are presented, after which Test Group 2.

### 3.1 Test group 1 results

Sections 3.1.1 and 3.1.2 include independent samples test results for Test Group 1, and section 3.1.3 includes the results for correlation analysis for Test Group 1.

#### 3.1.1 Non-parametric average tests – pooled material

Participants' age, age group and sex were used as grouping variables (coded in SPSS). Results from Mann-Whitney U test showed that there was a significant difference (p=.008) between two age groups regarding SQ1.2. Further, results from ANOVA test showed that the aforementioned difference was significant (p=.012). Results from Mann Whitney U test showed that there was a statistically significant difference (p=.044) between age groups also regarding Q2. However, ANOVA test did not reach statistical significance (p=.075) between age groups for RQ2. Statistical significance between age groups was not reached for other RQs. Further, there was no significant difference between sexes.

Results from Kruskall-Wallis test showed a significant difference between different participant ages for Q1 (p<.001) and borderline significant difference for Q2 (p<.05) and Q5 (p<.05). Corresponding ANOVA tests showed statistically significant results between different participant ages for question 1 (p<.0001), question 3 (p=.031), question 4 (p=.033) and question 5 (p=.030). Based on these results the null hypothesis that there was no significant difference between young users and older users was rejected.

Planned post hoc –tests showed that significant differences emerge mostly between participants aged 26-30 and for participants under 26. Based on these results, the data was divided in to two sub-sets, where young users and older users were examined separately. These results are reported in section 3.1.2.

### 3.1.2 Non-parametric average test – young users versus senior users

There were no significant differences between sexes among the average scores of young users. For older users, there was a significant difference between sexes regarding question 3 (p=.02). The age of testers had a significant effect for the averages in question 1 (p=.001) and question 2 (p=.037). Similarly, age had a significant effect on the average responses of older users for question 1 (p=.018) and question 5 (p=.006).

### 3.1.3 Results of correlation analysis

Results from correlation analysis between questions suggested that the correlations are not strong enough for the questions to be interpreted as measuring the same effects. However, these results also showed that question 5 was different from the other questions as the correlation coefficient was negative, although not statistically significant apart from correlation between question 1 and question 5 (p<.05).

The internal consistency of the measure was tested by calculating Cronbach's alpha. Reliability test where all five questions were included, Cronbach's alpha (α =0.358) suggested that the internal consistency of the measure was low. A follow-up test showed that by removing question 5 from the measure, the internal consistency reached a reliable level (α=0.724). These results suggested that question 5 was conceptually different from the other four questions (questions 1-4).

### 3.2 Test group 2 results

In section 3.2.1, due to small sample size (n=10), limited statistical testing was possible.

#### 3.2.1 Non-parametric average test results

In this dataset, the grouping variables were age, age group and sex. Results from a Mann-Whitney U test suggested that there were no significant difference between sexes regarding question 7 (p=.021). Therefore, the null hypothesis of no difference between groups was rejected. No significant difference was found for the other grouping variables (age, age group), and the null hypotheses were accepted. Due to small sample size (n=10), ANOVA and correlation analysis were not conducted.

The internal consistency of the measure was tested by calculating Cronbach's alpha. Reliability test where all 16 questions were included, Cronbach's alpha (α =0.909) suggested that the internal consistency of the measure was high. Removing any questions from the measure did not improve the alpha-value.

References:


Heikkilä T (2001) Tilastollinen tutkimus. , Edita.

Metsämuuronen J (2002) Metodologia 4: Laadullisen tutkimuksen perusteet. E-Book. Printed 12: 2007.

Metsämuuronen J (2004) Pienten aineistojen analyysi: parametrittomien menetelmien perusteet ihmistieteissä. , International Methelp.