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Technologies for Ambient Assisted Living: Ambient Communication and Indoor Positioning

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Thesis for the degree of Doctor of Science in Technology to be presented with due permission for public examination and criticism in Sähkötalo Building, Auditorium SM221, at Tampere University of Technology, on the 22 of May 2015, at 12 noon.

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Abstract

In all industrialised countries, the population is aging rapidly as the average life expectancy continues to rise and the number of younger age groups grows smaller. Hence, due to economical and practical reasons, the elders of the near future will likely live longer in their own apartments, particularly because institutionalization is significantly expensive and there is not room for the entire elderly population in currently existing nursing homes. Even more important, nearly all people would choose to live independently as long as possible before moving into an assisted-living facility.

A longer period of independent living for elders can be enabled by technical solutions. In this work, two technology areas for assisted living are studied. First, the prevention of feelings of loneliness in elders living alone is studied, and a solution for social inclusion and remote presence is presented. The results of long-lasting field trials are presented and analysed. Secondly, as information regarding the location of the inhabitant in the apartment can be used to provide several assistive services, indoor positioning systems are also studied in this work. Several technologies for indoor positioning are presented and compared. Furthermore, a new system based on capacitive measurement and the results of testing of the system are introduced.

Technologies and systems developed here have been implemented into actual systems, and real end users have tested them over long periods of time. Thus, these technologies can be developed into commercial products with reasonable effort. Moreover, in this work it has been proven that the systems developed can actually be used to support the independent living of elders.

Preface and Acknowledgements

This study was carried out from 2011 to 2015 in the Personal Electronics Group at the Department of Electronics and Communications Engineering, Tampere University of Technology, Tampere, Finland. I am grateful for the opportunity to work toward my thesis.

I wish to thank my supervisor, Professor Jukka Vanhala, for his support and encouragement during the work. Also I would like to thank my colleagues at the Personal Electronics groups for interesting and stimulating conversations during the working hours. Specially, I offer my appreciation to MSc Antti-Matti Vainio, MSc Harri Pensas, and PhD Lasse Kaila, for the collaboration in the AMCOSOP project, and PhD Miika Valtonen, for the time we worked together with the capacitive positioning system. Further, I would like to thank Professor Karri Palovuori for many interesting discussions related to domestic and foreign policy during coffee breaks in the SmartHome laboratory.

I am grateful for the pre-examiners of my thesis, Professor Jonna Häkkilä and Professor Petri Vuorimaa, for their valuable time and constructive comments. Further, I am indebted to Professor Pauli Kuosmanen for agreeing to act as the opponent at my defence.

This thesis is based partly on work that was funded by the European Union under the Ambient Assisted Living Joint Programme.

Still further, I would like to extend my warmest gratitude to my parents, Raija and Raimo, for all the support they have given me during my journey in life. Finally, I wish give my warmest thanks to my wife, Minna, and to our sons, Aapo and Arvi, for their love and motivation.

This thesis is dedicated to the memory of my nephew Teemu Liukkonen (1989-2014).

Kangasala, April, 2015

Tero Kivimäki

Contents

List of Figures

List of Publications

The seven publications of this thesis have been categorised under two titles based on their content.

Ambient Communication and Sense of Presence

P1. Kivimäki, T., Liolis, K., Yildizoglu, U., Kaila, L., Vainio A-M., Konakas, S., Katsiouli, P., Pensas, H., Summanen, K., Pantazis, S., Moisio, H., Andrikopoulos, I., Vanhala, J.
On an Advanced ICT-enabled System for the Social Inclusion of the Elderly
The 5th International Conference on Pervasive Technologies Related to Assistive Environments 2012, Heraklion, Greece

P2. Pensas, H., Vainio, A-M., Kivimäki, T., Yildizoglu, U., Liolis, K., Vanhala, J.
Ambient Communication and Sense of Presence Device
Academic Mindtrek Conference 2012, Tampere, Finland

P3. Kivimäki, T., Kölndorfer, P., Vainio, A-M., Pensas, H., Vuorela, T., Vanhala, J.
User Interface for Social Networking Application for the Elderly
The 6th International Conference on Pervasive Technologies Related to Assistive Environments 2013, Rhodes Island, Greece

P4. Pensas, H., Vainio, A-M., Garschall, M., Kivimäki, T., Konakas, S., Costicoglou, S., Vanhala, J.,
Using Ambient Communication and Social Networking Technologies to Reduce Loneliness of Elders
The 6th International Conference on Social Computing and Social Media 2014, Heraklion, Greece

Positioning Systems for Assistive Environments

P5. Kivimäki, T., Vuorela, T., Peltola, P., Vanhala, J.
A Review on Passive Device-free Indoor Positioning Methods
International Journal of Smart Home, Volume 8, Number 1, 2014

P6. Kivimäki, T., Vuorela, T., Valtonen, M., Vanhala, J.
Reliability of the TileTrack Capacitive User Tracking System in Smart Home Environment
20th International Conference on Telecommunications 2013, Casablanca, Morocco

P7. Valtonen, M., Kivimäki, T., Vanhala, J.
Capacitive 3D User Tracking with a Mobile Demonstration Platform
Academic Mindtrek Conference 2012, Tampere, Finland

Author's Role in the Publications

Ambient Communication and Sense of Presence

P1: The author worked as a project manager on the project described in the publication and took part in the research, specifications, and design of the system. The author also wrote the manuscript.

P2: The author joined in the designing and implementation of the device and worked as a project manager on the project. The author shared in the writing of the manuscript.

P3: The author took part in the research, design, and implementation of the user interface and also arranged the pilot period with the end users. The author wrote the manuscript.

P4: The author joined the research, implementation, designing, and testing and worked as a project manager. The author shared in the writing of the manuscript.

Positioning Systems for Assistive Environments

P5: The author performed the research as a literature review and wrote the manuscript with Timo Vuorela and Pekka Peltola.

P6: The author analysed and compiled statistics on the raw result data of the reliability testing of the tracking system. The author wrote the manuscript.

P7: The author joined the research, development, and testing of the tracking system and wrote the manuscript with Miika Valtonen.

Summary and Main Contributions of the Publications

Ambient Communication and Sense of Presence

P1: The publication substantiates that loneliness is a major factor that can decrease the quality of life of elders living alone. The publication also proves that sense of presence can be provided by means of social networking systems. Furthermore the publication presents an ambient communication and sense of presence system for the elderly.

P2: The publication presents the Home Terminal device, which is an appliance that is meant to be used by elders to enforce their connectivity with their safety-net.

P3: The publication proves that the conventional social networking applications are too difficult to use for elders with limited computer skills. The publication describes the design process and implementation of a user interface for the elderly for a social networking application. The results of a long-lasting field trial are also presented.

P4: The publication describes the technical implementation of the social network application for senior citizens.

Positioning Systems for Assistive Environments

P5: The publication describes the need for passive positioning systems in ambient assisted living environments. The publication explains the main technologies that can be used in device-free passive positioning. Technologies are compared, and implementations based on these technologies are presented.

P6: The publication presents a passive and device-free human tracking system that is implemented by capacitive measurements. The publication also provides results of the testing of the system's reliability and capability to track moving humans.

P7: The publication describes a mobile capacitive tracking system that can detect the location and posture of multiple persons. The system can be easily transported to and assembled in a new location.

List of Abbreviations

2G	Second-generation Wireless Telephony Technology
AAL	Ambient Assisted Living
AAL JP	Ambient Assisted Living Joint Programme
ACM	Association for Computing Machinery
AMCOSOP	Ambient Communication and Sense of Presence
AoA	Angle of Arrival
API	Application Programming Interface
CSE	Computer Self-efficacy
CURE	Centre for Usability Research and Engineering
DfP	Device-free Passive
DiFP	Digital Family Portrait
EMFi	Electromechanical Film
EU	European Union
GPS	Global Positioning System
GWT	Google Web Toolkit
HTML5	Hypertext Markup Language version five
HSQLDB	HyperSQL DataBase
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
INS	Inertial Navigation System
IR	Infrared
LED	Light Emitting Diode
MVC	Model-View-Controller
OWL	Web Ontology Language
PEOU	Perceived Ease of Use
PU	Perceived Usefulness
QML	Qt Modelling Language
ReST	Representational State Transfer
RF	Radio Frequency

RFID	Radio Frequency Identification
RSS	Received Signal Strength
RTLS	Real-time Locating Systems
SAM	Self-Assessment Manikin
SERSC	Science and Engineering Research Support soCiety
SNS	Social Networking Services
SMS	Short Message Service
SQL	Structured Query Language
Symbian^3	Symbian operating system version three
TAM3	Technology Acceptance Model 3
TDoA	Time Difference of Arrival
ToF	Time of Flight
TUT	Tampere University of Technology
UCD	User-centred Design
UI	User Interface
USB	Universal Serial Bus
UWB	Ultra Wideband
UX	User Experience
Wi-Fi	Wireless Fidelity
XMPP	Extensible Messaging and Presence Protocol

1 Background and Motivation

In all industrialised countries, the proportion of people aged over 65 years is growing faster than any other age group; the number of people over the age of 80 is projected to quadruple between 2010 and 2050. By 2050, the world will have over 400 million people who are at least 80 years of age [UNWPP]. This trend is a result of a longer life expectancy due to progress in medical treatment and pharmacies and also of declining fertility rates, and this change will be most dramatic in Europe. Figure 1 presents the change of the dimensions of the major age groups in Finland until the year 2100. The development is very similar in all developed countries especially in Europe, the figure would be almost uniform for any western Europe country.

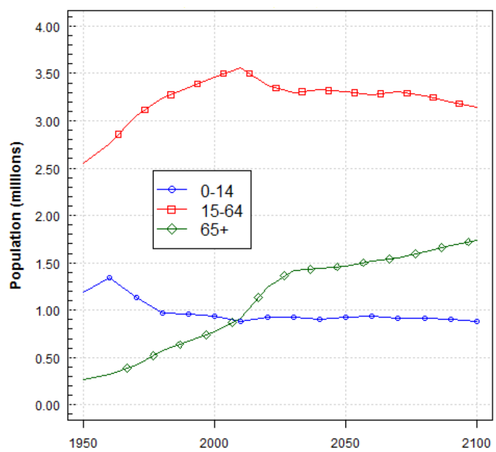


Figure 1. Total population in Finland by major age groups [UNWPP].

The ageing of the population can be seen as a success story for socioeconomic development and for public health policies, but it will also cause challenges and produce consequences. In the near future, it will be impossible for all these elders to live in retirement homes or nursing homes just for economic reasons, as the institutional care is considerable expensive. At least as significant as the economic reason, people prefer to age in a familiar and comfortable place, as the quality of life is usually considered to be better in home than in institutional care. Thus the elders are keen to remain in their own homes and apartments as long as possible [Koc12].

Different types of motor, cognitive, or memory disabilities usually appear later in life that are specific to ageing, and support is often required for independent living. The need is greater for elders who live alone, such as after the loss of a spouse. Ambient Assisted Living (AAL) is a term used to describe the aim to assist elderly people to live in their preferred environment in a safe and pleasant way and thereby provide a better quality of life. This goal is achieved by providing ambient intelligence devices and services to assist in the activities of daily living [Kle07] [Sun09].

AAL has been the domain of study for hundreds of research projects around the world during the last years. The interest toward this area in academic world is constantly increasing, the number of publications published related to AAL has multiplied during the last five years. The research has focused to develop single devices or applications that would compensate the effects of some physical illness or impairment. Representative examples of services developed in these kinds of research projects are HearMe [Har11], which provides medication management service for visually challenged elders, and Activity Compass [Pat02], a cognitive aide for Alzheimer's patients. Research related to improving the quality of life of an elder living alone by providing him or her sense of safety by technical solutions has not been widely conducted earlier.

To respond to the challenges caused by the demographical trend towards an older population, the European Union (EU) started the Ambient Assisted Living Joint Programme (AAL JP). The objective of the AAL JP is also to round up the numerous research groups in Europe that are working in the field of AAL and to share information and findings between them. The AAL JP is a funding activity intended to combine social, technological, and business aspects with a goal to improve the elderly's quality of life and to strengthen the Information and Communication Technologies (ICT) industry in Europe [AAL]. A significant part of the work that this thesis is based upon was funded by the AAL JP.

2 Scope, Objectives and Outline of the Thesis

The main objective of this thesis is to facilitate the independent living of the elderly by providing a sense of safety to both the elders and their relatives. To meet this ultimate objective, this thesis studies issues related to intelligent assistive environments and wellbeing of the aged by practicing software technology, usability and user experience theory and electronics.

To create a sense of safety, this thesis will seek to provide answers to the following research questions:

1. How can feelings of loneliness in elderly people who live alone be prevented by technical solutions?

2. What types of indoor human positioning systems are most suitable for ambient assisted living?

The justifications for selecting these two questions as the main research questions are as follows:

1. In single households, the feeling of loneliness is the most important factor that decreases the quality of life of an elder [Hol02] [Ekw05]. In addition, a clear correlation between loneliness and health status has been found; lonely elderly people have a significantly increased risk of falls in dementia [Fra00] and also to other illnesses as loneliness has been shown to have negative impacts on the immune system [Rus97]. Social media applications, that are extremely popular among younger people, provide new means to be in contact with others and can prevent loneliness. However, these applications are not commonly used by elders. The reason for this is that the starting to use them by someone who has never used a computer is too difficult. So there is a need for remote presence system that is designed to elders from outset.

2. It has been proven that the dependable real time location data of the inhabitant enables the implementation of innumerable divergent applications to improve the wellbeing of the person [Hel03] [Tor10]. Furthermore, the current activity of the person can be concluded from the real time location information [Val12], and the activity information is valuable when implementing assistive services. Positioning system can also be used in conjunction with an application developed to prevent loneliness. Information related to the location, status or activity provided by the positioning system can be fed to a remote presence system. The research on indoor positioning systems has been going on for decades, but the overwhelming solution for positioning at home environment has not been found.

The main hypotheses of this thesis are:

1. A social media system, that can be used without any experience in using computers and that can prevent the feeling of loneliness, can be implemented.

2. An unobtrusive, robust and accurate positioning system can be installed in an apartment at a reasonable price and with a legitimate amount of work.

This thesis contains seven publications (P1-P7) and an introduction. The publications present the main results of the thesis, which comprises prototype design, implementation, and evaluation as well as research on social inclusion and on technologies that could be used to locate humans. The interconnection between the participants and the publications is shown in Figure 2.

The introduction of the thesis presents the main findings of the publications and describes the application field. The introduction starts in Chapter 3 by explaining the remote presence and ambient communication and the research results provided in P1-P4. Chapter 4 covers indoor human positioning in the case of ambient assisted living. Research results of P5-P7 are presented. Finally, Chapter 5 includes the main conclusions of the study.

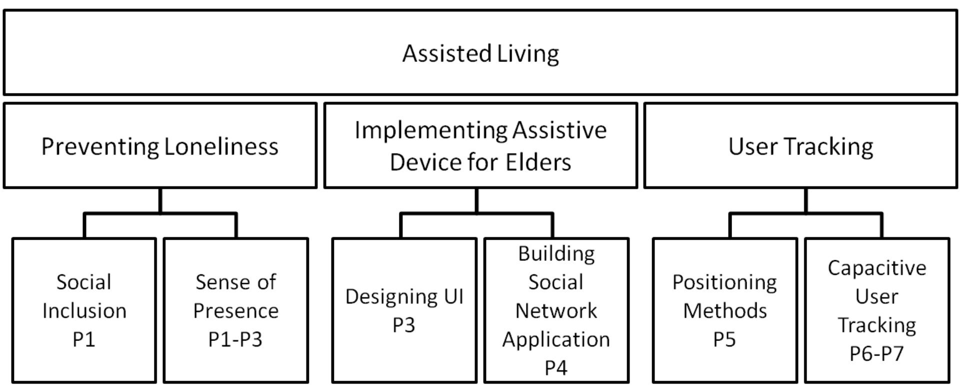


Figure 2. Structure of this Thesis.

3 Preventing Loneliness Using Ambient Communication and Sense of Presence

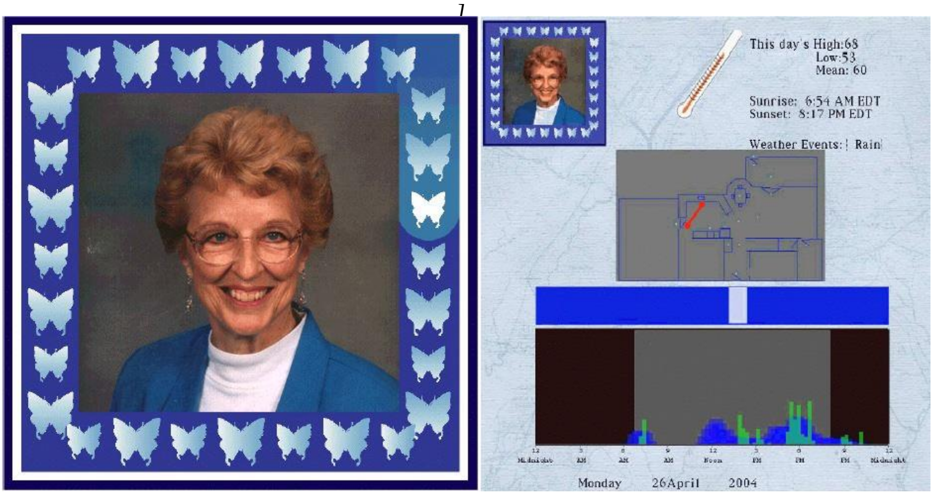
As people age, their mobility often decreases and their number of face-to-face social contacts could also decrease due to retiring or the loss of a spouse. Currently, people often live far away from their family and relatives and do not always find it easy to stay in contact. This lack of connection and communication may cause social isolation, loneliness, and fear [Sha11], [Ili07]. Loneliness can be defined as a lasting and distressing condition that arises when a person feels separated or rejected by others and lacks appropriate social contacts [Roo84]. The feeling of loneliness increases rapidly in the later years of life; approximately 10% of people over the age of 65 report frequently feeling lonely, while more than half of those over 80 years often experience loneliness [Pin01]. Relationships between loneliness and physical and mental problems have been identified, including the risk of Alzheimer's disease, other types of dementia, and depressive symptoms, which have been shown to increase in those who lack face-to-face contacts [Ver03] [Tii05]. Loneliness has also been shown to be one of the most impressive factors related to the welfare of the ageing population; it is a genuine problem for about one-third of the elderly and a serious threat to the health of 1 out of 10 senior citizens [For96] [Per04].

Loneliness can be reduced and a sense of safety can be restored with a remote presence. This type of presence provides intimacy at a distance, which means that the user can sense the "presence" or activity of another person by some signals provided by the remote presence system [Tol00]. Only small hints are enough to provide the feeling of a remote presence and the sense of safety [Tol02] [Egg03].

Meaningful activities and social interactions that have positive effects on both the physical and the mental health of the elderly can be provided by social media. However, older people often do not use traditional online social networks because they are too difficult for people with very limited computer experience and the possibility of physical impairments [Gib10]. This is a grievous and increasing problem as social life and different types of services are rapidly moving to network.

3.1 Related work

Digital Family Portrait (DiFP) [Myn01] is one of the first and best-known remote presence systems. The portrait presents qualitative visualizations of the elder's activity, well-being, and the conditions of the living environment. The idea is to present the observations that would naturally occur if the elder were living in the same neighbourhood. DiFP also provides representations of the past in addition to the present to enable the observation of trends over time, such as "Has her mobility decreased?"



a) b)

Figure 3. The Digital Family Portrait, a) The persistent display, b) The detail screen, modified from [Row05].

The DiFP is shown in Figure 3. Figure 3 a) is the main display where the frames of the photograph are populated with icons; in this case, the butterfly icons indicate the activity. The size of the icon is mapped to the level of activity, and a larger size indicates a higher level. The activity is shown for four weeks (28 days), and one icon represents one day. The current day is coloured white, and the current day and the recent past are highlighted using a gradient of background colours. More detailed information related to the level of activity can be accessed from the detail screen, which is shown in Figure 3 b), which is opened by touching the icon in question. The detail screen shows information about the weather, a plan drawing showing the last sensor firings, and also an activity graph.

The Digital Family Portrait was tested in real life in a field trial that lasted for one year [Row05]. The test was performed by one 76-year-old female and her adult son who lived in another locality. The house of the elderly woman was equipped with 16 sensors; one of the sensors was attached to the alarm system, while the others were placed in a location where they could sense human activity and activate when the elderly person is nearby. The son had a DiFP display that showed the information gathered by the sensors. Based upon the results collected both during and after the trial, it was found that the elder experienced less loneliness and felt more comfortable knowing that her son was monitoring her with the system. The son was also able to easily see if everything seemed to be fine with his mother; by using the detailed view for a particular day, he could almost feel how his mother was moving around the house. After the field trial period ended, the mother and son were willing to continue to use the DiFP at their own expense.

The CareNet display resembles a Digital Family Portrait [Con04]. It is also an interactive digital picture frame that provides information about an elderly person's daily life and activities. It uses seven icons to organise and display information about activities, the calendar, falls, medications, meals, mood, and outings. The main difference is that the CareNet display is meant to be used by the local members of the elder person's care network who are responsible for the elder's day-to-day care [Con05].

Both the Digital Family Portrait and CareNet are intended mainly to provide peace of mind for relatives or to assist persons who take part in the treatment of the elder. As a result, they do not provide elderly people with the feeling of a remote presence or a new means to be in contact with relatives or loved ones.

Traditional online social network services (SNS) like Facebook, Twitter, or Google+ provide a means to communicate and to keep in contact with people from a distance. SNS are used by most middle-aged people, youth, and even children almost continuously. Unfortunately, they have been designed and implemented for and by younger people, and they are too complex for elders with limited computer experience to use [Gib10]. Other reasons for keeping elders out of SNS are that they consider the Internet to be a dangerous place and regard social networking sites as places of socially unacceptable behaviour [Leh09].

Attempts have been made to make the use of common online social networks easier and less intimidating. Go-myLife [Go-myLife] provides a middleware over the common core social network. The purpose of the middleware is to collect content from the core network and to present it to the user with an easy and accessible interface. The principle of Social Interaction Screen [Bur12] is similar solution than Go-myLife, it provides adapted user interface to present content gathered from SNS by a middleware. Idea of ePortrait [Cor10] is to filter designated content from traditional SNS and present it to elder by using a specific UI. ePortrait collects all new photographs that have been published to Facebook by any of the contacts of the elder and presents the photographs via a digital picture frame. These systems could provide elder a kind of sense of remote presence and prevent the feeling of loneliness. However, our presumption was that the system, service and user interface should be designed for the elders from the beginning to have a chance at being accepted by the majority of senior citizens.

3.2 Ambient Communication for Sense of Presence

The Ambient Communication for Sense of Presence (AMCOSOP) project was started as a part of AAL JP in November 2010. The total amount of work performed in the project was about 300 person months, and it ended at the end of March 2013. Tampere University of Technology (TUT) was the main organisation responsible and the coordinator of the project. The other participants were the Centre for Usability Research and Engineering (CURE) [CUR], Space Hellas [SPA], and Pirkanmaan Senioripalvelut Oy [PIR].

The objective of Ambient Communication for Sense of Presence project was to create a system, which provides users with a sense of the presence of their family and friends and assures that the elderly people are never left alone. The system encourages people to stay in contact with others by providing availability information of possible and known communication partners.

The welfare and assistive technology has concentrated on helping in physical condition problems mainly by monitoring events and providing assistance in the case of a accident or a bout of illness. The way AMCOSOP utilises ICT technology deviates from the typical assistive solutions in which elderly people are monitored. Instead, information from other people is collected and displayed in a visible form for the elderly, giving them the ability to decide when to have social connections or other activities.

3.2.1 AMCOSOP System

AMCOSOP system facilitates the maintenance of social connections and provides users with a sense of that their family and close friends are present. The system encourages people to stay in contact by affording availability information and by providing a means to send messages [P1].

The main target user group for this study includes people over 65 years of age who are living independently. These primary users are still active and do not suffer from serious symptoms but may experience loneliness and fear. The group of secondary users comprises family, relatives, and friends of the elder. These important contacts of the primary users form the safety-net. Tertiary users are companies or communities that provide services to the elders. They can include health care providers, geriatric centres, or hair dressers. The user groups and the safety-net are presented in Figure 4.

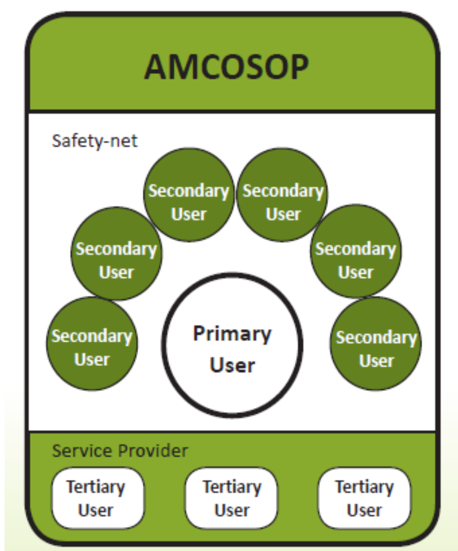


Figure 4. The user groups of the AMCOSOP system.

The system maintains status information of the users, such as the availability, the location, and the activity. This status information is delivered to the contacts of the user in question. The users are also able to send messages to each other, and third-party service providers can deliver and endorse their services via the system.

3.2.2 User Interface for Elderly

The elders are using the AMCOSOP system via Home Terminals. As the Home Terminal is destined to be used by seniors with probably no or very limited experience of computers, the design and implementation of its UI had to be done extremely carefully. Principles of User-centred Design (UCD) were observed. The idea of UCD is to find out how target users would actually and naturally act or operate rather than forcing users behave as demanded by the system or application [Rub08]. The real end users were involved to the whole design process. The main phases of the design process are shown in Figure 5.

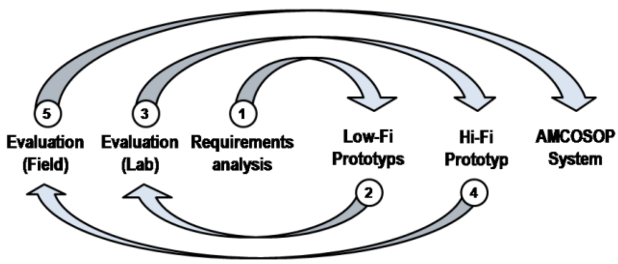


Figure 5. Phases of the Home Terminal Design [P3].

The design started with requirement analysis that consisted of two phases, focus groups [Ste14] and cultural probes [Gav99], [Jää03]. Primary and secondary users participated in focus groups that were succeeded by discussion and questionnaires. The objective was to identify the communication behaviour between the elders and their safety net. The AMCOSOP system was presented, and the intention for using the system was surveyed, with a focus on what information the users would like to share and who should be able to see it and also what information about people in your contact network you would like to receive. The target of cultural probes was to collect ideas and preferences for the graphical layout, to define more carefully the communication habits, and to find out where the users would place the Home Terminal. Every participant received a cultural probe package, including a mock-up of the Home Terminal with various printed UIs, a communication diary, an intention-of-use questionnaire, and a disposable photo camera. The participant recorded all outgoing telephone calls and their circumstances before and after the call in the communication diary. The mock-up was asked to place wherever participants thought it would be best fitted, and several locations were tried to determine the best fit. A photo from each location was taken, and some comments were recorded explaining why the mock-up was placed in that location. Participants were asked to test all the supplied display designs and to make comments and record notes on a semi-structured questionnaire. They were also asked to create their own interfaces using drawings and sample parts included in the cultural probe package. At the end of the seven-day cultural probe period, the participants were asked to complete the same intention-of-use questionnaire that was given in the focus groups to explain how their expectations and feelings had changed. Based on the results of the focus groups and cultural probes, the functionalities of the Home Terminal were identified and prioritised, and the list of prioritised functionalities is shown in [P3]. [P3] also provides more detailed information about the focus groups and cultural probes.

Drafts of the main views layouts were drawn based on the results of the requirements analysis phase. Examples of the drafts are shown in [P3]. The layouts were estimated in Evaluation labs as paper prototypes. The participants performed different tasks with the prototypes, and the thinking-aloud method was used. In this method, the user verbalises all thoughts during the operation and offers expectations for what will happen after an action is performed [Rub08]. The participants were also interviewed in regards to their aesthetic feelings and the usability of the product, and their emotional reactions were recorded. The collected feedback was used to implement the first click dummy version of the UI. The UI was evaluated in another Evaluation lab using the Home Terminal and a click dummy UI with static content and by the same methods as in the first lab. The version to be used in the field trials was implemented based on the results of the Evaluation lab phase.

The final UI consists of four main views: Home, Contacts, My Profile, and Settings. The icons in the lower left corner of the screen are used to switch from one view to another. In the Home view, the contacts of the user are shown as photographs. The availability of the contact is indicated by the size of the photograph; a large photograph indicates that the person is available and willing to communicate. The final Home view is shown in Figure 6.

Figure 6. The Home view of the Home Terminal [P3].

If a user touches the photograph of a contact, a User Details view that shows the status, activity, mood, location and the conversation history of the contact opens. The User Details view is presented in Figure 7. This view also allows messages to be sent to the user in question.

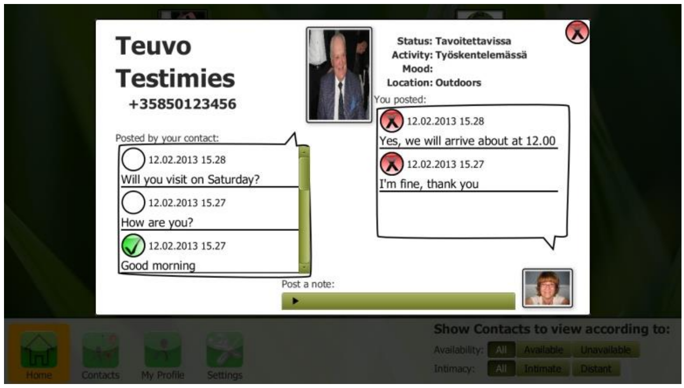


Figure 7. The User Details view of the Home Terminal [P3].

Primary users maintain the values of the status, activity, mood, and location in the My Profile view. The values are selected from a dropdown list, as shown in Figure 8.

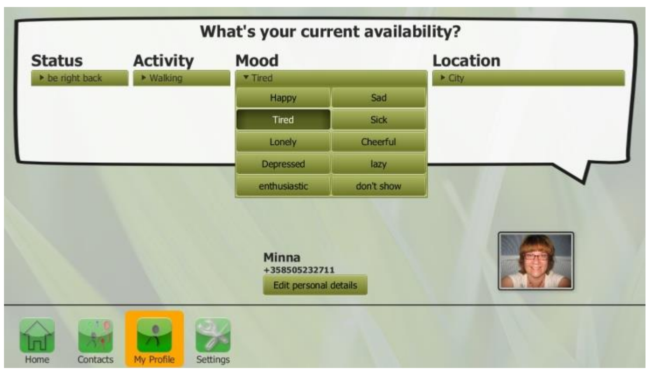


Figure 8. The My Profile view of the Home Terminal [P3].

The Contacts view, shown in Figure 9, offers the ability to delete contacts and to rank contacts as intimate or distant. This intimacy value can also be used in Home view to filter the contacts. The Settings view allows the user to adjust text size, sound effects, and the background image. The functionality of all views is described in more detail in [P3].

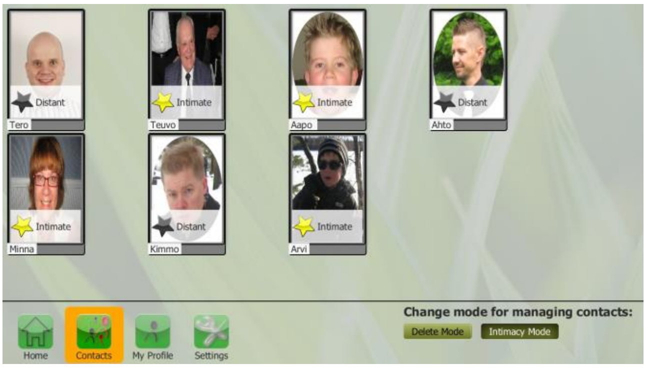


Figure 9. The Contacts view of the Home Terminal [P3].

The requirements for the Home Terminal hardware were determined based on the specified functionalities, and a suitable commercial, off-the-shelf device was selected: an ASUS All-in-one-PC ET1611 touch screen computer with the Windows 7 operating system [ASUS]. The selected device, shown in Figure 10, is more powerful than would be needed to run the Home Terminal software, but its substantial memory and processor power also allowed the Home Gateway to be installed and to run on the same device. In addition to the touch screen, the device has only a couple of input buttons for the user to adjust the brightness and contrast of the screen and to turn the device on and off. For the field study stickers with explanations of the functionality of the buttons were applied above the buttons (not applied in Figure 10).

Figure 10. The Home Terminal device.

3.2.3 Information Flow and Components

The main idea of AMCOSOP is to gather information from the users and in a controlled way to provide it to other users of the system. The information shared by the AMCOSOP system is shown in Figure 11.

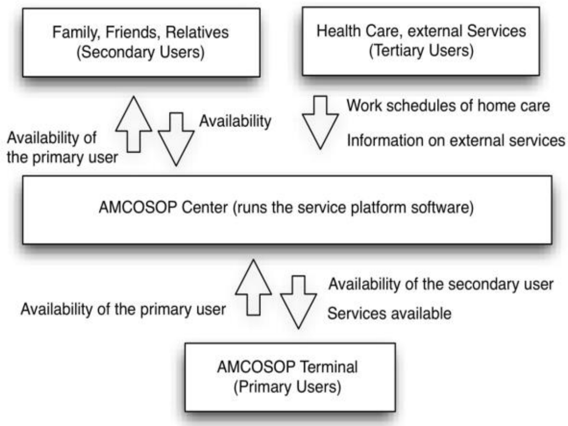


Figure 11. Information delivered by the system [P1].

The main components of the system are the Home Terminal, Home Gateway, Service Platform, and Client Terminals. The components with their connections to the users are shown in Figure 12. The Home Terminal is the user interface for the elders. It communicates their presence and availability information and messages. The Home Terminal is described more carefully in subsection 3.2.2 and secondary user's terminals in subsection 3.2.4. The Home Gateway is a cache and a proxy that feeds data to and from the Home Terminal. The Service Platform stores and maintains the user and communication information and manages the information flow between the clients.

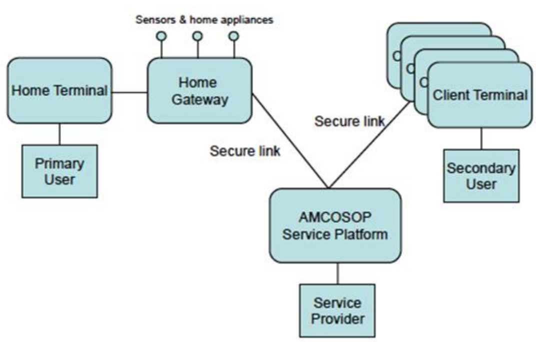
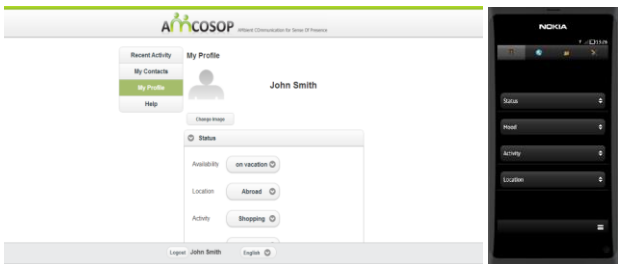


Figure 12. AMCOSOP System Components [P1].

3.2.4 Secondary User Interface

For secondary users, two client terminals (user interfaces) are provided: a web client application and a native mobile phone application. The secondary user interfaces are shown in Figure 13. The main functionalities provided by these applications are interaction with primary users and access to personal status and profile information. The difference between the applications are that the mobile application provides some additional features, like using the location and profile information provided by the mobile device to automatically adjust the status value of the user. Furthermore, it is possible to make phone calls from the mobile application and to send SMS to persons in the contact network. For tertiary users and for piloting purposes, we created a simple web application that clients can use to add their services to the system.



a) **b)**

Figure 13. Secondary user interfaces, a) Web application, b) Mobile application, modified from [P4].

3.2.5 Implementation

The main functionality of the AMCOSOP is to deliver messages and information; as shown in Figure 12, the system consists of several separate components. Therefore, fluent and dependable communication between the components is vital and was taken into account when selecting and implementing the communication methods. Extensible Messaging and Presence Protocol (XMPP) [XMPP] is the main messaging protocol between the Service Platform and the clients. XMPP is an open extensible protocol for presence, instant messaging, and request-response services. The protocol is used to deliver updates in a user's status information and also to handle invitations from contacts. The users' contact lists could also be delivered through XMPP, but Representational State Transfer (ReST) [Jak05] gives Service Platform the ability to handle the user management in more diverse way and save the records to its own database. ReST is an architectural software style used widely in distributed systems. ReST is employed in AMCOSOP to handle the users' contact lists and the list of available third party services. The Home Gateway and Home Terminal use Java Remote Method Invocation (RMI) [Gro01] to communicate. Java RMI is a Java application programming interface (API) that makes it possible to invoke the methods of a remote Java object from another Java virtual machine. This enables the Home Terminal and Gateway to be installed on different hosts; however, in our pilot platform, they were running on the same computer.

The Service Platform is responsible for maintaining user and service information and for delivering user and service messages. This Service Platform consists of six components, as shown in Figure 14. The database was implemented with PostgreSQL [PSQL], and it stores user and service data and also maintains logs of the users' activity. An Instant Messaging Server manages communication between the users, while Service Administration oversees the tertiary users' services. The User Management component is a web application that is used to update the user information stored in the database. All user-related information is modelled using Web Ontology Language (OWL) [Hit12] in the User Modeling Component. The Service Dispatcher disseminates service information to relevant users.

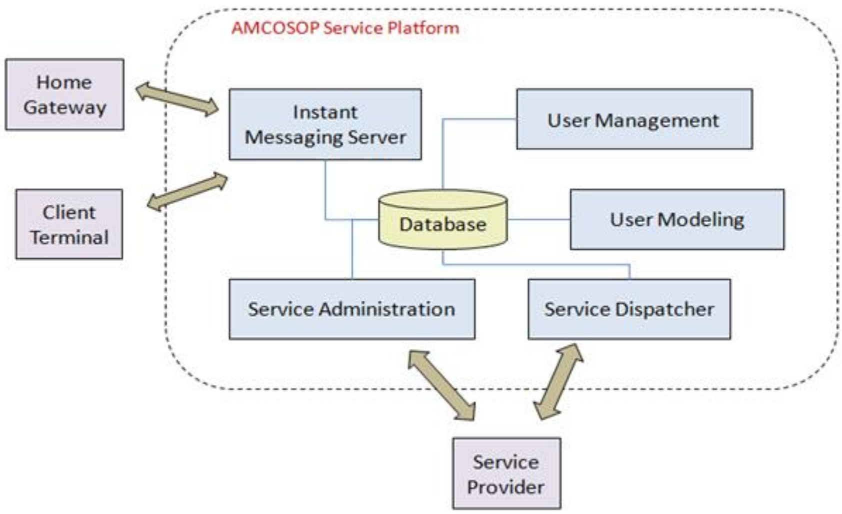


Figure 14. AMCOSOP Service Platform components [P1].

The design, functionality, and hardware of the Home Terminal are explained in Subsection 3.2.2. The implementation of the Home Terminal software follows a model-view-controller (MVC) pattern, which allows for the possible future modification of the software so that it can be used with different types of hardware. JavaFX 2.0 [Wea12] was selected as the implementation platform for the UI although it was still in its beta testing phase when the implementation began. This decision proved to be satisfactory, as the second version of JavaFX turned out to be proficient tool to implement user-oriented and reliable user interface.

The Home Gateway operates between the Service Platform and the Home Terminal. It receives REST and XMPP messages, parses and transforms them to the internal AMCOSOPMessage format, and delivers them to the Home Terminal. The architecture of the Home Gateway is presented in Figure 15.

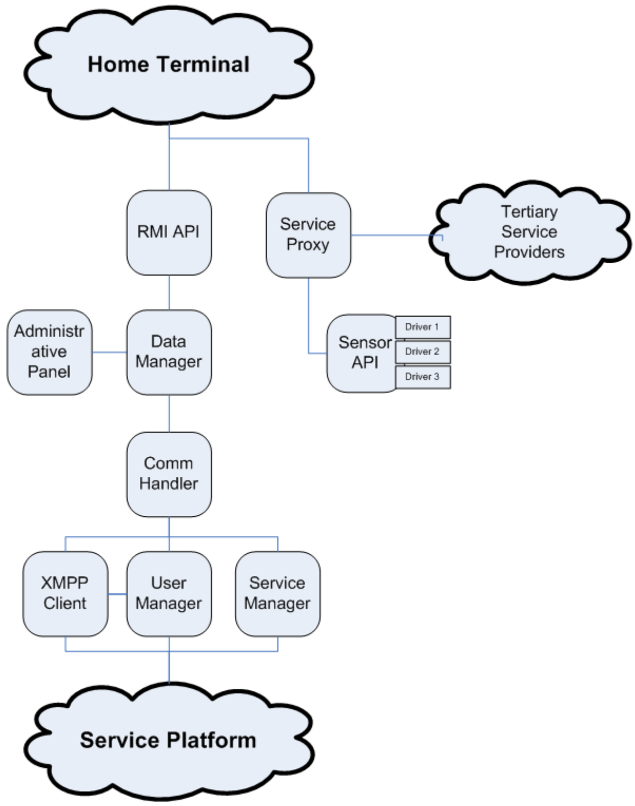


Figure 15. Home Gateway architecture.

The RMI API is used to communicate with the Home Terminal. The Home Terminal receives and transmits all data by native Java classes and Java method calls using RMI. The Service proxy is used in providing Home Terminal access to services. These services are accessed as web content from an external server. To provide faster service or availability in cases when a network connection is temporarily unavailable, a proxy is implemented. For possible future needs, a Sensor API is also implemented and can be used to provide services that rely on information received from some sensors. The Data Manager stores a local copy of all data received from the Home Terminal or from the Service Platform. The HyperSQL DataBase (HSQLDB) [HSQLDP], which is integrated inside the software, is used for this purpose. The Administrative Panel offers a simple UI for configuration and management of the Home Gateway. The CommHandler is a data channel used to deliver messages from other threads to the communication thread. The XMPP Client transforms XMPP messages to the same internal Java classes used by the Home Terminal and vice versa. This XMPP client is implemented with the Smack Java API [SMACK], an open source client library. The User Manager takes care of all user-related ReST-requests, while the Service Manager handles all requests that are service related.

The secondary user web application has five main pages, which are shown in Figure 16. Google Web Toolkit (GWT) is an open-source development toolkit for implementing and optimizing complex web applications [GWT]. The GWT and especially the Smart GWT [SGWT] UI components were used to implement the HTML5 [Ber14]-based user interface. The application was tested and proved to work in all main web browsers on a typical PC and also on devices with smaller displays, like tablets.

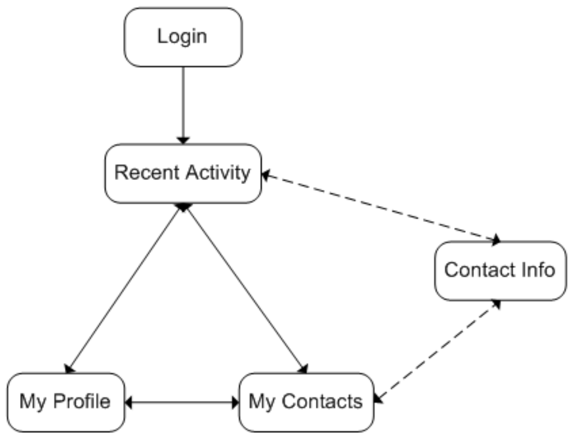


Figure 16. Pages transition graph of secondary user web application [P1].

The mobile application, also known as MobSOP, works on all Symbian version three (Symbian^3) mobile devices. At the moment when this particular mobile platform was selected, Symbian was the most widely used smart phone operating system in Finland. The MobSOP application was implemented with Qt, which is a cross-platform application framework often used to implement graphical user interface software for mobile devices [Qt]. The Qt Modelling Language (QML) is part of the Qt framework, and it is destined to design the user interfaces of applications for mobile devices with touchscreen input. MobSOP UI is implemented using the QML. If the user changes the mobile's profile to silent or to meeting, MobSOP automatically sets the status information of the user to a value of unavailable. The profile of the mobile device is observed by using Qt's Profile API. MobSOP also uses the location information of the device, and users can teach locations to MobSOP. For example, the user can determine that the current location is "work." The MobSOP automatically sets "work" as the value of location whenever the user enters the vicinity of the specified location. The information about the device's current location is retrieved via the Qt Mobility's Location API.

The evaluation was performed by target user group in Finland and Austria, and a Greek company was involved in its implementation and also in the testing. Thus, four language versions were already required for the testing and evaluation phases: Finnish, German, Greek, and English, which was the working language used for the project.

Therefore, the localization of the AMCOSOP system had to be possible and easy. The localization was implemented with simple separate language files, so the addition of new language versions would be feasible. This strategy is in line with the main principle followed in the software development that called for the expandability of the system. Other examples of taking the expandability into account are the implementation of the Sensor API for possible future needs and the use of an MVC pattern in the Home Terminal software.

3.2.6 Evaluation

The evaluation of the system was performed with target user group with authentic use context in two field trial periods in two countries, Finland and Austria. The first period continued for 10 weeks, and the second lasted 17 weeks. After the first period, modifications to the system were implemented based on the feedback from the users. During the pilots, the primary users used the Home Terminals in their own apartments, and the secondary users tested the web or the mobile application. For the first field trial period, 12 primary users and 24 secondary users participated; for the second period, the numbers of primary and secondary participants were 22 and 25, respectively. The gender and the age range of the users in both countries are presented in Table 1.

Table 1. The gender and age of the field trial participants.

	Finland						Austria					
	Primary users			Secondary users			Primary users			Secondary users		
	Female	Male	Age	Female	Male	Age	Female	Male	Age	Female	Male	Age
Phase 1	6	2	67-91	8	9	20-72	3	1	58-69	3	4	28-65
Phase 2	7	2	67-91	7	2	20-72	8	5	58-73	6	10	28-82

The main methods used to collect the results were the Self-assessment Manikin (SAM), Technology Acceptance Model 3 (TAM3), EmoCards, and UX Curve. All these methods are widely used and the project group had earlier experience on using them. All methods were applied as paper forms that the primary users were asked to fill in once every other week during the field trial.

The Self-assessment Manikin is a text-free, three-dimensional assessment of emotions [Bra94]. It is used to measure people’s internal feeling states towards some type of stimuli. SAM supposes that internal feelings can be modelled by using just three basic dimensions: pleasure, arousal, and dominance. The users were asked to select one value from the nine-step scale for these three dimensions to describe their feelings related to attractiveness, ease of use, degree of use, utility, and communication. The SAM form is shown in Figure 17.

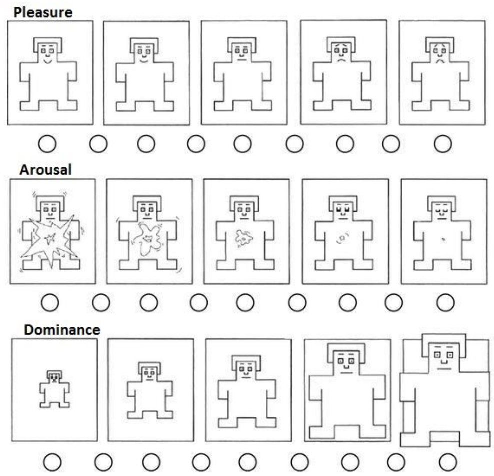


Figure 17. The Self-assessment Manikin.

The Pleasure scale ranges from a happy smiling figure (pleasant) to a sad figure (unpleasant). The Arousal is scaled from a wide-eyed figure (excited) to a sleepy figure (calm). The Dominance, which is scaled from dominated to dominating, is represented by the size of the figure; a large figure indicates maximum control in the situation.

According to the Technology Acceptance Model 3 [Ven08], the main factors that determine the intention or attitude toward using a given form of technology are perceived usefulness and perceived ease of use. Perceived ease of use has a causal effect on perceived usefulness. The actual usage correlates directly to the person’s attitude toward using. The system characteristics influence the perceived ease of use and also the perceived usefulness, thus having an indirect effect on the actual usage of the system. These dependencies are presented in Figure 18.

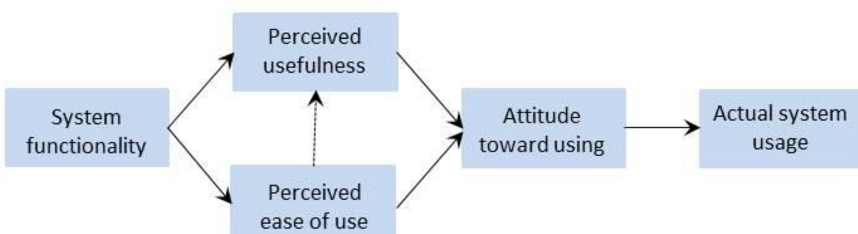


Figure 18. Simplified Technology Acceptance Model.

In the evaluation we applied TAM3 using paper Likert scale questionnaires. The questionnaires consisted of 30 claims related to the AMCOSOP system and especially to the Home Terminal. The answer was given by selecting one out of five gradients, which ranged from strongly agree to strongly disagree, for every claim.

The UX Curve is a qualitative method for evaluating long-term user experiences [Kuj11]. The user sketches a curve of how the user's relationship with the tested system changes over time. The user also marks peaks and lows on the curve and explains what caused the change. In this evaluation, UX Curves were used to qualify attractiveness, ease of use, utility, and communication. The test users were provided a template with a two-dimensional graph area and lines for describing the reasons for the changes. The used template is shown in Figure 19.

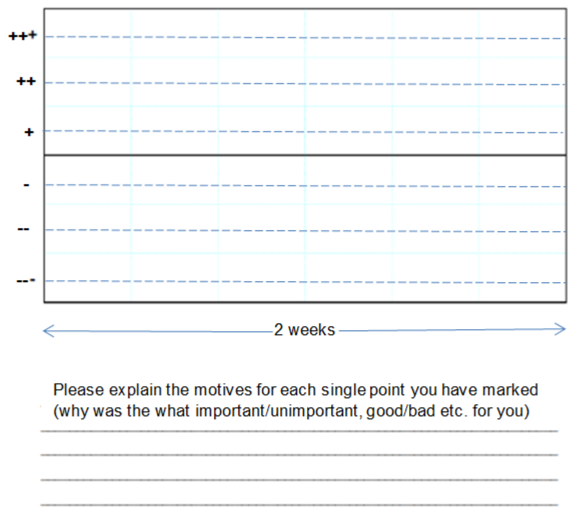


Figure 19. The template for the UX Curve.

Emocards [Des01] were used in the second phase of the field trials instead of the SAM figures. The reason for this decision was twofold; some users found SAM difficult to use, and we were also interested in comparing these two methods. Emocards are similar to SAM, and they provide a way to express emotional responses without words when the emotions are difficult to verbalise. Emocards consist of eight cards with faces printed on them, and the expression illustrates a value pair for pleasantness and arousal. The faces and the value pairs are shown in Figure 20. In our study, we used the female face (the left-hand faces in Figure 20) so that the users would select a card that best expressed their emotional response.

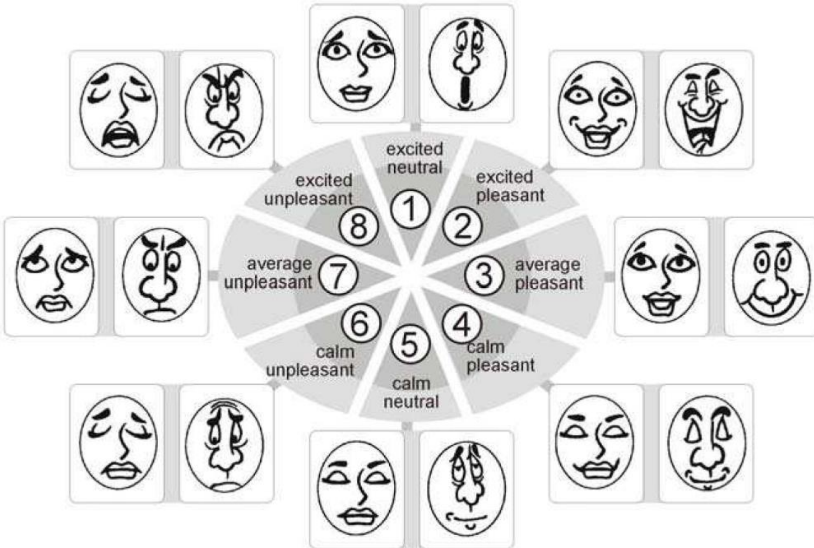


Figure 20. The Emocards and their related emotional categories [Des01].

In addition to the aforementioned surveys, the test participants were interviewed by telephone in the middle and at the end of both field trial periods. The interview was concerned with the general feelings about the system, the weaknesses, and the strengths of the Home Terminal, the usability issues, and the influence on the respondent's communication behaviour or on the everyday routines.

Still further, the Home Terminals recorded log files. These log files included information about the internal behaviour of the Home Terminal and all the interactions users performed with the terminal. No personal content, such as the content of the sent or received messages, was collected or stored to the log files. At the end of both pilot periods, the log files were collected and analysed.

In Figure 21 the used methods are shown on a timelines for both trial phases. The schedule of the trials was same in both countries, so the timelines in Figure 21 are valid for both Finland and Austria.

	2012										
	25	26	27	28	29	30	31	32	33	34	Week
TAM3		X		X		X		X		X	
UX Curve		X		X		X		X		X	
SAM		X		X		X		X		X	
Telephone interview					X					X	
Log files										X	

a)

	2012				2013													
	49	50	51	52	1	2	3	4	5	6	7	8	9	10	11	12	13	Week
TAM3		X		X		X		X		X		X		X		X		
UX Curve		X		X		X		X		X		X		X		X		
EMO Cards		X		X		X		X		X		X		X		X		
Telephone interview										X							X	
Log files																	X	

b)

Figure 21. The timelines of a) phase one, b) phase two, of the trial.

After the field trials the collected data was analysed. The data was inserted to Excel sheets and mean values, median values and standard deviations were calculated for all measured magnitudes. Line or column diagrams were drawn for all values to visualise the results.

The main findings to emerge from analysis of the collected data were as follows:

1. The users found the system very easy to use.
2. The primary users felt that the system improved their life, but the improvement was moderate or minor.
3. The system caused reasonable change in the communication behaviour of the primary users.
4. There was almost no discrepancy in the results of Finland and Austria.
5. There was no significant discrepancy in the results based on the gender of the primary user.
6. There was no significant discrepancy in the results based on the age of the primary user.
7. Minor modifications to the user interface might have a prominent effect on UX.

In the following section, the results of both field trial periods are briefly analysed.

The mean values of the main results of the TAM3 questionnaire for the first period in Finland are shown in

Figure *22*. The value of the Perceived Usefulness (PU) indicates that the system provided some improvements in the lives of the users. The high value of the Perceived Ease of Use (PEOU) indicates that the users felt that the Home Terminal is easy to use and the interaction with it is effortless. Also, the Computer Self-efficacy (CSE) has a very high value. The users found the Home Terminal intuitive and reported that the displayed information was clear and easy to understand. Users’ expectancy of the system was met.

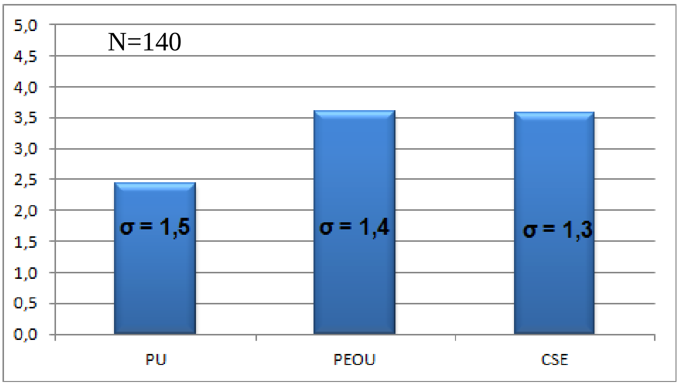


Figure 22. The main results from the TAM3 of the first field trial period in Finland, mean values and standard deviations (σ).

The SAM method was used to measure the Pleasure, Arousal, and Dominance values. In Figure 23 the results from the first period in Finland are shown. For Pleasure, the values are slightly higher than average, which means that the usage of the system was a quite neutral experience for the primary users. Ease of Use shows highest value, meaning that users found it easy to use the Home Terminal. The values for arousal were quite high except for Ease of Use. This may indicate that the users were a bit excited to use the Home Terminal and the AMCOSOP system. The users commented that they had some concerns of breaking the system or doing something wrong. This response is typical when elders with limited experience with computers begin to use a new system [Rou10]. The Dominance values are on an average level, indicating that the primary users were not dominated by the system and they felt as though they were able to use the system in the way they desired.

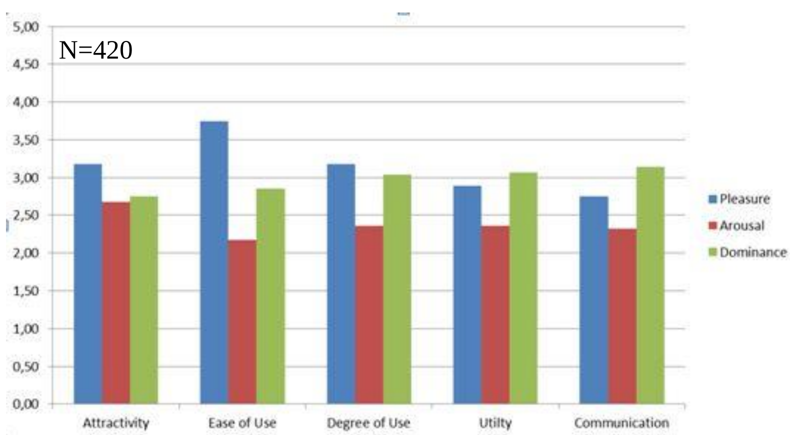


Figure 23. The results from the SAM of the first field trial period in Finland, mean values.

A UX curve was drawn related to attractiveness, ease of use, utility and communication. The collected data ensures the results from TAM3 and SAM methods. The mean UX curve for ease of use from Austria is shown in Figure 24. The curve demonstrates that the system was easy to use. First there was a learning phase after which the value remained high, but during the last week of the trial period it plunged. That is explained by the problems with network connections that appeared at that moment and made the use of the system challenging.

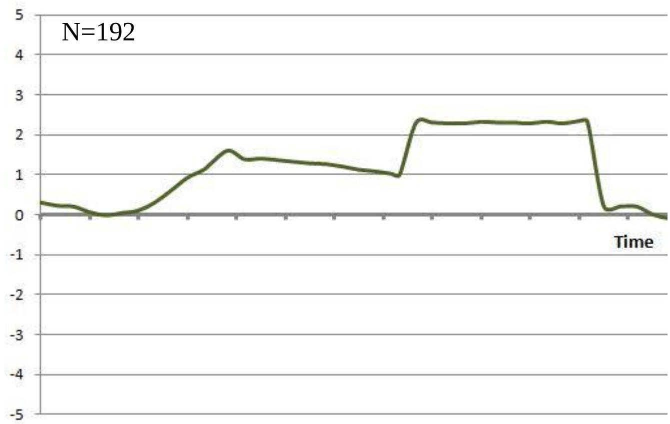


Figure 24. UX curve for Ease of Use from Austria field trial period one, mean values, modified from [P3].

After the first trial period, some modifications and improvements were made to the system based on the feedback. The most visible change for the primary users was that the possibility to write one's own messages was made available instead of allowing only predefined messages. For this purpose, a keyboard was provided for the second period, and all participants were willing to use it. The functionality of the keyboard was modified so that any keys that would not be needed and that might cause any undesirable function (such as the Windows, Esc, and Alt keys) were disabled. The number of choices that the user could select for Status, Activity, Mood, and Location was also increased. Still further, some technical improvements to make the system more robust were implemented.

For the second period, the results of the TAM3 were better than those obtained for the first period. This finding indicates that the improvements and modifications made after the first period were successful. Most of the primary users in the second field trial period had joined during the first period, so they already had some experience using the system, which also explains the improvement of the PEOU. The main results from the TAM3 of the second field trial in Finland are presented in Figure 25.

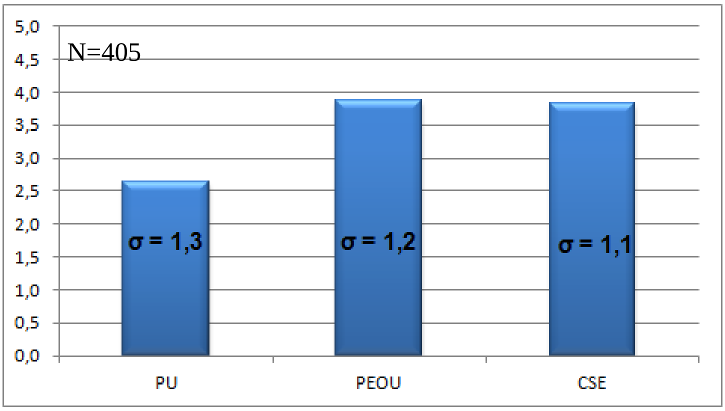


Figure 25. The main results from the TAM3 of the second field trial period in Finland, mean values and the standard deviations (σ).

The results of the users' attitudes and affections from trial period two in Finland, which were collected using the EmoCards method, are presented in Figure 26. EmoCards were found to be easier for the users than SAM. When compared to the results of the SAM for trial period one, the results had higher values except for the value for Ease of Use, which was lower. The primary users were provided a keyboard for period two; some of them had no prior experience with using a keyboard, and they found the keyboard difficult to use, especially at the beginning of the period. The lower value for Ease of Use might appear to be inconsistent to the results from TAM3, where PEOU had higher value in period two, but this is caused by the dissimilar point of view between the TAM3 and EmoCards methods; TAM3 measures the intention or attitude toward using and EmoCards are used to gather the users' affective reactions to the system. Higher result values for variables other than the Ease of Use indicated that the quite simple modifications made after period one had a remarkable influence on the user experience (UX).

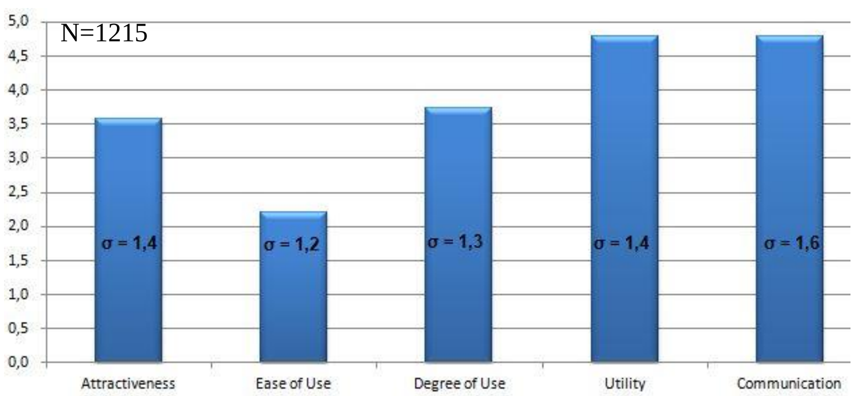


Figure 26. The main results from the EmoCards of the second field trial period in Finland, mean values and the standard deviations (σ).

The ease of use measured by the UX curve for the second field trial period in Austria is shown in Figure 27. Similar to the first period, there is an initial learning phase after which the value remains high until the end of the trial.

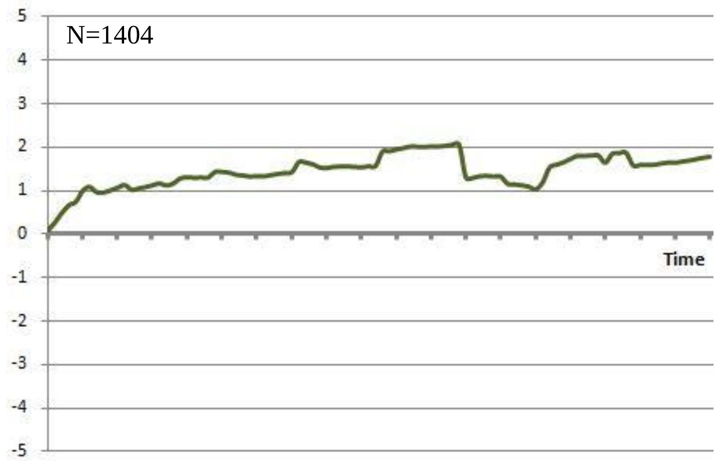


Figure 27. The UX curve for Ease of Use from Austria field trial period two, mean values.

The activity of the primary users was analysed from the log files collected by the Home Terminals. The only significant discrepancy between the results in Finland and Austria in the entire evaluation was in the user activity. The total activity was similar, but there was notable divergence in the preference for status updates and messages. In Finland, primary users updated their status more often and regularly than in Austria, whereas messages were sent by primary users in Austria more frequently than in Finland (Figure 28 and Figure 29). The average numbers of status updates done in the first ten weeks of the second trial periods in both countries are presented in Figure 28, while the average number of messages sent by primary users is shown in Figure 29. The reduction around week four, which can be seen in Figure 28 a), was due to the time of year, as it was Christmas time.

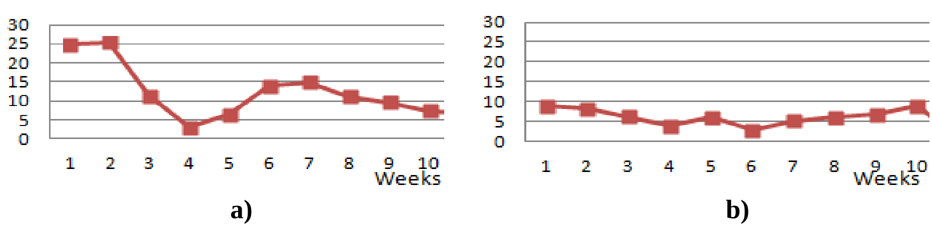


Figure 28. The average amounts of status updates per user during the first ten weeks of the second trial period, a) in Finland and (N=10 users) b) in Austria (N=13 users), modified from [P4].

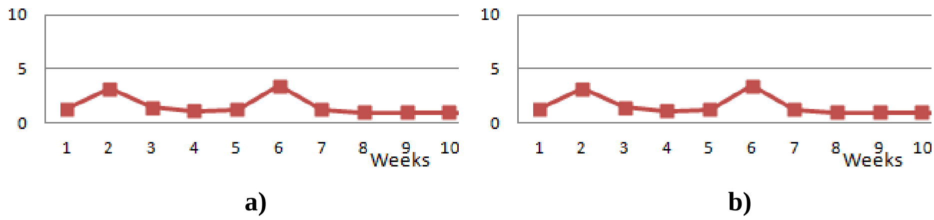


Figure 29. The average amounts of sent messages per user during the first ten weeks of the second trial period, a) in Finland (N=10 users) and b) in Austria (N=13 users), modified from [P4].

From the log files, it was also calculated that the primary users used the Home Terminal during phase one for an average of 40 minutes each day in Finland and for 29 minutes per day in Austria. For phase two, the average usage times were 27 and 32 minutes, respectively.

3.3 Summary

Loneliness is one of the main factors that reduces the quality of life of the elderly, and it can be associated with increased use of healthcare services as well. Our study substantiated the idea that feeling lonely and being socially isolated can be prevented using technical means, which has also been suggested by previous studies [Tol02] [Egg03] [Gib10] [Bur12]. The AMCOSOP system developed during our research indicated that elderly participants with no previous computer experience could easily learn to use a system, if the system has been designed for them and involves them in the design process.

The AMCOSOP system does not automatically collect information of the senior citizen's life, as for example Digital Family Portrait and CareNet do. As a result, AMCOSOP does not violate privacy, as the elder decides what information to share. Furthermore, information automatically collected by sensors is not always as dependable as information entered by a human. For example, if other people are temporarily present in the apartment, sensor-based systems are not able to provide correct information.

In the future, AMCOSOP could be further developed to provide the elderly with the ability to adjust the visibility of the shared information so that some information would be provided only to certain members of the contact network. Another limitation in the current system is that elder is able to use the system only at home, as the home terminal is too large to carry along. Obvious issue for future work is the development of mobile UI for elders.

The effort involved in the installation of the AMCOSOP is minimal as no input devices like sensors are required. The only device to be fitted in the elder's apartment is the Home Terminal, which needs electricity and a network connection to operate successfully. The amount of information sent to or from the Home Terminal is low, so there is no demand for a high-speed network connection; in the pilot periods, 2G USB network sticks were used to connect the terminal to the Internet.

The evaluation of our system was done in long lasting field trials with two phases. To collect the results, both qualitative (telephone interviews) and quantitative (questionnaires) methods were used. The results indicated that elderly people were willing to learn to use and to apply new means for communicating. Furthermore the results demonstrated that the AMCOSOP system increased the willingness to communicate with relatives and friends and so prevent the feeling of loneliness. After the field trial period, some primary users were unwilling to return the Home Terminal; they felt that it offered them better means to communicate with their safety net and provided a feeling of remote presence with their relatives. The results and feedback from the field trials and the exploitation and commercialization studies performed during the project showed that there is a need and a commercial demand for a service with similar functionality than the AMCOSOP system.

Moreover, we proved that the current software and hardware technology provides sensible tools and means to implement a straightforward and innovative user interface that can be tailored to the special needs of its users. Particularly, the touch screen devices and JavaFX software platform proved to be an excellent combination.

One potential risk of this remote presence and new means to communicate is that it might reduce the amount of face-to-face communication and encounters. That risk, however, cannot be considered as a serious one because nothing can substitute for physical appointments with other human beings. Thus, remote presence systems are not intended to replace traditional one-to-one communication but instead offer an additional method for communicating.

4 Positioning Systems for Ambient Assistive Environments

To best aid the occupant, the ambient assistive environment must collect information about him or her. One of the most valuable pieces of information is the location of the user. The knowledge of the position of the person enables the implementation of various kinds of applications to make the living environment safer and easier [Elb12] [Nak10]. Examples of these kinds of applications are the automatic adjustment of electric devices, such as turning off the sauna stove when the user has left the sauna, or switching off the kitchen oven when the user has been out of the kitchen for some time. Furthermore, “follow-me” applications can use location data to adjust lighting or sound playing so that the lighting is on or music is played only around the user [Kai09] [Kem08]. Additionally, the reliable real-time location data enables the detection of abnormal activity; these position systems can provide peace of mind for the relatives of an elder who lives alone.

Outdoor positioning can be done reliably almost everywhere using a Global Positioning System (GPS). Indoors, however, GPS does not work properly, and there is no overall solution based on a single technology that could be used in all interiors. Indoor attenuation and multipath reflections of the measurement signals from walls, floors, ceilings, or from furniture make the positioning more challenging compared to outdoor positioning. As the home is the intended operating environment, further requirements are needed for the positioning system. The system should be easy and effortless to use, and the positioning should not require the users to perform any specific actions. In addition, the system should be unnoticeable, preferably totally invisible, as people usually do not want any extra sensors or actuators to be in sight in their homes [Elb12].

Identification is closely associated to the positioning. From a positioning systems perspective, there are two distinct identities: the absolute identity of the person and the identity used by the system, which is an internally generated ID for each person during each run of the positioning application. The absolute identity is not essential for the positioning application, but the maintenance of the consistent person ID is needed to enable the tracking of several people simultaneously [Kru00].

Indoor positioning is also required or useful in several areas outside of assisted living. It would be advantageous to know the location of personnel, customers or devices in many workplaces, like in hospitals [Nis04]. There has also been research conducted related to using the location information in the military [Ran12], fire and rescue services [Har13], and in law enforcement agencies [Fra96]. The first pilots of location-based advertising were arranged in the beginning of the 21st century [Kiv04], and now there are numerous applications that even provide users with advertisements of shops and services nearby.

4.1 Introduction

In this thesis, the positioning systems have been divided into two main categories: tag-based and device-free passive (DfP). Other kinds of divisions have also been presented. In [Tor10], the positioning systems were classified to radio frequency, photonic, sonic, and inertial based on the measured physical quantity. An obvious categorization of the systems is based on the technology employed or the measurement principle, as reported by [Son11]. [Mau12] indicated that the systems can be separated into either centralised or distributed based on if the position determination is performed at a central server or onboard at each node based on local observations. From the user's point of view, the most notable distinction between the systems nevertheless is whether he or she has to carry any device or perform any specific actions to be positioned.

Camera-based positioning systems can be implemented as DfP systems or set up so that the user wears a mobile camera. Furthermore, camera-based DfP positioning systems have several characteristics that make them dissimilar from the other DfP systems. Therefore, camera systems are presented in their own sub-section.

4.1.1 Tag-based Systems

In tag-based systems, a transmitter emits a measurement signal that is detected by sensors. The location of the transmitter or the sensors is fixed and known, and the user either carries or wears the other. The user's location is determined based on the signal level, the signal's angle of arrival, the time difference of arrival at several receivers, or using a time-delay of the measurement signal. Several of these signal parameters can be used in conjunction in order to increase accuracy [Elb12].

The first widely known indoor location system was the Active Badge system [Wan92], which was developed by the Olivetti research organization in 1991. In this system, every person to be tracked has a personal active badge. The badge sends a unique infrared (IR) signal that is picked up by a network of sensors placed around the building. A master station polls the sensors and keeps track of the positions of the badges.

Since then, several similar but more advanced systems have been introduced. Ultrasonic systems use ultrasonic pulses whose time of flight (ToF) from the transmitter to the receiver is measured [Hig01]. The distance between a transmitter and a receiver is calculated based on the ToF. If there are several receivers and one transmitter or several transmitters and one receiver, the position of the object can be determined based on the distances between the devices. Ultrasonic systems have been implemented so that the user must carry the transmitter [Har99] and also in a way that the user wears the receiver [Pri00].

Radio frequency (RF) can also be used for positioning. With RF systems, a fingerprinting technique is usually used. In fingerprinting, values from one or more metrics of the radio signal are first recorded at all possible locations in the tracking area. These metrics include the received signal strength (RSS) [Kam04], ToF [Wib09], and angle of arrival (AoA) [Pen06]. These values and their location information are stored in a database. When the positioning system is running, the values are measured at the user's location, and the measured values are compared to the values in the database to select the corresponding position.

A RF positioning system can be implemented using wireless communication nodes like Wi-Fi [Lee07] [Mar10] [Mah12] or Zigbee [Gro07] [Zha08]. If this type of wireless communication network is already installed in the positioning area, no additional devices will be required to be installed. Problems with these systems include radio signal propagation errors caused by multipath and other error sources. Furthermore, signal strengths are unstable and fluctuate with time, temperature, and objects in the measurement space [Lee07].

Radio Frequency Identification (RFID) positioning operates similarly to Wi-Fi or Zigbee positioning, except that instead of measuring the wireless communication signal, the measurement signal is emitted by dedicated RFID beacons, whose location is previously known [Sec10]. RSS is usually used as an indicator of distance [Zho09]. Various types of construction for different environments have been proposed. RFID positioning for a complex multi-floor hospital building is implemented in [Li04]. The position of active tags, which are carried by the patients and the personnel, is determined by comparing the signal strengths from the tag and also from landmark tags installed in the area.

Ultra wideband (UWB) systems can be implemented without the laborious fingerprinting by using signal triangulation as a sole localization technique. This is possible as the short duration pulses of ultra-wide band are almost immune to the multi-path radio propagation. The user carries a tag that emits UWB pulses when triggered by the system. Pulses are received at fixed receivers, and the user's location is determined based on RSS [Gig07], AoA [Mut09], or on time difference on arrival (TDoA) [Zwi12].

In inertial navigation systems (INS), the positioning is implemented in a totally different way. In INS, the object to be tracked is equipped with inertia sensors that are able to detect a change in its geographic position. If the object's initial position is known, the current position can be calculated based on the information received from the sensors. Inertial navigation has been used in submarines, ships, and aircrafts for decades, but today small and cheap inertial sensors are available that can be used to track humans. The inertial sensors used for human positioning are gyroscopes, which provide angular rate information, and accelerometers that provide velocity rate information [Eve06]. The sensors can be so small that they can be installed in a shoe [Fox05]. The advantage of the INS systems is that no sensors, receivers, or any other devices are needed in the environment of the object to be tracked. They are also accurate for the short term, but due to the noise of the sensor, filtering techniques are needed to reduce the drift [Eve06]. The drawback is that the system must be provided its initial position before it can operate; thus INS systems are commonly used in conjunction with some other technology. [Woo08] combines Wi-Fi and INS so that the user's approximate initial location is defined by simple Wi-Fi positioning, and after that the exact location is defined by INS using a foot-mounted inertial unit.

The main advantage of tag-based systems is that if personal tags are used, the identity of the person in the tracking area can be reliably detected in addition to the location.

Consequently, tag-based systems are usually able to simultaneously track several persons, as their identities can be easily separated by the system. Moreover, a tag-based location system tracks the tags, not the people, which can be considered as an advantage in specific situations. For example, if one does not want to be located, the tag can simply be taken off.

The main disadvantage in all tag-based systems is that the users must wear or carry some type of additional device with them. The user must pay attention to the device, such as when changing clothes, and also the batteries of the device must be replaced occasionally. Furthermore, visitors can not be located and intruders noticed when they are not equipped with the necessary tags. Still further, it is hard for the system to monitor whether people are wearing the devices, the system cannot notice when a user undresses the device.

In ambient assisted living, there is usually a need to continuously track all the people in the tracking area, which is normally the whole apartment. Furthermore, the tracking must be fully automatic so that the tracked persons do not need to perform any activities or participate in any way in the localization process. People are not willing to carry any extra devices with them, especially not in their home environment [Val12]. Hence, DfP positioning systems [You07] are the most suitable ones for ambient assisted living.

4.1.2 Camera Systems

Camera positioning systems can be categorised as mobile camera solutions where the camera is carried along by the participant being located or as fixed camera systems where the cameras are installed in fixed locations in the environment [Mau11].

Obviously, mobile camera systems, also called as ego-motion systems [Dav03], are not device free. Indeed, the installation of the camera reasonably to a human in such a way that the camera works and that the carrying is not disturbing is almost unfeasible. Therefore ego-motion systems are not widely used in human localisation; instead, they are common in robot systems. The positioning process resembles the fingerprinting method of the RF systems. Images are captured from all possible locations of the tracking area, and selected features of the images with the location information of the camera are stored in a database. When the system operates, the mobile camera captures an image, and the image features are used to select the best match from the feature-location database [Tor10].

SenseCam [Ngu09] is widely used mobile camera system. It is a wearable digital camera that automatically captures photographs of the environment of the user. It is usually and initially used to explore day-to-day patterns and routines of the user [Wil13], but obviously it provides information that can be used to localize the user [She14].

Fixed-camera systems detect elements from the view of the camera that are not part of the static background. The segmentation of the human blobs from the background can be done based on luminance contrast [Fue06], colour intensity [Pet06] [Mit03], or depth analysis [Kru00]. The location of the object is determined based on its position within the image with respect to the camera's known fixed position. Colour information is usually used for identity maintenance. This is implemented by using a representation of the distribution of colours in a human blob (colour histogram) [Mit03] [Kru00] or by the average vertical colour of the blob [Pet06].

The main problem with visually based solutions is that they cause privacy concerns, especially with elders [Cai06]. Most people do not want cameras or any other devices seen as intrusive or as invasive to be installed in their homes [Row05]. Furthermore, line of sight from the camera to the user is required, and illumination affects the operation of the camera systems; they do not work at all in the dark [Tap04]. Moreover, the processing of the images is computationally expensive, which might be problematic for real-time positioning.

4.1.3 Non-camera Based DfP Systems

Device-free passive positioning systems that are not visually based are classified in [P5] as follows: pressure sensing, thermal positioning, sound source localization, ultrasound, electric field, infrastructure mediated sensing, and radio frequency. Below a short summary of these methods is presented. In [P5] they all are explained more carefully, and examples of the systems implemented with these technologies are presented, and also the original references provided.

Pressure sensing uses sensors to detect pressure caused by persons located on the sensor. This is a traditional, robust, and accurate way to implement positioning. The installation is laborious; large amounts of sensors and cabling are needed to cover bigger areas and these sensors should usually be installed under the floor surface. Sensor mats consisting of hundreds of sensors and wiring have been implemented to facilitate their installation, but nevertheless it is challenging to install them invisibly or aesthetically.

The human body emits thermal radiation. In the thermal infrared systems, the user's location is defined by recording the thermal radiation in the area with infrared detectors. Heating elements, like lamps, ovens and heaters, or metallic surfaces that reflect infrared radiation can cause errors or inaccuracy if located in the tracking area. The accuracy depends strongly on the used detectors, the use of high resolution, very expensive microbolometers can be made the system remarkably accurate. Tracking of several persons simultaneously is challenging with thermal positioning.

Sound source localization uses several sensors (microphones) and the TDoA method to determine the location of the sound source. Accuracy of the positioning is dependable on the number of the sensors. Only objects that produce sound can be positioned, so sound source localization is not optimal for positioning single persons at home. In addition, background noise, reverberations and simultaneous sound sources may cause inaccuracy. Also the computational burden in sound source localisation is relative high.

The human body reflects ultrasound signals. The position of a human can be detected by transmitting an ultrasound signal and calculating the ToF after the signal is reflected off from the person's head and detected at the receiver. As the speed of an ultrasound wave is relatively low, the time that wave travels from one point to another can be precisely measured. These pilot systems are very accurate when implemented, but they require numerous sensors and are therefore are suitable only for small areas where exact location information is needed.

Infrastructure-mediated positioning uses the pre-existing structures of a building. Used structures include ventilation system, residential power lines, and water and drainpipes. The accuracy is poor, the location can only be determined in the room level at best. The installation is not burdensome, and the system can usually be installed totally invisible. And as no new sensing infrastructure is required, the system is cheap.

The human body attenuates signals of wireless networks. This phenomenon can be used for positioning. A fingerprinting method is used to collect the RSS of the radio signal at all locations of the tracking area without human presence. When operating, the measured RSS is compared to the collected ones, and the location of the human is determined based on the attenuation of the RSS. The installation effort is low, and the system is cheap, especially if the wireless network is previously installed to the area. The positioning accuracy is poor, and the physical configuration of the system has a great influence to the achieved accuracy. Furthermore, the implemented systems are not able to track several persons simultaneously.

The human body generates changes to the electric field when located between transmitter and receiver electrodes. Capacitive positioning systems are using this phenomenon when detecting the location of a human. Capacitive systems are described more carefully in Section 4.2.

The price, installation effort, accuracy, and obtrusiveness of the non-camera based DfP systems are compared in Table 2. In the case of ambient assistive home environments, capacitive systems have some advantages over other systems: 1) they cause no privacy concerns, 2) they can be installed invisibly, 3) they can recognise both moving and static humans, and 4) they are affordable. The rest of this Chapter concentrates on the capacitive systems.

Table 2. Characteristics of the non-camera based DfP positioning technologies, modified from [P5].

Technology	Price	Ease of Installation	Accuracy	Obtrusiveness
Pressure sensors	Expensive for large areas, as accuracy requires several sensors.	Laborious. Sensors are usually installed under the floor surface.	5 cm	Invisible
Thermal infrared sensors	Pyroelectric and thermopile applications are inexpensive. Microbolometer-based cameras are expensive.	Moderate. Ease depends on the number of sensing elements used.	5-20 cm	Invisible
Sound source localization	A microphone array is needed, but relatively inexpensive miniature microphones can be used.	Moderate. At least three microphones are needed. However, accuracy increases as the number of microphones increases.	30 cm	Almost invisible. Microphones can be hidden, e.g. in picture frames
Ultrasound	Expensive for large areas due to the number of sensors required.	Laborious. Several sensors are required.	5–10 cm	Invisible
Electric field	Cheap. About €20 per m^2.	Laborious. This system usually requires the installation of electrodes under the floor surfaces and in the ceiling.	15–30 cm	Invisible. Electrodes can be installed under the floor surface and in ceilings
Infrastructure-mediated sensing	Cheap. Hundreds of euros per household.	Moderately easy. This system usually only requires the installation of a couple of sensors.	Room	Invisible. Sensors can be installed outside of the living area, in the basement or in the loft.
Radio frequency	Cheap. Hundreds of euros per household.	Easy.	1 m	Almost invisible

4.2 Capacitive User Positioning

At Tampere University of Technology (TUT), there has been long-lasting research related to capacitive positioning. Valtonen and others have developed a pilot system called TileTrack [Val09] [Val11] [Val12]. In this thesis the testing and reliability [P6] and modified mobile version [P7] of the TileTrack are discussed.

4.2.1 TileTrack Positioning System

The principle of capacitive positioning systems is that the human body conducts low-frequency electric signals well and when a human body is between a transmitter and a receiver, it affects the capacitance measured between them [P5]. When there are several transmitters, the user's location can be determined by measuring the capacitance between every transmitter and the receiver. The capacitances existing with the TileTrack system are presented in Figure 30.

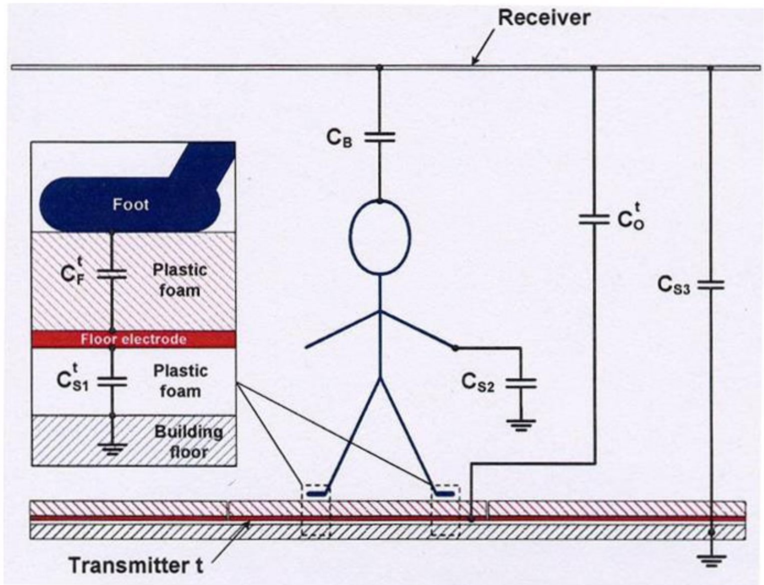


Figure 30. The capacitance model of the TileTrack system, modified from [Val09].

C^t_F is the capacitance between the transmitter installed in the floor and the user's foot. It increases when the common area between the transmitter and the foot increases or the distance between them decreases. C_B is the capacitance between the user's body and the receiver. C^t_O is the offset capacitance that exists between the receiver and the transmitter when there is no human nearby. The value of the C^t_O is dependent on the structure of the system, mainly on the distance of the receiver and transmitter, but also on the environment, so the C^t_O must be measured every time the system is installed in a new location. Stray capacitances C^t_{S1}, C_{S2} and C_{S3} appear between the user's body, the transmitter, the receiver, and the ground. These values remain almost constant at all times and can be neglected during the operation. Based on the capacitance model, the traditional circuit diagram shown in Figure 31 can be drawn.

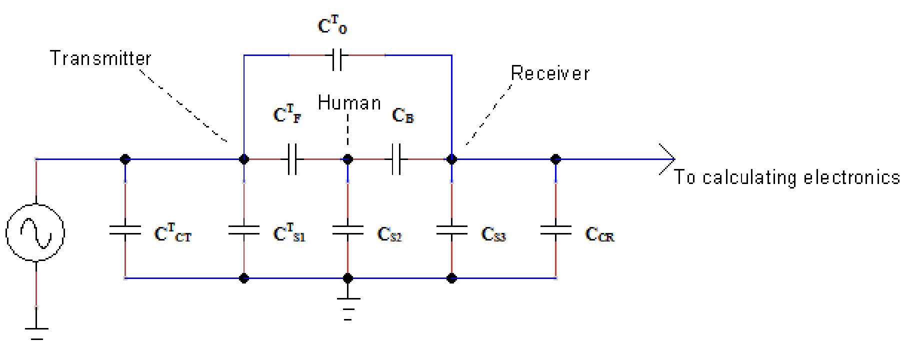


Figure 31. Circuit diagram of the capacitance model, modified from [Val12].

C^t_{CT} and C_{CR} are capacitances between the transmitter and receiver cables and the ground. Their effects are eliminated when calibrating the system before operation.

From the circuit diagram and the hypothesis presented above, it can be seen that the capacitance C^t between a transmitter and the receiver is the serial capacitance of the C^t_F and the C_B in parallel with C^t_O

$$C^t = \frac{C^t_F C_B}{C^t_F + C_B} + C^t_O \tag{1}$$

The actual implementation of the TileTrack includes transmitting electrodes made of copper foil and of steel plates and installed under the floor's surface. The transmitters are connected to the measurement electronics by cables. The measurement electronics are also wired to the receivers as well as to a computer that runs the tracking algorithm. The hardware and software of the system are presented in detail in [Val12].

4.2.2 Robustness Testing of the TileTrack Positioning System

To be used in a real-life home environment, the system must be robust and work reliably. For testing purposes, TileTrack was installed in the TUT SmartHome laboratory. SmartHome is a complete 69-square-meter apartment with a living room, a bedroom, a kitchen, a bathroom, and a sauna. It is used in real-life testing of intelligent environment devices, software, systems, and user interfaces. The laboratory can be seen in Figure 32.

Figure 32. The SmartHome laboratory at the TUT Department of Electronics and Telecommunication.

TileTrack is operational in the living room, kitchen, and bedroom of the SmartHome. The transmitters are installed under the surface of the segmented floor. Transmitters of two sizes are used, as shown in Figure 33. Smaller transmitters provide more exact location information [Val12], but the measurement is slower with them and the amount of wiring needed is increased.

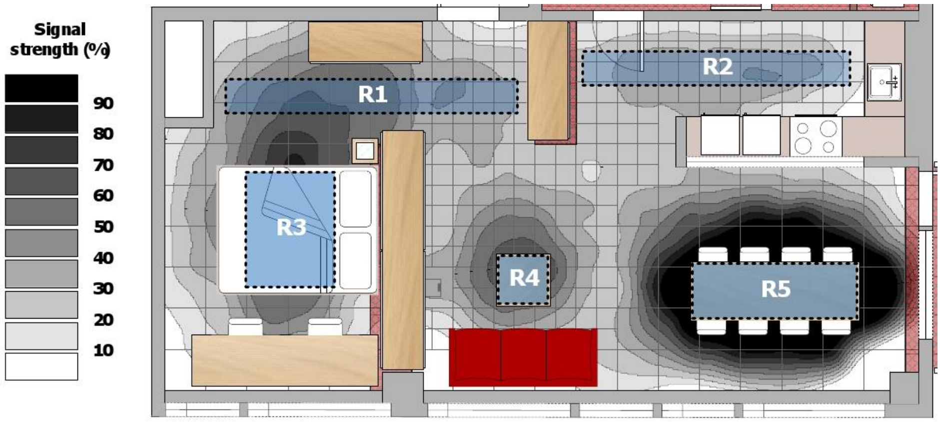


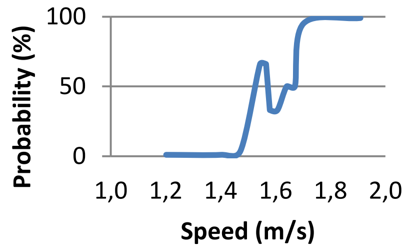
Figure 33. The positions of the receivers R1-R5, the transmitter floor tiles, and the received signal strength [P6].

In the test setup, five parallel-connected receivers were used and are shown as R1-R5 in Figure 33. R1 and R2 were installed below the ceiling, R3 in the bed, R4 in the living room's coffee table, and R5 in the dining table. R1-R3 were manufactured of conductive textiles and R4-R5 were made of copper foil. Figure 33 also shows the received signal strength as a percentage of the maximum signal value.

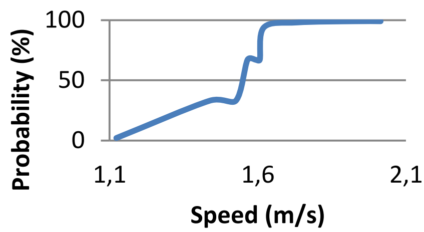
In previous initial tests, it was found that a single human could be located with about 7 cm accuracy while standing on a smaller transmitter tile and with about 11 cm accuracy using a larger tile. For a human in motion, the corresponding accuracies were 17 cm and 33 cm, respectively [Val12]. In real-life applications, however, the robustness is more important than the accuracy, which ensures that the system is continuously able to provide the location. As TileTrack has a specific update rate, there is also a breakpoint value for the speed of the moving object above which the system is not able to track the object.

In the robustness tests, the test person walked three predefined routes multiple times and in both directions. The test person used variable walking speeds to determine the speeds that will cause the system to lose track of the person. Tests were performed by one test person, but as there was a presumption that shoes may influence the accuracy and reliability of the system; therefore, the test walks were performed both with and without shoes.

The system was monitored during each walk to observe if it would lose track of the person. This binary information was stored along with the walking speed for each test walk. The collected data were used to plot the probability curves, which indicated the probability that the system would lose the person as the walking speed increased. Two examples of the curves are shown in Figure 34. These curves are from the same walking route walked in the same direction both with and without shoes. More results and a more detailed analysis are provided in [P6].



a)



b)

Figure 34. Probability that the user tracking system would lose the person, a) without shoes, b) with shoes [P6].

The test results pointed out that a breakpoint value for the walking speed, above which the reliability of the system decreases dramatically, could be found. This value was above the normal walking speed. Furthermore, it was noticed that the reliability was weaker when the test person wore shoes, as shown in the curves a) and b) in Figure 34. The reason for this result is that the shoes reduce the measurement signal emitted by the body.

4.2.3 Mobile Positioning Platform

Capacitive positioning systems are usually laborious to install, and this fact was the main motivation to study if a moveable capacitive user tracking system could be developed. The developed solution is a mobile version of the TileTrack system, and its measurement principle and implementation are similar to that described in the previous subsection.

The floor of the system is constructed of soft, interlocking floor tiles. The floor consists of 24 tiles 30 x 30 cm in size and of nine tiles measuring 60 x 60 cm. The transmitter electrodes are made of copper foil that is glued on the bottom surface of the tiles. Every electrode is connected to the measuring electronics by a coaxial cable. The tiles and a transmitter electrode are shown in Figure 35.

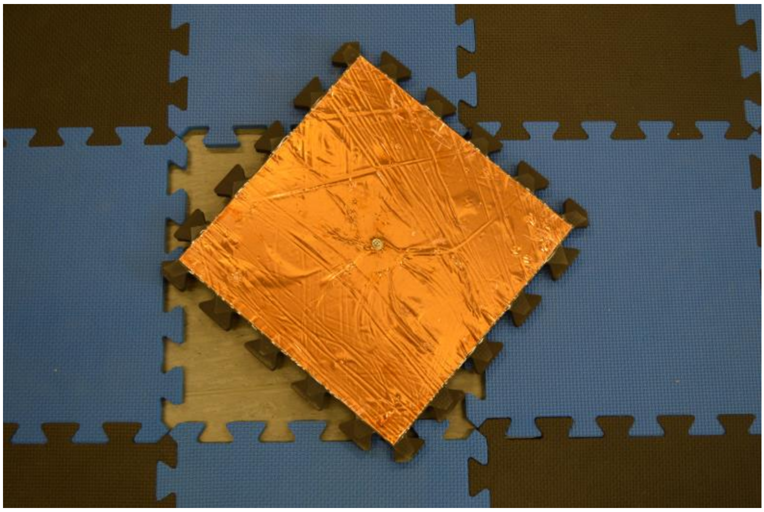


Figure 35. The transmitter electrode (size 30 cm x 30 cm) of the mobile tracking system.

The receiver is made of silverised textile and is placed above the tracking area and supported by four plastic poles. The system includes also a display that is used to show the user’s position. The entire positioning platform is shown in Figure 36.

Figure 36. The mobile positioning platform showing the locations of one standing and one exhausted researcher on the display in the middle.

The electronics measure the capacitance between a single transmitter and the receiver, one at a time. If a person is located on the tile, the capacitance increases for the transmitter on which the person is located. The measuring electronics, as shown in Figure 37, include three main components: the actual measurement chip AD7745 [AD05] that performs the measurement of the capacitance and converts it into digital form, the microcontroller that communicates with the computer running the tracking algorithms and takes care of the timing of the measurements, and the multiplexer that delivers the measurement signal to one tile at time.

The tracking algorithm positions the user to the midpoint of a tile if the user stands only over a single tile. If the user is standing on multiple tiles, the centre of mass is calculated using all the increased capacitance values. In addition to the horizontal location, the system is able to determine the posture of the user. This is done by converting the capacitance between the user and the receiver to a distance between them, which is converted to user height. A simple threshold-type classifier determines the user’s posture as one of three classes: standing, sitting, and lying on the floor.

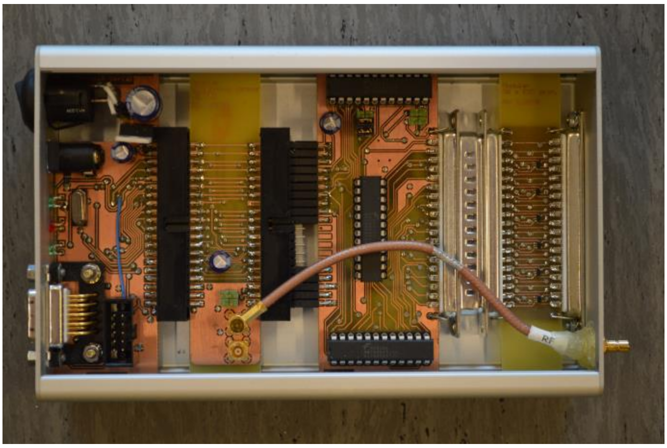


Figure 37. The measuring unit of the positioning platform.

The system is able to reliably track five people simultaneously. The assembly of the positioning platform is easy and fast, requiring only about 15 minutes when performed by two people. The system must be calibrated after the assembly, which is done automatically when the system is started and takes only a couple of seconds. Once disassembled, the platform can be packed and easily carried along.

4.3 Discussion

Capacitive positioning systems are unobtrusive, affordable, and do not require any actions from the inhabitant. These characteristics make them to be the most suitable positioning technology for ambient assisted living when no detailed analysis of the person's activities is needed. The installation of a capacitive positioning system is inexpensive and undemanding if it takes place during the building stage of an apartment. While installation in existing apartments is often laborious, [P7] demonstrates that the problem of the installation can be simplified.

The positioning system must be able to track several moving persons simultaneously. [P6] and [P7] prove that a capacitive system can qualify this requirement. In [P6], it is pointed out that shoes have a significant influence on the accuracy and reliability of a capacitive system. This is not an issue for cultures where shoes are not worn indoors, but for other cultures, this is an issue that requires still further study.

Users must feel that they are getting some benefit from the positioning system before they will be convinced to install it in their homes. The location data provided by a positioning system enable the implementation of various applications that can provide a sense of security to the elderly residents and peace of mind to their relatives. Furthermore, the users must know how the location data is used and stored and who can access it. Often the users initially have doubts related to the positioning system, but their concerns usually diminish after the system has been used for some time [Wan92].

5 Conclusions

The ageing of population that is rapidly taking place in all developed countries implies challenges but also opportunities for the citizens and industry. Ageing in place, which suggests the ability to live in one's own home and community safely and independently, regardless of age or ability level, is prioritised by elders. Assistive technical applications can help the elderly to live fuller lives by improving their participation in activities and also their independence.

The effects of the demographic change are already visible. Nowadays the majority of middle-aged adults are having living parents. Often the adult children are living at a considerable distance from their parents and are concerned with how their father or mother is coping. Day-to-day awareness is the most important issue to provide peace of mind to the adult children and to other relatives of the elder. For the elder, it is restful to know that someone is looking after him or her, and that someone is available if needed.

This thesis deals with technologies to provide ambient assisted living for elders. It covers two particular areas: to prevent the feeling of loneliness by means of a social networking system designed from the outset for the elders and to collect dependable real time location information of the inhabitant. Both these technologies can be used to provide day-to-day awareness of the well-being of the elder to the relatives.

In Chapter 2 the following research questions were expressed:

1. How can feelings of loneliness in elderly people who live alone be prevented by technical solutions?

2. What types of indoor human positioning systems are most suitable for ambient assisted living?

The traditional online social networking systems are too difficult for senior citizens to use. In this thesis it is explained how an extremely easy-to-use social networking and communicating system for elders was designed, implemented, and evaluated. It was indicated that the loneliness of single seniors can be prevented by remote presence system that is designed particularly to elderly. This finding gives answer to the research question 1.

Positioning data is vital for providing assistive services at home. Implementing the positioning system in a passive, device-free, and unobtrusive way at a reasonable price is challenging. In this thesis it is demonstrated that by using capacitive positioning the location of the inhabitant can be determined in a suitable way to be used at home environment for AAL purposes. This finding answers to the research question 2.

The elders of the future will have more experience in using computers, but perceptual, cognitive, and psychomotor complaints will continue to occur along with aging. Therefore, there will also be a future need for devices and systems designed specifically for use by the elderly. In addition to assistive applications and services, there is a need to revise our perception towards ageing and an ageing society. Ageing should be seen as an opportunity to live longer and better after a lifetime of work has ended, and it should be realised that an ageing society presents many interesting advantages at the social level, as older persons are a precious resource in terms of experience, wisdom, and adaptability to societal changes.

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