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Designing Tangible Interaction for Accessible Communication Technologies for Elderly People

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Für Teresa, Ella und Paul.

Erklärung zur Verfassung der Arbeit

Wolfgang Spreicer

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Abstract

The changes in demographic structures and the concurrent rapid technological development pose challenges to our ageing society. In this thesis, we investigate, whether systems with Tangible User Interfaces can help to provide accessible communication technologies for elderly people. Based on a theoretical foundation from the area of tangible user interfaces, tangible interaction, intuitive usability, and multimodality, we have systematically analysed the impact of interface design, user involvement, and multimodal interaction on accessibility. The core of this thesis is the description of a three-year participatory design process of a concrete, tangible communication technology, with a total of 35 participants, aged between 53 and 83. During the workshops, various prototypes were tested and further developed with potential users. The detailed planning, the thorough implementation, and the structured analysis of these workshops were essential criteria for the successful elaboration of valuable contributions to the research field of accessible technologies for elderly people and the implementation of a functional technical device. The resulting prototype allows the use of communication channels through tangible interface elements. The interface elements consists of objects with generic form and personal objects with special meaning to the users. The use of generic objects creates a token + constraint relation with a strong perceived affordance for the interaction. The visual language of these objects is chosen by personal annotation and design according to the user's preferences, which additionally supports intuitive use. The communication partner is selected via personal objects with special meaning to the user. The evaluations show that the resulting cognitive bridge between the personal objects and the underlying functionality supports the user interaction. To summarize, we provide the AMPTA model (**A**ccessibility, **M**ultimodality, **P**ersonalization, **T**angible User Interface, **A**ge) to visualize the interplay of our results.

The findings of this thesis show that elderly people benefit from Tangible User Interfaces through the use of a clear form language, the use of personalized and autobiographical interface elements and increased learnability. Furthermore, multimodality is an essential factor, not only for the design of the user interface, but also for the evaluation and analysis of user-centred workshops. Our results represent an important contribution towards providing accessible communication technologies for elderly people and encompass approaches to design and develop them participatorily.

Kurzfassung

Die Änderungen der demographischen Strukturen und die gleichzeitig rasante technologische Weiterentwicklung stellen unsere alternde Gesellschaft vor Herausforderungen. Diese Dissertation untersucht, ob der Einsatz von Tangible User Interfaces die Accessibility von Kommunikationstechnologien für ältere Menschen unterstützen kann. Basierend auf einer theoretischen Fundierung aus den Bereichen Tangible User Interfaces, tangible interaction, intuitiver Nutzbarkeit und Multimodalität. Den Kern dieser Dissertation stellt die Beschreibung einer dreijährigen, partizipativen Entwicklung einer konkreten Kommunikationstechnologie mit insgesamt 35 Teilnehmer_innen zwischen 53 und 83 Jahren dar. Jede Design-Iteration bestand aus einer Design-, einer Workshop- und einer Analysephase. In Workshops wurden mit potentiellen Benutzer_innen Prototypen getestet und weiterentwickelt. Die detaillierte Planung, die qualitätsvolle Umsetzung und die strukturierte Analyse dieser Workshops waren ein wesentliches Kriterium für die Ausarbeitung wertvoller Beiträge für das Forschungsfeld der accessible Technologien für ältere Menschen und die Implementierung eines funktionsfähigen technischen Geräts. Der daraus entstandene Prototyp kann per USB an Computersysteme angeschlossen werden und erlaubt den Aufruf von Kommunikationskanäle über greifbare Interface Elemente. Dafür wurden Objekte mit generischer Form und persönliche Objekte mit besonderer Bedeutung verwendet. Durch den Einsatz von generischen Objekten kann eine token+constraint Relation mit starker Affordanz für die Interaktion hergestellt werden. Die Bildsprache dieser Objekte wurde durch Annotation und Gestaltung nach den eigenen Vorstellungen gewählt, was die intuitive Bedienbarkeit weiter verstärkte. Die Auswahl der_des Kommunikationspartners_in erfolgt über ein persönliches Objekt mit besonderer Bedeutung für die_den User_in. Unsere Auswertungen weisen darauf hin, dass die daraus resultierende kognitive Brücke zwischen den persönlichen Objekten und der zugrunde liegenden Funktionalität die Benutzerinteraktion unterstützt. Zusammenfassend präsentieren wir das AMPTA Modell (**A**ccessibility, **M**ultimodality, **P**ersonalization, **T**angible User Interface, **A**ge), um das Zusammenspiel unserer Ergebnisse zu visualisieren. Die Ergebnisse dieser Arbeit zeigen, dass ältere Menschen von einer klaren Formensprache, der Verwendung von personalisierten und autobiografischen Interface Elementen und einer erhöhten Erlernbarkeit von Systemen mit Tangible User Interfaces profitieren. Weiters ist Multimodalität ein wesentlicher Faktor für das

Design des User Interface und die Auswertung und Analyse von Workshops. Die in dieser Arbeit abgeleiteten Empfehlungen stellen einen wesentlichen Beitrag zur Bereitstellung zugänglicher Kommunikationstechnologien für ältere Menschen dar und umfassen Ansätze für deren partizipative Gestaltung und Entwicklung.

Contents

Chapter 1

Introduction

In today's society, the Internet is widely used in many aspects of our daily lives like interpersonal communication via e-mail, online chats, voice over IP, public services (eGovernment) or television (IPTV). But the usage of this technologies is not distributed evenly throughout society: A major part of the elderly population is excluded from the profits of new information- and communication technologies (ICTs). However, an essential factor in the everyday life of older people is the maintenance of the social network or contact with family and friends. The predominant forms of household in old age are one- and two-person households. Contact with family and friends is maintained via telecommunication technology, especially when the geographical distance is large. The possibility of exchanging information is an essential factor in today's society, also from an economic point of view. Limited access to information can also lead to economic disadvantages (*digital divide*). Furthermore, mobility generally decreases with age, and older people spend more time in their own four walls than younger people. At the same time, maintaining one's own home for as long as possible and managing one's own household are essential goals in life for seniors. In this thesis, we therefore examine the possibilities of alternative user interfaces to improve accessibility of modern communication technologies. Therefore we focus on the relevant factors that are needed for the development of such alternative interfaces. This includes the design of the interface elements as well as possibilities to increase user acceptance and a successful integration of future users into the development process. In this way we want to contribute to the research field of accessible technologies, which aims to help elderly people to use products and services of the digital society and thus to benefit from the advantages of modern communication technologies.

1.1 Motivation

The projections of changes in the population structure within the EU 28 provide a clear picture. The share of the population aged between 15 and 65 will fall drastically by 2080, whereas the share of older people in the total population will increase (Figure 1.1). The share of people who are 80 years or older will rise from 5.4% in 2016 to 12.7% by 2080.

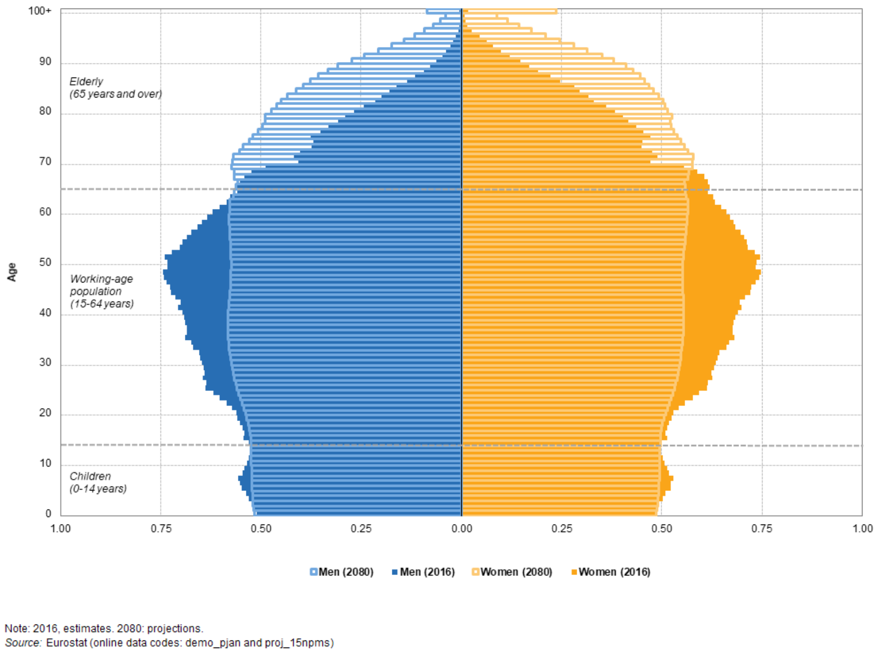


Figure 1.1: Eurostat: Demographical changes in the population structures of the EU28 [30]

These demographic changes will pose a challenge for many sectors of our society. One of them is the accessibility of modern ICTs. This is addressed in the European Accessibility Act [15]. It aims to increase the number of accessible products and services, and primarily addresses those technology areas that have the highest risk of being concerned with diverging accessibility. Among other areas, the following sectors are listed which are relevant for this thesis: computers and operating systems, smartphones, digital television services, telephony services, audiovisual media services, banking services, and e-commerce. The importance of improving accessibility is supported by recent Eurostat figures on Internet usage. Based on data from 2016, figure 1.2 shows the percentage of people in the age groups 55 to 64 years and 65 to 74 years who have never used the Internet in their lives.

Individuals - internet use **[isoc_ci_ifp_iu]**
Last update: 28.06.18
Source of data: Eurostat

INDIC_IS: Internet use: never **UNIT:** Percentage of individuals

GEO	European Union (current composition)	European Union (current composition)
IND_TYPE	Individuals, 55 to 64 years old	Individuals, 65 to 74 years old
TIME		
2010	46	68
2011	42	65
2012	39	62
2013	36	57
2014	32	53
2015	28	49
2016	25	45
2017	22	42

Figure 1.2: Eurostat: Percentage of individuals who never used the internet [29]

It is apparent that the share has decreased over the last few years. However, even in 2017, 42% of 65 to 74-year-old citizens in the European Union have never used the Internet, and still 22% of 55 to 64-year-old citizens. Figure 1.2 and Figure 1.3 show examples of selected areas of Internet usage.

Individuals - internet activities
Last update: 28.06.18
Source of data: Eurostat

UNIT: Percentage of individuals **IND_TYPE:** Individuals, 55 to 64 years old

GEO	INDIC_IS	2010	2011	2012	2013	2014	2015	2016	2017
European Union (current composition)	Internet use: sending/receiving e-mails	42	:	48	50	53	55	57	59
European Union (current composition)	Internet use: telephoning or video calls	10	12	15	15	18	19	22	26
European Union (current composition)	Internet use: reading online news sites/newspapers/news magazines	:	:	:	36	40	43	47	50
European Union (current composition)	Internet use: Internet banking	26	27	30	31	34	36	39	42
European Union (current composition)	Internet use: seeking health information	25	29	:	35	:	39	42	44

Figure 1.3: Eurostat: Percentage of individuals (55 to 64 years old) using Internet services [28]

Looking at the Internet usage of elderly onliners, a strong focus on email traffic and online news reading can be observed, followed by research on health information and e-banking, and at the very end, telephony and video telephony. In the group of people aged 65 to 74, the percentages in the areas of Internet usage are also increasing, but remain at a rather low level. However, in addition to these general figures on Internet use in old age, the risk of disability in old age is a major factor in the need for accessible products and services. By 2020, the European Accessibility Act expects around 120 million people in the European Union to have multiple and/or minor disabilities [15]. Furthermore it is stated that "Given the strong correlation between disability and ageing, accessibility is essential for older persons to remain active, live independently and contribute to the silver economy" ([15], page 6). The term "silver economy" describes

Individuals - internet activities
Last update: 28.06.18
Source of data: Eurostat

UNIT: Percentage of individuals **IND_TYPE:** Individuals, 65 to 74 years old

GEO	INDIC_IS \ TIME	2010	2011	2012	2013	2014	2015	2016	2017
European Union (current composition)	Internet use: sending/receiving e-mails	23	:	30	33	36	38	41	43
European Union (current composition)	Internet use: telephoning or video calls	5	6	9	9	11	12	14	17
European Union (current composition)	Internet use: reading online news sites/newspapers/news magazines	:	:	:	22	25	29	31	34
European Union (current composition)	Internet use: Internet banking	13	14	17	19	22	24	26	28
European Union (current composition)	Internet use: seeking health information	15	17	:	22	:	26	29	31

Figure 1.4: Eurostat: Percentage of individuals (65 to 74 years old) using Internet services [28]

the part of the economy that targets elderly people.

In line with the contents of the European Accessibility Act, this thesis will examine how the social interaction of older people can be supported and facilitated by the possibilities offered by information and communication technologies. Many of the current technological developments for the elderly are going towards medical surveillance and telecare. Beside this indisputably important and necessary assistive character, we believe that older people also want to use new communication technologies to maintain social networks or simply in a playful way.

The field of assistive technologies for older people and people with disabilities has grown steadily in recent years and now represents a significant field of research. The aim of these technologies is to support the target group in activities of daily living. Assistive technologies range from sensory impairments and telecare to home automation systems and systems to foster digital inclusion. One of the most important requirements for these technologies is accessibility. People with different needs and requirements must be able to use these systems equally. A central element in ensuring accessibility in the development of new technologies is the inclusion of the target group in the design process. There is already considerable research on the involvement of older people in the development of a new technology [25, 33, 49, 79, 89, 93, 154]. However, only few studies exist for the user-centred design of Tangible User Interfaces for and with the elderly. In this thesis, we describe our approach of integrating older people into the development process of a Tangible User Interface and its interface element in order to achieve the goal of a accessible and senior-friendly system. The inclusion of the target group should take place at the earliest possible point in time in order to obtain early feedback regarding the interaction and system design and to use the resulting implications in iterative redesign cycles [80]. In order to achieve optimal results, we will focus on a respectful and pleasant atmosphere during our user workshops. The joint design work should result in an accessible communication tool that is not only functional, but also accepted by older users and enables them to actively participate in the digital world.

According to the *Unified Theory of Acceptance and Use of Technology* [145] model, every precondition for the acceptance of new technologies is strongly influenced by the age of the user. The reasons for this are diverse: Decline in cognitive capacities like general cognitive speed or the fluid intelligence [143] [18], biological factors like reduced vision or hearing [38], but also the fear of new technologies and the lack of accessible and user-friendly systems [1]. Although we take into account these age-related impairments throughout our research iterations, our design approach will not be solely deficit-driven. By incorporating the strengths of older people and their involvement as a strong partner in the design process, we want to enable the joyful use of modern communication technologies (cf. [146]). Thus, we focus on scrutinizing the design of Tangible User Interfaces to support and enhance communication and social interaction of the growing number of elderly people with regard to their special needs. This area of research has received little attention so far, as a recent study by Bong et al. shows [10]. Our approach for improving accessibility is multimodal, personalized and focused on the needs of older people. It is based on the principles of Tangible User Interfaces as an innovative form of interaction.

1.2 kommTUi: Tangible Communication for the Elderly

This PhD thesis is part of the human-ressource project *kommTUi*[1], funded by the *benefit* program of the Austrian Research Promotion Agency (FFG). This program supports research and development of innovative technologies preserving and enhancing quality of life of elderly people. To achieve the goal of an accessible and senior-friendly system, *kommTUi* focused on a very high level of user integration and the design of a tangible interface for user interaction. The involvement of potential future users throughout the whole design process ensures early feedback on the interaction and system design and therefore avoids possible design flaws from the very beginning of the development.

In this way, the project *kommTUi* aims to design and develop a product to establish and maintain communication and exchange for older people. The aim was to develop an executable prototype that could serve as a preliminary stage for industrial product development. A main focus lied on the design of tangible interface elements for user interaction. Well-known and often cited examples for Tangible User Interfaces, like the Marble Answering Machine [113] and the reacTable [66], are using generic objects with geometric shapes as interface elements, i.e. marbles, or cubes. The usage of

[1] Project team: Hilda Tellioglu, Lisa Ehrenstrasser, Wolfgang Spreicer. More information: http://media.tuwien.ac.at/project/kommtui/

generic objects like cubes supports users in the interaction through natural and perceived affordances of their shapes [98]. They can also be easily included in a token+constraint setup to trigger well-known chains of actions and shape patterns [139]. While generic objects support the user through triggering simple interactions, personal objects can enrich user interfaces on a very individual and emotional level. Personal objects refer to everyday or self-made objects with autobiographical character. Based on a participatory approach, several versions of prototypes were evaluated and further developed in three iterations. The analysis of the observations as well as the reactions and comments of the participants throughout our workshops were used to derive implications for the redesign of the prototypes.

1.3 Methodological Approach

Since we aimed at the fundamental investigation of the potentials of Tangible User Interfaces for improving accessibility for elderly people, our research is based on qualitative research methods. Thereby the focus is on the user-centred design process, which was realized in three iterations, each containing a (re)design phase, and a series of user workshops. In the design phase, the workshops of the previous iteration are analyzed and the results are used to further develop the prototype. The workshops are build upon usability testing [33, 121], participatory design [9], and qualitative interviews [35] as core elements. For the analysis of the workshops, multimodal analysis frames are used, referring to existing approaches for the analysis of multimodal interaction [101]. Chapter 3 provides a deeper insight into the methods used in this thesis.

1.4 Research Questions

The main focus of this thesis is to investigate how the user-centred design of systems with Tangible User Interfaces can improve intuitive use and accessibility of modern communication technologies for older adults. Therefore, it is necessary to scrutinize definitions and underlying concepts of intuitive use and accessibility of technologies, Tangible User Interfaces, and tangible and embodied interaction, explicitly taking into account special needs of elderly people. The theoretical foundation will be done not only through literature research, but also in discussions and exchange with experts and scientific communities working in this research fields. This will form the basis of the user-centred design process. Together with potential future users, a communication system with Tangible User Interfaces will be designed and developed in iterative design and redesign cycles.

> **Main question: Can systems with Tangible User Interfaces help to provide accessible communication technologies for elderly people?**

Although Tangible User Interfaces have taken a place in research for some time, there is still little activity towards user-centred design of systems that work with haptic objects. In particular, older people have so far only been considered insufficiently as a target group. In our research, we explore the possibilities of Tangible User Interfaces for supporting communication.

> **Sub question 1: Can tangible interface elements be used to support elderly users in the interaction with communication technologies?**

Inspired by Tofflers definition of *prosumers* [134], users will be actively involved in the interface design. To find an appropriate and user-friendly way for the personalization of tangible interface elements is a major concern of our user-centred design approach.

> **Sub question 2: Does the use of personalized and autobiographical elements improve the user interaction of elderly users with communication technologies?**

Additionally, it is necessary to scrutinize the workshop design itself. Therefore, this thesis will also reflect on workshop settings, which ensure the well-being of the participants, take into account the needs and expectations of the elderly participants [118] and provide a multimodal and creative surrounding for valuable workshop outcomes.

> **Sub question 3: Can elderly users be successfully involved in the design and development of innovative and intuitive communication technologies?**

For our design approach, we want to adopt a holistic approach to the interaction of older users with a new communication technology. In order to get an exact idea of the needs of the users and to offer the best possible support in interaction, we focus our research on a multimodal approach. Especially when using Tangible User Interfaces, it is necessary to develop a deeper understanding of multimodality.

> **Sub Question 4: Can we use multimodality in the design of user interfaces and the user-centred design approach to foster accessible communication technologies for elderly people?**

1.5 The Author's Role

The author of this thesis was significantly involved in all research and development activities. Any involvement of other persons in technical developments has been explicitly mentioned in the text. The planning, conducting, and analysis of the first iteration (see 4.1) were carried out by Hilda Tellioglu, Lisa Ehrenstrasser, and the author. Here, the author's involvement was primarily focused on the planning and execution of all stations and especially on the implementation of station 4 and the analysis of this Station (see 4.1). The second iteration was planned, carried out and analysed by the author together with Lisa Ehrenstrasser (see 4.2). The technical development was completely taken over by the author, the analysis was mainly carried out by the author with the support of Lisa Ehrenstrasser. The distribution was also similar in the third iteration (see 4.3), except that the entire technical development and conducting of the workshops was done by the author. The initial analysis was supported by Lisa Ehrenstrasser.

The papers published as part of the research activities of this thesis can be found in Chapter 7. For those publications written by Lisa Ehrenstrasser and the author, the contributions were divided equally. The publications, in which the author is mentioned as the first author, were mainly carried out by the author. The publication "Multimodality in Design of Tangible Systems" was written under the lead authorship of Hilda Tellioglu. The author's contribution focuses on the parts describing the project "kommTUi" and Station 4 of the first iteration.

1.6 Thesis Structure

Chapter 1 introduces to the topic, describes the motivation for carrying out our research in this area, and presents the research questions. Chapter 2 provides an overview of the existing literature in the relevant research areas. At the end of the chapter, the research questions are addressed in the context of the insights gained. The third chapter describes the methods used to carry out and analyse the research activities. The research and development activities conducted as part of the three design iterations are described in detail in Chapter 4. Chapter 5 discusses the results of the analysis of the user-centred design process. Finally, Chapter 6 first describes the limitations and future research fields in relation to our research work and then summarizes the major contributions as answers to our research questions. The thesis ends with the publications that have emerged from our research work.

Chapter 2

Background

In this chapter, we discuss concepts and approaches which serve as a theoretical foundation for this thesis and are needed for a better understanding of the topic. The first part dedicates to evolution, state of the art implementations, and interaction design of Tangible User Interfaces. The second part scrutinizes dependencies of ageing and usage of technology. It consists of an overview of possible definitions of age and ageing, impacts of ageing on usage of and interaction with technologies, and an overview of existing technologies for elderlies relevant to the thesis. This section ends with a summary, which includes a reflection of the related work on our research questions.

2.1 Tangible User Interfaces

Tangible User Interfaces combine digital data with physical objects. Through interacting with tangible elements of a user interface it is possible to access or manipulate the data linked to these elements. Unlike in Graphical User Interfaces there is not necessarily a clear separation between a systems' input and output, it is also possible to have direct feedback at the input elements.

While the interaction with communication technologies with traditional user interfaces (such as mouse and keyboard) is abstract and needs to be learned, physical interaction elements of a Tangible User Interface are directly accessible. The handling of physical objects is a familiar interaction pattern since childhood. Through this familiarity Tangible User Interfaces have the potentials to lower access barriers for the use of communication technologies. Briefly, a Tangible User Interface is a material realization of computer interfaces that enable physical, haptic interaction.

According to Ishii [61] systems with Graphical User Interface have a strict separation of control elements and representation of data, whereas systems with Tangible User Interfaces combine control and representation of digital data (Figure 2.1). Intangible representations can be added as additional feedback channels for the user.

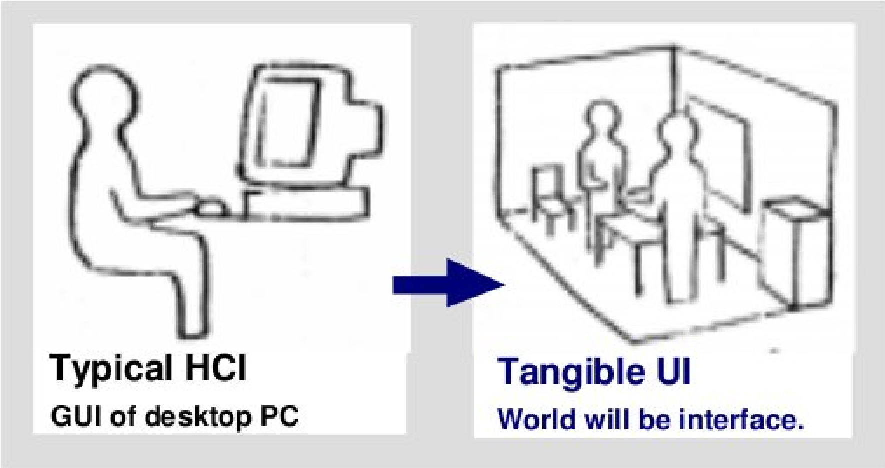


Figure 2.1: From GUI to TUI [64]

From WIMP to TUI

The standard interface to work with PC or Mac is more or less the same since the 1970s: A keyboard for written input and a computer mouse to point and click. With the Xerox Alto the so called WIMP concept ("windows, icons, menus and a pointing device" [141]) came up, which enabled the user to interact with a graphical user interface through a pointing device like a computer mouse. Subsequently, Microsoft Windows and Apple Macintosh adopted these concepts for their user interfaces. Through the continuous commercial success of these operating systems, this GUI concept became a standard for user interaction with personal computers [61]. This is the case particularly for younger users, who are familiar with this type of interaction since childhood. The combination of computer mouse and keyboard allows a fast and efficient operation of usual computer programs, like office applications, web-browsing, or communicating over the Internet.

Since the rise of mobile Information and Communication Technologies, touch interaction is getting more and more important. The usage of smartphones, tablets, and other mobile devices is very similar to the traditional WIMP concept, with the difference of using the finger as "pointing device". Beside writing and clicking, there are numerous so-called touch gestures, which users have to learn when using such devices [40].

However, there are several groups of people for which the traditional way of user interaction, whether through computer mouse and keyboard, or touch interaction, can be challenging. For example, age-related physical or cognitive impairments can be major hurdles when it comes to interacting with a traditional GUIs [33]. The WIMP concept requires targeting small graphic icons or performing a double click, which can be very challenging, e.g., for users with fine motor impairments. Additionally, the WIMP concept is based on the usage of icons. This graphic representations need to be interpreted correctly, which is not equally easy for all user groups. Shin et al. identified problems of elderly users when trying to remember the meaning of icons of a smartphone camera interface [130]. Schröder and Ziefle observed a much slower reaction time of elderly users when recognizing graphic icons in contrary to younger users, even though the elderly users were not above 65 years old and regular computer users [125]. Holzinger et al. came to the conclusion, *"that designers must be willing to increase their understanding of the symbols familiar to the older generations and adjust their designs accordingly"* [55, p. 190]. These difficulties in human-computer interaction have affects on the acceptance of such technologies and lead to reduced usage of related services like Internet browsing or E-Mail [108] [27].

While operating of a computer system through a WIMP/GUI interface is an abstract interaction pattern which has to be learned actively, the physical interaction-objects of a Tangible User Interface are graspable and manipulable directly. In contrary to traditional GUIs, where the user input via computer mouse and keyboard is strongly separated from the systems output through a monitor, Tangible User Interfaces merge the interaction objects with digital information [62]. By user interaction with this objects the linked digital data can be accessed or manipulated and the result can be shown directly at or close to the interaction object.

The concept of Tangible User Interfaces arose from different research efforts in the early 90s of the 20th century. Mark Weisers and John Seely Browns work on "Ubiquitous computing" and "Calm Technology" at the "Xerox Palo Alto Research Center" had major influence on the emergence of Tangible User Interfaces. Also research in the field of "augmented reality" had an impact on the Tangible User Interface area, like Pierre Wellners DigitalDesk [54]. Almost simultaneously Hinckley et al. [53] and Fitzmaurice et al. [34] indicated the advantages of graspable interfaces in their research:

- Two-handed interaction:
  - It encourages two handed interactions [34, p. 2]
  - Users will naturally use both hands to manipulate real objects [53, p. 6]
- Familiarity:
  - Leverages off of our well developed, everyday skills of prehensile behaviours for physical object manipulations [34, p. 2]
  - Manipulating real-world objects is a familiar task and exploits existing user skills [53, p. 6]
- Palpability:
  - Facilitates interactions by making interface elements more "direct" and more "manipulable" by using physical artefacts [34, p. 2]

– Users are immediately and continuously aware of the physical existence of each prop [53, p. 6]

In addition, the interaction with physical objects is an interaction pattern which is already learned in early childhood. Therefore, the familiarity with this kind of interaction lowers the acceptance threshold for using computer systems [58].

One of the first design concepts for a Tangible User Interface is the *Marble Answering Machine* (Figure 2.2) by Durrell Bishop from 1992 [58], who at that time was a student at the Royal College of Art.

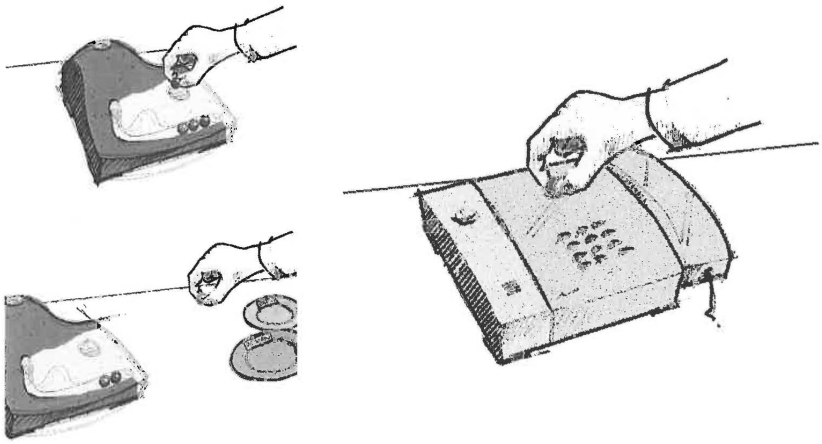


Figure 2.2: Marble Answering Machine [113]

As the name indicates, the marble answering machine design depicts a concept for an answering machine, where the messages of the missed calls are linked to small marbles. The user can play a message by grabbing one of the marbles and dropping it into the indentation in the machine. Furthermore, the marble can also be used with a special telephone. When dropping it in the according indentation the number of the caller which left the message is dialled automatically [113]. This early design of linking digital information (message/phone number) and physical objects (marbles) has been implemented in multiple prototypes [64].

While generic objects like marbles have been used since the first concepts like the Marble Answering Machine, the usage of personalized tokens for user interaction came up within the last decade. The MEMODULES project uses a combination of RFID-technology (Radio-Frequency Identification) and image recognition for creating „tangible shortcuts“ to ease the use of new technologies [88]. The Alcatel Lucent venture touchatag used RFID-stickers to link objects with different functionalities of traditional computer systems [21]. Ishii et al. propose a different approach for personalized tangible objects in their vision for future tangible systems called radical atoms: pre-produced dynamic physical materials react and transform according to user input [63]. As van Hoven argues, the interplay between generic and personal tokens in the field of Tangible User Interfaces is still worth observing and scrutinizing further [142]. The author identified a lack of studies regarding personal symbolic tools and personal iconic tools and recommended to implement examples that fit these categories to get more insights in this field. The author also described a Recollection-Supporting Device, which, among other objectives, was used as external cue for reminiscing.

In this thesis, we scrutinize Tangible User Interfaces as an alternative approach to suite the needs of elderly people when it comes to human-computer interaction. Before we go deeper into senior friendly communication technologies and the user-centred design approach, we provide an overview of the most relevant conceptual approaches for defining and designing Tangible User Interface systems and give examples for existing technologies used for the implementation.

Conceptual Approaches

Tangible User Interfaces are mentioned for the first time in 1997 by Ishii and Ullmer of the MIT Media Lab as part of their Tangible Bits project [64]: *Tangible User Interfaces will augment the real physical world by coupling digital information to everyday physical objects and environments.* They define Tangible User Interfaces as physical objects and environments that represent digital information in the real world. However, Ishii and Ullmer don't see Tangible User Interfaces just as an extension of the real, physical world. Through the use of Tangible User Interfaces, the world itself becomes an interface.

Later, Ullmer and Ishii extent their definition by the terms *representation* and *control* (cf. Figure 2.1). While *controls* (input devices like mouse or keyboard) are still strictly separated from the *representation* (screen output) in graphical user interfaces, this is not the case with Tangible User Interfaces. Here, the physical objects used to manipulate digital data can be part of the output [137].

Ishii and Ullmer define three critical factors that are crucial in the development of Tangible User Interfaces [137]:

- The physical control elements and the possible manipulations by the users must be linked optimally to the underlying functionality.
- Shape, design, and the desired degrees of freedom of the control elements must match with the intended interaction possibilities. Ishii and Ullmer mention an object with the shape of a bottle as an example for this factor. Here, opening the bottle would be an obvious interaction.

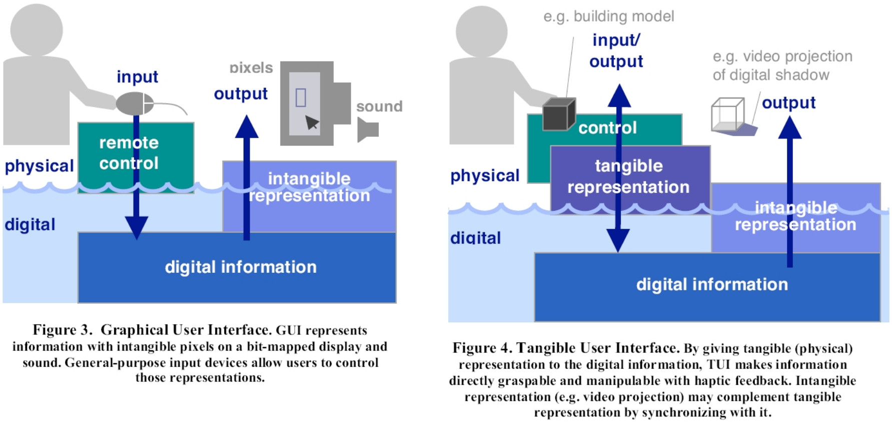


Figure 2.3: Comparison GUI and TUI [61]

- Any user interaction with the controls must produce immediate feedback from the *intangible representation* (usually audio and/or video). Thus, the effects of the interaction are perceived instantaneously by the user.

In his dissertation, Ullmer introduced the concept of *token+constraints*, which he later further development with Ishii et al. [139]. It provides a simple but efficient concept for the design of physical control elements of a Tangible User Interface (Figure 2.4). First, it defines how a physical token is associated with a constraint structure. Second, it scrutinizes token manipulation within the borders of the constraints [139, p. 83]:

> *In the context of this paper, tokens are discrete, spatially reconfigurable physical objects that typically represent digital information. Constraints are confining regions within which tokens can be placed. These regions are generally mapped to digital operations which are applied to tokens located within the constraint's perimeter.*

In addition, it discusses the interplay between multiple tokens with one or more constraints and the corresponding possibilities to manipulate digital data (Figure 2.5).

Based on Ullmers *tokens+constraints* concept, Shaer et al. designed a model for describing and specifying Tangible User Interfaces: the T(oken) A(nd) C(onstraints) paradigm [129]. The components of a Tangible User Interface can be divided into five categories:

- Pyfo: Synonym for physical object. Can be a token or a constraint or both.
- Token: A token is a tangible, mobile pyfo which is coupled to digital information or a functionality of the system.

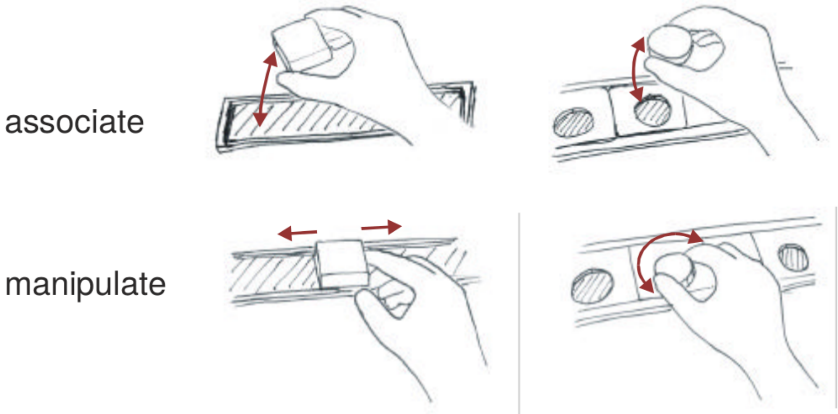


Figure 2.4: Token association and manipulation [138]

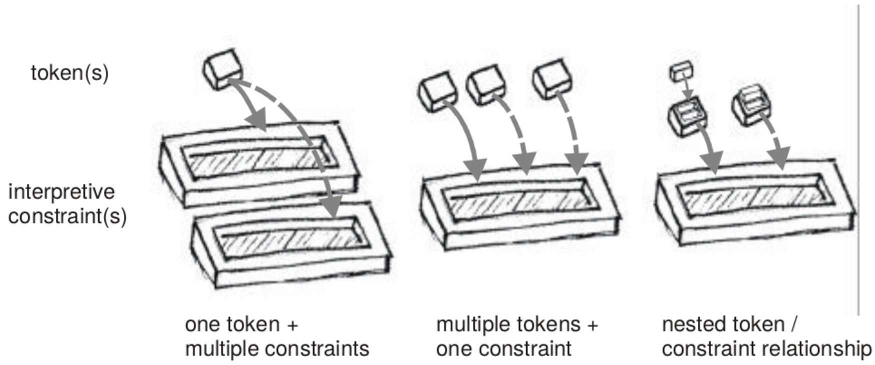


Figure 2.5: Token+constraints [138]

- Constraint: A pyfo, which defines or limits the possibilities of manipulating an associated tokens.
- Variable: Represents digital information or functionality of a system.
- TAC: Represents the relationship between a token, its variable, and the associated constraints.

Using these components, the linkage of physical objects and digital information can be specified. The Tangible User Interface can thus be represented as the set of TAC relationships. This allows a simple description of the structure and functionality of Tangible User Interfaces. For Shaer et al., this description is a starting point for a future design of a high-level definition standard or a software toolkit for the development of Tangible User Interfaces [129].

Tangible Interaction

While the conceptual approaches described so far concentrate on the linkage of digital data to physical objects and possibilities for the interface design, Hornecker and Buur extend the view on Tangible User Interfaces by putting a stronger focus on the role of tangible interaction [59]. Therefore, they introduce a framework on tangible interaction based on four themes (Figure 2.6):

- Tangible Manipulation refers to the material representations with distinct tactile qualities, which are typically physically manipulated in tangible interaction.
- Spatial Interaction refers to the fact that tangible interaction is embedded in real space and interaction therefore occurs by movement in space.
- Embodied Facilitation highlights how the configuration of material objects and space affects and directs emerging group behavior.
- Expressive Representation focuses on the material and digital representations employed by tangible interaction systems, their expressiveness and legibility.

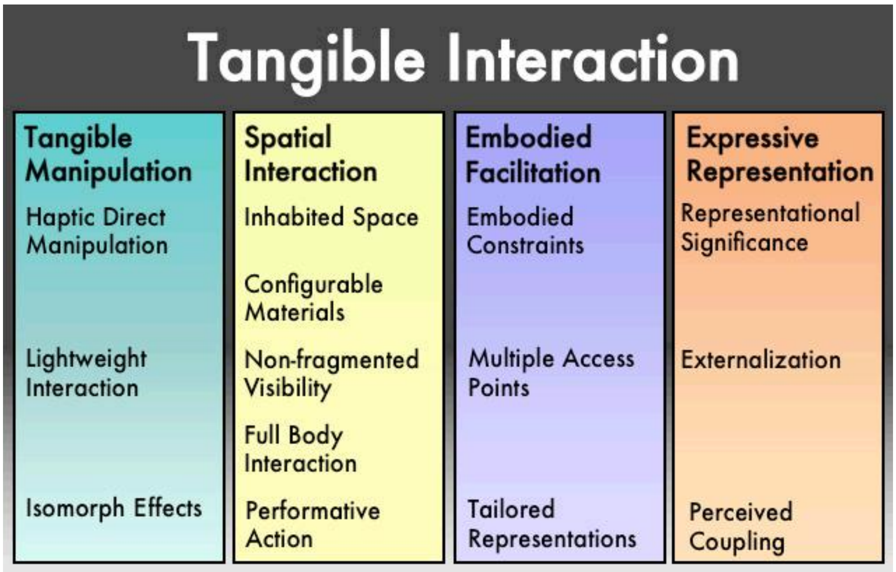


Figure 2.6: Tangible Interaction Framework [59]

While those parts of the framework which target in-situ collaboration or full body interaction are of less importance, the elements dealing with tangible manipulation, representation and coupling play a major role in our research: The interaction elements need to be easy to grasp and moved. It will be important, that the elderly users intuitively recognize the important elements of the user interface. The interaction should take place in definite steps, followed by multimodal feedback. It is necessary to find an interface design which fits also users with varying computer experience. The representations of the interface elements have to be meaningful to the elderly users and coupled to their functionalities. This has to be valid both for generic interface elements and objects with personal meaning.

Intuitive Use

When discussing interaction design, the term intuition or intuitive use is of major relevance. Some previous research into interaction design has focused on intuitive use of user interfaces. Blackler et al. define intuitive interaction as follows [7, p. 75]: *"Intuitive use of products involves utilising knowledge gained through other experience(s). Therefore, products that people use intuitively are those with features they have encountered before. Intuitive interaction is fast and generally non-conscious, so people may be unable to explain how they made decisions during intuitive interaction"*. They identified familiarity as decisive for using a feature more quickly and intuitively. They also came to the conclusion, that making the appearance of a feature familiar enables intuitive use [7]. Blackler et al. furthermore observed, that age has a negative impact on intuitive use. They have identified age-related changes in speed of reaction times and cognitive processing, especially in the area of fluid intelligence [7], and different levels of knowledge when it comes to using complex contemporary products as reasons [75]. Lawry et al. propose to integrate the knowledge of older adults into the design process as a solution for lower technology familiarity of this target group [75]. In addition to the work of the group of researchers around A. Blackler, there is also a focus in Germany on the topic of intuitive interaction, Mohs et al. define this term as follows [86, p. 130]: *"A technical system can be used intuitively if it leads to effective interaction through unconscious application of previous knowledge by the user"*. The term effectiveness used here is based on the ISO standards series 9241 (EN ISO 9241-11 1999). In the context of intuitive interaction, effectiveness can be achieved if it leads to sufficiently accurate and complete interactions for the affected user [86]. Furthermore, in connection with effectiveness it is argued that TUIs can be highly intuitive, since they require less cognitive resources compared to graphical user interfaces [90]. Both Blackler et al. and Mohs et al. see the user's previous knowledge as a basic prerequisite for intuitive operability. This previous knowledge is used unconsciously in intuitive processes. Figure 2.7 shows a classification of different levels of previous knowledge into four levels:

- innate or genetically determined knowledge (instincts, reexes).
- sensomotoric knowledge: General knowledge acquired at an early stage, such as the recognition of faces or automated courses of action. In this level the author

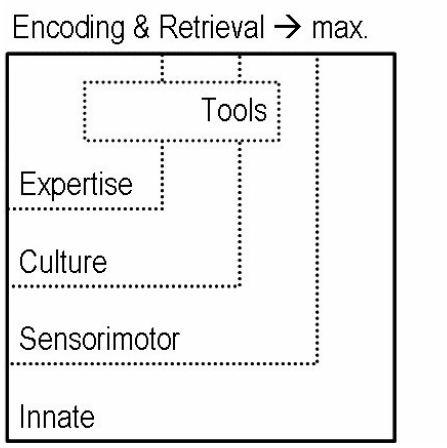


Figure 2.7: Classification of previous knowledge [90]

settles also the concepts of affordance, which play a role with the organization of the control objects of TUIs.

- culturally acquired knowledge (e.g., meaning of colours).
- Expertise or expert knowledge (e.g., knowledge of medicine, machines).

From this classification it could be deduced that the operation of an interface is intuitively possible for many people if only or to a large extent innate or sensomotoric previous knowledge is necessary. In contrast, user interaction will be less intuitive if a high degree of expert knowledge is required to operate it. When designing a Tangible User Interface, it is therefore recommended that a minimum of prior knowledge from the areas of expertise or cultural knowledge is required for user interaction in order to reduce the need for special prior knowledge.

In the area of Tangible User Interfaces, the concept of affordance is also decisive for the design of intuitive interaction. Donald Norman coined the term affordance in the research field of human computer interaction. His definition extends that of James Gibson [41] and adds a focus on perceived affordance. In his book *The Psychology of Everday Things* he describes affordance as *"a relationship between the properties of an object and the capabilities of the agent that determine just how the object could possibly be used. A chair affords ("is for") support and, therefore, affords sitting."* [97, p. 11]. Later, he emphasized, that actions, that the user perceives to be possible, is actually a perceived affordance and not necessarily what is a real affordance [98]. In addition, he distinguishes very clearly between physical and digital elements in the field of product design. In the area of physical objects there can be real and perceived affordances, in the virtual area product designer can control only perceived affordances. From this a clear advantage of Tangible User Interfaces can be derived, that is to be able to provide real and perceived affordances for user interaction [128].

Multimodality

As described in Subsection 2.1, Ishii and Ullmer defined three critical factors for the development of Tangible User Interfaces. These points are not only crucial for the interface and interaction design, they also outline the multimodality inherent in systems with Tangible User Interfaces. Multimodal systems are referred to as systems, which *"coordinate the processing of combined natural input modalities — such as speech, touch, hand gestures, eye gaze, and head and body movements — with multimedia system output"* [102]. As Figure 2.3 shows, intangible representation is expanded by direct feedback in the area of tangible representation. Through object-based interaction, additional modalities can be addressed both in user interaction and in the area of system feedback. The user can take the object in his hand or both hands, turn it around, shake it, press it, sweep over it, take a closer look, and put it down in another position. The interface element itself can provide visual, auditory or haptic feedback. This multimodality of Tangible User Interfaces will facilitate learning, because they allow the visual and motor systems to interact and form important links for learning [65]. The effects that multimodal/sensorimotor information drives cognitive development of children are described in the psychological theory by Jean Piaget [110]. He emphasized the important factor of children's interactions with their environment for learning. Recent theories and findings from psychology show that the inclusion of multimodal stimuli is not only relevant for the cognitive development of children, but has also a positive effect on general memory performance. Engelkamp and Zimmer expanded the memory systems by taking motor processes into account [26]. They argue that the additional activation of the motor program improves retention performance (e.g., just hear the word *knock* vs. additionally perform the action). Accordingly, it is assumed that the entire episode experience, which includes sensory and motor experience, is reactivated when remembering. Numerous studies show that remembering activates different aspects of the episode experience in addition to its meaning, such as specific viewpoints on objects or the motoric motion sequences during their use. Recognition is thus influenced by sensory and semantic encoding processes, as well as by motor congruence [39]. These findings can be of particular importance for the design of new technologies with Tangible User Interfaces for older adults. Furthermore, the role of haptics was the subject of numerous studies. Norman et al. observed in their experiments, that there was no effect of age regarding haptic shape recognition [99]. In a previous study, Norman et al. already outlined, that there is also no effect of age upon the haptic ability to estimate 3-D surface shape [100]. Ballesteros et al. studied the effect of age and Alzheimer's disease on haptic priming [6]. Their study showed, that the priming effect did not differ from the control group with healthy older adults and the control group with younger adults.

This findings suggest, that implicit memory for haptically explored objects is preserved even for Alzheimer's disease patients and there is no difference in haptic priming between younger and older adults. These research outcomes provide a further indication of the advantages of the multimodal nature of Tangible User Interfaces.

Interaction Cues

As Dourish proposed in his book *Where the action is*, coupling and therefore creating relationship between entities is managed by the user, whereas designers can only suggest coupling [24]. In the case of tangible interaction it is essential to reach a meaningful coupling of the tangible interface elements and the digital data or functionality. Although generic tokens as containers with well-known geometric shapes, predefined size and material can be easily integrated into a token+constraints set-up as a support for known chains of actions and shape patterns, it is necessary to provide cues for the elderly users to correctly identify the embodied abstract digital data. On the other hand, it is also possible to use personal tokens as individual objects with a special meaning to the user as interface elements. There has been several studies to investigate the role of appropriate cues to support memories and reminiscing. Gonzalez work on Autotopography introduce personal tokens turned into keys through the emotional linkage between the object and the user [45]. This keys can only be decoded by the owner of the object. Based on this work, Petrelli et al. introduced *mementos* for the design of technology for personal memories [109]. They define a memento as an object given or deliberately kept as a reminder of a person, place or event. Sas explored how self-defining memories represent significant emotional events [123]. The author not only identified cue selection from personal artefacts as trigger for autobiographical memories, but also recommend to involve people in cue creation. The author further proposed *"novel interactive systems integrating tangible interfaces with elements of art therapy to support not just capturing the event, but also reflecting on and processing of negative self-defining memories and their progression into redemption narratives"* [123, p. 158]. Talamo et al. scrutinized uses and meanings of objects and domestic spaces in the daily practices of older adults [133]. They also came to the conclusion, that meaningful objects were *mementos*, which support remembrance as *tangible memories* through their physical appearance. One of their major findings suggests, that *"domestic environments in elderly people's homes are strongly characterized by objects that promote the preservation and recall of past experiences and relationships"* [133, p. 13]. Golsteijn et al. argued that physical objects have advantages through *"a sense of self of the owner through their positioning in the physical environment, digital objects are often hidden on devices"* [44, p. 663]. While *"physical objects [..] are much more embedded in the everyday landscape and may trigger memories simply be being seen"* [44, p. 663], a better linkage of physical and digital objects would lead to new reasons for cherishing also digital objects [44].

Technologies

There are different technologies available for realizing tangible interfaces: visual tracking, radio-based tracking and embbeded microcontrollers, sensors or actuators [128]. A well-known and often used technology for visual tracking is the reacTIVision framework [69]. It is based on marker tracking and provides support for a lot of different operating systems and programming languages. The most famous device using this framework is the reacTable, an electronic music instrument with Tangible User Interface (Figure 2.8) [66].

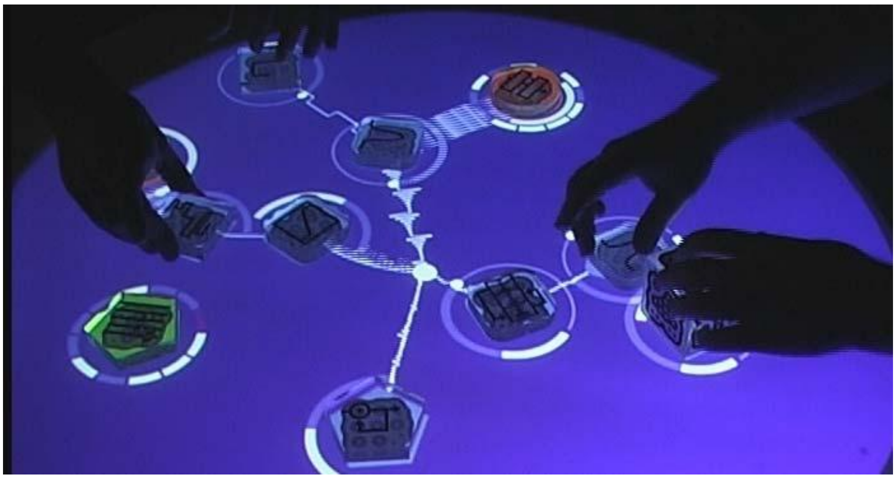


Figure 2.8: Reactable [66]

The OpenCV library is a more general tool for image processing [104]. As a powerful feature for tangible interfaces, this library allows recognition of everyday objects and therefore using them as interface elements. It also runs on several operating systems and provides interfaces for different programming languages.

However, the technical setup of Tangible User Interfaces based on visual tracking is not trivial. Figure 2.9 shows the setup of the reactable. It uses a camera to track the symbols of the physical control elements from below. The tracking data is then processed and forwared to an audio synthesizer to provide audible feedback and to a visual synthesizer, which uses a camera to project visual feedback back on the table. As tracking and projection use the same area, a special light setup is necessary, using infrared light. There are also systems which use tracking and projection from above the interaction area [36] [82]. These systems need well-balanced external lighting conditions for good enough tracking results and visual user feedback. Furthermore, it is crucial to use high-performance hardware and software for Tangible User Interfaces with visual tracking. Only thus the system is able to provide realtime feedback, which is necessary for a flawless user experience.

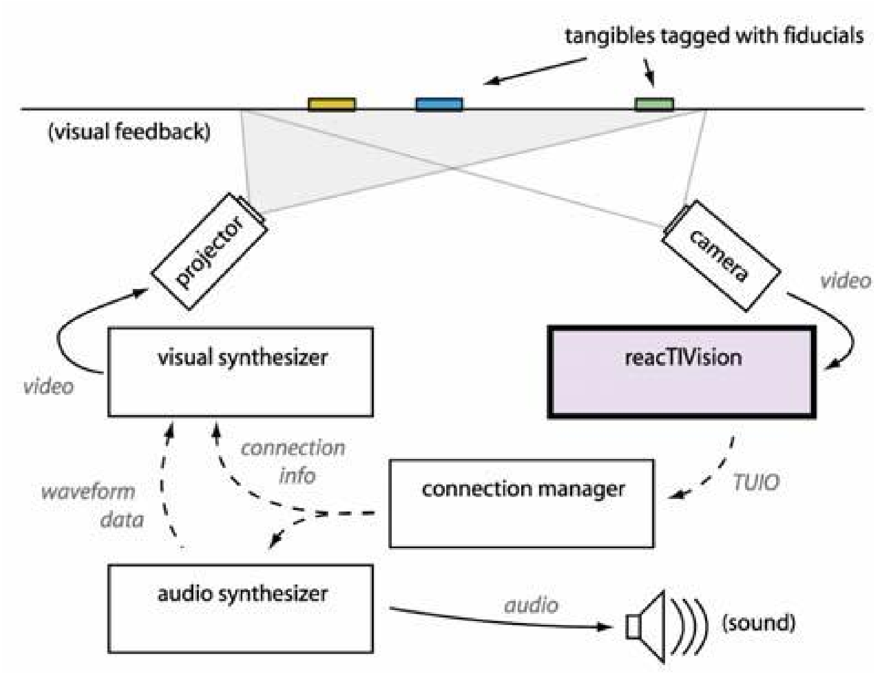


Figure 2.9: Setup of the reactable [66]

A often used non-contact tracking technology based on radio-frequency communication is RFID (Radio-Frequency Identification) [129]. RFID readers can identify so-called RFID tags, which can be attached to physical objects. Two examples for Tangible User Interfaces using RFID-technologies are *Mediablocks* [136] and *Smart blocks* [42]. Mugellini et al. use RFID tags together with visual tracking to combine personal objects with digital data. Through a webcam and a RFID reader digital information can be attached to personal objects, which can be used as *Memodules* object afterwards (Figure 2.10). The tracking is realized with a strong RFID antenna, which is able to locate a RFID-tagged object in a room [88].

As NFC was established as a standard sensor at least for Android devices, smartphones can be used as control device for RFID-based Tangible User Interfaces. E.g. Samsung has released the Samsung TecTiles, attachable to every object and usable with every NFC-enabled Smartphone [122]. Pyykkönen et al. present design guidelines for NFC-based user interfaces. They propose to use mobile phones for multiple services like multimedia player service for a tourist attraction, presenting photographs on a wall display or downloading and joining a game [115]. De la Guia et al. use simple cards equipped with NFC-chips to foster user interaction with digital books [22].

Microcontrollers are small devices which can be embedded in physical object. Together with sensors (light, positioning, crash, gravity, current, ...) and actuators (pres-

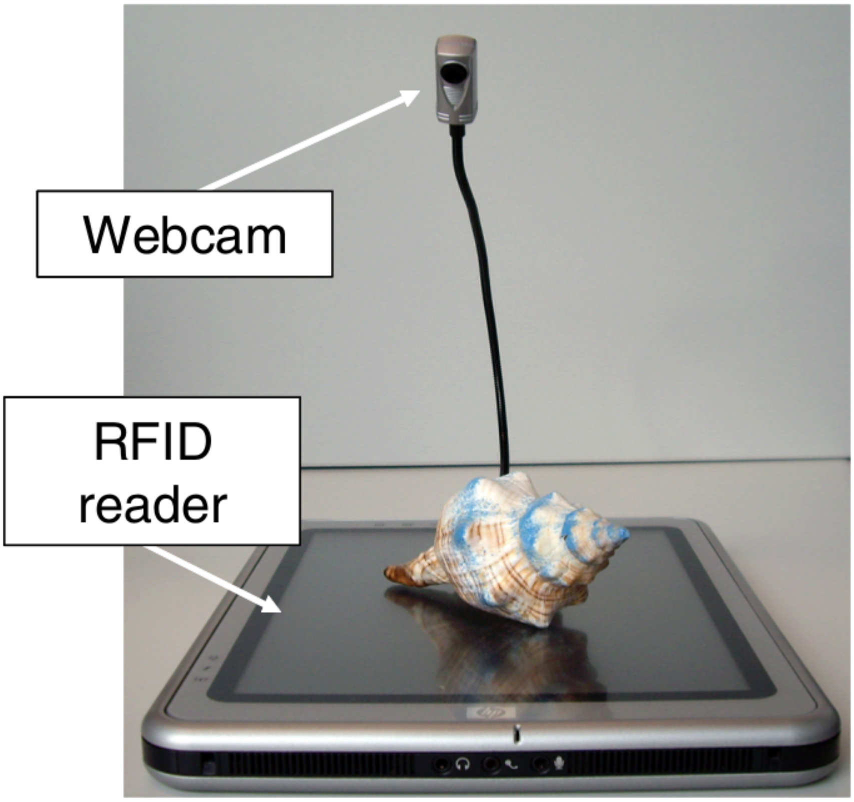


Figure 2.10: Memodules: RFID and image recognition [88]

sure, sonic, temperature, motion, ...) they provide a powerful basis for designing diverse systems with Tangible User Interface. A very accessible tool for building tangible interface prototypes is the Arduino micro-controller [3]. Equipped with an USB interface it allows easy-to-use handling of several sensors and actuators. The *Memodules* project uses a central operations module for the user interaction, called the *Console* [88]. For the implementation of the *Console* prototype, the authors used the Phidgets toolkit with different sensors, like infrared or touch senors [60]. Merrill et al. use multiple microcontrollers to build a Sensor Network User Interface. It consists of small devices equipped with sensors, wireless communication and graphical displays. This Tangible User Interface unites control and representation and additionally allows to interconnect the individual control elements [84]. With the increasing popularity of smartphones, also Tangible User Interface research more and more focused on the use of these powerful devices to operate sensors and actuators or even as control element for user interaction [103].

2.2 Senior-friendly Communication Technologies

Innovation in the area of communication technologies is usually geared to younger people and early technology adopters. Mobile communication devices like smartphones and tablets use high resolution graphical user interfaces with touch interaction to unify different channels of communication like telephony, e-mail, social media, instant messaging, chat, or sms. Also the tv is getting more and more transformed into a smart device, including streaming media over the internet, social media or video telephony. Although there are some tailored products for elderly users, they form an exception in the rapidly growing market of communication technologies. The needs and expectations of this growing demographic group are often neglected in the design of new communication devices. In this section, we first provide an overview of age-related changes with impacts on the usage of technology. After a definition of the term *age* we scrutinize existing technologies with Tangible User Interface which were implemented to be used by elderly people. Concluding, we address the concept of user-centred design and the inclusion of older adults in the design process.

Age-related Changes

Reduced vision or hearing [38] interfere the interaction with graphical user interfaces and audio feedback. Scepticism towards new communication technologies and the lack of accessible and user-friendly systems [1] often spoil a positive attitude towards and a ludic use of new technologies. Also more recent literature, like Karimi and Neustaedter [70], Grigoryeva et al. [47], Kumar et al. [74], or Vacek and Rybenska [140], emphasize the importance to include the needs and expectations of older adults in the design of new communication technologies. Arning and Ziefle argue in the same direction [5]. Although critics claim that the problem of lack of computer literacy will be solved by the change of generations over time, they raise two main reasons against this assumption. On the one hand, they see the innovation cycles of new technologies accelerating. This could pose challenges not only for older people but also for younger, technology-affine users. On the other hand, Arning and Ziefle argue that the younger generation will also become older and thus be affected by the problems of cognitive aging [5]. Veldhoven et al. confirm the perpetuation of age-related impairments for the area of reduced fine motor skills and limited cognitive resources [144]. These arguments underline the need *"of research activities, which contribute to a transgenerational design, where even the "weakest" user is able to handle a technical device successfully"* [5, p. 133].

Arning and Ziefle's argument that the younger generations are also later affected by age-related impairments is supported by statistical studies [5]. In 2007, Statistik Austria asked people in private households in Austria about long-term impairments (additional microcensus questions) [76][1]. Two questions served as the basis for this survey: "Are you restricted in everyday life due to a health impairment?" and "Have you had this impairment for more than half a year?". 48% of people over 65 stated that they were affected. The most frequently reported impairments are problems with mobility (13%), chronic impairments (allergies, hypertension, migraine, asthma, diabetes, chronic pain, etc.; 7%), problems with vision (3.9%), nervous and psychological problems (2.5%), problems with hearing (2.5%), mental problems or learning problems (1%), problems with speech (0.8%). This underlines the need to make information and communication technologies as accessible as possible.

Previous research has established that age-related physiological and cognitive changes (cf. 2.2) affect the approach to the usage and acceptance of communication technologies. Decline of the general cognitive speed [143] or the fluid intelligence [18] affects learning and adoption of new technologies and alternative user interaction like touch and gestures. Van Gerven et al. refer in this context to cognitive aging, with which they mainly associate two cognitive age impairments: general cognitive speed and cognitive control [143]. Losses in general cognitive speed mean a general slowdown in all cognitive processes. Age-related impairments of cognitive control affect mechanisms for information processing and planning behavior. This also applies to the function of the working memory. It is responsible for the temporary storage of information that is currently being processed. These impairments make it considerably more difficult to learn new cognitive skills, such as the use of new technologies. Czaja and Lee come to similar conclusions using Cattell's fluid and crystallized intelligence model [19]. The fluide intelligence stands for the ability to learn new things without previous knowledge, to successfully master new problems and situations. Crystallized intelligence, on the other hand, stands for problem solving through the use of existing knowledge acquired through education and experience [19] [127]. There is a direct correlation between age and fluid intelligence decline. The crystallized intelligence, on the other hand, remains relatively stable or, under certain conditions, can increase with increasing age [57]. Besides fluid intelligence, other cognitive capacities that are important for dealing with new technologies decrease in old age. Losses in the field of spatial cognition - responsible for spatial imagination and the handling of spatial knowledge - make the processing of complex tasks more difficult [19]. The speed of information processing also decreases with age. The impairments in these cognitive areas occur increasingly when dealing with new technologies [19] [87].

The impact of ageing on the decline of memory processes has been subject of nu-

[1]https://www.sozialministerium.at/cms/site/attachments/5/1/5/CH3434/CMS1450699435356/statistik_-_menschen_mit_behinderung_20131.pdf, 11.08.2018

merous studies in the field of cognitive psychology. Age-related differences in memory performance are usually tested through recall and recognition tests using word lists or, in the context of visual memory, pictures. There are several findings throughout literature which are relevant for our research. For both verbal and pictorial memory tests, free recall showed the highest degree of age-related differences. Free recall is defined by Goldstein et al. [43] as: *"In free recall, a participant is simply asked to recall stimuli. These stimuli could be words previously presented by the experimenter or events experienced earlier in the participant's life."* [43, p. 182]. Goldstein et al. define cued recall as: *"In cued recall, the participant is presented with retrieval cues to aid in recall of the previously experienced stimuli. These cues are typically words or phrases."* [43, p. 182]. Using such cues as support for the recall task, the differences tend to decrement. For recognition tasks, the differences are the lowest. In the context of verbal memory tasks, Hedden et al. identify processing ability as limiting factor regarding free recall [50]. Processing ability includes speed of processing and working memory. Their research findings emphasize, that age differences in memory tend to be largest in free recall tasks, when processing ability is most invoked and environmental support is through cues is lowest. Whereas in recognition tasks, with processing ability less invoked and environmental support through cues highly available, the differences are smallest. Hedden et al. conclude from their results that older adults show an increased use of knowledge to the detriment of processing ability regarding memory tasks, where environmental support is available [50]. Naveh-Benjamin showed in their verbal memory testing, that older adults tend to lower performance in cued recall tasks with unrelated word pairs, while there was no age difference in cued recall with related word pairs [91]. Recalling memories without related context requires the use of episodic associative information, which is harder for older adults than to recall information using existing association like semantically related word pairs. The positive effect of integrating contextual information is also present for recalling pictorial memory. Park et al. showed that well-integrated target-context relationships facilitated the recall of older adults [106]. They benefited both from conceptual and perceptual integration. Conceptual integration means semantically related context and target, e.g. pictures of a related category of animals like spiders and ants. The target and context pictures of the perceptually integration were not semantically related, like a spider and a cherry. The findings of Park et al. provide evidence for the validity of the positive effects of contextual integration and emphasize, that *"older adults were able to utilize well-integrated contextual information effectively, regardless of whether it was general (as in the semantic condition) or specific (as in the interacting condition)"* [106, p. 55]. The support through the contextual integration in cued recall tasks is especially interesting for our research, because there was no training or active strategy manipulation required to achieve the positive effects for the older adults. Later, Park and Gutchess integrated these results in their work on cognivite aging and everyday life [107]. They concluded that *"the impact of cognitive deficits on* *everyday behaviors is most pronounced when older adults are in unfamiliar environments and must perform tasks that are novel to them"* [107, p. 228]. Kensinger confirms the positive effects of familiarity to overcome deficits in memory of older adults. This is especially valuable for recognizing previously encountered people or items [71]. Kensinger adds that *"older adults have difficulties initiating effective encoding 'strategies' that would promote memory for the associative details of an experience [..]. When they are given a strategy to use as they learn information (e.g., if they are asked to tell a story that binds the item to its context), older adults often perform as well as young adults on tasks requiring associative or contextual memory"*. Schieber provides a list of design guidelines to compensate possible age-related differences in memory performance as described above [124]. This list contains several recommendations directly addressing relevant areas for our research:

- Minimize the need to manipulate or transform information in short-term memory.
- Optimize working memory capacity. Attentional capture of "irrelevant" stimuli may inefficiently "tie up" working memory capacity.
- Leverage recognition memory, which is relatively robust in old age.
- Design environmental supports to guide and/or enhance memory encoding processes.
- Leverage intact automatic memory processes (such as semantic priming) to support or off-load volitional memory processes. (Remark: This relates to contextual integration discussed above).
- Technological interfaces need to be carefully designed to algorithmically optimize the rate of stimulus presentation or implement "user-paced" I/O strategies.
- Explore the potential of multisensory/multimedia presentation formats for improving the encoding and retention of to-be-remembered information.

We should take into account these insights regarding the importance of familiarity and also the advantages of cued recall and recognition over free recall that as important prerequisites in our research and especially in the user interface design.

Technology Acceptance

The described possible physiological and cognitive impairments have to be taken into account when designing new technologies for elderly users. Another important factor for the suitability of a new technology is the acceptance of older people to use it. There are various models for describing which factors are the main determinants of the acceptance of new technologies. The *Technology Acceptance Model* is based on six different factors, some of which influence each other [20]: External Variables, Perceived Usefulness, Perceived Ease of Use, Attitudes towards Use, Behavioural Intention to Use, Actual System Use. Perceived usefulness and perceived ease of use are of central importance in this model. Both factors influence whether the users' attitude towards the technology is positive or negative. Perceived usefulness also influences the users' intention to actually use the technology. Renaud and van Biljon propose the *Senior Technology Acceptance & Adoption Model* as an extension of the Technology Acceptance Model. The results of their study with older mobile phone users show that *"acceptance or rejection is predicted by ease of learning & use and actual use, with the former more strongly influencing acceptance."* [119, p. 211]. The *Unfied Theory of Acceptance and Use of Technology Model* includes factors that determine behavioral intention (as in the Technology Acceptance Model) as well as four aspects that influence these factors: experience, voluntariness, gender and age [145]. Characteristics of the user are therefore included in the model. The Effort Expectancy factor is influenced by the users' gender, age and previous knowledge. According to Venkatesh et al., Effort Expectancy stands for the ease-of-use of a technology and has a higher degree of influence on the behavioral intent of female users, older workers and users with little prior knowledge than it has on other users. Age plays a decisive role in this model, influencing all four decision factors. While the three other properties are represented as binary variables, age is defined as a continuous variable. This strong influence of the age of the users on the intention to behave towards new technologies was investigated in a study by Morris and Venkatesh [87]. Niehaves and Plattfaut analysed the UTAUT together with the more differentiated MATH (11 independent belief variables) regarding the digital divide related to elderly users when it comes the Internet usage [94]. They observed a *"strong impact of the extent to which elderly people have faith in their own skills and capabilities [..] and of how easily the Internet is perceived to be used"* [94, p. 721]. Although focussing on Internet usage, the authors argue, that the results, at least to a certain extent, can be generalized to apply to IT as a whole. Also Steele et al. define the ease of use as an important for the technology acceptance: *"[..] our findings suggest that systems with a simple interface that require the least amount of interaction are more likely to be accepted by an elderly person. This is mainly due to the fact that elderly users may find it challenging to memorize what functionalities different buttons may serve, they also have different design requirements to the average users as their abilities are diverse"* [132, p. 798]. Furthermore, they have identified as an important criterion for the acceptance of supporting technologies that they are not to be perceived as stigmatizing. The use of a technical aid must not make the user look frail.

Accessibility

The term accessibility is very broad and has meaning in many contexts. A comprehensive definition exists from the World Health Organisation [56, p. 7]: *"Accessibility* *describes the degree to which an environment, service, or product allows access by as many people as possible, in particular people with disabilities"*. For the termin Disabilities, the WHO defines *"Disabilities is an umbrella term, covering impairments, activity limitations, and participation restrictions"* [105]. The European Commission summarizes the term in the European Disability Strategy 2010-2020 as follows [14, p. 5]: *"Accessibility is defined as meaning that people with disabilities have access, on an equal basis with others, to the physical environment, transportation, information and communications technologies and systems (ICT), and other facilities and services"*. Accessibility in the area if information- and communication technologies is often referred to as *e-Accessibility*. For the WHO, *"e-Accessibility refers to the ease of use of information and communication technologies (ICTs), such as the Internet, by people with disabilities"* [150]. In this area, a strong focus lies upon the accessibility of web application, with well known guidelines like the *Web Content Accessibility Guidelines (WCAG)* [147]. Although the guidelines and recommendations for web accessibility cannot be directly applied to the field of Tangible User Interfaces, some points can inform the design of our research prototypes. The recommendations of Pühretmair and Miesenberger, for example, are not only relevant for web applications [114]. They define accessibility as a prerequisite of usability. Both should be an integral part of an user center design process. They conclude, that accessibility improvements can increase usability for all users, with and without disabilities. However, not only because existing guidelines for accessible web applications are being viewed more and more critically and have weaknesses especially with regard to older people, they are not sufficient for the present thesis [155]. As Hedvall describes, it is important to understand accessibility in the context of the advancements in the field of human-computer interaction [51]. This is particularly relevant for this thesis, which aims at the use of non-traditional user interfaces with older adults as target group. Therefore, we will scrutinize the potentials of Tangible User Interfaces to provide accessible information- and communication technologies for elderly people. A main focus will be to address the requirements for technology acceptance and the cognitive or physical changes described in the previous subsections, that lead to disabilities in old age. These requirements will be assessed in a user-centred design process. The early involvement of users in the design of technologies is particularly relevant, because according to Czaja and Lee *"to a large extent lack of accessibility is due to the fact that designers are unaware of the needs of users with varying abilities, or do not know how to accommodate their needs in the design process"* [19, p. 342]. Before we provide an overview of existing technologies for older adults using Tangible User Interfaces, we will address the possible definitions of the term *age*.

Age Definitions

The term age or aging is connotated differently depending on the context it is used. On the one hand side, there is the image of the active seniors. It is often used to address well-situated elderly people, for example by the advertising industry. On the other side, a great deal of previous research especially into AAL (cf. 2.2) has focused on supporting elderly people confronted with physiological or sensory impairments, social isolation, or cognitive decline. Although getting old is not necessarily correlated with this negative factors, the general risk of health impairments including perception, cognition, and the control of movements increases [33].

There are several dimensions regarding a definition of old age. The chronological age uses the years that have passed since birth. Different approaches exist to define sub-groups of older adults. Forman et al. use three categories: *the young old (60 to 69 years), the middle old (70 to 79 years), and the very old (80 years and older)* [37]. Zizza et al. also use three sub-groups in their evaluation of water intake by older adults: *young-old, 65–74 years; middle-old, 75–84 years; and oldest-old, >=85 years* [158]. A more comprehensive definition comes from the World Health Organization [148]:

- 50 - 59 years: aging person
- 60 - 64 years: older person
- 65 - 74 years: decisive point in the regression phase
- 75 - 89 years: old person
- 90 - 99 years: very old person
- 100 - 115 years: long-lived

However, chronological age alone is insufficient to explain the process of aging satisfactorily. Not least in the field of user interface design, it is important to use other factors in order to achieve a better understanding on user groups. Thus, for example, a 70-year-old user with minor audiovisual impairments may find it easier to use a computer system than another 70-year-old user with stronger audiovisual impairments. For this work physiological, psychological and social factors of aging will play a role when it comes to designing the user interfaces of our prototypes. Accordingly, three additional dimensions can be found in the definition of age or aging: biological, cognitive, and social aging [148] [33].

- The *biological age* is defined by physiological changes such as decrease in muscle mass, lens dislocation or increased blood pressure [148]. Impacts such as decreased visual acuity or fine motor impairments make it many times harder to cope with classical graphical user interfaces: It is getting more difficult to read the screen output, which in most cases is designed for people with normal vision, also using a computer mouse and keyboard will be harder or even impossible [108].

- *Cognitive aging* is described by changes in human cognition- and information processing. These changes include not necessarily only impairments, but also improvements such as an extended experience or the increased ability to concentrate on the near future in planning processes. A major problem in dealing with technologies such as computer systems, at least for the current generation of older users, is the age-related decrease in so-called fluid intelligence. It reflects the ability to adapt to new problems and situations without the need for extensive prior learning. As a result, older users find it more difficult to accept new technologies or to learn how to use a new application than younger users [19].

- The *social age* is determined by social relations or societal norms and roles [148]. In particular, the age of retirement (generally between 60 and 65) is mentioned as an indicator of the age at which a person is regarded as old. In addition to changes in the private domain, retirement is the main reason for the reduction of daily social contacts among older people [126].

These categorizations describe age from an external view and according to Burkart represent the macro-level of looking at the process of aging [11]. On the other hand, the micro level is the subjective perception of each individual to the development of their life [11]. The categorization and selection of the test users for the empirical part of this work must take place both according to criteria of the macro level as well as the micro level. On the one hand, it is relevant to select the users so that the results of the investigations permit conclusions on a larger user group. On the other hand, it is indispensable for the design of the user tests to take into account individual experiences and living conditions of the test users.

Example Technologies Using Tangible User Interface

The main field of research and development regarding technologies for elderly people is the area of Ambient Assisted Living (AAL). AAL is referred to as *"interoperable concepts, products and services, that combine new information and communication technologies (ICT) and social environments with the aim to improve and increase the quality of life for people in all stages of the life cycle."* [111]. Large research projects like SmartSenior [131] provide holistic smart home environments to support elderly people in their daily life and enable them to stay in their homes as long as possible. TV-sets (e.g., SmartSenior, SOPRANO [152]) or interactive picture frames (e.g., Casa Vecchia [77], 3dscan [31]) are often used as user interfaces of such AAL-systems. Reasons are high availability and commonly known interaction patterns of TV-sets as well as the possibility of using picture frames as metaphorical interface.

These projects largely stay with graphical user interfaces, partly combined with touch interaction. Also existing literature in the area of technologies for elderly people stick to traditional user interfaces when analyzing the needs of this user group. Truong et al. present a prototype consisting of a digital picture frame, which allows to show digital pictures in the homes of elderly people [135]. Photos can be uploaded over the Internet, which are then converted in a slideshow and presented in the digital picture frame. However, as the upload has to be done over a central website, there are the same usability hurdles for elderly users as for browsing other websites. Markopoulos et. al. designed a prototype of a communication system called *ASTRA*, which aimed for keeping contact with family over great distances [83]. ASTRA uses a handheld-device to send photos, sketches and handwritten notes to a base-station, which is located at the home of family members or friends. Thereby, it is possible to keep the owner of the base-station updated about daily life or special occasions. The usage of *ASTRA* requires that family members are able to interact with both the user interface of the handheld device and the base-station, which can be challenging especially for older adults. Leonardi et al. use a tabletop device to evaluate gestural interaction with older adults [78]. During the user evaluation they encountered challenges regarding using gestures. It was often not clear for the elderly users how they can use the drag-and-drop gesture and what elements they are able to drag. As main reasons the authors identify the lack of cues and affordances for the gesture interaction and that the provided feedback-animations should be accompanied by redundant information in other modalities. Charness et al. provide an overview of age-related impairments which have an impact on the usage of new technology by the elderly [12]. Caballero et al. anaylze the impact of mental decline in older adults by means of a distributed graphic user interface [17]. Coelho et al. use smart-TV and tablet-based prototypes to examine advantages of state-of-the-art information and communication consumer technologies for this user group [13].

However, there is also research focusing solely on using Tangible User Interfaces for the group of older adults. One of the first Tangible User Interface especially designed for older adults was *Nostalgia* [95]. Nilsson et al. described the design process of their prototype for listening to old news and music from the twentieth century. It was based on cultural probes and creative workshop to gather the needs and expectations of the elderly users. For them, these methods covered deeper insights than just asking questions or observing. Pastel et al. describe the potential of RFID-cards to implement an E-Mail client with Tangible User Interface [108]. Although they just provide a gedankenexperiment without evaluating their ideas, they describe a key interaction technique for Tangible User Interfaces.

An early Tangible User Interface prototype for elderly users created by a product designer was *Jive* or later *Bettie* [4]. The purpose of *Bettie* was to enable older adults to send message to their relatives and friends or to receive news from them. *Bettie* consists of a screen, a keyboard for user input and so-called *Friend Passes*. The *Friend Passes* are small tokens with a picture of the contact on the front, a magnet on the backside and a RFID chip, with a protective cover made out of plastic.

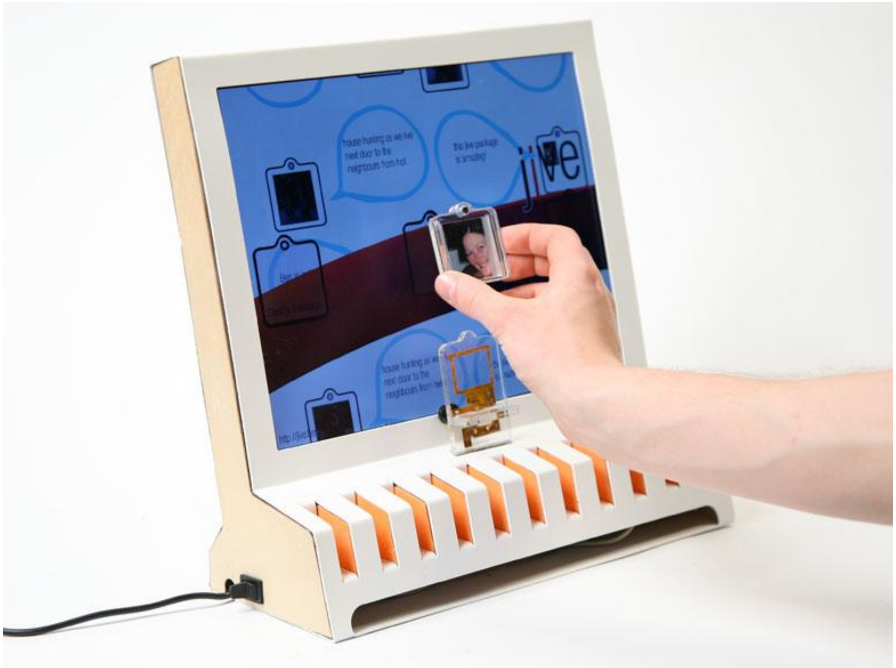


Figure 2.11: Jive/Bettie [4]

The RFID chip is used to identify the *Friend Passes* and track their current position. The magnet on the back makes it possible to place the *Friend Passes* on the screen. If the *Friend Passes* are placed on the left side of the screen, an external keyboard can be used to enter a message and send it to the contact. When placing the *Friend Passes* in the center of the screen, it shows an overview of the person. More detailed information can be obtained by placing the *Friend Passes* on the right side of the screen. The *Friend Passes* are also connected to social-media profiles of the respective person. Therefore, it is possible to receive messages or status updates from there.

Kalanithi and Bove designed a social network tool which combines the principle of Tangible Interface Design with everyday social behavior [68]. Through the mutual gifting of small objects, the so-called *Connectibles*, users can establish a permanent connection among themselves. The users can send messages, images or simple light signals via the *Connectibles*. However, some interactions require establishing a connection with a PC, e.g., sending pictures.

The design of user interfaces for medical applications plays a major role in the field of AAL and research regarding technologies for elderly people. A number of authors have considered the effects of the usage of Tangible User Interface in this area. Meza-Kubo et al. are using video projection to implement a game-based prototype with Tangible User Interface for elderly people [85]. Their implementation aims for stimulate cognitive stimulation activities to reduce the risk of suffering cognitive impairments. They found first indicators, that *"providing natural interaction interfaces, users, particularly illiterate older adults, reduce their anxiety levels and consequently make themselves more willing to use the system, regardless of their previous literacy level or experience on the use of computers"* [85, p. 11]. Wang et al. present an interactive game to support elderly post-stroke survivors improving their motivation and adherence toward rehabilitation exercises [149]. The evaluation of their "Lights Out" prototype shows two interesting outcomes for our work in the kommTUi project: It is important to aim for a multimodal interface design, especially including sound feedback. Furthermore the participants would have prefered to compete with other players. Riche proposes to scrutinize less typical desktop computing paradigms for elderly people who are not necessarily at ease with typical user interfaces [120]. Zhao et al. investigated the usage of art-based tangible interfaces for asynchronous communication devices [157]. Their prototype *Blossom* consists of the artificial flowers which are able to record and play voice messages. To support user interaction through visual cues, the flowers open up when a new message arrives. The aim of this prototype is to overcome social isolation of elderly people, which *"results in considerable amount of physical and mental illness among the group of older adults"*. They evaluated *Blossom* by gathering qualitative feedback of visitors of an exhibition. While the authors underline the necessity of additional field studies, they were able to extract the importance of multimodal design from the analysis of their first results. They plan to redesign the *Blossom* prototype, including the enhancement of the existing visual cues through additional LEDs and providing acoustic feedback. Rebola et al. discuss a high-level framework of basic design approaches and methods for the design of technologies for elderly people [117]. This framework is based on six dimensions:

- product functionality
- product interface
- co-design activities
- universal design
- product experience
- technology use

They also emphasize the importance of tangibility and contextualization of user interfaces [117, p. 152]: *"Physical tangible computing can afford more accessible interfaces* *for older adults. Beyond physicality of the interface, contextualization should be exercised. Contextualization is referred as to the physical arrangement of technologies in use"*. However, the authors don't provide a deeper insight in the process of defining and developing the dimensions of their framework or why they suggest tangible interfaces for elderly users. The importance of the physicality of an user interface is underlined by Criel et al [16]. They argue, that "It is essential to provide seniors with technology that offers a tangible and mechanical experience. Although current research is geared towards making tiny and invisible interfaces, for this class of user group it is still important to keep the tangibility and mechanical quality of experience. Pressing a button or turning a knob etc. is preferred over touch screen or other context driven triggers (e.g., position, location, etc.)" [16]. There is also research building upon the concept of familiarity, which addresses similar fields of research as this thesis. Zhang et al. propose a *Framework of Familiarity Design*, which is based on literature review. They suggest to include symbols, actions and cultural patterns known from the real world when designing new technologies for elderly people [156]. They plan to conduct field studies in the future, to underline their theoretical approach. Herstad and Holone introduced both co-creation and familiarity in their research on co-creation for tangibles [52]. They presented a study with children with disabilities, interacting in a familiar surrounding and people. The dimension of co-creation was covered by rearranging tangible cushions. As we saw in this literature review, research has illuminated providing technology including the needs of elderly users. To our knowledge however, there are still no studies that have developed a deeper understanding of the design of interface elements, multimodality and the user-centred design process itself when it comes to developing technologies with Tangible User Interfaces for older people.

User-centred Design

The user-centred design approach is based on active involvement of users to gather their needs and expectations regarding a product or a technology. The involvement in the design process and its evaluation is done in an iterative way [80]. This approach is already an evolution of the original user-centred design concept, which was coined by Norman and Draper [96]. Although it considers the understanding of users' needs to be central, it does not necessarily include the participation of potential users in the design process. More recent definitions of the user-centred design concept consider inclusion to be a fundamental element. According to the standard DIN EN ISO 9241-210:2011-01, a human-centered approach should follow the principles listed below [23]:

- the design is based on a comprehensive understanding of users, work tasks and work environments
- users are involved during design and development

- the refinement and adaptation of design solutions shall be pursued on an ongoing basis on the basis of user-centred evaluation
- the process is iterative
- the entire user experience is taken into account in the design
- interdisciplinary knowledge and perspectives are represented in the design team

Based on this principles of user- or human-centred design, we have placed a strong focus on the involvement of older people in the design process from the very beginning of our research. However, especially for this user group, participation must be planned and organized very carefully. As Czaja and Lee have already pointed out, the lack of understanding of the needs of older people is largely to blame for the low accessibility of new technologies [19]. Pühretmair and Miesenberger also emphasize the need for joint development of measures to increase accessibility, and thus usability, in a user-centred design process [114]. It is necessary to create a pleasant and familiar atmosphere for the participatory workshops [89], which forms the basis for motivating older people to commit themselves to a cause whose meaning and advantage they cannot yet recognize [49]. On the one hand, this atmosphere should create a productive cooperation between the different participants [79] and motivate them in a respectful way to achieve the goals [154]. On the other hand an inhibitory feeling of a test situation is prevented [93]. At the same time, a user-centred design process with older people must also take into account their age-related limitations as described in this section and overcome possible fears of technologies through unfamiliarity [25].

However, obtaining contributions to design from older people, whose main experience of computing is that they get things wrong, requires careful management of their interaction with the designer and with the prototyping situation [49] These references from literature show that there is already concrete prior knowledge about the participation of older people in the design and development of information and communication technologies. However, these recommendations almost always target the design of traditional WIMP user interfaces, remote controls or mobile phones. Since this work focuses on the design of systems with Tangible User Interfaces, an attempt is made to apply these recommendations to our situation. A good overview of principles for the participation of older people is given by Fisk et al [33]:

- Make sure the research sample is representative of the target population of interest, and remember that not all older people are alike.
- Clearly define participant inclusion and exclusion criteria and protocols for assessing these criteria.

- Use multiple methods for recruitment, and recruit participants from locations that are representative of the target population of interest.
- Make sure the testing environment is as stress-free as possible and minimize interfering distractions.
- Make sure the lighting conditions are optimal and that ambient noise is kept to a minimum.
- Adhere to existing guidelines for formatting text and speech information.
- Use nontechnical and familiar vocabulary in instructions, task materials, and measurement instruments.
- Eliminate highly paced task demands and allow participants sufficient time to respond.
- Minimize the demands on working memory.
- Minimize participant burden and ensure that participants are provided with sufficient rest breaks.
- Familiarize research personnel with the basics of aging.
- When using standardized instruments, choose those that have been normed with older populations.
- Pilot test all protocols, measurement, and data collection instruments with representative samples of older people prior to formal data collection.

To meet the needs of older users, it is indispensable to involve them as early as possible in the design process. This is substantial to integrate wishes and suggestions from the relevant target group directly into the development of new technologies [116] [19]. As the exitence of the ISO norm mentioned above seems to implicate, the concept of user-centred design already arrived at product developers and designers. However, when it comes to real world implementation, it's execution is often deficient. Often only quantitative methods similar to market research are used to query customer's wishes, but they can not provide a deep insight into context and user experience, as required for the development of new technologies [38]. Furthermore, time-consuming user integration in the design process is reduced due to pressure from management to develop a technology as quickly and with as little resources as possible [33]. For the successful integration of elderly users in the design process, Friesdorf et al. have identified seven possible entry points among a total of twelve product development steps, in which the inclusion of users would be reasonable [38]:

- Entry point one: Already during the generation of the first product ideas, elderly users can be involved through surveys. However, talking about abstract and very general tasks could cause difficulties for elderly users.
- Entry point two: The product ideas resulting from the first phase can be presented to elderly users and together with them the most promising idea can be selected.
- Entry point three: The refined product idea is presented to the seniors in order to identify possible weaknesses in the run-up.
- Entry point four: The product developers create first concept variants, which are presented to the elderly users as two- or three-dimensional models and are evaluated by them.
- Entry point five: The most promising concept is implemented as mock-up. Together with the elderly users the model can be improved by means of creative design methods.
- Entry point six: Based on this mock-up a prototype of the product is developed and evaluated with the elderly users.
- Entry point seven: After completion of the development process, the elderly users can be furthermore involved in the evaluation of the product.

User involvement in the area of designing Tangible User Interfaces for older adults is not widely adopted in literature. In a recent literature review regarding Tangible User Interfaces for elderly users in regard of social interaction, Bong et al. identified six out of 21 papers used a user-centred design approach [10]. However, the author of this thesis was involved in three of the six papers. The remaining studies involved only low-level prototypes or a very low number of users, e.g. Kern et al. with two elderly participants [72].

Before we present the methodologies used in this thesis, we summarize this section and relate our research questions to the background and related work described above.

2.3 Summary

This thesis builds upon the previous work described in this chapter. It aims to enrich current GUI dominated user interfaces of ICT for elderlies through pointing out the advantages of tangible interaction for intuitive interface design and furthermore proposing ways to integrate it into existing technologies. In this section, we will summarize the previous work by reflecting them on our research questions.

Sub question 1: Can tangible interface elements be used to support elderly users in the interaction with communication technologies?

In Section 2.1 we provided an overview of both the emerge of Tangible User Interfaces and the associated concepts. For this thesis, the token+constraint approach and the principles of the Tangible Interaction Framework will form the basis of our interface and interaction design considerations, as they represent key concepts in the area of Tangible User Interfaces. To answer sub question 1, we will have to scrutinize tangible interaction in our research iterations. Therefore, we will provide tokens as physical control elements and constraints to define the user interaction for the tokens. These token+constraints setup should benefit from well developed skills for physical object manipulation [34], partly already since early childhood [58], and also encourage intuitive tangible interaction, aiming at a playful interaction with our prototypes [53]. We will have to design a lightweight interaction with pleasant materials, where users profit from isomorphic effects between token and constraints in their interaction with the tangible interface elements. We will have to scrutinize ways of optimize the representation of the digital information linked to the relationship between token and constraint for elderly users. We need to take into account the characteristics of spatial interaction and the possible advantage of Tangible User Interfaces regarding age-related changes in fine-motor control and reduced mobility of our target group.

Sub question 2: Does the use of personalized and autobiographical elements improve the user interaction of elderly users with communication technologies?

Following the idea of objects as personal cues for reminiscing, we will embrace both the integration of personal objects as powerful representations in our research and the generation of personal cues through the users themselves. Personal objects can be everyday or self-made objects, representing physical, autobiographical objects of memory, reminding the owner of special moments or friends. We will benefit from the findings of Mugelini et al. [88], including everyday objects in tangible interaction. Through generating personal cues through the users, we embrace the recommendation of van Hoven et al. [142] regarding future research of an interplay between generic object and personal meaning and thus aim to improve the recall of functionalities of the underlying digital system. The use of familiar objects builds upon the recommendation for using a feature more quickly and intuitively. Including personalized and autobiographical elements also adds to an atmosphere of familiarity, which addresses the challenges of older adults in unfamiliar environments and novel tasks.

Sub question 3: Can elderly users be successfully involved in the design and development of innovative and intuitive communication technologies?

We will embrace user-centred design principles as our approach to include older adults in our design process, which consists of three major iterations. Along the recommendations of the ISO 9241-210 [23] standard, we will extend the original concept of Norman and Draper by involving users during the whole design process. Through detailed analysis of our design iterations, we will ensure a comprehensive understanding of the users' needs and the quality of the user's interaction with our prototypes. A strong focus will be on the design of participative workshops and their materials in order to meet the special needs of our target group. We will use the guidelines of Fisk et al. [33] and Rauhala [116] as a concrete basis for planning and conducting our workshops. For the possible entry points of user inclusion we will consider the recommendations of Friesdorf [38].

> **Sub question 4: Can we use multimodality in the design of user interfaces and the user-centred design approach to foster accessible communication technologies for elderly people?**

We will focus on the multimodal nature of Tangible User Interfaces to support older adults in their interaction. Object-based interfaces address additional modalities both in user interaction and in the area of system feedback. Literature review showed that multimodal interaction can help older adults in learning and recognition. This is essential when using new technologies, both to recognize the functionalities and to remember the interaction sequences. Multimodal feedback can be provided in the tangible and the intangible representation.

Chapter 3

Methodology

As we conduct a user-centred design process, we decided to use qualitative methods, which allow the direct involvement of viewpoints and living environments of participants. This is especially important when working with older people with low affinity for technology, where very little literature is available, especially in the field of Tangible Interaction. Furthermore, qualitative research methods support the exact observation and analysis of detailed communication and interaction processes. The strong focus on personalization for the interface design also calls for elements of qualitative research, which allow to scrutinize biographical and ethnographic information.

3.1 User-centred Design

The term *user-centred design* is frequently used in the research field of human-computer interaction, often in connection with related terms such as *participatory design* or *interaction design*. However, the definition of user-centred design remains ambiguous. The term was originally coined by Norman and Draper, who stressed the importance of focusing on user needs when designing a new system [96, p. 61]:

> *"But user-centred design emphasizes that the purpose of the system is to serve the user, not to use a specific technology, not to be an elegant piece of programming. The needs of the users should dominate the design of the interface, and the needs of the interface should dominate the design of the rest of the system."*

This shift from a technology-driven approach to an emphasis on the user as the central element of the design process remains the common ground in the literature on user-centred design. Rubin et al. describe user-centred design as [121, p. 12]:

> *"the techniques, processes, methods, and procedures for designing usable products and systems."*

In line with Gould and Lewis' pioneering work [46], they emphasize three basic principles of user-centred design, including early focus on the user, evaluation and measurement of product usage, and iterated design. We embrace these principles in our research by involving users from the very beginning. We conduct three design iterations, where users test and evaluate our prototypes with Tangible User Interface. We aligned the setup of the iterations to the specification of ISO 9241-210:2010. This ISO standard identifies four main elements of a user-centric design process [23], which are illustrated in Figure 3.1:

- Understanding and specifying the context of use: The context of use includes the characteristics of the relevant user groups, the tasks they want to carry out and the physical, social and cultural environments. For our research it was necessary to put a special focus on the special characteristics of our target group of older people and easy-to-use communication tasks.

- Specifying the user requirements: Based on the context of use, the user requirements include challenges arising from ergonomics and interface design, usability and, when relevant, organizational specifications.

- Producing design solutions: Producing design solutions according to design and usability guidelines and standards. This include user tasks, user interaction, and user interface, using design methods fitting the current state of the user-centred design process.

- Evaluating the design: Conducting user-centred evaluation, based on user-based testing or inspection-based evaluation using usability and accessibility guidelines or requirements.

Each of our design iterations started with the specification of the context of use and also the user requirements. In the first iteration the requirements were derived from literature review, in the following iterations from the analysis of the evaluation of the previous iteration. Based on these requirements, we further developed our prototypes. Afterwards, we evaluated our design solutions in user workshops. In the workshops we applied focus group methods and usability tests. The iterations ended with an analysis phase, in which the implications for redesign were identified, which formed the basis for the specification of the user requirement in the next iteration.

For our user-centred design process, we used a mixture of different qualitative research methods. For the specification of the context of use and the user requirements, we initially used literature review and after the first user evaluations our multimodal analysis frames as tools for extracting user requirements. For the development of our design solutions, we used different kinds of prototyping tools like Arduino, Processing, 3D printing and diverse tinkering materials. For the evaluation of our user workshops,

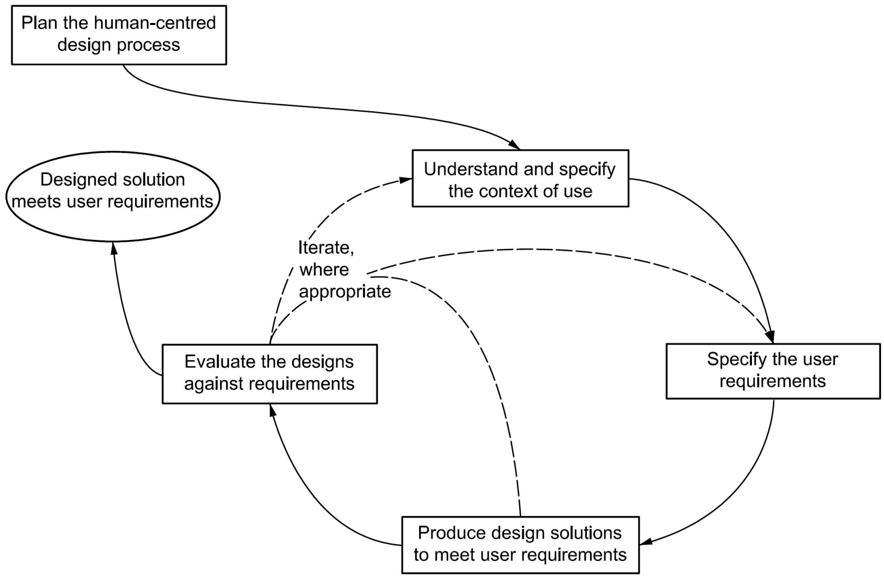


Figure 3.1: User-Centred Design process [23]

we combined elements of focusgroups, usability testings, and accompanying interviews. As we applied the principles of Tangible User Interfaces, we need to record user interactions and statements by video monitoring. In this way, we were able to analyse not only the direct interaction with the interface elements but also the usage of the surrounding space. In the following, we describe the methods applied in more detail.

Interviews

There are several different types of interviews, ranging from highly structured interviews with clearly defined guidelines to very open or narrative interviews, where the interviewer only gives the rough direction [35]. In principle, the interviewer should take a neutral position in order to influence the interviewee as little as possible. Interviews in the context of a usability workshop should take place directly after the workshops, so that the memory of the interaction is as up-to-date as possible [33]. In addition to interviews with workshop participants, interviews with experts were conducted as part of this thesis. The results of these discussions were used in the further development of the prototype as well as in the planning, preparation and implementation of the workshops.

Focus Groups

Focus groups are often used to discuss the experiences people made with existing technology and to identify user requirements for the design of a new technology [8]. Discussions on certain topics are held in smaller groups, typically with six to twelve people. In contrary to the interview setting, the researcher plays a more active role, facilitating discussion and interactions between the participants. Not only the results of the discussion, but also the stimulation of a discussion, and the dynamics within the discussion are used as a source of knowledge [35] [33]. Focus groups are a promising method in the development of new technologies to discuss the needs of users at the beginning of the development process. We also used this method to create familiarity and a relaxed atmosphere at the beginning of the user workshops.

Usability Testing

A very important method in the context of user-centred design is usability testing. It was used as a basic structure for the workshops conducted as part of this thesis. One or more representative users of the relevant target group are observed interacting with the device to be developed. It is often carried out in combination with other methods, such as interviews, in order to reflect on the interaction situation again afterwards. The aim of this observation can be to find problem fields in the interaction or to measure the time required to complete previously defined tasks [33] [121]. Rubin et al. described the basic elements of usability testing as follows [121]:

- Development of research questions or test objectives rather than hypotheses.
- Use of a representative sample of end users which may or may not be randomly chosen.
- Representation of the actual work environment.
- Observation of end users who either use or review a representation of the product.
- Controlled and sometimes extensive interviewing and probing of the participants by the test moderator.
- Collection of quantitative and qualitative performance and preference measures.
- Recommendation of improvements to the design of the product.

It is advisable to prepare a test plan in advance to provide an overview of the general setup and the usability testing process. In this plan basic elements of usability testing mentioned above are dealt with in more detail: What are the objectives? How are users selected and how many are needed? Is a functional prototype used or a mock-up? How should the interaction process be recorded? Should users communicate their thoughts aloud during the interaction in order to better understand their actions or would this distract too much? Consideration must be given to where the observations are to take place.

In a laboratory environment or in an environment familiar to the users? Especially older users can be irritated by an unfamiliar environment [33]. How should a camera be positioned without violating the privacy of the users, but still keep the interaction process with the device clearly visible? Many different factors must be taken into account when usability testing is carried out. In our user workshops we used usability tests together with the think-aloud method. We asked the participants to speak out loud during the interaction with our prototypes about what was going through their minds. This was especially important as the participants in iterations 2 and 3 did not receive any help or explanations in advance in order to test the intuitivity of the interaction with the prototypes.

One of the advantages of the think-aloud method is the ability to identify the strengths and weaknesses of a user interface. Therefore we asked the participants to articulate their feelings and observations during all interactions with the prototypes. Although in a traditional think-aloud setup the researcher should step into the background, this was not always easy or possible in the context of our research iterations. As Blandford et al. describe, a complete restraint is not always beneficial, interventions in a think-aloud session can be useful to sought participant explanations and opinions [8]. Especially when working with elderly people, it is important that they do not feel left alone. This can quickly lead to frustration of the participants which can affect the outcome of the usability tests.

Observation

In the history of qualitative methods, observation is a frequently used method for data collection. There are different forms of different observation procedures: hidden/open, non-participating, systematic/unsystematic, etc. [35]. Blandford et al. describe several dimensions of observational studies [8]:

- The extent to which participants are aware they are being observed.
- The extent to which obtaining informed consent is necessary.
- The extent to which the observer becomes a participant.
- How realistic the environment in which observation takes place is.
- Whether the observation regards established or new systems.
- How structured the observation notes are.

In our research we have always worked with open observation. Participants were always aware that their actions were captured either through video observation or sound recording. The participants also always gave their active consent. The observer was also a participant in our workshops to a certain extent. As described in Section 3.1, the observations of the user interaction were also intervened to gain a deeper insight into the thoughts of the participants, or to guide them when they were stuck in the interaction and actively demanded support. The environment of observation played an important role in our research. While in the first iteration a completely unfamiliar environment prevailed for the participants, this circumstance changed already in Iteration 2 for a part of the participants. In Iteration 3, the observations were moved to the participants' homes, thus achieving the greatest possible familiarity with the environment. The interplay between the usability testings and the environment was also described in detail in our publication *kommTUi - A Design Process for a Tangible Communication Technology with Seniors*, Section 7.6. Our user workshops focused on observations of new technologies. Therefore, the goal was a detailed analysis of the user interactions with the prototypes. This was mainly achieved by video observation and the subsequent analysis using our analysis-frames. Observation notes were additionally generated during the usability tests, but were mainly of a complementary nature.

3.2 Multimodality

In principle, multimodal interaction encompasses any kind of interaction, but it should be emphasized that low-level interaction, such as the distance to the device or the movements of the field of vision, is also included in the analysis. Here some categories according to Norris are listed that can be used for the analysis of video material [101]:

- Spoken Language: What is important here is not only the content of a statement, but also the context in which things are expressed.
- Proxemics: How far away are participants from each other and from important objects? For example, a large distance may indicate a lack of familiarity with a person or a device.
- Posture: Which posture do the participants adopt during the interaction? Are arms and legs crossed? Is the participant sitting straight on the chair or on the side? Is the body aligned with or away from the relevant object?
- Gestures: Gestures often underline the meaning of spoken words and can thus contribute to the clarity of statements made.
- Head movement: Head movements can have various meanings. For example, nodding or shaking the head can signal approval or rejection, lowering or raising the head can change the posture (closed or open posture) or the focus can be changed by shifting the field of vision.

Our design process builds upon a high level of user integration through participatory workshops. We explored the users expectations and needs using interviews, design sessions, and playful interactions with technology probes. To gather the high amount of data we used video observation, photos, audio recordings, and textual notes during our workshops. As a tool for the analysis of our workshops we designed consistent, multimodal analysis-frames. These frames represent the principles of analysis of multimodal interaction by Norris [101]. Our multimodal analysis-frames consist of:

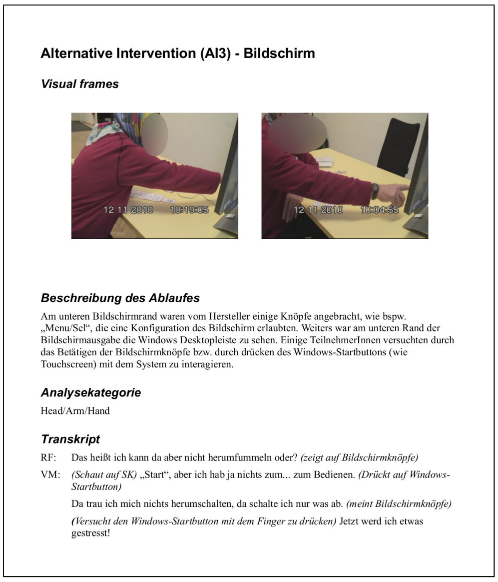
- Analytical category: Determines the criterion of selection for the distinct activity.
- Visual frames: A collection of video stills of user workshops for a visual description of the activity.
- Context description of activity: In this section, the observed user interaction is described in a textual way.
- Transcription: A collection of quotations out of the video analysis.

The above structure allows a congruent frame design and enables comparability between the analytical categories. Figure 3.2 shows two examples of our multimodal analysis. As we take our analytical categories, select situations we want to analyze accordingly, we set-up multimodal frames, showing all relevant content from each category in one sight (on one or two sheets of paper). This makes it possible to compare the selected situations by spreading out the analysis frames on the table. The categories for the analysis are drawn from the observation categories defined before the participatory workshops, eg.: usage of interface surrounding space and spatial arrangements, participants' organization of interface elements, user interaction and communication, token usage, and relation between user and artefacts.

We describe the usage of Multimodality for our research in the publications *Multimodality in Design of Tangible Systems* (Section 7.3) and *Defining Multimodality for Tangible Interaction* (Section 7.1). In the first paper, we present our approaches to take into account multimodality not only in the design of our mock-ups and prototypes but also in the design of our user-centred workshops. The second paper describes our tool for analyzing the multimodal interaction in our workshops (*Analysis-Frames*).

3.3 Ethical Framework

As the involvement of future users plays a crucial role in this project, it is particularly important to address the ethical issues related to user testing. In the process of contacting the test subjects, an Informed Consent is sent to them, which contains central information about the project in order to give the test subjects an overview of the most



Alternative Intervention (AI3) - Bildschirm

Visual frames

Beschreibung des Ablaufes

Am unteren Bildschirmrand waren vom Hersteller einige Knöpfe angebracht, wie bspw. „Menu/Sel", die eine Konfiguration des Bildschirm erlaubten. Weiters war am unteren Rand der Bildschirmausgabe die Windows Desktopleiste zu sehen. Einige TeilnehmerInnen versuchten durch das Betätigen der Bildschirmknöpfe bzw. durch drücken des Windows-Startbuttons (wie Touchscreen) mit dem System zu interagieren.

Analysekategorie

Head/Arm/Hand

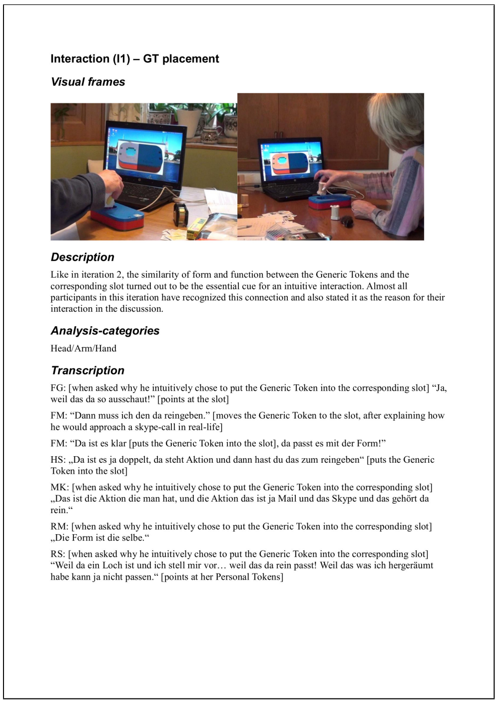
Transkript

RF: Das heißt ich kann da aber nicht herumfummeln oder? *(zeigt auf Bildschirmknöpfe)*

VM: *(Schaut auf SK)* „Start", aber ich hab ja nichts zum... zum Bedienen. *(Drückt auf Windows-Startbutton)*

Da trau ich mich nichts herumschalten, da schalte ich nur was ab. *(meint Bildschirmknöpfe)*

(Versucht den Windows-Startbutton mit dem Finger zu drücken) Jetzt werd ich etwas gestresst!



Interaction (I1) – GT placement

Visual frames

Description

Like in iteration 2, the similarity of form and function between the Generic Tokens and the corresponding slot turned out to be the essential cue for an intuitive interaction. Almost all participants in this iteration have recognized this connection and also stated it as the reason for their interaction in the discussion.

Analysis-categories

Head/Arm/Hand

Transcription

FG: [when asked why he intuitively chose to put the Generic Token into the corresponding slot] "Ja, weil das da so ausschaut!" [points at the slot]

FM: "Dann muss ich den da reingeben." [moves the Generic Token to the slot, after explaining how he would approach a skype-call in real-life]

FM: "Da ist es klar [puts the Generic Token into the slot], da passt es mit der Form!"

HS: „Da ist es ja doppelt, da steht Aktion und dann hast du das zum reingeben" [puts the Generic Token into the slot]

MK: [when asked why he intuitively chose to put the Generic Token into the corresponding slot] „Das ist die Aktion die man hat, und die Aktion das ist ja Mail und das Skype und das gehört da rein."

RM: [when asked why he intuitively chose to put the Generic Token into the corresponding slot] „Die Form ist die selbe."

RS: [when asked why he intuitively chose to put the Generic Token into the corresponding slot] "Weil da ein Loch ist und ich stell mir vor… weil das da rein passt! Weil das was ich hergeräumt habe kann ja nicht passen." [points at her Personal Tokens]

Figure 3.2: Examples for analysis-frames

important aspects. The purpose of the Informed Consent is to make transparent what the intention of the request is, what the role of the test person is and what the test situation will look like. Furthermore, the type of user tests and their recording (e.g., video recordings) are informed and how the test person's personal data is handled.

The "Experience-based Framework" of Rauhala [116] was used for working with older people. This framework is based on the analysis of other scientists' experiences in user integration. From this, a series of recommendations were derived, which were used as a basic structure for planning and conducting the workshops:

1. Let the encounter be based on respect.
2. Pay attention to the individual. Be attentive.
3. Treat the user as an expert.
4. Be open-minded.
5. Make careful preparations.
6. Flexibility: adapt to the situation.

7. Be clear (also about roles and expectations).
8. Benefit from the presence of significant others.
9. Allow for plenty of time.
10. Employ techniques of user involvement that are appropriate for the user group in question and that build on their strengths and not weaknesses.
11. Design tasks for user tests that are appropriate and acceptable for the primary and secondary users.
12. Learn to recognize when to involve whom in a research project. Early involvement is not suited for all end users.
13. Be sensitive to other work cultures and professional routines involved in the project.
14. When working with groups of older persons and disabled persons, reduce group size to accommodate for possible communication difficulties.
15. If possible, work with users in a stable condition.
16. Appreciate the fact that participation is for many users a social event.
17. Ensure the end users' voice is heard.
18. Recognize the fact that inclusion in research may turn into an issue of fairness.
19. When possible, let users use their own tools in their own environments.

3.4 Summary

In this chapter, we have presented the methods used for our research. It is a mixture of different qualitative methods to meet the needs of our user-centred design process. The strong focus on mulitmodality is reflected also in our tool for analysis. The analysis-frames allow a comparison of selected situations of workshops through textual description, pictures of the scene and transcription of recorded statements. While we have provided examples of analysis-frames to clarify their structure and usage in this chapter, we abstain from depicting all the analysis-frames used for our analysis described in the next chapter. The whole methodological approach is embedded in an ethical framework, which provides recommendations for working with elderly people. Building upon these methods, we have developed an iterative design process for the participatory design of our prototypes, which we present in the next chapter.

Chapter 4

Implementation

This chapter describes the implementation of the *kommTUi* design process. It is based on the methods described in the previous chapter and realized in three iterations. Each iteration consists of a (re)design phase, a workshop phase, and an analysis phase. The (re)design phase contains the technical development for the workshops, based on design principles extracted from literature and the analysis of previous iterations. In the workshop phase, the designed technical probes and prototypes are evaluated in participatory user workshops. The results of these workshops are then analysed in the finalizing phase of the iteration. On the basis of the findings of the workshops we conclude with implications for the redesign of the prototype.

4.1 Iteration 1

The first iteration process started with an extensive literature and technology review. The literature review had the aim to assess previous and current research activities in the areas of (tangible) user interfaces, technology for elderly people and active ageing, intuitive use and RFID. The gathered information was presented in background Section (2). During the technology research potential technologies were investigated which can be used for the kommTUi prototype. Here RFID, various image processing systems and microcontrollers (as a technical basis) emerged as practicable. The first explorative prototypes were created from these technologies, such as an automatic photo scanner, a fast boot mini device, or a tangible RFID interaction device.

Design and Development

Results of literature research and product analysis form an essential basis for the first developments in the project. The project team defined the goal of the first workshop as a review of the motivation, type, and transmission channel of everyday communication of older people. From the results of the preliminary research, important basic prerequisites for planning and conducting workshops with older people could be extracted. In order to create an atmosphere of trust and to reduce possible barriers as early as possible, the workshop was planned in great detail and attention was paid to a cosy, playful atmosphere. The venue for the workshops was chosen from the facilities of the university institute where the author is employed. This had the advantage that sufficient space and equipment was available, but the disadvantage was the *university flair*, which represented an unfamiliar ambience for the participants. Potential participants were sought through personal contact with senior citizens' organisations, within the family circle of students, and through posters in senior citizens' homes. An important decision was to set certain age limits. This problem is also frequently mentioned in the literature. The project team decided that the development of *kommTUi* should focus on the age group 55 to 70 years. A decisive reason for this determination was the consideration that the development of a future technology should build on the level of knowledge of the *old* of the future. As a basic principle for the design of the workshop it was determined that as many senses of the participants as possible are used for the completion of the workshops. This principle influences both the spatial structure, the invitations with preliminary information, and the design of the individual workshop stations.

Workshops

The workshop design consisted of a welcome package as information for the participants prior to the workshops and four workshop stations, covering the diverse research questions to discuss with the participants.

Welcome Package

In order to introduce the participants to the workshop topic at an early stage and to collect information in advance, a Welcome Package was designed and sent to the participants in the run-up to the workshops. This contained information about the workshop and the organizers, as well as three tasks, which were filled out by the participants and brought along to the respective workshop date.

The aim of the first task was to collect information on the most frequent topics of the participants' (everyday) communication. For this purpose, 13 cards with general questions or questions on a specific topic were provided (Figure 4.1). In addition to the cards dealing with a specific topic, there were also cards containing general questions such as "What further topics would you like to talk about regularly with others" or "What would you like to send to a friend in Australia?". On each card it was also possible to specify the preferred communication channel or several communication channels by checking the corresponding check boxes. For illustration purposes, matching pictures were provided on the back of the cards with predetermined themes.

Figure 4.1: Welcome Package of Iteration 1

In the second task the participants were asked to bring some objects to the workshop which symbolize common reasons of communication in everyday life (Figure 4.2 - bottom left corner). These items were used in the interview sessions of the workshop. In the third task some symbols and five stickers with written descriptions of communication activities were provided (Figure 4.2). Participants were asked to attach the stickers to the symbols with which they best connect the respective communication activity. This was intended to check whether certain communication activities tend to be assigned certain symbols.

Workshop Setting

Four different stations were planned for the workshops, which included different types of interaction and communication. Some of the technologies used were designed and developed together with students as part of university internships. In total, five technical probes in different versions were developed in the time before the workshop. The project team decided in advance that only two of these probes should be used in the first workshop, as the workshop should focus on understanding everyday communication and testing interactions. The other probes should be used during the course of the project. We have decided to use technologies that make it possible to build systems that can also be operated from a seated position. This was an important limitation of

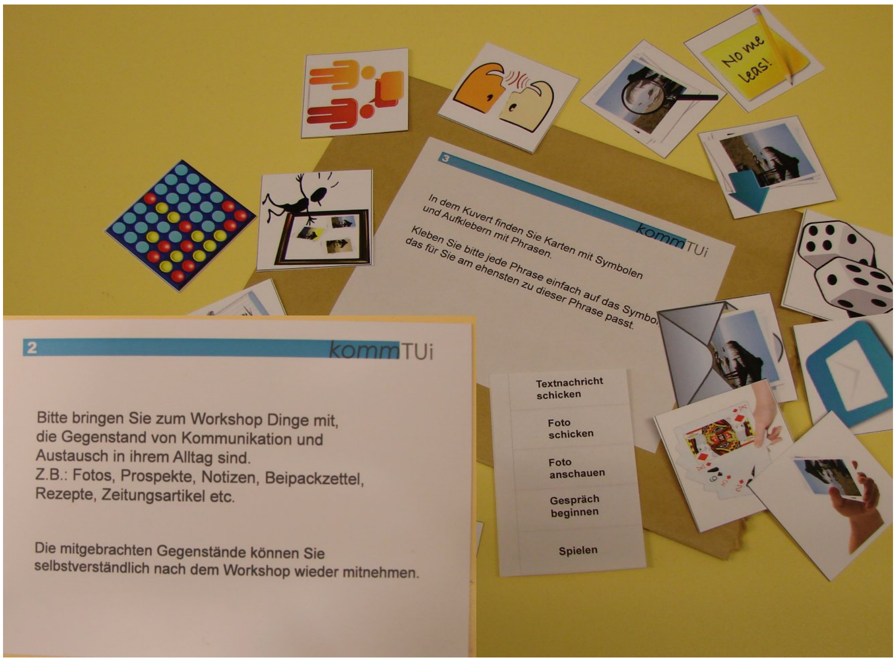


Figure 4.2: Welcome Package of Iteration 1

the interaction space to meet the special needs of our target group. For example, we decided to use RFID technology and opposed the use of visual tracking. The latter usually requires a higher spatial structure and special lighting conditions to enable tracking by cameras from below the interaction surface. This is the case with tabletop systems, for example, where interaction must take place while standing and it is not possible to position oneself under the tables with a wheelchair.

All stations were equipped with video cameras to document the workshops. In addition, photos were taken from time to time by the workshop supervisors. All conversations were recorded on tape.

Two workshops with a total of 11 participants were held. The age of the participants ranged from 55 to 70 years, with an average of 63 years, and a standard deviation of five. The first workshop had six participants and the second five, both took place from 9 to 12 o'clock a.m.. Due to the early time of day and to create a relaxed atmosphere, a small breakfast buffet was provided on both days. After the welcome, there was a short introduction with explanations on the agenda of the workshops. As soon as the participants were ready, they could visit the individual stations in any order.

Stations 1 and 2 dealt with different communication behaviour during a playful activity and how communication behaviour differs when playing at a table or via electronic communication channels.

Figure 4.3: Station 1 of Iteration 1

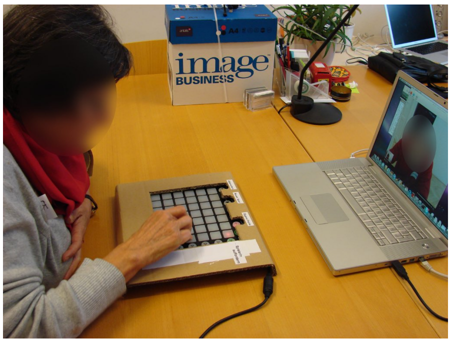


Figure 4.4: Station 2 of Iteration 1

Station 1

Station 1 contained a *Connect 4* 3D board game designed for the active use of different senses (Figure 4.3). Through its multimodal design, it can be played with both visual and tactile senses, but also blindfolded.

The original *Connect 4* is a game for two players, in which they first choose a color and then alternately drop their tokens from above into a seven-column, six-row, vertically suspended board (Figure 4.5). The tokens fall straight down one shaft and occupy the next free space within the respective column. The aim of the game is to connect four tokens of the same color vertically, horizontally, or diagonally before the opponent achieves this. There are different sizes of the board, the most commonly used being 7x6, followed by 8x7, 9x7, and 10x7.

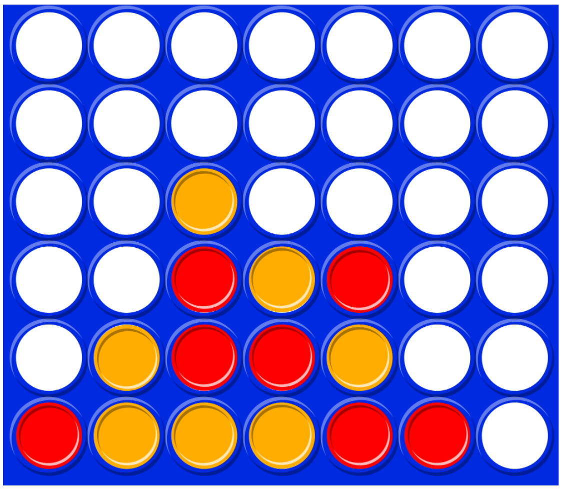


Figure 4.5: Example of the game “Connect 4”

The wooden game board was designed by the research team and afterwards crafted by a carpenter. The game tokens were first designed on the computer as 3D models and then printed out using a 3D printer. We used red and white colouring to ensure a high visual contrast. The tokens differed not only in colour but also in form (Figure 4.6). This also made it possible to haptically feel the difference of the tokens. Just like the original game, two players can play the game in a direct face-to-face interaction. The participants were invited to play the game first without restrictions (as often as they wanted) and then to play a second round blindfolded.

Figure 4.6: The Board Game created for Iteration 1.

Station 2

Station 2 was divided into two rooms, in each room was an electronic *Connect 4* board, which could be operated by LED buttons[1]. For the implementation *Novation Launchpads* were used, which are usually used as sequencers for DJs (Figure 4.10). A launchpad consists of 64 LED buttons, which glow red, orange, yellow, or green and can take on different light intensities. Pressing a button in the respective column animates the falling of a piece. A screen with audio-visual connection to the other player was provided as a communication channel.

[1]This prototype was implemented by our student Mischa Magyar in his voluntary work at our institute.

The possible states of the digital board game and the state transitions are illustrated in Figure 4.7. The state transitions when the *cancel* button is pressed are shown in Figure 4.8, those for pressing the *new game* button in Figure 4.9.

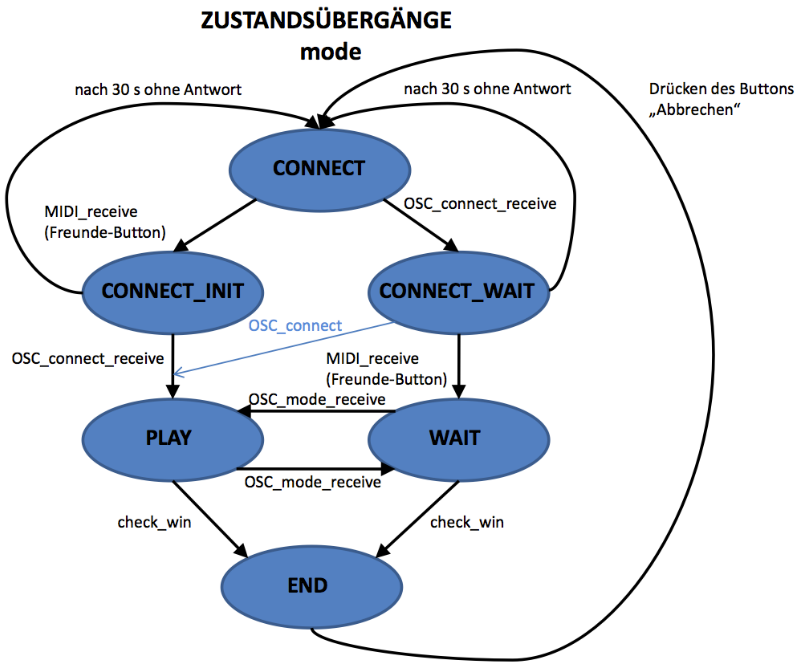


Figure 4.7: The states and transitions of the digital Connect 4 game

Our digital Connect 4 game had following features:

Confirmation by the other player: To start a game, the other player must confirm this. The player can request a game by pressing the corresponding friends button. This button now starts flashing yellow for both the player and the other player. As soon as the other player presses the blinking friends button to confirm, the game starts. If the other player does not press the button, the status of the launchpad and the buttons is reset after 30 seconds. Pressing *Cancel* and *New Game* while a game is running also require confirmation from the other player. If the other player does not confirm, but continues to play, the corresponding buttons are reset.

Throw in the tokens: There were different possibilities to realize the insertion of the tokens. Either the token appears at the point where the player presses into the board and then falls until it either arrives in the last row or lies on another token or the token always falls from the very top onto the board. The following considerations led to the final decision for one of the variants: If the token does not directly appear where the player presses, it could confuse him. However, the token falls down automatically and behaves like a physical token in real Connect 4, so there should be no uncertainty. If

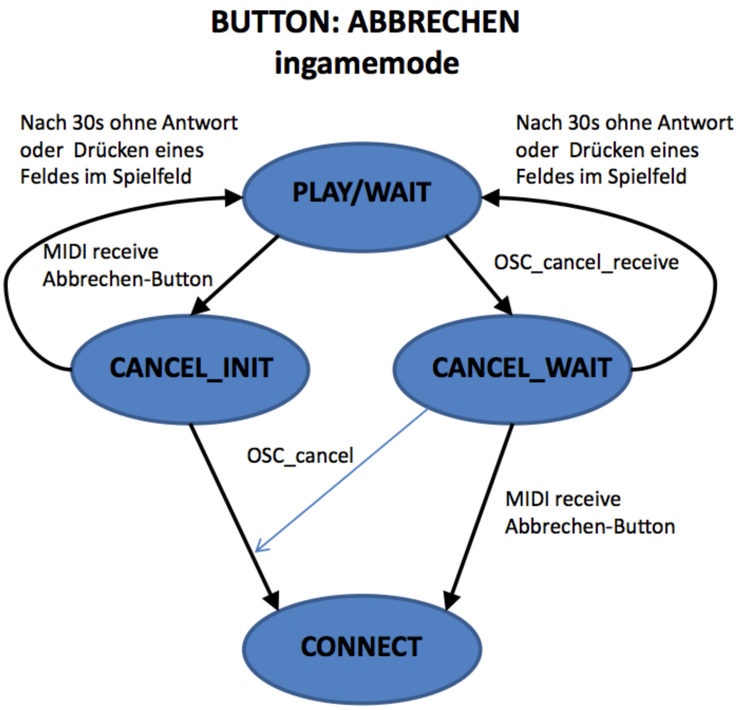


Figure 4.8: State transitions for the *cancel* button

the token would appear directly where it comes to rest on the other board, the opponent could easily overlook this and might have to ask which token the player has thrown in. The prolonged fall animation draws the attention of the other player and also has a longer period in which he sees where the token was thrown in.

Displaying the color of the player's tokens: In real Connect 4, you have your tokens in front of you or in your hand and thus always have your own color in view. In this Launchpad conversion, this multimodal element was missing. It was not possible for a player to find out his own color while the game was running without throwing in another token. Displaying the player's own color was therefore necessary.

Friends – Buttons: The number of friends—buttons depends on the number of IP—addresses entered in the configuration file. In one of the first variants, the button was activated, regardless of whether a Launchpad– client is running at this IP address or not. You could press the button and the button signalled by a yellow flashing button waiting for the other player even if he is not available. Later, the addition was made that a client sends a handshake signal to all other launch pads at regular intervals. In this status message the game status of the client is also sent, whereby the friend button can represent different statuses by several colors.

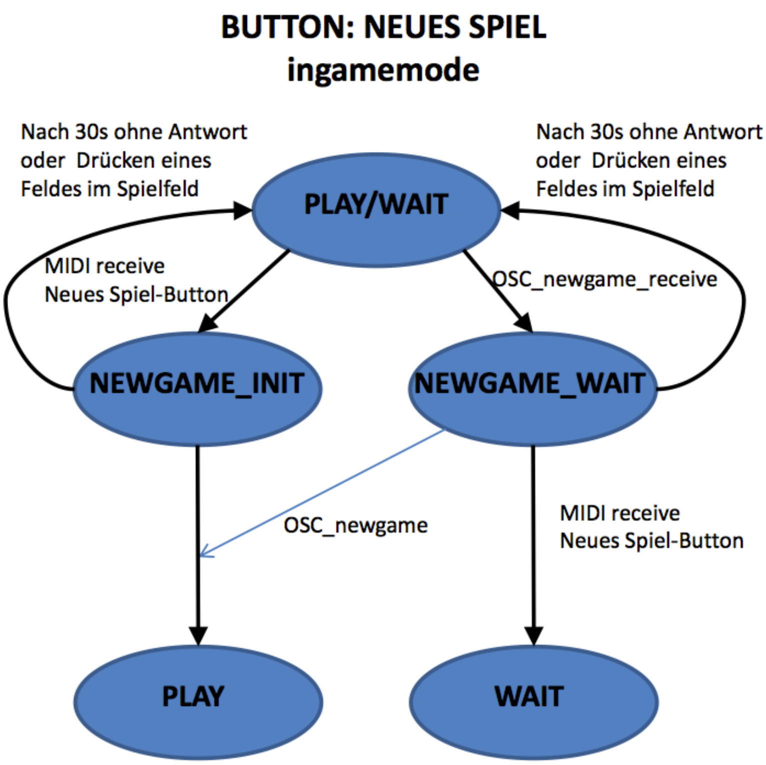


Figure 4.9: State transitions for the *new game* button

Cancel and New Game: The Friends button indicates the status during the game with green and yellow. Originally the client should be reset to its initial state at the end of the game by pressing the Friends—button. This doubled functionality of the Friends— buttons however was - for the sake of clarity - discarded and so a separate button for *Cancel* and *New Game* were implemented. The button for a new game has the same function both during the game and at the end of a game: a new game is started after confirmation by the other player. The Cancel—Button resets the client to its initial state at the end of the game. During the game you need the confirmation of the current player.

To further improve the user interface and guidance for the users, we created a cardboard hull for our Launchpad MIDI controller to realize our digital version of the *Connect 4* board game (Figure 4.11). Although we used most of the predefined function descriptions and buttons of the device, we needed to add additional information to our game device. This was achieved by adding textual description on a cardboard. Additionally. we needed an additional audio and video channel. Therefore, we connected the Launchpad to a computer, so we were able to use Skype for the direct communication of the participants (Figure 4.12).

Figure 4.10: The Novation Launchpad device

Figure 4.11: The Launchpad Game

In contrary to the original *Connect 4* game, the players were sitting in different rooms. To be able to play our Launchpad game together, they communicated via Skype call. Our digital pendant for throwing in a *Connect 4* token, the participants of our workshop had to press one of the LED buttons in the column. This started an animation, augmenting the drop of a *Connect 4* token on our Launchpad device.

Figure 4.12: Audio and video communication via Skype during gaming.

When one player started a new game, the other player was automatically invited and had to confirm the invitation with the *invite a friend* button on the right side of the launchpad. This button then started flashing on both boards. When the invited player pressed the flashing button, the game was started. The same behavior of the user interface was initiated when you wanted to cancel or stop a running game and start a new one.

Station 3

In Station 3 the participants were asked to talk about their daily communication habits. The interviews have been conducted on the basis of the information and personal items gathered through the welcome package, which was sent to the participants some time before the workshops. In this way, the most common communication topics, reasons for communication, and communication partners have been identified (Figure 4.13). To further describe their most frequent communication partners several sheets of paper with human silhouettes have been provided. The participants were asked to write down attributes of the communication partners on the silhouettes or stick post-its with the attributes on it. Finally, they were asked to use their personal items and further materials, provided in the workshop station, to try to reify communication partners.

Figure 4.13: Station 3 - Creating communication habits during interviews

Station 4

In Station 4, we provided a prototype for hands-on interaction by the participants. It was used to scrutinize tangible interaction by interacting with a desktop application through paper cards tagged with RFID-chips. The devices of the RFID system we designed for this station were located on a table, which stood in the middle of a room. We provided chairs on the long sides of the table, so the participants could choose to sit on one of the long sides of the table or just stand in front of it. The monitor was placed on the fourth side of the table, so the participants had a good line of sight to it. The RFID reader covered in the cardboard box was mounted in front of the monitor, the RFID cards were grouped according to the use cases. It was up to the participants to use this predefined arrangement or change it according to their needs and requirements (space).

The main research goal of this station was to find out how the participants interact with this system, which they have never seen or used before and without having any information about how to use the system. To support the interaction, the cardboard box had a red rectangle on the topside and the RFID cards had a red border.

When placing a card on the RFID reader, a visual feedback was given by changing the screen output according to the card's content. In addition, an audio feedback was given, either complementing the new screen output or indicating a wrong interaction order.

Two use cases were designed for the workshop: Interaction with a cat (petting, feeding) and making tea (filling tea kettle, putting tea kettle on stove). In order to start one of the applications, the respective start card had to be placed on the depositing surface (red rectangle on the box). The start cards were provided with pictures in addition to the inscription. The interactions could then be performed with the remaining action cards. By placing a card, the screen output was changed and a sound output was made.

The two use cases differed in the interaction process in order to be able to observe different interaction modes: In the Cat application case, the order of interaction was left to the user, with the exception of the start using a start map. The cat could be stroked or fed at any time or it was possible to let the cat *meow*. If a certain sequence was kept (*Meow* - feeding - stroking) an extra output was unlocked (purring). The order of interaction during tea boiling was fixed. Here, a certain sequence had to be observed after the start card was discarded; an acoustic signal (horn) was used to indicate a deviation in the sequence.

In order to investigate the intuitive character of the RFID prototype, the introduction to the workshop was reduced to the bare essentials. At the beginning, the participants only received instructions to use the materials on the table to carry out the two use cases on the screen. The way of interaction and the functioning of the system were not explained. In this way it can be checked how intuitively the participants can interact with such an RFID system and how the individual's previous knowledge influences these interactions.

Station 4 focused on space (body position in relation to interface, arrangement of cards), visual (object design, visual interaction feedback), audio (auditive interaction feedback) and posture (toward interface).

A more detailed description of this station can be found in our publication *Multimodales Design - Multimodality in Design of Tangible Systems* in Section 7.3.

Analysis

As the extensive documentation of the workshops produced a large amount of data, a very extensive analysis was necessary. For this purpose, the analysis data was distributed among the project members. This was only possible because the project team consisted of three people at that time, but was reduced to the author during the project iterations.

The analysis method used was the creation of uniform, multimodal analysis frames in order to be able to examine all types of interaction in detail and to have a uniform, easily comparable structure. After including all video data, audio protocols or transcriptions and feedback rounds, the analysis frames were classified according to different interaction categories and compared with each other. As a result, the first design implications for technological development have already been gained.

Much of the work consisted of the planning, organization, design and implementation of the first user workshop. The workshops were designed in a very user-centred way, great importance was attached to creating a pleasant atmosphere, which should allow constructive work and take away the participants' fear of the unfamiliar environment and technology. This turned out very well, the participants felt very comfortable and gave very positive feedback. The workshops were very productive and a large amount of data could be collected. These data were examined using the multimodal analysis frames and outlined the future technical, interaction, and methodological direction to be taken for the next workshop.

Station 1 and 2

Station 1 (komm+spiel) combined all six categories of multimodality: Audio (spoken words), Visual (tokens, game boards, visual interaction feedback, communication), Haptic (tokens, game boards), Gesture (tokens, game boards, interpersonal communication), Posture (towards interface and other players), Space (body positions in relation to other players and the interface).

One research goal of this workshop station was to analyse the differences in the body language and body posture when playing the traditional board game sitting side by side and playing the digital game sitting in two different rooms, connected to the other player through a digital communication channel. Therefore, the spatial arrangement of the station was very important both for the board game and the digital game. We tried to influence the players position by placing the board game on a table corner, with the seats for the players on each side of the corner. In this way, the players were sitting in close proximity and also their bodies were aligned to each other.

When first confronted with our wooden board game version of *Connect 4*, most participants did not know how to start and play the game. Sitting side by side, participants were talking about their experiences with the original game and possible ways of playing our game version. Participants used to grab a token and play around with it with both hands. This playful approach to the game is important to get familiar with it and its tokens. The spoken exchange was an example of unified cognition, whereas sensing and scanning a game token is distributed. As an additional challenge and although it was completely up to them, participants often decided to play the game blindfolded (Figure 4.14). This was possible due to the special design of the tokens: The red tokens had a round shape and the white tokens had a triangular shape. So, there wasn't just a visual difference between the tokens but also a haptic.

Figure 4.14: Example of material interaction when played blindfolded.

After the participants tied a scarf around their eyes, they started to sense the board with the marks and holes (2) and its edges (1). This example of haptic guidance helped with the participants' orientation before they started to play. When a token was placed into a hole in the game board, the other player asked if he has already made a move while already holding a token in his hands (3). When it was the other player's term, he/she tried to find the right hole with one hand and held the token with the other hand. Then the player often used both hands to place his piece in the hole of the board (4). This sequence could be observed repeatedly throughout the game. As we could also see in other stations of this workshop, the participants used to talk very briefly, only in case of guiding the other player or to clarify things. Playing the game just using hands and fingers to interact with the the game board and the tokens led to a more complex game situation and prolonged the game. Here we could observe the characteristics of material interaction and the restrictions when visual interaction is prohibited. The Board Game combined all six categories of multimodality:

- Talking - about rules or the status of the game. Who is next, who wins the game, negotiating about playing another game.
- Visual guidance - through the arrangement of the game board with letters and numbers and coloured tokens. Also the state of the game could be observed the best visually.
- Haptic guidance - Orientation at the beginning of the game and material interaction when playing blindfolded.
- Gestures - to support articulation or to show emotions.
- This is connected to posture and space - participants sit around the game board in different ways, how and when they approach the game board and also move away. We also observed different body positions in relation to the other player and the game board.

When playing the digital version of the game, the players were sitting in front of a table, with the digital board game and a monitor in front of them. This arrangement was necessary to ensure, that the players are located on the right side of the digital game board and have a direct line of sight to the monitor.

The analysis of the Launchpad board game revealed some interesting user interactions:

- Players chose different types of touch interaction when it was their turn to place a *Connect 4* token (Figure 4.15): some participants pushed the button on top of the column (1), others pressed the button of the exact position where they wanted to place the next token (2).
- Communication with the other player took place rather during unclear situations, during a regular game the participants concentrated fully on the game board. The other player was most likely addressed in the event of technical problems, unusual game situations, misunderstandings in the course of the game or to discuss

the rules of the game. In addition, the participants specifically talked about the launchpad buttons that start a new game, cancel a game or invite the other player to another game.

- Some participants also talked to themselves, reflecting on their next move. They also used pointing gestures with hands and fingers on the Launchpad to support their thinking aloud (Figure 4.16).
- Hands and fingers were not only used to interact with the game board itself. Participants also used the space around the game board, some for playing with their fingers while waiting for the next move of the other player, some to adopt a concentrated posture with their hands (Figure 4.17).
- The necessary interaction for setting up a new game or stopping the current game was not always clear to most of the participants. The main reason for this was the limited notification and feedback mechanism available on the launchpad. A status change was only indicated by the use of different colors or the flashing of a function key. In order to provide greater clarity for the participants, additional feedback channels, such as audio signals, would be needed.

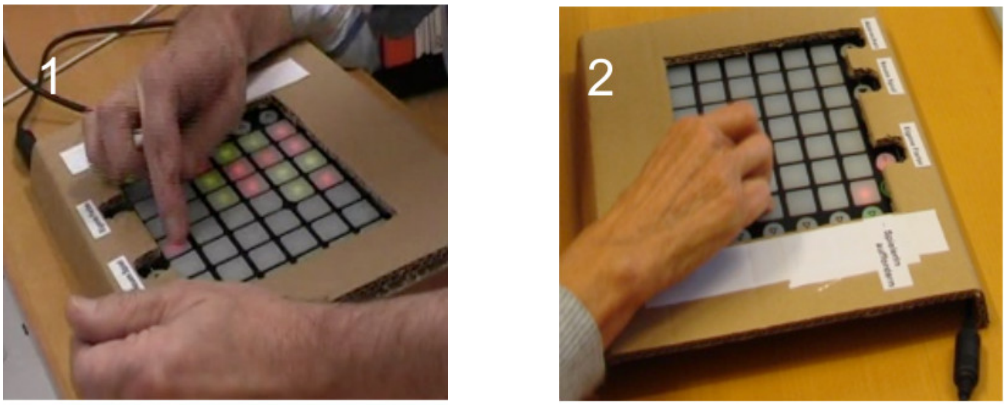


Figure 4.15: Different buttons pushed.

Especially the last observation turned out to be a very important insight for our further development. This was emphasized by the implementation for starting a new game. If the invitation for a new game was not confirmed by the other player, the system timed out after 30 sec. This happened a few times during our workshop, which confused the participants. Obviously, they had no technical insight and didn't know why this happened and why the blinking suddenly stopped. This shows that on the one hand side the visual feedback has to be very clear and intuitive and on the other hand it is also necessary to amplify user feedback through adding additional channels, like

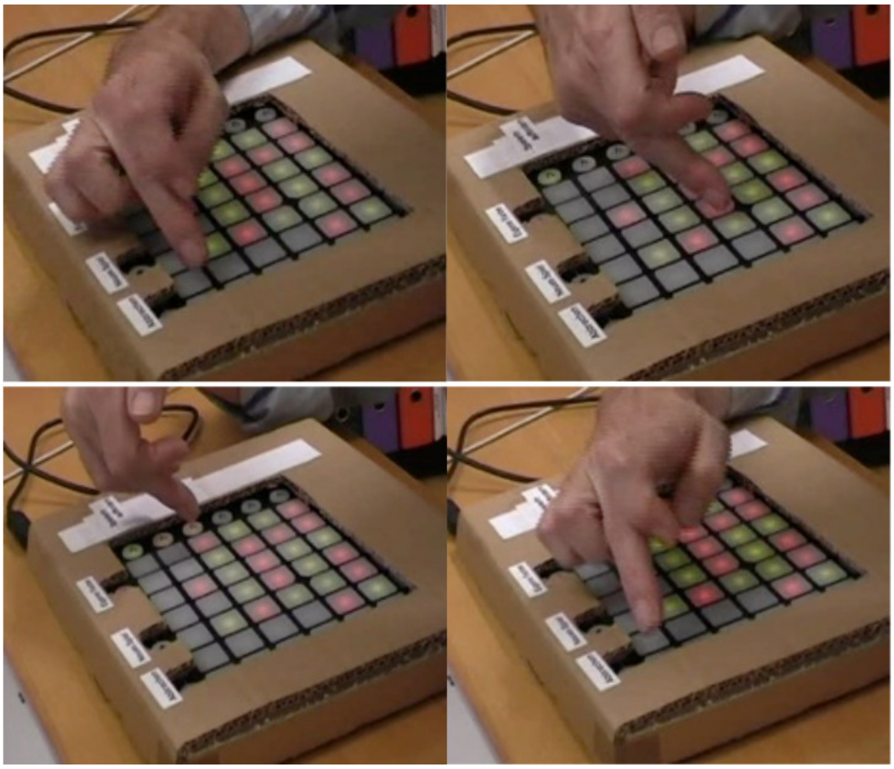


Figure 4.16: Gesticulating - thinking aloud.

aural notifications. This is essential for interaction with a device, especially when the actions of other players can not be seen directly and must be made visible to all.

Station 3

In this station, we tried to design multi-level communication. The welcome package provided the basis for the conducted interviews. One task of the welcome package was that we asked the participants to choose one out of various icons for different communication related activities. The analysis of the welcome package showed that the participants had very different ideas of the *right* visualization. Figure 4.18 shows the choice of the participants of the first workshop. The choices of the participants of the second workshop were similar diverse. This indicates, that predefined graphical visualizations in user interfaces could lead to misinterpretations by the users. This should be avoided by trying to allow users to choose their preferred visualization.

The information from the welcome package was discussed with every participant, thereby extracting further details about their communication habits. This information was visualized during the interviews by writing it down on the human silhouettes. The silhouettes formed the basis for the next step in Station 3. We asked the participants

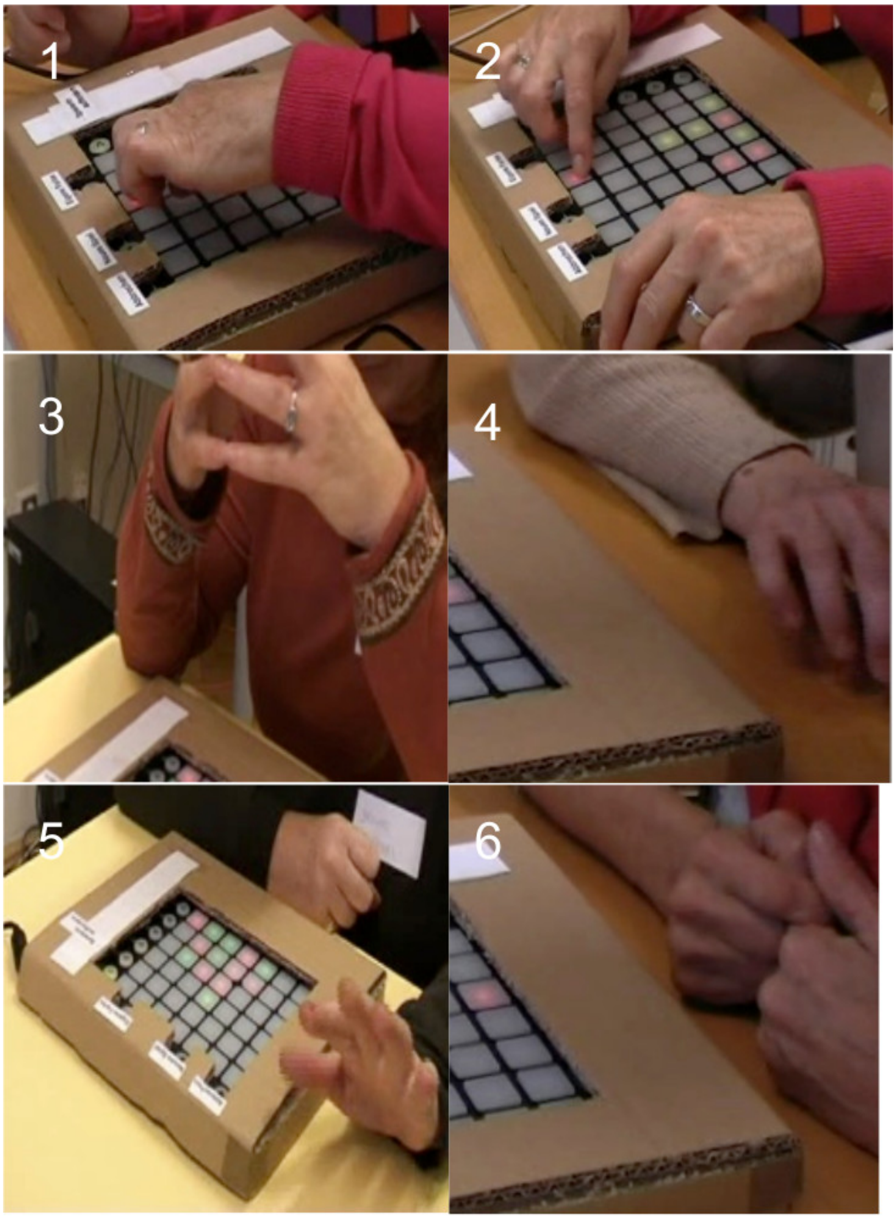


Figure 4.17: Positioning and dealing with the Launchpad.

to create an object representing the communication partner described by the silhouette with the help of different materials and everyday objects (Figure 4.19). The resulting tangible token represented a highly personal and individualized object and could be used to address the communication partners in future versions of the kommTUi prototype. In this way, the users can build their own tangible interface element, which creates

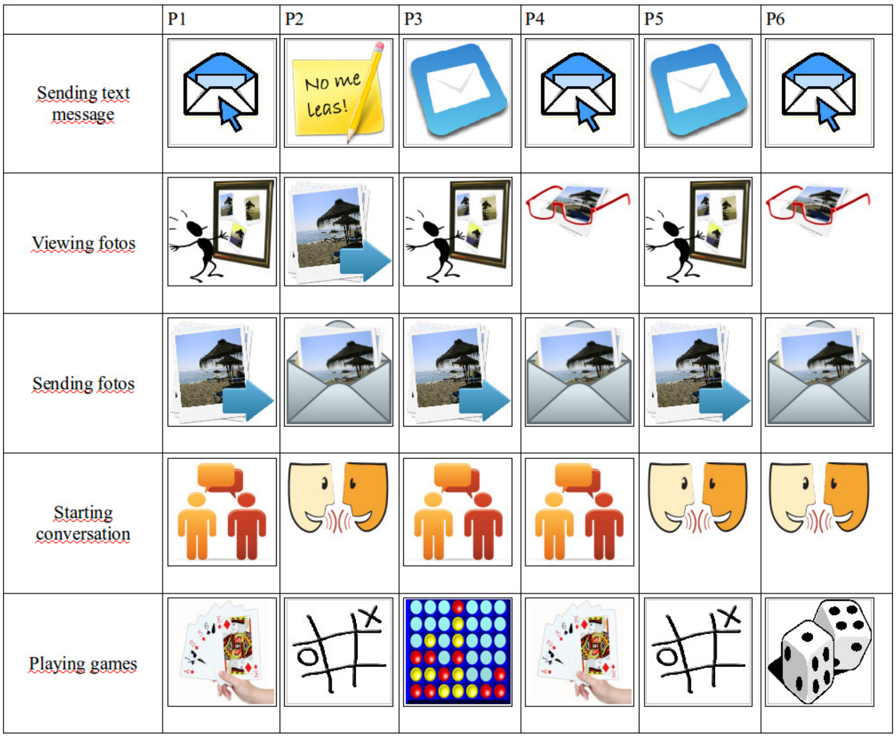


Figure 4.18: Station 3 - Icon choices of the participants of the first workshop.

a strong personal connection to the object and therefore increases the chance that the users successfully recognize the meaning of the interface element.

Station 4

A detailed analysis of the user interaction in Station 4 with special focus on mulitmodality can be found in our publication *Multimodales Design - Multimodality in Design of Tangible Systems* in Section 7.3.

Implications

Based on the analysis in the last section, the following design implications could be developed for the next iteration step:

- Haptic interaction
  - The design of tangible interaction objects (size, shape, and material) should make them comfortable to hold.

Figure 4.19: Station 3 - User collection of important persons and corresponding items

  - The design of the prototype should not evoke (unintentional) associations with existing technologies (visible cables - computer mouse). Otherwise, this leads to unintentional user interactions.
  - Both interaction objects and prototypes should be robust enough to withstand more rustic interactions. Users are not always careful when trying it out.
  - A large number of available interaction objects invite to ad-hoc interactions (e.g., take in hand, sort, touch surface).

- Visualisation

  - It is difficult to use predefined icons for communication activities due to the individual ideas of the *right* visualization. It is important to find a way to let the users choose their own graphical visualization for user interfaces.

- Multimodal design

  - The haptic guidance through significant shaping and material was well implemented in Station 1.

- Multimodal design is not only important for feedback, but also as a call to action for users (token+constraints). Exclusively visual guidance as in Station 4 is not sufficient, additional hints by the shape facilitates user interaction.

- Organization of the interaction space

  - Well planned support for user interaction is important. However, users should also be given a certain amount of freedom to organize their own space of interaction.

4.2 Iteration 2

The data obtained from the analysis of the first workshop series was used as a basis for the further development of the kommTUi prototype and the next user workshops. For the technological development, a strong focus was placed on interface and interaction design. Regarding the research setup, the basic structure of the user workshops was retained. In contrast to the workshops of Iteration 1, the new workshop series was held at different locations (Vienna and Klagenfurt) and with participants with different prior knowledge of tangible interaction. The analysis of the 2011 workshops was also carried out on the basis of multimodal frames. From the results of this analysis, design implications for the next and final iteration step were derived.

Design and Development

After the analysis process of Iteration 1, the planning for the workshop series of the next iteration step has been started. In addition to the results of the analysis, feedback from the project evaluators on the first iteration step was an important basis for the planning process. This was initially done by means of written evaluation reports, later the discussion could be deepened at a personal meeting where the whole kommTUi project team as well as the evaluators were present.

The structure of the workshops with preliminary information for the participants, welcome round at the beginning, various stations, discussion with non-active participants and a final round was retained due to the positive reactions of the participants in 2010.

An information package was again sent to the participants in advance: General information about the project kommTUi, dates of the workshop (time, place), task: Bring your own token! Take an object with you that symbolizes your most frequent communication partner.

Workshops

As part of the second iteration, two workshops were held, this time with a total of 15 participants. The age of the participants ranged from 53 to 83 years, with an average of 64 years and a standard deviation of 7,6. The participant, who was 53 years old, stepped in at short notice for a participant who had to cancel. A workshop was held in Vienna with participants from the first workshop series. The second workshop was held in Klagenfurt with completely new participants. Participants were asked to bring a personal item to the workshops. The object should be a souvenir that reminds the participant of a special person. This object was then equipped with an RFID tag in the initial phase of the workshop and could thus be integrated directly into the interaction. While the workshop series of the first iteration was still very explorative and only allowed direct interaction with a prototype in one of the stations, the focus of this iteration was clearly on testing the developed technologies. The workshops were divided into three stations. The first station was an introductory design session on the one hand and a relaxed round of talks for those participants who were not currently employed at the other two stations on the other. Stations 2 and 3 aimed at testing various prototypes based on the results of Iteration 1.

Welcome Session

The participants were welcomed and the procedure was explained at the beginning of the workshop. Here the participants were presented with their workshop set. It consisted of a cardboard box with the name of the participant and three neutral function tokens.

Station 1

In Station 1 we provided each participant with a workshop package containing three small wooden objects. These objects were made from wood and should be equipped and annotated in the design session at the beginning of each workshop. They had a specially designed shape to create a strong connection between the shape of the token and the corresponding slot of the prototype in Station 2. Size and form of the objects were designed to fit smoothly into the hand of the user and can grasp easily. The bottom part consisted of a worked wooden block. The top part was a wooden cylinder with a flattened side, which was intended for stickers or other materials. From this point in our research, we called those objects *Generic Tokens*, as they had the same shape and were used to control to select a distinct functionality of our prototypes. We have provided various materials and stickers with the symbols from the welcome package of Iteration 1 for labelling these Generic Tokens. This design session took into account the findings from Iteration 1. As it is difficult to use predefined icons for communication activities due to the individual ideas of the *right* visualization, we let the users choose their own information design for the interface elements (see Figure 4.20).

Figure 4.20: Station 1 - individually designed Generic Tokens

We also asked each participant to bring an object that reminds them of a very special friend or relative. These personal objects have been quickly equipped with RFID tags during the workshop to be used directly for user interaction. We called this combination of everyday objects with special meaning to the user together with RFID tags equipped for interaction with our prototypes *Personal Tokens*. The Generic and Personal Tokens were used for our interactive prototype in Station 2.

Station 2

This Station was a further development of Station 4 of Iteration 1. As a result of our findings, we made significant changes to both the technical setup of the prototype as well as the design of the user interface and interaction.

Technical setup

To avoid associations with a traditional PC setup, the prototype for this iteration has been designed as a single device solution (see Figure 4.21). It consisted of a netbook and two Phidgets RFID readers[2]. We conducted an in-depth technical analysis regarding which RFID reader we should choose. In the end, we decided on the Phidgets RFID reader. It is very easy to use and works perfectly under different operating systems. The manufacturer offers libraries for many programming languages and there are also some code examples on their homepage. The disadvantages of the reader are its limited range of max. 12cm (applies to the tag with the largest surface) and the non-existent

[2]https://www.phidgets.com, 09.08.2018

multitag capability. Material tests have shown that the range of the reader was strongly influenced by metals, other materials such as plastic or wood had no effect. In addition, the area of the tags at the locating range contributes. Tags with a larger surface area can be received further than those with a smaller surface area.

The netbook and the RFID readers were embedded in a wooden case. The decision for wood was based not only on the easy workability of the material, but also on the pleasant haptics, for example when the user takes the tokens in his hand. The RFID readers were located right above the screen. On the top left side of the screen, there was a slot shaped like the bottom side of the Generic Tokens, where users could insert the Generic Tokens to select predefined functionalities like starting a telephone call or sending a picture. On the top right side of the screen there was an coloured area for the Personal Tokens, which determined the communication partner. The core of the system was a Java application, which received the data from the RFID readers and handled the visual and auditive feedback.

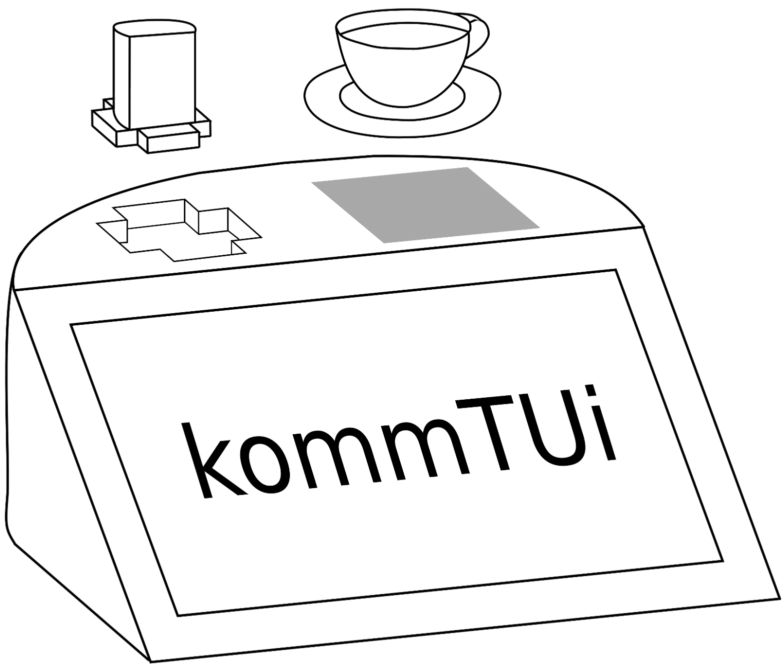


Figure 4.21: Station 2 - model view of the iteractive prototype

User interaction

We defined three use cases for interacting with our technical prototype: Starting a voice-over-IP call, sending a photo, and sending a note. Every participant had three different Generic Tokens, one for each use case, and one Personal Token to select the communication partner. To select one of these use cases, the user had to choose by placing the particular Generic Token in the corresponding slot. The similarity in form between

Generic Token and slot should show the user where and how he could position the token on the prototype. In this way, we combined the advantages of generic shapes regarding their suitability for the token+constraint interaction and an individualized information design, which fitted the personal expectations of the users. We provided a textual hint on the screen to signal the participants that they should place a Generic Token now. In addition, a green arrow spotted to the upper left corner of the screen, where the token-slot for the Generic Token was located. As the Generic Tokens were provided by us to the participants, we were able to prepare a token - user mapping before the workshop, which allowed a individualized user experience. After placing the Generic Token, the green arrow changed into a check mark and another arrow appeared, pointing to the upper right side of the screen. The text on the screen now asked the participants to place a Personal Token to start the communication. This was done by placing the Personal Token. When the participants placed the Personal Toke on the coloured area, a pop-up window appeared on the screen, indicating that the communication started. These three steps are visualized in Figure 4.22. Each interaction was followed by acoustic feedback and visual feedback on the screen. The visual feedback was adapted to the individual participant: Each Generic Token was equipped with a RFID tag having a unique ID. This ID was mapped to the individual workshop participants. Therefore, we were able to identify which Tokens belonged to which user and to design an individualized interaction workflow and feedback on the screen.

The first use case was “calling a special friend”. The participant have been asked to take a look on the device and then try to solve this use case with the tokens. Afterwards, the participants were free to choose the next use case.

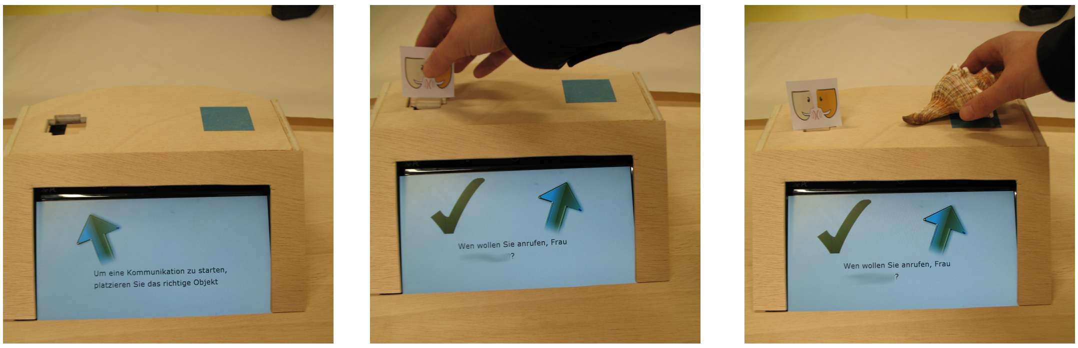


Figure 4.22: Interaction sequence - prototype Station 2

Station 3

This station was an in-depth study of Station 2. Notes were created and sent afterwards, with the same interactions as in Station 2. On the one hand the participants could write a message with paper and pen, scan it in and send it, on the other hand they could write this note on an iPad with a special pen (Figure 4.23). At the same time, the participants were questioned about their habits regarding taking notes.

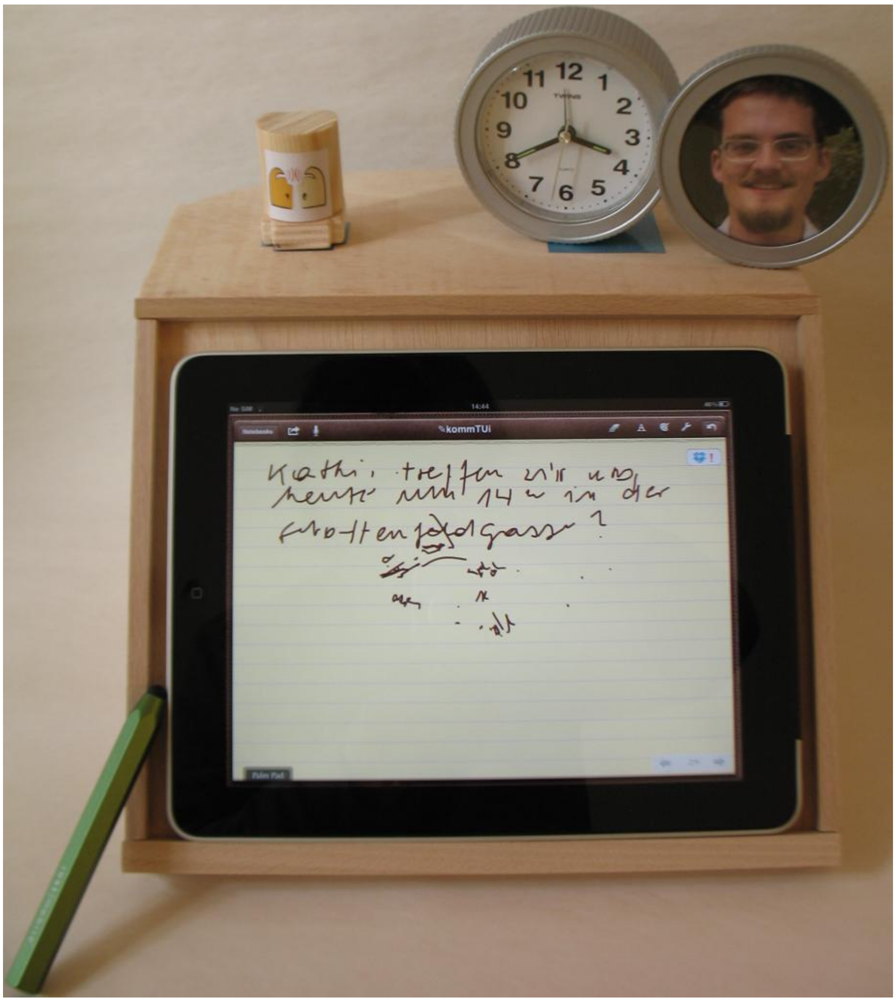


Figure 4.23: Station 3

Analysis

As in Iteration 1, the structure and organization turned out to be essential factors for the course and success of the workshops. Detailed and clear information and the creation of a pleasant atmosphere quickly reduced uncertainty among the participants. In Iteration 2 this could be observed especially at the second workshop, where the participants felt particularly well and got involved in the situation. One reason for this was certainly that, based on the experience of the first workshop, the project team had already more routine.

One possibility for an improvement would be an even more detailed advance planning of the workshops and in particular the welcome rounds, which, however, is again at the expense of spontaneity and flexible design. A good start can have a significant influence on the quality of the workshop. Another possible reason for the more creative outcome of the second workshop was the fact that each participant could tell his or her personal story, which was connected to the object he or she brought with him or her. This created on the one hand familiarity among the people present and on the other hand a deeper connection with the object or the Personal Token.

The extremely positive feedback from the participants suggests that the participation in the workshops was an exciting and interesting experience. In one case, an initially sceptical participant even apologized to the project team after graduation that he was so critical at first.

Principally, the basic idea of kommTUi - an object-based control of interpersonal communication - was perceived very positively by the participants. Interestingly, at both workshops many participants found the kommTUi setting (reduced functions with object control) particularly suitable for their parents. The simple triggering of calls through RFID interaction was highlighted in particular. Upon request, most participants confirmed that this would also be a practicable solution for themselves. A recurring feedback was the hassle of purchasing a new technical device. Many participants were convinced that they would like to use the kommTUi system at home, but refused to buy an additional device. The reasons were that on the one hand they did not want to buy again and that there was no more spare room in the apartment. During the workshops, participants also generated many ideas on how technologies with alternative and Tangible User Interfaces could be used: As a control centre in the context of smart home systems, in the AAL area or the use of personal tokens for central storage of important data such as bicycle lock numbers, pin codes, etc.

In order to enable an analysis of the user interaction with the prototypes provided, the individual stations of the workshops were equipped with video cameras that were oriented to the respective interaction area. The video recording was not a problem for any of the participants. The experiences from the workshops of the first interaction and the analysis of the video data from Iteration 2 show that it is very important to hold back with instructions as long as possible during the user interaction. This can be difficult especially for people with little technology experience, as the observing researcher wants to help particularly quickly in order to keep frustration among the participants as low as possible.

An analysis of our workshops of Iteration 2 especially with focus on Generic and Personal Tokens can be found in our publication *kommTUi - A Design Process for a Tangible Communication Technology with Seniors* in Section 7.6.

A clear result was also provided by the interactions with the prototype of Station 3. It has emerged that actually a lot (notes, telephone numbers) is still being written down. Interestingly, the participants did not perceive this as such, only by asking further questions did this gradually become clearer. Various notes and messages are usually left for others via post-it, there was no indication that this should be done digitally in the future. There was also no desire to send handwritten material. When writing, the personal typeface is very important. Writing on the iPad was not satisfying for many, on the one hand the experience is not natural (like putting the palm down), on the other hand the writing is not to be recognized more than the own. Overall, the reactions to this station were restrained, so the project team decided to discontinue developments in this area in favour of the prototype of Station 2.

Implications

The implications of our workshops of Iteration 2 can be found in our publication *Personal Interaction through Individual Artifacts* in section 7.4. In the following, we complement the implications described in this publication:

- It was very different how quickly the participants started interacting. Some work very descriptively and need requests for action, others simply go for it without fear of contact. The period until the very first action is taken varies greatly from person to person. The repeated application of what they had just learned, however, was no problem for all participants. Although there is room for improvement regarding the initial approach to the prototype, the interaction design turned out to be quick to learn and easy to use. The basic elements should therefore be transferred to the next iteration.

- The form similarity between Generic Tokens and the corresponding slot worked out very well and can be reused in Iteration 3. The shape was remarkable enough, even a participant with visual impairments recognized it well.

- Unfortunately, a repeated design flaw also had to be observed, which must be emphasized as a clear instruction for action for Iteration 3: Again, no textual description of the scan areas was used. With it, the Personal Token area could have been identified even better. Text can also be an eye-catcher.

- As in Iteration 1, a touch interaction was tried from time to time, but this occurred very limited. For Iteration 3 it is important to find a way to deal with the interaction patterns associated with a technology. Here, the graphic display as the most important instrument for providing visual feedback presents a particular challenge. Either the associated interaction patterns must be embraced and integrated into the interface design or the screen must be removed from the user's main focus.

- Exciting future scenarios could be generated from the feedback of the participants: RFID interaction with mobile devices of different sizes, such as smartphones, phablets, tablets. This would require the same functionality to be transferable to different versions of mobile devices. Through the idea of the token as a personal identifier we move away from the pure Tangible User Interface element to a personal identification object, where the question is whether this is still a Tangible User Interface or a new term would be necessary.
- Most participants profited from the visual feedback on the screen. This needs to be taken into account for the redesign in Iteration 3.

4.3 Iteration 3

The third and final iteration on the one hand preserves those parts worked out well in the previous iterations and on the other hand is a further development of our research tools, driven by the needs and prerequisites identified in the first and second iteration. The design phase of this iteration includes an extensive further development of the *kommTUi* hardware. While the interaction design more or less stays the same, the design of the workshops also underlies a major revision based on the new challenges for user integration through the redesign.

Design and Development

The analysis of the data gathered in the second iteration led to new requirements for the technology design. As a reaction to the statement, that many elderly people already have computers and do not want to have another device in their homes, we decided to redesign the *kommTUi* prototype from stand-alone to a pluggable device. This demands for a totally new technological foundation, because the hardware setup of the prototype of the second iteration consists of a netbook included in a wooden case. The sensor control, signal processing and feedback output was done by the netbook. Now the sensor control had to be transferred to a pluggable device, whereas signal processing and also part of the feedback output had to be outsourced to the user's computer system. Therefore, the further development of the *kommTUi* prototype consists of two main parts: The development of the hardware device and the development of the corresponding software for the user's PC.

Hardware

As we didn't want to change the principal interaction design, the hardware had to provide enough space for the Generic and the Personal Token. Yet, it should also be as small as possible to reduce the requirements for additional space next to the user's computer to a minimum. As basic technology we stayed with RFID, because it allows building compact prototypes and is well supported by the tools we used for the development, like Arduino[3], processing[4], or the JAVA SDK[5]. As core element of the hardware prototype we used an Arduino Duemilanove (Figure 4.25). This microcontroller allows to easily connect different kinds of sensors and actuators, including RFID readers. For data exchange with an external computer, the Arduino Duemilanove provides a USB interface. For the token identification, we used two very small sized RFID readers based on 26 bit Wiegand code (Figure 4.27). This kind of RFID reader provided a port for connection an external antenna. To connect the RFID readers to the Arduino it would have been necessary to have multiple RX/TX interfaces on the micro-controller. Unfortunately the Arduino Duemilanove didn't meet these requirements, so we had to add a switch between the Arduino and the two RFID readers (see Figure 4.24).

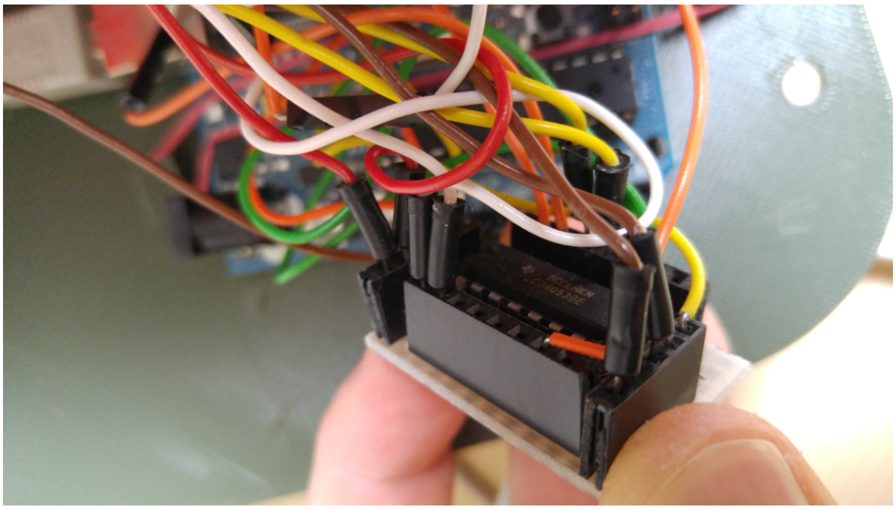


Figure 4.24: Interconnection Arduino/RFID readers

This wasn't problematic because according to our interaction design, we didn't need both readers active at once. We could have used an Arduino Mega instead, which includes multiple RX/TX interfaces, but this Arduino model is bigger than the Arduino Duemilanove and this would have let to a bigger device.

Because a small scale prototype demands for optimal usage of the technical interior, we decided not to build the case from wood but use a 3D-printer instead. In this way, the prototype interior can be designed and produced very accurate. As 3D printer we

[3]http://www.arduino.cc
[4]http://www.processing.org
[5]http://www.java.com
[6]http://commons.wikimedia.org/wiki/File:Arduino_Duemilanove_0509.JPG

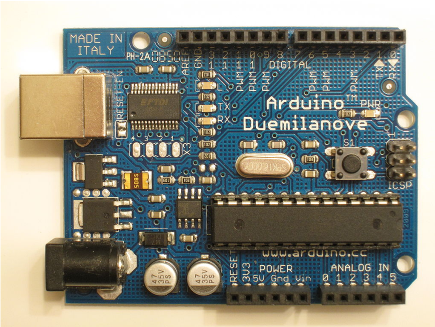


Figure 4.25: Arduino Duemilanove[6]

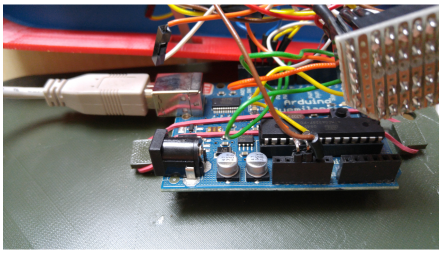


Figure 4.26: Attached Arduino

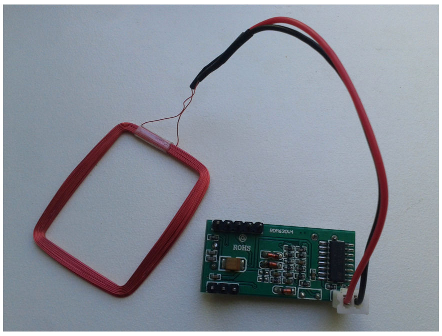


Figure 4.27: RFID reader with antenna

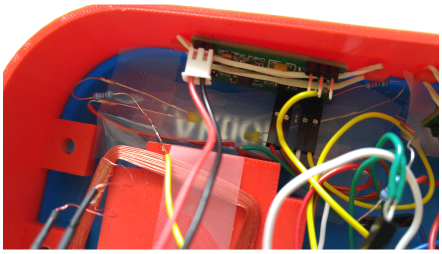


Figure 4.28: RFID and LEDs

used the model uPrint SE of Stratasys, which is advanced enough to allow printouts of the desired size and uses support material for the print, which is especially important when printing protruding parts. For the creation of the necessary 3D wire-frames we used Google SketchUp. We printed out the hardware in two parts, first the bottom part with screw holes on the left and the right side and the mounting for the Arduino microcontroller (see Figure 4.29 and Figure 4.26). The second part contained the slot for the Generic Token, the Personal Token area, again screw holes, and mounting parts for the two RFID readers (see Figure 4.30 and Figure 4.28). The mounting parts had the form of hooks, so both the Arduino and the RFID readers could be attached to the case with elastic bands. This allowed to flexibly attach and detach the hardware, which was important during development. The external antennas of the RFID readers have been attached directly under the slot for the Generic Tokens and the Personal Token area.

The biggest challenges for the print-out were the modelling of the Generic Token slot and the characters of the lettering of the areas for the Generic and the Personal Token. The concave structure for the Generic Token slot was hard to model, the 3D-printer often failed to correctly connect the slot with the top hull of the device. Also the lettering needed several attempts until it was printed correct. It was important to print the lettering as thin as possible to allow visual feedback through lighting elements.

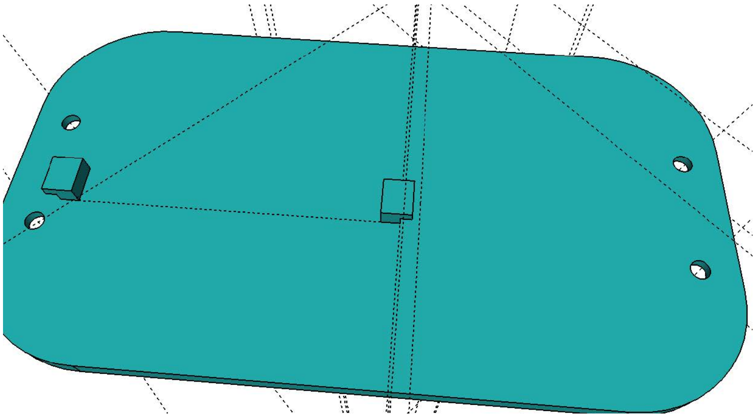


Figure 4.29: 2012 model of prototype - bottom

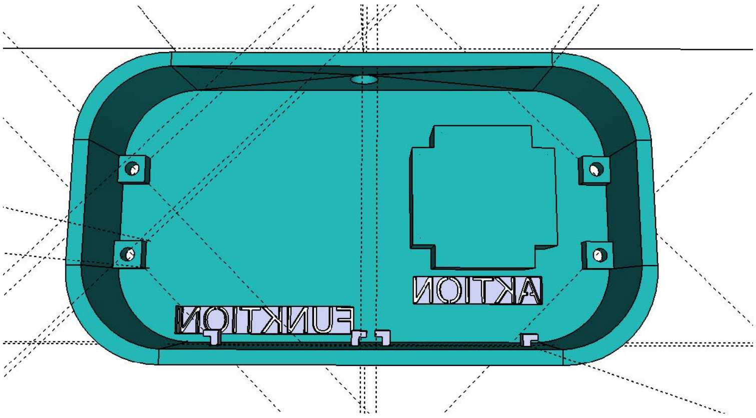


Figure 4.30: 2012 model of prototype - top

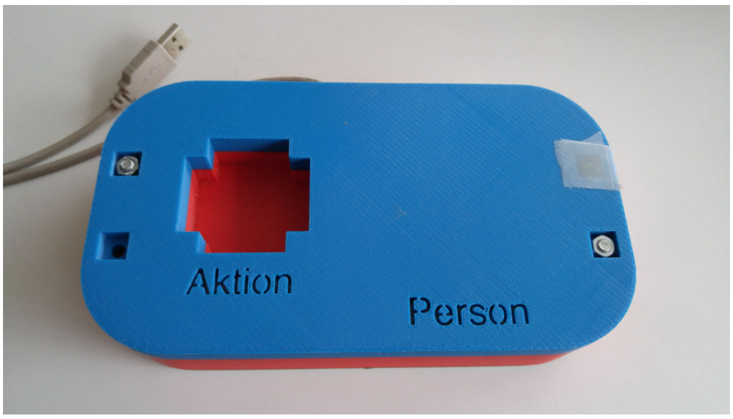


Figure 4.31: kommTUi prototype Iteration 3

Therefore we included space beneath the lettering, where we added two LEDs on each side. On top of it we attached frosted glass for diffuse illumination. Through the screw holes on both parts of the device, we could easily screw the parts together and unscrew them if necessary.

Software

We used the Arduino programming language for the Arduino microcontroller programming, which is based on C/C++. When the prototype was plugged in, the Arduino was powered through USB and initiated the program and both RFID readers. Then, it sent a handshake signal via the USB interface. The Arduino also processed the signals from the RFID readers. When the generic or the personal token has been placed on the corresponding slot, the Arduino received the RFID serial number and passed it through the USB interface. For the processing of the Arduino data we implemented a Java service. This service had to be installed on the user's computer and run in the background. It then waits for the handshake signal from the Arduino board. After receiving the signal, it sends back a confirmation to the prototype. When receiving a RFID serial number, the service looks up the information assigned to this number and sends back a signal to the Arduino. This signal triggers the visual feedback on the kommTUi prototype. Simultaneously, the Java service generates an auditive feedback via the computer's speakers. Furthermore, the java service shows a visual representation of the hardware prototype on the screen of the laptop. This was used to provide visual guidance for the user interaction. When the user has to place the Generic Token, the corresponding side of the illustration is blinking and the other side is shown darkened. When the user has to place the Personal Token, it is the other way round (cf. Figure 4.35 and Figure 4.36).

When the Java service has received a RFID serial number from a generic token and a personal token, it started the corresponding external service, like a Skype call or the E-Mail Client (cf. Workshop description). Figure 4.32 shows the kommTUi interaction sequence in a diagram.

Workshops

The workshop setting of the 2012 iteration differed from the previous iterations. We transferred the workshops directly to the users to scrutinize interaction in the home context. We visited nine participants in Upper Austria and Salzburg in their homes. The participants were between 58 and 83 years old, with an average of 67,2 and standard deviation of 7,5. For establishing and keeping up contact we were supported by two contact persons known by the participants. We tried to stay with the workshop agenda from the iteration in 2011 and adapt it to the changing surroundings, to keep the workshop design consistent over all three iterations. However, the focus of the workshops has undergone another shift in the direction of testing and discussing of a stand-alone

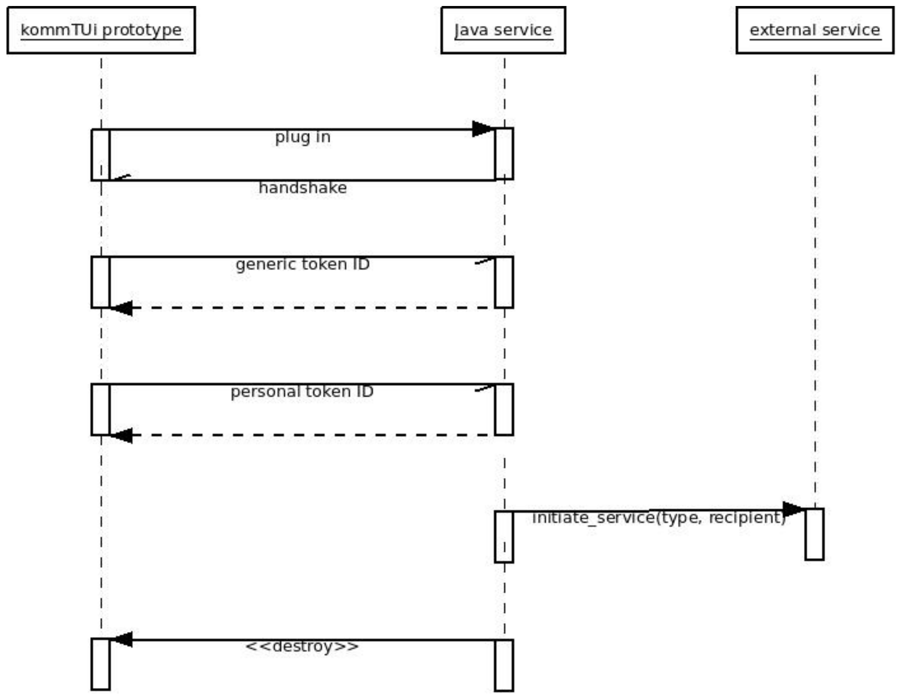


Figure 4.32: kommTUi interaction sequence.

kommTUi prototype. The workshops consisted of four parts. The first part was an initial discussion to both learn about the communication habits of the participants and get closer to the participants. The questions included preferred ways of communication (e.g. landline, mobile, letters, etc.), what they like about it and what they are missing, whether they use a computer/touchscreens and how they get information about leisure time activities.

The second part of the workshops was hands on design session, including the creation of Generic and Personal Tokens. While the design of the Generic Tokens was very similar to the workshops in 2011, the process of Personal Token design changed: Instead of bringing a personal object to the workshop location, the participants were asked to search their homes for an appropriate object during the workshop.

After the design session, the user interaction with the kommTUi prototype took place as third part of the workshops. We defined two use cases for it: Start a Skype session with person XY and view photo albums shared with person XY.

The concluding fourth part of the workshops consisted of a reflection of the workshop activities by means of a discussion about how they liked the interaction with the kommTUi prototype, whether they would use this kind of technology, what they would change about it, which additional functionalities they would like to add and whether they would also use this kind of interaction for online banking authentication.

Each workshop was recorded on video tape with consent of the participants. Additionally, we took notes of remarks or questions of the participants during the workshop.

Initial Discussion

In the initial discussion we wanted to learn about the communication habits and computer and Internet usage of the participants. Most participants use or would like to use their computers to access specific information on the Internet. Those participants who already accessed the Internet use it to get information about hobbies or leisure time facilities like results for different kinds of sport (soccer, table tennis, bowling), upcoming dates for the choir or the hiking group, information about every kind of events and getting access to online lexicons and dictionaries. One participant also uses the Internet to search for information for writing a book. Apart from that, Internet usage of the participants is very focussed on one or two activities and the common way to access information on the Internet is via Google. The bookmarking functionality of browsers is used only by one participant. E-Mail is often used for sending text messages to relatives or friends, organisational tasks for hobbies or sending photos.

Those participants with basic computer skills use the computer, beside their online activities, for viewing photos, writing and printing out letters or other documents, using Skype, creating basic spreadsheets, and playing games. Participants with very basic or no computer skills expressed their interest in using E-Mail, searching for train connections or using Skype.

Participants often use an old computer from their children or grandchildren in their homes. The members of the family are also the first point of contact when the participants need help with using the computer. Most participants also said that although their children showed them how to use a certain program or how to accomplish a certain task on the computer, they have difficulties to remember what they have learned the next time.

Some of the participants have experiences in touchscreen interaction from sightseeing, city infopoints and ticket vending machines. But most of the participants said, that they are trying to avoid using systems with touchscreen. One participant prefers using buses over trains for travelling, because in buses she can buy the ticket at the driver and isn't forced to use the vending machine with touchscreen. Another participant told about an acquaintance who only buys tickets at travel agencies, because she doesn't want to use touchscreens.

For telephone communication the participants use both landline and mobile phone. Some of them prefer mobile phones, because the numbers are stored there. Very few participants had already used voice over IP technologies like Skype. However, one of them even told us that he prefers using Skype over landline phones because of the advantageous audio characteristics. Due to his hearing impairments he sometimes has problems to understand his communication partner when using a landline phone. Although the quality of the connection is below the quality of landline phones, he has no problems to understand his communication partner when using Skype.

Design Session

While the design of the Generic Tokens was part of the initial group session in Iteration 2, we were able to establish a more personal setting for this task in Iteration 3. For each workshop we prepared a set of icons printed on paper and different additional materials for the design of the Generic Tokens. The participants could either use the icon, which he or she thought fits best for the task, write on the token, color or decorate it. The use cases we prepared for the workshops were sending an E-Mail, visit a website or starting a Skype call. Based on the information of the initial discussion, we discussed the optimal use case for the workshop with the participant. Figure 4.3 shows two examples of Generic Tokens. The left one shows a Generic Token with a commonly used icon for sending E-Mails, with *mail* written on it. The other Generic Token is equipped with a piece of paper with the words *Google* and *Wiki* written on it. For the participant who designed this token, *Google* and *Wiki* are the best description for the Internet, that's why she used this design for her Generic Token.

Figure 4.33: Design Generic Tokens

After the participant finished the design of the Generic Token, the next task was to choose a Personal Token. In Iteration 2, the participants were asked before the workshop to bring an object with them, which represents a special person. In Iteration 3, we used the gathered information from the initial discussion to determine this person together with the participant. After the communication partner had been chosen, we asked the participant to search his or her home for an object, which represents the communication partner. This spontaneous approach had the advantage, that the choice of the person fitted perfectly to the workshop progress so far. On the other side, it forced a quick adaptation of the settings of the kommTUi prototype. For example, we needed to add the E-Mail address from the communication partner to the kommTUi system, when the participant chose *sending an E-Mail* as use case. Therefore, we asked the participant for the E-Mail address after he told us the name of the prefered communication partner and before he or she started to search for the personal object. While the participant was looking around in his home, we carried out the necessary adaptations in the kommTUi system. This included assigning the right RFID number according to the chosen use case and adding the E-Mail address and the right text blocks for the subject/body. After the participant had found the right object, we added a RFID chip to the object. Then, it was possible to use it immediately as Personal Token for the kommTUi prototype. Figure 4.3 shows two examples of Personal Tokens. The left image shows a pack of lozenges against hoarseness, which was used as a Personal Token for the website of a choir. The right image shows a plush toy rabbit, which belongs to the son of one participant since he was a baby.

It was not necessary to reassign the RFID number after equipping the chip to the object in the kommTUi system, because we always used the same RFID chip for the Personal Tokens throughout all workshops. After this task was accomplished successfully, everything was set to begin with the interaction with the prototype.

Figure 4.34: Personal Tokens

Prototype Interaction

The interaction design of this version of the prototype was similar to the workshops of Station 2 and 3 of Iteration 2. On the left side of the prototype was a slot for the Generic Tokens and on the right side an area for placing the Personal Tokens. The biggest difference to the previous iteration was that the screen was not coupled with the input device. In this setting, the hardware prototype was used only for the user interaction, whereas the system output was implemented via a standard notebook. The earliest plans for the workshop included the usage of the personal notebooks or PCs of the users. This idea was rejected during the development, the installation of the software and the necessary drivers would have been a too great interference with private property of the user. Therefore, we decided to prepare and bring our own notebook for the workshops. The additional advantage of this approach was that the preparation time in the user's homes was minimized for the researchers.

When the notebook was turned on, the Java background service started automatically in the background. After plugging the kommTUi base station into an USB port, the Arduino transmitted the handshaking signal to the notebook and the kommTUi GUI was started in the initial stateby the Java service with *Aktion* blinking (Figure 4.35). Simultaneously, also the *Aktion* letters on the kommTUi base station started blinking.

Figure 4.35: 2012 Prototype - GUI initial state, *Aktion* blinking

The token interaction was very similar to Iteration 2. The participants were asked to use the tokens and the kommTUi base station to complete the use case defined in the design session. No further explanations were given to the participants, in order to be able to analyse to which degree the interface design is self-explaining. When the participant placed the Generic Token into the corresponding slot of the kommTUi base station, the notebook played a confirmation sound and changed the state of the kommTUi GUI to *Person* blinking (Figure 4.36). At the same time, the state of the *Aktion* letters of the *kommTUi* base station changed from blinking to solid and the *Person* letters started blinking. When the participant placed the Personal Token on the corresponding area on the base station, the notebook started the external service according to the use case.

Analysis

Our decision to visit the participants at home made the course of the workshops much more spontaneous. However, this was accompanied by new challenges, such as reacting

Figure 4.36: 2012 prototype - GUI GT placed, *Person* blinking

very quickly to the content of the introductory talks with the participants. For example, one participant was interested in information about his shooting club. In order to be able to integrate this information directly into the prototype, the URL of the homepage of the shooting club was already searched for during the interview and mapped to the ID of one of the RFID chips. The search for the personal tokens of the participants has given some time for this. To be able to react fast enough and enter mail addresses, URLs, etc., a GUI with database access was programmed in advance. For the search for personal items in connection with the design of the Personal Tokens it was very helpful that the location of the computers/laptops in the apartments of the participants was usually not limited to one place. Laptops, for example, were simply installed in living rooms when required. A dedicated desk or workplace for the PC or laptop was rare.

Generic Tokens: The form repetition of Generic Tokens was a complete success, even participants without computer experience had few problems. Through the personalized design of the Generic Tokens functionality was always recognized correctly.

Personal Tokens: The personal objects used as personal tokens were searched for by the participants in their homes between the initial conversation and the start of the use-cases and then immediately equipped with an RFID tag. The linkage with the person was very clear for the participants, the intuitive understanding of the interaction with the prototype was very diverse. Some immediately put the personal token on the scan area, some needed more time or even hints. A dependence on the gender of the participant could be observed, female participants could in principle complete the tasks in connection with our prototype faster and easier. Some of the participants made great suggestions for a redesign, e.g. participant HS: Provide a symbol that is on the visible backside of the RFID tag as well as on the scan area for the Personal Token of the

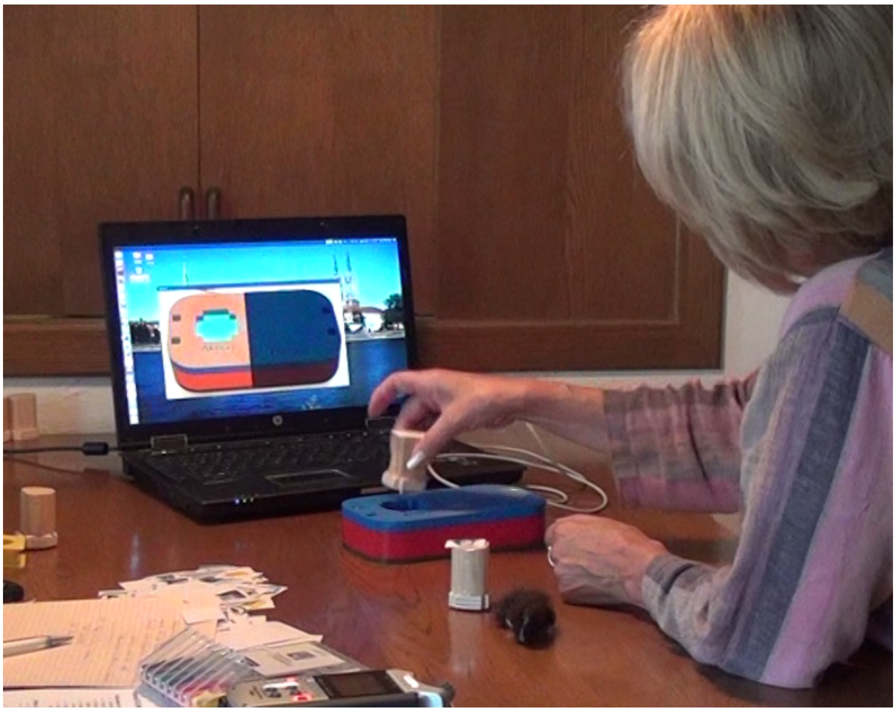


Figure 4.37: User interaction with prototype

prototype. This should lead to another interaction cue. The repeated interaction was again very fast for all participants, as in Iteration 2. Here are some examples of difficulties with personal token design. Participant FM had to work with computers in his last years of employment. He had to train a lot to learn to operate the computer and the user interaction. He interacted with the computer in a way similar to cook a meal be means of a recipe: "*I knew I had to do a double-click on this specific yellow rectangular symbol and then the windows appeared where I had to enter my data.*". He always pragmatically followed the necessary steps of the computer workflow but never thought about the functionality behind it, or how the process could have been change or improved. He follows the same approach when starting a Skype call on the computer, which he learned from his daughters. He follows the necessary steps without a deeper understanding about the functionalities behind it. His usage of computer systems is strongly based on trained step-by-step interactions. This previous knowledge was not only not helpful but actually obtrusive when he tried to use the Tangible User Interface of *kommTUi*. He was always searching for known patterns like digital icons to click on or pressing on illuminated areas on the prototype.

When designing the tokens for the *kommTUi* prototype, participant FM had difficulties to choose a symbol for the *Generic Token* and to find an appropriate object for the *Personal Token*. He didn't use one of the provided paper icons for the Generic Token, he wrote the word *Skype* on it instead. He also used one of the wooden *Generic Token* objects as *Personal Token*, because it was hard for him to find an appropriate object.

Touch interaction: Again, participants tried to press on the scan area during the personal token interaction, rarely also on the screen.

Personal Identification Object: The idea that an object could be used instead of a password was very positively received by the participants. Especially for advanced computer users this would be an interesting feature.

Audio/Visuelles Feedback: The assignment of visual feedback to the prototype was only once not fully understood, otherwise it was always clear that the visual representation on the screen was a reference to the prototype. In any case, this visual feedback did not distract from the Token+Constraint design of the Generic Token. Audio feedback was acknowledged and explicitly mentioned as an important cue for action.

Implications

The RFID tags for the personal tokens should be more actively integrated into the design. For example, a participant's idea is promising: put a symbol directly on the tags and also point the same symbol to the scan area for the personal tokens. This way, the user knows immediately where and how to place the personal token. The interaction should also be reversible. For example, if a generic token has already been stored in the slot and is then removed again, the screen must respond visually and return to its initial state after a certain time. There was a difference regarding visual feedback. On the device itself only the font was blinking, on the screen the whole area. Therefore the connection is not completely clear and the design is not congruent. This is a design breach. One participant had very big problems dealing with it. This must be taken into account in the redesign. The predefined setting which functionality is called with the Generic Token must be precisely adaptable and finely adjustable by a third person. It only makes sense to open a homepage if the person wants to actually go there. With email interaction, for example, the cursor of the mouse should already be in the text field, a simple solution would also be to automatically insert a generic text in the subject. Mapping a 2D image of 3D objects to the screen as visual interaction support can be difficult for people with little screen experience. In the discussions during the workshops it became clear that many could imagine the use of a personal identification object for security-critical applications. Especially participants with more experience in working with computers see an exciting advantage of Tangible User Interfaces.

Although the determined interaction sequence - Personal Token follows Generic Token - seemed to be helpful for most participants in Iteration 2 and 3, there were also situations where a higher degree of freedom would have been advantageous. For example in Iteration 3, participant FG used the *Personal Token* as first step of interaction with the prototype. Then he was trying to put the *Generic Token* into the corresponding slot. Due to the determined order, first *Generic Token* and then the *Personal Token*, this approach wasn't successful and lead to an irritation of the participant.

In this chapter we presented both the content of the workshops and the technical development of our mock-ups and prototypes. In the next chapter we will discuss the results of our research on the basis of the findings described here.

Chapter 5

Analysis and Discussion

The research described in this thesis contribute to our understanding of the possibilities of personalized, tangible interaction to encourage elderly users to use modern ICT. The first iteration of our design process helped us to get a sense of the attitude towards technology usage of this user group (Section 4.1). In the second iteration we introduced the initial version of the kommTUi prototype, which was already based on the principles of tangible interaction and a high degree of personalization (Section 4.2). The third iteration included a technological evolution of the prototype towards a pluggable device and intensified the element of personalization by conducting the design sessions in participants' homes (Section 4.3). On the basis of the results of our design process, we first outline the emergent themes that arose from our research. Afterwards, we present the final version of our kommTUi prototype as contribution of this theses. Conclusively, we interrelate the pillars of our findings with each other, resulting in the AMPTA visualization presented in Section 5.6. These insights serve as implications for the future design of technologies for elderly people.

5.1 Tangible Interaction

In our research, we embraced tangible interaction to create a very inviting and intuitive user experience. We used the possibilites of Tangible User Interfaces to create a playful interface design to reduced fear and scepticism of technology. Our findings indicate, that Tangible user interfaces offer unique possibilities to improve the accessibility of a technology. According to Czaja and Lee, older adults *"often express more anxiety about their ability to use these systems and less confidence in their ability to use them successfully"* [19]. Also Eisma et al. identified the feeling, that using a technology is too difficult as an important factor creating a negative attitude towards technologies [25]. Haptic elements can decisively reduce the initial barrier to experimentation. This was already evident in the first iteration of our workshops. Participants started interacting with the provided mock-ups and prototypes, without previous knowledge:

Right at the beginning of the game two participants got together and sit down at the table. They knew the game little and not at all.

> TR: *"I don't even know" [underlines the statement with a defensive attitude]*
>
> TL: *"I played once - at Christmas"*. [TL immediately took a token in his hand and played with both hands. The interaction with the token was independent of the spoken word. During the game, the two of them repeatedly dealt with the rules of the game and tried to play correctly - the linguistic concentration was on the sequence of the game and the type of game. At the same time there was an accompanying haptic involvement with the game pieces, the pieces were not only picked up and placed but also constantly held in the hand.]
>
> TL:*"I'll put it in there now"* [does it with the right arm and hand in a coherent movement]
>
> TR: *"then we simply take the stones out again and play again", takes a second stone while he already has another one in his hand.*
>
> TL: *"then we make it new", also helps with one hand when removing two stones*

This was also the case when participants had a general negative attitude against gaming. For example in a workshop of Iteration 1: Participant TB of the first iteration found no partner, but sat down at the table and immediately picked up some of the tokens. With these tokens she then filled up a row of the board in quick succession without being asked. She then stroked the remaining tokens and groups them.

> TB: *"kenn ich nicht, ich bin kein Spieler"* [at the same time she interacts with some tokens using her right hand]

The haptic elements of the user interface were quickly accepted by the older participants. They started interacting immediately without being put off by the unknown tools.

This was also observed in Iteration 2. After talking for five minutes about how he refuses everything that has to do with computers and that his wife does all these tasks, participant GW immediately took the correct generic token in his hand after the start of the first use case *phone call*.

> FW: *"Naja gut, das ist ja naheliegend für mich, dass ich – wenn ich sie anrufen will – das nimm. Ich meine das ist für mich Anrufen und Kommunikation, sprachliche."*

It was fascinating to see how the participant immediately took the correct generic token in his hand and described the functionality associated with it, even though he had just clearly expressed his reluctance to use new technologies.

Token+constraint

When it comes to the design of the elements of a Tangible User Interface, Ullmer's token+constraint approach is a relevant standard [139]. This approach is of great importance in the research question of this work, whether tangible interface elements can be used to support elderly users in the interaction with communication technologies. Therefore, we have included the token+constraint approach as an essential design element in our mock-ups and prototypes from the very beginning in order to test whether this approach can contribute to achieving our goal.

Two prototypes were made using it already in Iteration 1: The holes of the wooden board in Station 1 matched the shape of the tokens exactly. In Station 4, a constraint was designed by means of coloured markings on the depositing area. In the second iteration, on the one hand, a hole was sawn into the wooden panel of the interactive prototype that had the same shape as the generic tokens to establish a form-function relationship. On the other hand, a coloured marking was applied to the same prototype in order to mark a further interaction area. And in the third iteration, the advanced prototype was finally equipped with similar elements. The case created from a 3D printer contained a specially shaped indentation that matched the shape of the generic tokens. In addition, there was a colour-coded scan area for the personal tokens. The design of the advanced prototype in the last iteration was based on insights from the previous iterations.

Due to the differences between the tokens of Iteration 1 and the similar token design in iterations 2 and 3, we first discuss the findings of the first iteration, followed by the findings of the subsequent iterations.

Iteration 1

In Station 4 of Iteration 1, when placing the action cards on the scan area, several participants tried either to place two cards next to each other onto scan area or to position one card over another card (Figure 5.1). On the one hand, action cards were placed on the start card that was already placed on the scan area. On the other hand, two action cards were placed next to each other on the storage area to indicate a coherence or a problem and its solution (*Meow* + *Feeding*).

Due to the technical requirements, no regular feedback could be given in these cases. The RFID reader used could only read several RFID tags one after the other and not simultaneously. If a second tag is brought within range of the RFID reader, reception of the first tag is disturbed. However, the participants removed the second card quickly because no change could be seen on the screen, although they had placed a new card on the scan area.

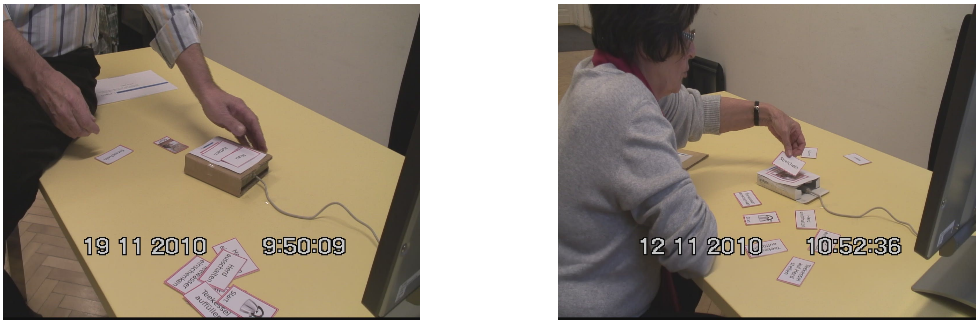


Figure 5.1: Placing two cards at the same time

> MF: *“Kann man das übereinander legen auch, nein oder? Geht immer nur eines, oder?”*
>
> LR: *“Jetzt lege ich das (Aktionskarte) da (Startkarte auf Ablegefläche) so drauf, oder tausche ich das aus?”*

For many participants, the design of the scan area was an indication that there is a connection between the cards and this area. Some saw no connection at all (Figure 5.2). The color and shape of the frames of action cards and the scan area were named as the key factors for a positive link. In one case, the *kommTUi* label, which was located below the red frame of the scan area, was decisive for linking the cards and the scan area. Participant LR read *komm* (the german word for *come*) and linked it to the fact that she must now come with something. The red frame was only confirmation for her when she put the map on top that the interaction is so correct.

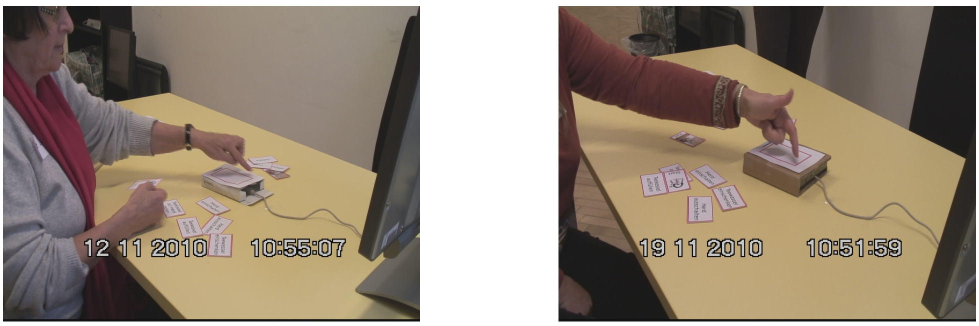


Figure 5.2: Identifying the relation between card and scan area

BM: *"Das war für mich klar, das (Karte) hat den Umriss und das (Ablegefläche) auch. Das gehört irgendwie zusammen." "Die Form, das Eckige."* [He mentioned that he would call himself a visual type]

MG: *"(Auschlaggebend war ...) . . . dass die roten Karten dort (Ablegefläche) rein passen."*

LR: *"Es ist dann da (unter der Ablegefläche) gestanden 'komm' und ich habe mir gedacht ich muss mit was kommen." "Ich hab dann gesehen, dass die roten Rahmen zusammenpassen."*

HE: "Die roten Rahmen hab ich überhaupt nicht gesehen."

The orientation of the cards in which they were placed, i.e. whether the card was placed on the scan area with text or image facing up, was the same for all participants but one. The first card was always placed with the text facing up. Only participant MG first placed the first card with the text face down on the table, but all following cards with the text facing up. The cards were usually placed in such a way that they fit into the red frame of the scan area, but it also happened (although only rarely) that the cards were placed transversely to the scan area (Figure 5.3).

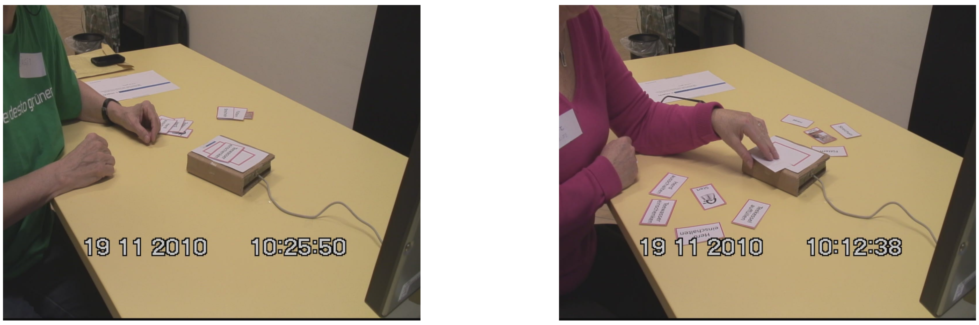


Figure 5.3: Alternative placement of cards

These findings of Iteration 1 regarding user interaction with a system with a Tangible User Interface showed, that it was necessary for us to improve the token+constraint relation for the following design iterations. The design of the interface elements was good enough for our aim to have a glimpse on how elderly users handle interaction with an RFID-based Tangible User Interface. Most participants were able to learn the interaction quite fast and without instruction. However, there still have been interactions that did not correspond to the intended outcome. This underlines the necessity of an adaption of the interface elements:

- Using a coloured frame as constraint was not always enough. When users should place an tangible interface element on a corresponding area, the area should have an indentation to avoid placing the interface element in an unintended orientation. This could lead to technical difficulties in regard to RFID reception, due to its limited range. This would limit the user experience of the system.

- The token+constraint relation should prevent the system from malfunction. If it is technically not possible to read multiple RFID tags at one time, the interface design should avoid such a situation as far as possible.
- The physical parts of the system must be robust enough, to withstand alternative user interactions. Especially when designing an interface which does not follow the usual interaction patterns, it is important to design all parts of the system in such a way that they can withstand impacts by applying pressure with fingers or the hand.
- Every small piece of information on the user interface can be important for users. If there is written text on the tangible system, users might interpret it in their own special way. Thus, textual elements should be used only in context of the intended user interaction.

Iteration 2 and 3

The connection of form and function in the interaction with the Generic Tokens turned out to be very intuitive, the connection was immediately recognized by most participants. However, it was the combination of the personalized design of the Generic Token and the similarity of the form, which triggered the interaction with the prototype.

> MV: *"Dann schätze ich da, dass diese Form da reingehört."* [puts Generic Token into the corresponding slot]
>
> GD: *"Das habe ich von vorher im Kopf gehabt [from Station 1], dass das so ausschaut."* [holds a Generic Token in her hands and points at the slot] *"Da passts da her. Das war klar, absolut verbunden. Das war gleich klar."*
>
> IA: [before getting explained the use case, she immediately put the Generic Token for sending a note in the corresponding slot] *"Also, was soll ich hinschreiben?"* [performs a typing gesture with her fingers]

Participant RL clearly emphasized the interaction cue through the form of the Generic Token. This was the decisive factor to start the interaction for her. When asked why they put the generic token into the corresponding slot, participants clearly refer to the form of Generic Token and the slot:

> EH: *"Weil da die Öffnung dafür ist!"* [points to the slot for the generic tokens]

AH: [asked why he intuitively put the Generic Token into the corresponding slot] *"Das erinnert mich an gewisse Kinderspiele, wo man bestimmte Teile wo hineinstecken muss. Für die ganz Kleinen, so glaube ich für 1- bis 2-jährige. Die kriegen das als Aufgabe, müssen das richtige Objekt in das richtige Loch einstecken."*

IA: [asked why he intuitively put the Generic Token into the corresponding slot] *"Die Form, das habe ich gleich gesehen."*

WW: [After having a hard time with the intuitive use of our prototype he answered to the question whether he could spot any similarities in form of Generic Token and the prototype] *"Ja sicher, da sehe ich was"* [and put the Generic Token in the slot]

GK: [asked why he intuitively put the Generic Token into the corresponding slot] "Die Form, die passt einfach da rein."

MH: [asked why he intuitively put the Generic Token into the corresponding slot] *"Das ist ja die Form, nicht. Aber das strahlt ja überall hin, da ist es eigentlich egal wie man das reinlegt"* [tries several positions for the Generic Token in the corresponding slot]

Also participants without any previous knowledge in the area of ICT identified the Generic Token slot as important part of interaction. For example participants GW in Iteration 2 while exploring possible interactions with the user interface:

FW: *"Weil das ist sicher, da gibst du was hinein"* [talks about Generic Token slot] *"Naheliegend ist für mich, dass da die gleiche Struktur ist wie da"* [points at the Generic Token] *"Das hat eine gewisse Norm, da kann man nicht alles reintun, sondern nur etwas genormtes."*

The form for token and slot was chosen especially enough, even a participant with macular degeneration was able to see the interrelations.

Like in Iteration 2, the similarity of form and function between the Generic Tokens and the corresponding slot turned out to be the essential cue for an intuitive interaction in Iteration 3. Almost all participants in this iteration have recognized this connection and also stated it as the reason for their interaction in the discussion.

FG: [when asked why he intuitively chose to put the Generic Token into the corresponding slot] *"Ja, weil das da so ausschaut!"* [points at the slot]

FM: *"Dann muss ich den da reingeben."* [moves the Generic Token to the slot, after explaining how he would approach a skype-call in real-life]

FM: *"Da ist es klar [puts the Generic Token into the slot], da passt es mit der Form!"*

> HS: *"Da ist es ja doppelt, da steht Aktion und dann hast du das zum reingeben"* [puts the Generic Token into the slot]
>
> MK: [when asked why he intuitively chose to put the Generic Token into the corresponding slot] *"Das ist die Aktion die man hat, und die Aktion das ist ja Mail und das Skype und das gehört da rein."*
>
> RM: [when asked why he intuitively chose to put the Generic Token into the corresponding slot] *"Die Form ist die selbe."*
>
> RS: [when asked why he intuitively chose to put the Generic Token into the corresponding slot] *"Weil da ein Loch ist und ich stell mir vor... weil das da rein passt! Weil das was ich hergeräumt habe kann ja nicht passen."* [points at her Personal Tokens]

This clear assignability suggests a strong perceived affordance between the shape of the underside of the generic tokens and the shape of the corresponding slot. Furthermore, with our design of generic tokens we were able to achieve a real affordance. The size of the tokens was chosen exactly in a way that it fits optimally in the hand of the user, the weight and the material of the wooden object supported lifting and holding in the hand. The suitability of this material has also been confirmed by Maquil [81]. In all workshops we could observe that the participants unconsciously picked up the generic tokens, played around with them and put them down again. Some of the participants also called the generic tokens stamps, which may have contributed to the generation of affordance.

Also the interaction with the Personal Token went well in most cases. However, there were still apparent differences in terms of intuitive handling in contrast to the Generic Tokens. Most participants of iterations 2 and 3 were able to complete the interaction with the Personal Token on their own after a certain time. Participants who had difficulties in the first run could easily complete the interaction with the Personal Token on a second attempt.

GS: [when asked why she put the personal object on this specific part of the prototype] *"Ich habe einfach probiert, probieren! Das muss irgendeinen Sinn haben, was da ist!"* [point at the scan area for the Personal Tokens]

One participant of Iteration 2 first put the Personal Token directly between die Generic Token slot and the scan area for the Personal Token. After a short discussion about the reason why nothing happens, he recognized what was the problem.

> FW: *"Na gut, Moment einmal, Blödsinn, ich muss ja das dahin tun!"* [moves the Personal Token from the middle to the coloured scan area]

Also the oldest participant of Iteration 2 (WW - 83 years old) had difficulties with positioning the Personal Token. He first tried to put it in front of the screen. However, he intuitively tried to put it somewhere. The tangible interaction was clear to him, at least after finishing the Generic Token interaction. A single participant of Iteration 2 put the Personal Token into the slot for the Generic Token (Figure 5.4). Because she could not recognize any positive feedback, she removed the personal token again and put it back into the box.

> MH: "Hallo lieber Edgar, ich würde dich gern anrufen! [..] Du hörst nicht, du reagierst nicht. Mein Ring ist auch kein Medium, dann tu ich ihn wieder in die Schachtel."

Figure 5.4: Personal Token placed into the Generic Token slot in Iteration 2

One participant of Iteration 3 put his personal objekt directly on the *Person* letters and not on the scan area. Thus, the Personal Token was not recognized by the RFID-reader.

> FM: [puts the Personal Token on the *Person* letters of the prototype. Afterwards he added] *"Hier müsste irgendein Feld oder sowas eingezeichnet*

sein" [moves his finger in a rectangular path over the Personal Token scan area] *"Weil wo stell ich das hin"*

Most other participants had no problems with the interaction, for them it was immediately clear to put the Personal Token on the corresponding scan area.

Figure 5.5: Intuitive interaction with Personal Tokens in Iteration 2 and 3

The token+constraints approach in the design of the *Generic Token* and the associated placement slot was a success. The participants instantaneously linked the shape of the *Generic Token* to the shape of the corresponding slot. For all participants this perceived affordance was the decisive factor for the placement of the *Generic Token*. Even participants without computer experience had few problems. It can thus be suggested that tangible interaction and especially the token+constraint approach provides an intuitive way of user interaction for elderly users and therefore can be used to raise the accessibility of modern ICTs.

Interaction Cues

In Iteration 2, the individual design of the Generic Tokens was very diverse. Some participants used a simple visual presentation or plain textual description, others drew complex messages on their tokens. This illustrates the high individuality in the memory encoding. The left picture of Figure 5.6 shows a Generic Token for *phone call*. The picture shows a mobile phone calling another mobile phone or a land line telephone. This was important for the participant, because he just cancelled the contract with his land line provider and therefore makes phone calls just via mobile phones, but both to other mobile phones and to land line telephones. The right pictures shows the Generic Token set of another participant, who chose not to use pictorial encoding, but plain text.

GS: [taking a Generic Token in her hand, looks at it and pointing at it with her finger] *"Das ist eine Notiz, das ist auch das Symbol das ich gewählt habe für Notiz."*

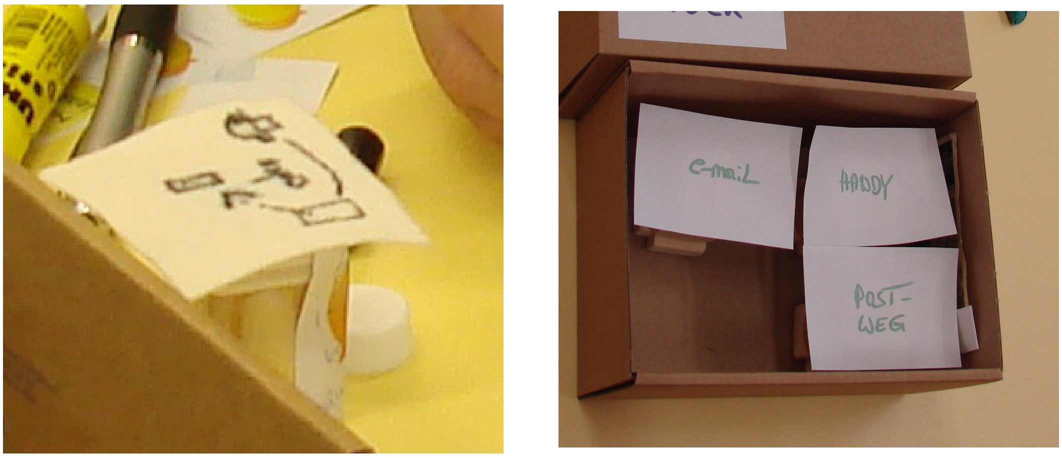


Figure 5.6: Generic Token design - different memory encoding in Iteration 2 and 3

> GD: [talking about her Generic Token for *phone call* - annotated with a curled telephone line] *"Über die Schnur habe ich ja nachher noch lachen müssen, die ich immer noch verwende [as symbol]. Ein junger Mensch heute könnte, wüsste überhaupt nichts damit anzufangen. Ich habe dann zu mir gesagt 'G., heute hat doch kein Telefon mehr eine Schnur', aber ich, für mich, ist das immer noch das Symbol für Anrufen! [..] Das Symbol ist schon 30 Jahre bei mir gespeichert! [laugs]"*
>
> GS: [she is reading the text on the monitor] "Platziere das richtige Objekt. Ja, das ist das da!" [takes the right Generic Token in her hand (Figure 5.7]
>
> MH: "Das ist das Objekt mit ich glaube anrufen zu können." [holds the corresponding Generic Token in her hand and observes it] *"So man redet miteinander, nicht, das finde ich ganz gut [the symbol on the Generic Token], ist einmal was anderes wie Telefon. Wobei ich das insofern auch noch nicht schlecht finde, weil es hier zwei und bei einem Kopfhörer hat man meistens auch sowas wie zwei. [points at her ear]"*

Also in Iteration 3, there were no doubts about which Generic Token inheres which functionality throughout all participants.

> DH: [after the start of the use case] *"Ja, also das ist der Stempel, mit dem ich Informationen erhalten möchte."* [taps with her finger on the top of the corresponding Generic Token]
>
> FM: [Although he had great difficulty in embracing the design of the tokens, he grabbed the correct generic token immediately after explaining the use-case] *"Also ich würde sagen, jetzt möchte ich sie anrufen."*

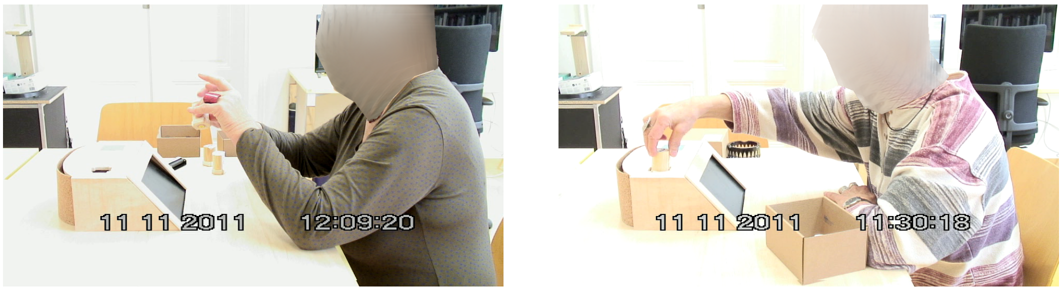


Figure 5.7: Recall functionality of Generic Tokens through support of individualized linked content

> MK: *"Da habe ich mir gedacht, die sind zwar alle zwei gleich, aber da ist halt das Bild oben"* [points at the Generic Token for skype call]

The context information of the Generic Tokens through the individual design of the interface elements was absolutely clear to the participants (cf. Figure 5.7). Through providing different icons and additional materials for annotating the Generic Tokens, we went further than Park et al. in their study regarding age-related differences in the ability to utilize integrative relationships between target and context as a memory support by directly manipulating the relationship between a target picture and context [106]. We let the participants of our workshop choose or generate the related context to recall the target information. This was important, because the complexity of our target information "start a Skype call" was much higher than "the spider ate the ant", which Park et al. were using in their study. Thus, when we would have simply provided an external context, the complexity of it would have decreased the probability of a positive impact on recalling the target information. As Sas recommends [123], we involved our participants in the generation of their personal cues. By choosing or generating the pictorial stimulus for the context themselves, the complexity was reduced and the participant were able to perfectly recall the target information. We observed no uncertainties or discussion about which Generic Token represents which functionality. The environmental support through the individualized pictorial stimulus helped the participants to recall the linked function of the token. This supports our hypothesis, that the individual design of the Generic Tokens supports recalling the corresponding function of the interface element.

Interaction Steps

In the literature review of Section 2.2, we learned that the acceptance of new technologies is tightly coupled to the perceived ease of use. Niehaves and Plattfaut as well as Steele et al. identified perceived ease of use and especially a simple interface requiring the least amount of interaction as crucial for technology acceptance by elderly users.

The interaction design of our final prototype aims at minimizing the necessary interaction steps for the execution of the different use cases. The interaction sequence using Generic Token and Personal Token can be used as a tangible shortcut to the WIMP interaction.

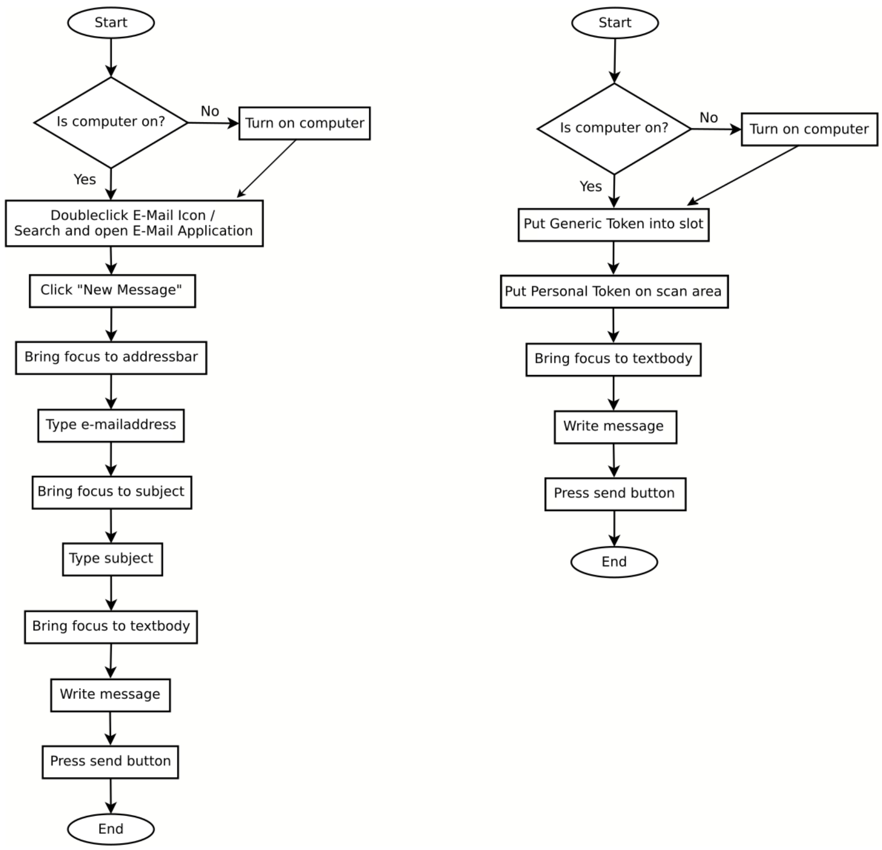


Figure 5.8: E-Mail interaction without and with kommTUi

The outcome of our research interations underlines the importance of a clear strategy for the interaction sequence. Our findings suggest two approaches: Defining clear constraints for the interface elements, so the user has just one way of interaction. Or providing enough degrees of freedom for the interaction, so the user can decide individually how the interaction is done. Taking into account the findings of Section 5.1, where we pointed out, that an interaction setting without clear instruction or interaction cues can lead to a stressful situation for the user, we decided to choose the constraints approach for our final prototype. This constraints need to be multimodal, with visual, aural and graspable elements, in order to achieve an optimal interaction cue.

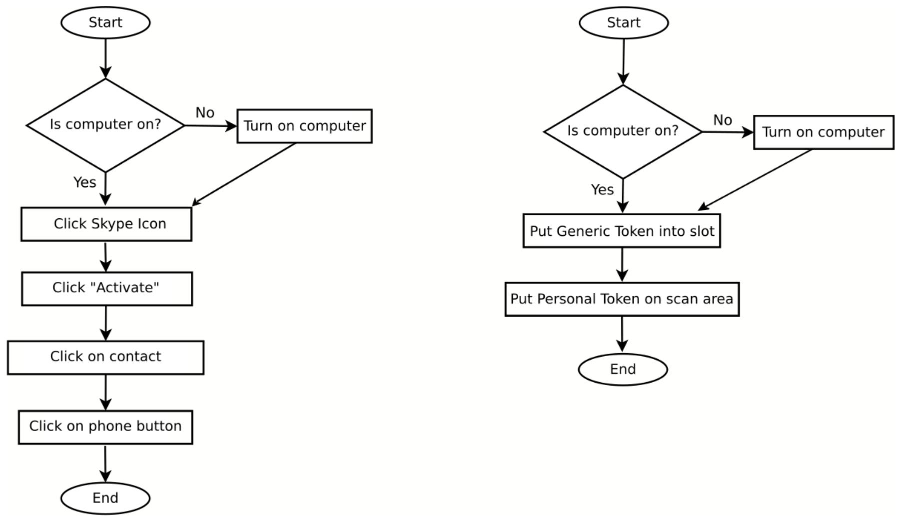


Figure 5.9: Skype interaction without and with kommTUi

Second Run

The user interaction with the prototypes in Iteration 2 and 3 was structured in such a way that another run was started after the successful completion of the first interaction sequence. Since the first attempt was made without any instructions to check the intuitivity, the learnability of the interaction should be observed in the second run. Most participants had no problems to start the second use case by changing the Generic Token. Some difficulties have been noticed with the Personal Token interaction in the second run.

> AH: [directly after second use case was started] *“OK, da muss ich mir das Notizdings nehmen”* [searches the Generic Token for sending notes and puts it in the slot]
>
> GD: [directly after second use case was started] *“Da muss ich halt das andere hinstellen, nicht.”* [searches the Generic Token for sending fotos and puts it in the slot]
>
> FW: [directly after second use case was started] “Da müsste ich so machen” [puts the correct Generic Token into the corresponding slot] “und da müsste ich so machen” [puts the Personal Token on the scan area, immediately after the successful Generic Token interaction] “Ganz blöd bin ich auch noch nicht” [laughs]

Many participants were really excited about how simple it is to reach a goal with the prototype, after finishing the use cases of the workshop. They underlined, that there is not much thinking needed to operate the device. Most participants said, that our tool would be valuable to them or other elderly people. In addition, some participant also provided feedback for redesign or future use.

> DH: *"Aha, tatsächlich, jetzt ist er ja schon da der Kirchenchor!"* [looks at the screen after finishing the interaction where to browser shows the homepage of her church choir] *"Das ist toll, wenn das so schnell präsent ist."*
>
> HS: "Da ist die Frage, ob man nicht den Cursor runter tun soll" [points at the new E-Mail window on the screen. The cursor was in the subject textarea, he proposed to initially move it to the textarea for the E-Mail text]
>
> TW: [Talking about the finished interaction] "Natürlich, wenn ich nicht denken muss, sondern gleich einsteigen kann, das ist viel bequemer."
>
> RM: "Ja, da brauch ich nicht mehr viel denken, da gehts zack zack." [points first at the Generic Token slot and then at the Personal Token scan area]
>
> TW: "Ja, das ist wirklich eine sehr gute Idee" [during discussion about suitability as security object]

Williams et al. investigated the problems of older adults using interpersonal communication software like Facebook Messenger and Skype [151]. They come to the conclusion that using this products is difficult, because *"it requires explanation, and time must be taken to teach the software to elderly users-those who take it upon themselves to learn the software often aren't able to understand it fully"* [151, p. 282]. This is confirmed by Czaja and Lee [19]. The authors indicate, that *"older adults learn new skills more slowly than younger adults and may not reach the same levels of performance"*. Hence, the fewer interaction steps are required for a task, the less older people need to learn how to interact. It has already been shown in Section 5.1 that a smaller number of interaction steps is possible in our interaction design compared to traditional WIMP interfaces. The results of the workshops also indicate that our Tangible User Interface approach supports learnability. In order to examine this, two interaction rounds with the prototype were carried out at the workshops in iterations 2 and 3. For the interested reader some basic statistical evaluations based on our video evaluations are presented at this point to provide a quantitative insight into the user interaction. Before we explain the columns of the tables, we repeat some context information about the user interaction in the workshops: The participants did not receive any information about the prototype or the user interaction prior to the workshops. Participants were invited individually to interact with the prototype. No information about the functionality or the user interaction was passed on to the participants at this time either. After the presentation of the first use case - usually calling the person associated with the personal token - the participants were only given further information if they actively asked for it. After the successful completion of the first use case, the participants were asked to perform a second use case. This included, for example, sending a photo to the person associated with the personal token.

Figure 5.10 shows some basic statistical parameters of interactions with Generic and Personal tokens, gathered in Iteration 2 and 3:

- Start/First GT: The duration in seconds between the end of the description of the use-case and the first interaction with the Generic Token of the participant.
- Start/First GT 2nd: The duration in seconds between the end of the description of the use-case and the first interaction with the Generic Token of the participant in the second use-case.
- First GT/Successful GT: The duration in seconds between the first interaction with the Generic Token and the successful placement of the token in the corresponding slot.
- First GT/ Successful GT 2nd: The duration in seconds between the first interaction with the Generic Token and the successful placement of the token in the corresponding slot in the second use-case.

Value	Start/First GT	Start/First GT 2nd	First GT/ Successful GT	First GT/ Successful GT 2nd
Sum:	312	120	1.223	225
Count (n):	21	21	21	21
Mean:	14,8571	5,7143	58,2381	10,7143
Median:	6	2	7	5
Minimum:	-22	0	1	0
Maximum:	50	25	347	73
Range:	72	25	346	73
Variance:	411,0748	49,6327	8.884,75	414,7755
Standard deviation:	20,275	7,045	94,259	20,366

Figure 5.10: Quantitative analysis of user interaction - Generic Tokens

In Figure 5.11, additional numbers are presented from Iteration 2 and 3:

- Successful GT/First PT: The duration in seconds between the successful placement of the Generic Token in the corresponding slot and the first interaction with the Personal Token of the participant.
- Successful GT/First PT 2nd: The duration in seconds between the successful placement of the Generic Token in the corresponding slot and the first interaction with the Personal Token of the participant in the second use-case.

- First PT/Successful PT: The duration in seconds between the first interaction with the Personal Token and the successful placement of the Personal Token on the scan area.
- First PT/Successful PT 2nd: The duration in seconds between the first interaction with the Personal Token and the successful placement of the Personal Token on the scan area in the second use-case.

Value	Successful GT/First PT	Successful GT/First PT 2nd	First PT/Successful PT	First PT/Successful PT 2nd
Sum:	2.396	209	1.882	38
Count (n):	21	21	21	21
Mean:	114,0952	9,9524	89,619	1,8095
Median:	46	4	11	1
Minimum:	-44	1	0	-9
Maximum:	710	54	474	15
Range:	754	53	474	24
Variance:	25.703,61	191,1882	16.843,95	15,1066
Standard deviation:	160,3235	13,8271	129,7842	3,8867

Figure 5.11: Quantitative analysis of user interaction - Personal Tokens

Although the presented figures do not provide a statistically significant statement, they support the tendencies that were already observed in the analysis of the workshops. The time between the start of the use case and the first interaction with the Generic Token was rather short. The time between the first Generic Token interaction and the successful completion of the interaction varied considerably. Often the participants explored different types of interaction, discussed communication habits and - in case of a longer duration - digressed to other topics. Other participants were able to complete the interaction very quickly, which is underlined by the variance.

Considering the numbers of the second use case, a significantly shorter interaction duration can be identified. This applies both to interactions with the Generic Token (Figure 5.10) and to interactions with the Personal Token (Figure 5.11). In the case of the Generic Tokens a general acceleration and therefore also learning effect can be determined. For the interaction with the personal token, the short duration between the first interaction with the personal token and the successful completion of the interaction is particularly remarkable. The evaluation shows that this duration is no shorter than for interaction with the Generic Tokens. This is particularly noteworthy considering the tendentially longer interaction duration between the successful completion of the Generic Token interaction and the first Personal Token interaction. As for *Start/First GT 2nd*, the values of *First PT/Successful PT 2nd* have a low range, indicating that these interactions were very clear for all participants.

Our findings indicate, that also existing software, which can be challenging for older adults, can be made more accessible through the use of tangible shortcuts. Furthermore, our approach of combining Tangible User Interfaces with personalized design elements and interaction cues may support learnability of user interaction for older adults.

5.2 Personalized Token Design

A key design tool regarding personalization of the *kommTUi* prototypes was the individual preparation of the interface elements. This was accomplished by both personalized *Generic Tokens* which were used to switch between the functionality of the prototype and the involvement of *mementos* as interface elements.

Generic Tokens

The participants of the workshops were able to equip their *Generic Tokens* with icons or materials of their choice and use personal objects as *Personal Tokens*. The individual design of the tokens sometimes led to unexpected outcomes: When choosing the icon for making a phone call, FG chose an image showing an envelope with photos in it. Participant SL put the @-sign on the *Generic Token* for the same use-case (Figure 5.12).

Figure 5.12: Generic Tokens for *phone call*

This shows the advantage of highly individualized token design. While standard symbols for making a phone call could be expected as an image of a telephone or a dialplate, these participants chose their very own visualizations of this action. Despite the large number of materials provided for the token design in the workshops, the participants mainly used the ready-made symbols and various pens to design the Generic Tokens. For example, participants painted an old, curled telephone line on the token with the *phone call* function.

GD: *"Natürlich, das wird für mich immer das Symbol für Telefon bleiben. Das waren noch Zeiten!"*

Joshi in his work on simplicity in the context of design of assistive technology emphasized *"the difficulty of reducing complex information into simplified metaphors*

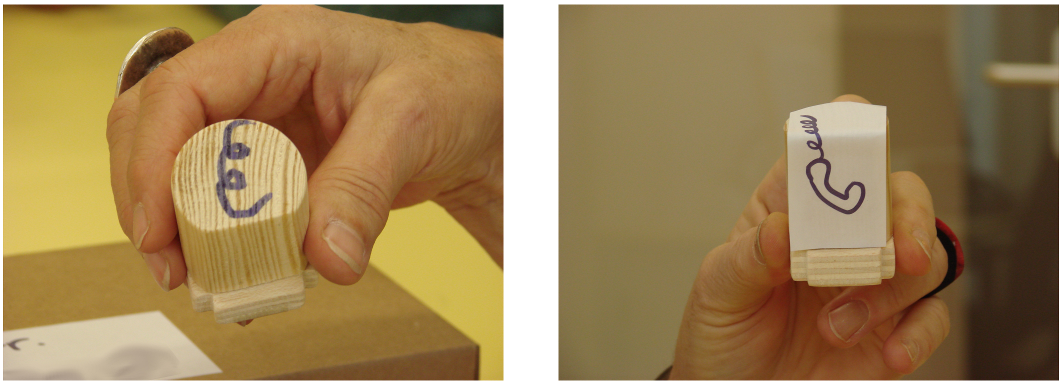


Figure 5.13: Generic Tokens for *phone call* annotated with a telephone line

where everyone understands both the metaphors and the symbolic meaning or feeling they encompass" [67, p. 334]. In our work, we let the users decide, which metaphors and symbols they want to use. For them personally, it was the clearest symbol of the corresponding interaction. The goal of achieving greater recognition of the token functionality was achieved through this type of personalization. During the interaction with the prototypes, the participants could easily assign the respective functions to the Generic Tokens. What we observed especially in Iteration 3 is that participants with a more pragmatic and less creative mindset have difficulties with designing the tokens. Participants with an more open-minded, creative nature had no problems both with the token design and the user interaction. With the personalization of the *Generic Tokens* we aimed to overcome the difficulties of elderly people in the correct interpretation of graphic icons. We involved the participants not only in the design of the interface elements, but also in the cue generation to recall the token functionality, as it was proposed as future direction by Sas [123]. This also goes beyond other approaches to the co-design of interface elements, such as Appert et al., who only integrate indirect token generation throuh users into their approach [2]. Our findings suggest that the freedom of equipping and annotating the tokens by themselves led to a clear understanding of the meaning of the *Generic Token*.

Personal Tokens

Another form of autobiographical personalization is represented by Personal Tokens. These were brought by the participants and symbolized a special friend or acquaintance. In Iteration 2, Personal Tokens were part of the workshops and user interaction for the first time. In order to integrate them directly into the interaction, the objects were tagged with an RFID tag and photographed right at the beginning. The IDs of the RFID tags were already built into the programming of the system during development. The photos of the objects were imported into the system during the greeting and were thus immediately available as visual feedback in Station 2. The Personal Tokens were also accepted by the participants, the concept behind it (defining the communication partners) was easily understood.

> RL: [She read the text on the screen aloud] *"Wen wollen Sie anrufen Frau L.?"* [she thought for a few seconds and then says] *"Na den da!"* [and put the Personal Token on the corresponding scan area]

This observation is particularly interesting in relation to the cognitive bridge between the personal objects that became interface elements in the workshop and the functionality that was associated with them. The participant was exploring how the prototype works. She read the text on the screen, placed the personal token on the scan area and said "na den da!". This is particularly remarkable in the German language, since the choice of the article made a clear reference to the person connected to the object (her partner).

When asked what was decisive for her that she placed her personal object on the scan area, she clearly confirmed:

> RL: *"Na das verbinde ich mit meiner Partner, ganz intensiv."*

Also our findings from Iteration 2 underline the understandability of the linkage between the personal object the participants brought with them and the recipient of the communication.

> FW: *"Nachdem keine Tastatur da ist... Wen muss ich anrufen... Naja, das assoziiert natürlich den Aschenbecher"* [taking the Personal Token in his hand] *"Aber ob er ihn erkennt, das ist natürlich seine Sache"* [talked about our prototype] *"Damit will ich diesem Apparat zeigen, wen."* [Remark: who he wanted to call]

> RJ: *"Ja, wenn das das Symbol für meine Tochter ist, dann ist es logisch"* [pointed at the plush toy she chose as Personal Token]

For participant WW, the use of personal objects was a strong reason to thoroughly examine and try out a technology, in contrast to something which is irrelevant for him.

> WW: [answering the question, whether the use of personal objects would support intuitive interaction with communication devices] *"Von der Technik her sicherlich nicht, aber vom Engagement her – ja. Wenn es ein Objekt ist, das mir viel gibt, egal ob diesseits oder jenseits, dann tue ich das mit viel mehr Engagement oder Hingabe versuchen zu lösen, als wie etwas was mir ziemlich egal ist."*

Also in Iteration 3, the perceived linkage between the personal object and the recipient of the interaction was strong. While the necessary interaction was not always intuitive for the participants, the meaning of the *Personal Tokens* was clear for them. Especially the quote from participant HS is an example of how fascinated participants were by the possibility of interaction through personal objects.

> DH: *"Ich kann ja das nicht einsetzen! [laughing]"* [pointed at her Personal Token – a box of cough drops]
>
> HS: *"Ist das etwa so ein tolle Sache, dass... "* [took his Personal Token and put it on the scan area]
>
> SL: *"Na, dann tun wir da den Kaiser her."* [put the Personal Token on the scan area. He chose a medal with a picture of the former Austrian emperor on it as Personal Token for the shooting association of his daughter]
>
> TW: *"Die Person ist jetzt der Verkehrsverbund."* [indicated a problem with the text on the scan area for Personal Tokens, however recalling the entity linked to the Personal Token]

These examples underline our observation of all workshops in Iteration 2 and 3, that the participants had very strong emotional ties with the objects they brought with them. The findings of our research shows that the possibility of creating personalized tangible interface elements has the advantage of taking into account the individual preferences and most of all previous knowledge and experiences the user made throughout his or her life. The best term to describe this creative and highly individualized approach of user interface design would be *autobiographical design*. However, Neustaedter and Sengers already used that term for *"design research drawing on extensive, genuine usage by those creating or building the system"* [92, p. 514]. They describe a research method that supports a design process through the use of a prototype by the designer him/herself. Our approach goes far beyond this concept: Elderly participants use their experience of life to design Tangible User Interfaces and therefore create highly individualized interface elements with unique autobiographical characteristics and a strong connection between the technical function and one's own conceptions. This also goes beyond the extend of tangible co-creation as found in literature so far. In their work on innovative technologies for children with disabilities, Herstad and Holone included participants in the creation of a Tangible User Interfaces by means of tangible cushions, which could be moved, thrown and built as the user liked [52]. Mugellini et al. propose the memodules approach, which also includes personal objects acting as physical reminders to some memories [88]. Through these objects users are able to manipulate digital content. However, to the knowledge of the author of this thesis, this approach was subject to only a small evaluation and was not further explored. Our approach emphasizes involvement by user creation of parts of the user interface. The resulting familiarity with the interface elements contributes to the intuitive usability of the underlying system.

Finally, it should be emphasized that in our research we have not only attached particular importance to personalization of technology and user interfaces, but also to personalization of the design process. The personal and familiarity is essential in order to create acceptance for participation in the workshops among the participants and to achieve good results. This is also reflected in the further development between the iterations. While Iteration 1 was realized for all participants in an unknown environment, this unfamiliarity was already decimated a step further in Iteration 2. One of the workshops in Iteration 2 took place in a clubhouse, the other workshop took place again at the university, but a subset of the participants of Iteration 1 took part repeatedly. As a result, these participants were no longer completely unfamiliar with the environment. In Iteration 3 the setting was completely adapted to the participants and the workshops were held directly at their homes. A detailed description of the design of the workshops can be found in Section 5.4.

5.3 Multimodality

The multimodal nature of Tangible User Interfaces addresses multiple modalities both in user interaction and in the area of system feedback. Therefore, we will discuss implications of the multimodal interface design of our prototypes and the impact of multimodal interaction on accessibility for our participants.

User Interface

The findings of the workshops show, that it is important to provide multiple and multimodal information channels to support intuitive user interaction. In the digital board game of Iteration 1, participants struggled with starting a new game in their initial attempts. When they pressed the button for *New game* or *SpielerIn auffordern* they didn't get a feedback good enough to be clear about the next step. A new game might start, but the participants were not sure about that. They struggle with inviting the other player, since there was no feedback provided by the system. Instead, only on the game board of the other player, a visual feedback was started. But also this feedback was not always sufficient.

> [RF repeated that TB should start, by talking to her through Skype.]
>
> TB: *"shall I start?"*

The situation could have been improved by providing a more distinct visual feedback (e.g., on the monitor for the Skype session) and multimodal feedback, including audio cues.

In Station 4 of Iteration 1 we provided acoustic feedback for the user interaction with our RFID-prototype. An acoustic signal (horn) sounds when an action card is placed in the wrong order on the tea surface during the tea interaction. When the *correct* action card was placed, not only the screen output was changed, but also an accompanying sound was output.

Error signal:

TB: *[Places the action card on the discard area with Turn on stove and the error signal sounds. He then hesitates and checks the available action cards again] "Teekessel auffüllen, ja natürlich!"*

RF: [Put the *Turn on stove* action card on the scan area. After he heard an error sound, he pressed on the action card, which was still on the scan area.]

VM: [Put the *Turn on stove* action card, error signal sounded] *"Das geht nicht Herd einschalten"*

HE: [Put *Switch on stove* on the scan area, after the error sound she took the card away again and tried the card *Fill tea kettle*]

LR: [As the sound of the error appeared, she looked through all the cards once more]

MF: [Interpreted the error sound as "it doesn't want to!"]

SG: [Error sound] *"Also, das war also nicht richtig"*

MG: [Despite the error sound she then placed the *Pour tea water* card. Put then *Turn off stove* card on the scan area, which again produced the error sound] *"Irgendwas hats da, irgendwas hab ich verkehrt gemacht"*

MB: [Put *Turn on stove* on the scan area, the error sound appeared. Said anyway] *"Zufrieden? Gut."* [Put *Turn on stove* back on her action card staple] *"Wenns piept ist es falsch? (laughed)"*

Acoustic feedback for images shown on the screen:

MB: *"Vielleicht muss ich warten bis es voll ist"* [Action card *Fill up tea kettle*]

MG: [Is delighted] *Ja, solche Töne hat unser Kater auch von sich gegeben!"* [Action card *Stroke cat*]

In the course of the workshops it was observed that the audio feedback prompted participants to rethink or revise their decisions. Some participants adapted their interaction through these sounds or linked the contents with their own experiences. However, it also became clear, that the feedback in case of an *error* was not sufficient for every user. The reason for this was the lack of a visual feedback channel in this iteration. The first visual feedback in the context of user interaction was provided when a start card was placed on the scan area. Here a tea kettle or a cat was displayed on the screen. The screen output changed depending on the action card. No visual feedback occurred when a *wrong* action card was placed, only an acoustic signal was emitted. This design flaw was a lesson for further development of the prototype.

In the analysis of the second iteration, it was not clear whether the acoustic feedback had an immediate effect when the tokens were placed. This could only be observed for one of the participants. This participant suffers from a macular degeneration and is probably therefore particularly attentive to acoustic signals.

> MH: [After hearing the acoustic feedback when placing the generic token, she moved her head near the screen and said] *"Ah, schön! Da tut sich ja was!"*

In Iteration 3, some users responded directly to the perceived acoustic feedback.

> DH: [she was asked what the sound meant to her, after placing the Generic Token] *"Da habe ich das Gefühl gehabt, dass etwas bestimmtes eingeschalten wurde."*
>
> RS: *"Da hat sich was getan!"*
>
> TW: [talking about the audio feedback after placing the tokens] *"Ja, da weiß ich dass das dann funktioniert hat!"*

In Iteration 2, participants profited by the provided additional visual feedback. The green arrows indicating the currently active scan area helped them to identify the next necessary interaction step. Also the check mark after a successful interaction provided valuable feedback for the participants.

> RL: [She read the text on the screen aloud] *"Wen wollen Sie anrufen Frau L.?"* [she then said] *"Ja, da habe ich jetzt einen Pfeil da her."* [holding the Personal Token in her left hand and pointing with her right hand to the corresponding scan area]
>
> EH: *"Das Hakerl ist für mich 'Ja, die will ich anrufen"' [pointing at the left side of the screen]*
>
> WW: [the 83-year-old participant had a hard time in his very first approach. After successfully finishing the Generic Token interaction, he was asked whether he perceives any feedback] *"Ja, dass ich es richtig gemacht habe"* [after the question how he saw this] *"Ja weil das Hakerl da ist!"*

Also the coloured scan area was a cue for some participants. When asked why she decided to put her personal object on this specific part of the prototype, she answered

MV: *"Naja, weil da so eine, so eine vorgefertigte Fläche ist. Und das eine Signalwirkung hat."*

Also participant AH was guided by the coloured scan area (Figure 5.14):

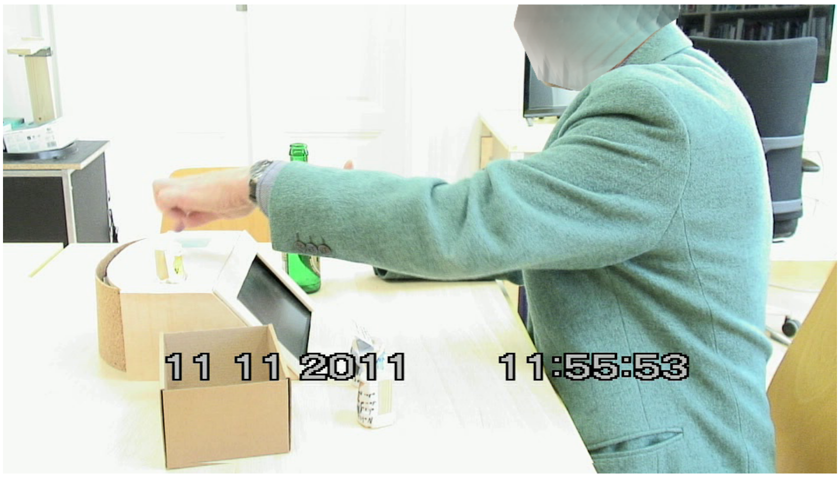


Figure 5.14: Personal Token interaction cue through coloured scan area

AH: *"Ok, ah, ein blaues Quadrat, da sagen wir ich könnte was drauf stellen!"* [put the Personal Token on the scan area]

The findings of Iteration 3 underline the importance of multimodal feedback. Not only the shape of the tangible object guided the user interaction, but also visual cues like icons or drawings on the token. When she was asked why she chose the Generic Token for starting a skype call and not the other one, participant MK said:

"Die Form des Objekts ist gleich, aber hier ist das richtige Bild darauf [pointing at the Skype GT]

Also the visual guidance on the monitor of the notebook helped the participants to fulfil the given tasks.

DH: [she described what the screen output meant to her] *"Da habe ich das Gefühl, dass das aktiv ist [pointed at the Personal Token side of the screen illustration] und das andere ruht zur Zeit"* [pointed at the Generic Token side of the screen illustration]

FG: *"Darauf drücken, da"* [pressed the Personal Token area, because he noticed the blinking area at the screen]

FM: [when asked what the illustration on the screen means for him] *"Das ist eine Anzeige wo ich sehe wie mein Tun oder Handeln hier reagiert. Was tut sich."* [he confirmed, that it was clear to him, that the illustration in the screen depicted the prototype]

HS: *"Also das ist klar, das kann ich gut vergleichen"* [pointed at the illustration on the screen and the prototype]

HS: [pointed at the Person letters on the prototype] *"Vielleicht das noch etwas verbessern, weil die Leute oft schlecht sehen."*

MK: *"Die Aktion hat geblinkt, deswegen stelle ich die Aktion da rein"* [made a gesture with her right hand as if she moves the GT into the GT slot] *"das war der erste Schritt und der zweite die Person"*

RM: *"Ja wenns da aufscheint musst du es dann da rein geben!"* [pointed at the illustration on the screen and the prototype]

SL: [when asked what the illustration on the screen means for him] *"Ja, das ist für mich so elektronisches Kastl"* [he confirmed that he notices the connection between prototype and illustration]

TW: [when asked what the illustration on the screen means for her] *"Also dieses Bild?"* [pointed at the prototype, indicating that she connected hardware and illustration]

The findings regarding acoustic and visual guidance showed, that different participants placed value on different modalities. For some participants, the visual guidance was important for interacting with the prototypes, some participants pointed out the acoustic guidance as relevant factor. Therefore, it is necessary to provide guidance for different modalities in the user interface design. This is especially important when aiming for an inclusive design, also taking into account special needs of people with impairments like the participant with macular degeneration in Iteration 2. She particularly appreciated the acoustic feedback and the usage of a large font on the screen.

Our findings of the first iteration show that it is also important to include the space directly next to the device in the design considerations. Most participants positioned their arms or hands next to the devices, when they start to focus on the interaction. Some used one hand, some both hands to play around in close proximity to the devices. Some used the space to put their arms on it, some then rest their heads on the arms to focus on the interaction. Some played with their fingers while waiting for the opponents move (see Figure 4.15).

The space sourrounding the prototype in Station 4 in Iteration 1 was also used by the participants. Initially, the cards were placed to the left and right of the cardboard box by the instructors. On the one side the cards for the interaction with the cat, on the other side the cards for the interaction with the tea kettle. The action cards were distributed around the start card. During the interaction with the cards, many of the participants sorted the cards in their own way. Several approaches were observed (Figure 5.15):

- The cards were sorted before the actual interaction.
- The cards (or part of them) were sorted during the interaction.
- The cards were sorted both horizontally and vertically.

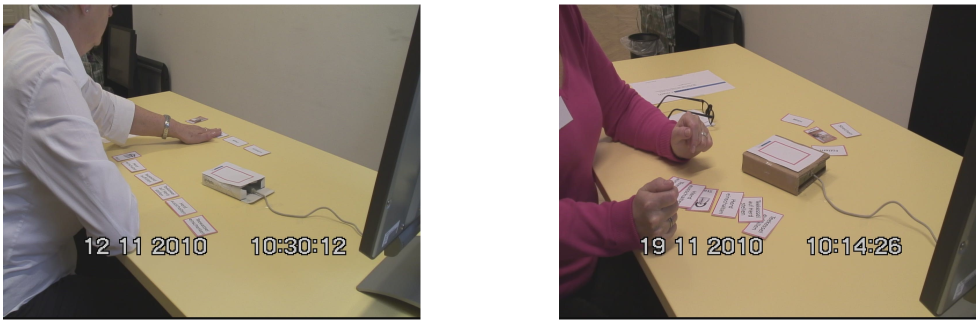


Figure 5.15: Identifying the relation between card and scan area

In Iteration 2 and 3, the usage of the space around the prototype was less relevant. However, in Iteration 2 we could observe, that the design of the prototype, with the scan areas for the Generic and the *Personal Tokens* above the screen and a relatively large area in front of the screen, sometimes was a limiting factor for the user interaction. The large surface of the wooden casing in front of the screen forced some participants to make unnatural movements. Furthermore, some participants tried to put tokens in front of the screen (Figure 5.16), possibly triggered by the generous space available or the relative distance to the scan areas above the screen.

In Iteration 3, the space around the prototype could be used well, since on the one hand its dimensions were kept as small as possible and on the other hand it could be moved freely as a pluggable device. Although the participants were actively asked how they wanted to set up the prototype, all participants positioned it similarly - directly in front of them. Similar to Iteration 2, the generic and *Personal Tokens* were placed to the left or right of the prototype.

For the design of our final prototype, we therefore draw the conclusion, that it is necessary the design the device in a way, that the user is able to also use the space around the device. This means that the dimensions of the device should be kept small to allow enough space for indirect interactions with arms or hands in the surroundings.

Figure 5.16: Personal Token interaction cue through coloured scan area

Multimodal Interaction

A major part of literature in the area of user interfaces for elderly users remains narrow in focus when investigating multimodal interfaces, dealing mostly with visual and acoustic cues. Komatsu et al. (2011) present a *Multi-modal Communication Interface* consisting of a smartphone [73]. They use both GUI and CUI (character-based user interface) for the iteraction and strive the possibilites of the build-in accelerometer. Also Piper (2010) and Ferron et al. (2015) use the touch interaction of surface computers and mobile devices as multimodal interaction approach [112] [32].

Our observations throughout the iterations support the hypothesis that the combination of a high degree of personalization and the multimodality of the token design is a key factor for accessible technologies for elderly people. The workshops showed that significant shapes and materials were an important factor for haptic guidance of the user interaction. This proved not only important for the design of the tangible objects, which should have the right size, shape and material to smoothly fit into the grasp hand of the users, but also for the design of the interface devices. In Iteration 1 we could also observe, that hands and fingers were intuitively used for the interaction with the devices by the participants, especially in combination with spoken words:

- To oneself as well as gesticulating with the hands, thinking aloud
- One tries to think about how to play the next move. He uses his finger to consider different options. The game is getting complicated; he wants to check all possible movements. His hand shows what he actually considers before deciding to push a button.
- When talking to the instructors

- When talking to the game partner, about the status of the game, e.g. who is going to win: *"because the one who starts the game always wins"*.

The workshops of Iteration 1 and especially the user interaction in Station 4 showed that visual guidance is important, but not always sufficient. While for participants BM and LR visual guidance was important, participant HE needed additional hints:

BM: *"Das war für mich klar, das (Karte) hat den Umriss und das (Ablegefläche) auch. Das gehört irgendwie zusammen."*

LR: *"Ich hab dann gesehen, dass die roten Rahmen zusammenpassen."*

HE: *"Die roten Rahmen hab ich überhaupt nicht gesehen."*

Through meaningful shapes and materials users get additional hints, which facilitates user interaction. This underlines the importance of multimodality not only for the feedback of a system, but especially as affordance for interaction. In Iteration 2, one participant started to talk about her need for an intuitive communication device for her mother. She mentioned, that even senior-related mobile phones would not fit, because the user interaction via pressing the buttons on the phone would not work out for her mother. She then said, that she would need a technology like our prototype:

UP: "Was ganz einfaches, ich will was von dir, ich will telefonieren" [putting the Personal and the Generic Token on the prototype to illustrate the simplicity of the user interaction]

This was a particular encouraging feedback for us. First, it underlines the observations so far about the intuitive nature of tangible interaction. Second, it indicates, that the interaction through tangible objects can be easier for people with impairments than using a mobile phone, even if it is especially design for elderly people. Third, it furthermore shows, that our design is seen as really helpful in tasks of everyday life of older adults.

To encourage users to try out different forms of interaction without fearing to damage the device, the interface elements should be designed very robust. This gives users a sense of security in dealing with the technology. Participant LF stated:

> *"Ich hab mir gedacht da liegt was, da hab ich mal draufgedrückt, das hat so seltsam nachgegeben, da hab ich mir gedacht, das kanns wohl nicht ganz sein."*

In Iteration 2, participants often tried the touch or swipe over the coloured scan area. This was not always to try out forms of interaction, but also to *feel* the scan area.

> GS: [when asked why she was striving over the scan area, she said] *"Ja, einfach einmal angreifen, was das überhaupt ist."*
>
> GK: *"Also ich würde jetzt, weil da so ein Fleck drauf ist, versuchen da drauf zu drücken."* [pressed on the colored scan area for the Personal Token]

In Iteration 3, participant FG said, that he doesn't use touch screen interaction in his daily life. Nevertheless, his first attempt to interact with the Personal Token was to press on it. As Personal Token for the *making a phone call* use-case he chose a photo of his wife (Figure 5.17).

Figure 5.17: Personal Token *phone call* participant FG of Iteration 3

After finishing the Generic Token interaction, when he was asked to select his wife as recipient of the phone call, his first reaction was to press on the photo:

> *"Wenn ich hier drücke..."* [pressing on his Personal Token]

Also when getting closer to the intended user interaction he tried to press on the *person* area of the *kommTUi* prototype. Another participant was also considering touch interaction. For her, the indentations for the screws were an indication. This is an important hint that such indentations must be integrated more seamlessly into the surface for the final design.

> DH: [pointed at the illustration of the prototype on the screen, more precise at the holes of the screws on the Personal Token side] *"Da sind, weil das sieht aus wie zwei so Knöpfe, nicht, dass ich vielleicht einen von den beiden mal drücken müsste."*

Although these observations would argue for including also touch interaction in the multimodal nature of the *kommTUi* prototype, we decided to stay with the *pure* tangible approach. The main reason for this decision was that the major goal of *kommTUi* was to scrutinize and propose an alternative way of user interaction, taking into account the special needs of elderly people, e.g., the age-related physical or cognitive impairments.

As already mentioned in a previous section, participant MK was able to identify the right token for the desired interaction through the usage of multiple modalities in Iteration 3:

> MK: *"Die Form des Objekts ist gleich, aber hier ist das richtige Bild darauf."*.

Participant RF was able to start the interaction with our prototype in Station 4 of Iteration 1 not until he used a combination of visual and tactile approach to the action cards. After turning around the card and spotting the RFID-chip on the backside of the card, he tried to put the card on the scan area. The discovery of this technical element aroused a childlike play instinct in him, which was the decisive factor for the first exploration of the interaction.

> RF: *"Weils für mich zuerst einmal das Entdecken, die Maus fehlt ja, wie bewegst du mal das Ganze. Bis ich dann einmal auf die Idee gekommen bin das Karterl umzudrehen und gesehen habe, dass das da geklebt war mit einem, ich sag jetzt einmal Sensor, ich weiß nicht wie das heißt. Dann bin ich auf die Idee kommen das draufzulegen und das hat mir einfach gefallen. Aber eher vom Kindlichen her, das erstaunt mich, dass man sowas machen kann."*

The visibility of the RFID-chip was also important for other participants to be able to interact with the prototype in a proper way:

> FA: *"Und ich habe zuerst die erste Karte verkehrt draufgegeben, habe mir gedacht, da kann was nicht stimmen, weil da hinten ist ja irgendwas, wo ein Kontakt hergehört und dass die draufgehört."*

Also in Iteration 2, participants with previous knowledge in the usage of ICT additionally used the RFID chip to identify the functionality of the Personal Token.

> GK: [Examined his personal object. After a while, he spotted the RFID chip, which was attached to the object] *"Ah, da ist er drauf!"* [then he immediately put the Personal Token on the scan area] *"Jetzt habe ich geschaut, wo da die Verbindungsmöglichkeit sein könnte und habe da diesen Chip gesehen. Und weil da ja auch einer drauf ist [pointed at the Generic Token in the slot] und das Gerät reagiert, habe ich den da raufgegeben [pointed at the Personal Token] und dann reagiert das Gerät dann auch."*

In Station 4 of Iteration 1, participants used different modalities for sorting the cards along their conception. Some used the space surrounding the prototype, some used their fingers to point on the cards, others sorted the cards by thinking aloud. By the order of the cards the participants prepared a (first) solution. However, this solution was not always the correct one or one specified by the system (especially when making tea). One participant had lined up the start card in the middle of the cards, whereby the system was reset to the start position in the middle of the interaction process. This behaviour of the system caused confusion.

> MG: *"Herd einschalten"* [put action card on the scan area] *"Dann Start!"* [put start card on the scan area, causing the system to reset to the start]
>
> HE: *"Ja, und ich hab mir gedacht, das mit dem Teekessel, das versuche ich jetzt mal in einer Logik aufzubauen."*
>
> RF: *"Ich habs mir zuerst in einer Reihenfolge aufgelegt . . . "*
>
> HE: *". . . genau ich habs mir auch vorher aufgelegt."*

The Generic Tokens provided in Iteration 2 and 3 had several multimodal design elements:

- A visual representation designed by the participants themselves.
- Form and size, which inherit a certain affordance. This encourage the user to lift it up and hold it in hands and, through its special shape, to interact with the token slot.
- A material that lies comfortably in your hand and invites you to understand.

The combination of these design elements was guiding the participants effectively through the interaction and therefore supported an intuitive use of the prototype.

> RL: *"Für mich war ausschlaggebend das Bild da auf dem Stempel da oben. Obwohl es schon klar war, dass wenn das, äh, diese Form hier hineinzustecken wäre [pointed with her finger to the Generic Token slot] und nicht da her zu stellen [pointed at scan area for Personal Tokens]."*

Participants were also guided through the multimodal design of the prototype during interaction with the *Personal Token*. In Iteration 2 the participants had visual clues on the screen (arrow, check mark), textual clues and the marking above the screen to support the haptic interaction. In Iteration 3, participants were provided with a digital image of the hardware prototype on the screen, including visual indications of the currently active storage area, and an interaction cue by the illuminated lettering directly on the prototype.

> EH: *"Da gibt's noch irgendein so ein Symbol [pointed at the scan area for the Personal Tokens], was auch immer das bedeutet. Keine Ahnung. Also der Pfeil führt dort hin."*

> MV: “Ich würde meine Mutter anrufen, da leg ich das daher [put the picture of her mother on the scan area], weil da ist so ein Pfeil rauf.” [pointed at the green arrow]
>
> RJ: [she was asked why she put the Personal Token on the coloured area] *“Der Pfeil, die Schrift – wen wollen Sie anrufen”* [when asked whether the coloured area was important for her decision] *“Nein, da habe ich eigentlich instinktiv drauf... Nachdem sich das abzeichnet, habe ich... ”*

One participant in Iteration 3 tried out a scanning interaction with the screen of the provided notebook. She held the Personal Token in front of the screen, trying to operate the device through image recognition. She added that from her point of view it would be an easy interaction if the system knew right away that she wanted to call up information about her church choir.

> DH: [holding her Personal Token in front of the sceen] “Aber wie registriert er das dann, wenn ich das hinhalte... Das wäre einfach, wenn der Bildschirm dann gleich reagiert – aha, sie will etwas über den Kirchenchor wissen.”

In Station 4 of the first iteration we could also observe that there were individual differences in the posture against the prototype between the participants. These differences were on the one hand dependent on the gender of the participants and on the other hand on the reluctance to use the new technology. One participant had difficulties to start interacting with the prototype. During this phase he took a distant posture to the device. Only after a few indications that he should look at the cards and the device to see how they resemble, he takes the start card and places it on the scan area:

> MF: *“Aha, that even works!”*

Immediately after this sense of achievement, the participant moves closer to the device and the cards. This shows that the personal attitude towards a technology can also have an influence on physical positioning.

Another interesting observation was, that female participants chose a position against the prototype in the beginning of the interaction and rarely changed it afterwards. In contrast, the male participants changed their position more often and were in principle more dynamic in their posture.

To make technologies accessible for elderly people, it is crucial to address the **special needs** of this user group, including own previous experience with technologies and also interaction patterns observed with others. In the first iteration of the design process participant VM tried to interact with the monitor in Station 4 (Figure 5.18):

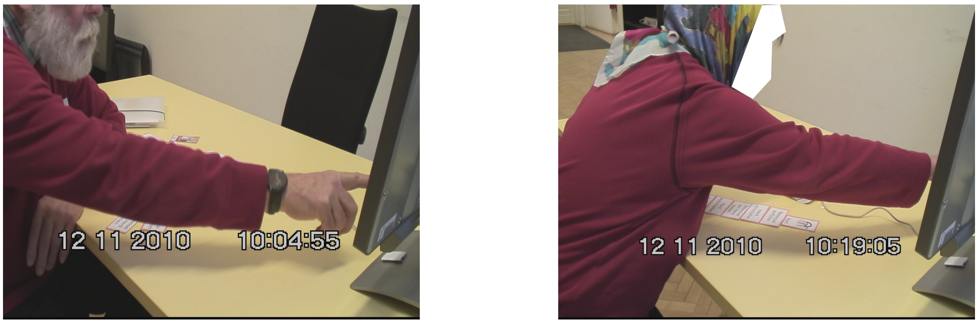


Figure 5.18: Interacting with the monitor in Iteration 1

> RF: *"Das heißt ich kann da aber nicht herumfummeln oder?"* [zeigt auf Bildschirmknöpfe]
>
> VM: [Notices the graphical Windows Start button on the bottom left of the screen, saying] *"Hier steht Start, aber ich habe nichts um zu... interagieren"*. [Keeps looking on the screen.] *"Ich drücke hier lieber nichts, sonst schalte ich noch etwas ab"*. [Tries to press the Windows Start button with the finger (like on a touch screen), then says] *"Jetzt werde ich etwas nervös"*.

However, although older people may have a lower affinity for technology and more difficulties in interaction due to physical impairments, this user group is also affected by interaction patterns of modern information and communication technologies. In Station 4 of Iteration 1, especially in the period immediately after initiation, attempts were often made to interact with the system by pressing (Figure 5.19). This was done by pressing both on the carton and on the scan area, as well as on the action cards that lay on the table or on the scan area. The participants looked either directly at the screen or at least immediately afterwards.

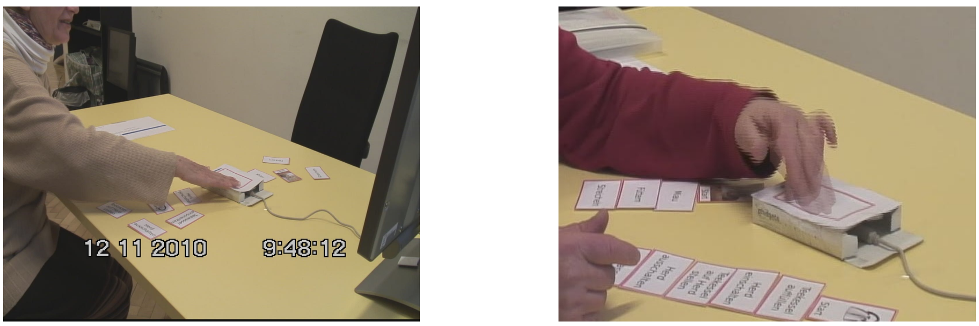


Figure 5.19: Using press and scroll interaction on the prototype of Iteration 1

RF: *"Und wo drücke ich da hin?"; "Die Schale von der Maus fehlt."; "Ich hab zuerst einmal die Maus malträtiert. Ich hab mir gedacht "des gibt's ja ned". Hab dann mal reingeschaut, da gibt's keine Hülle drüber, dann denk ich mir komisch... Wissens diese Schale."*

VM: *"Das geht nicht, die Maus, da lässt sich nichts drücken."*

LR: *"Ich hab mir gedacht da liegt was, da hab ich mal draufgedrückt, das hat so seltsam nachgegeben, da hab ich mir gedacht, das kanns wohl nicht ganz sein." "Als der Karton so nachgegeben hat, hab ich mir gedacht das wird's nicht sein. Dann ist da gestanden 'komm', dann hab ich mir gedacht 'so, jetzt leg ich was hin'. 'komm' dann hab ich was hingelegt."*

In the first iteration we were able to make this observation not only for interaction by means of pressure, but also with regard to *younger* forms of interaction such as wipe or scroll gestures (Figure 5.19). Various participants wiped the deposit area of Station 4 with their hands or fingers. Both general wiping movements (see left picture) and *scroll* movements (right picture) were observed.

VM: *"Wie soll ich das am Bildschirm ausführen, ich habe ja keine Maus und gar nichts?" [strokes over the placement surface] "Scrollen kann man auch nicht."*

We also observed touch interaction in Iteration 2. Participants EH and FM tried to press the green arrow on the screen of the prototype pointing at the scan area for the Personal Token.

EH: *"Also ich hätte da irgendwie [conducted a touch interaction on the monitor], ich hätte da den Pfeil gedrückt für den Telefon[anruf]..."*

FR: *"Also, mit dem dass ich es betaste, stehe ich jetzt mal an."*

For the use of the Personal Tokens, also extravagant interaction possibilities were at least considered by individual participants in the discussion. Participant FR thought about how to use his Personal Token, a bronze pig brought to him by his wife on holiday:

FR: *"Also telefonieren kann ich mal nicht damit"* [laughing]

Due to the new setup in Iteration 2 with the scan areas above the screen, however, we were able to determine a different influence through previous experience with GUIs. Those participants who had already used graphical computer systems overlooked the scan areas above the screen and could not interpret the green arrows as an indication of this. By focusing on the screen, the participants did not perceive the space around the screen.

> AH: [pointing on the top side of the screen, near the scan area of the Personal Tokens] *“Vielleicht ist oberhalb des Pfeils, wenn es ein touchscreen wäre, irgendwas zu finden, vielleicht ein Icon oder so, ja.”*

For one participant in Iteration 2 previous knowledge was very helpful for user interaction. She has finished an use case before even being presented with it.

> IA: [after placing the Generic Token, she immediately took the Personal Token and started the interaction. First, she held it against the screen and after a second she put it on the scan area] “Das weiß ich vom Autobus!” [showing her Personal Token to me]

This findings show, that whether or not personal previous experience with technology turns out to be helpful for user interaction, it has to be included in the considerations for interaction design.

Interaction Sequence

Another interesting point was introduced by a participant in Station 4 of the first iteration. When asked if she saw the control of the monitor output via the cards positively, she said that she was not able to control it at all, since the order of the cards is predetermined. However, this Station was designed in such a way that one of the two interactions allowed a free choice of sequence (cat), the sequence of the others was fixedly defined (making tea). The only exception in cat interaction: If a certain order was kept (Start - Meow - Feed), the cat could be purred. Which of the two interactions the participants started with was up to them. Yet, the participant had the feeling, that it was not possible.

> VM: *Das irritiert mich, steuern kann ich es nicht, es ist ja vorgegeben. Die Reihenfolge der Karten ist vorgegeben, weil wenn ich es in einer anderen Reihenfolge lege, funktionierts nicht, also ich kann gar nichts steuern.*

The order of interaction also led to lively discussions among other participants.

> HE: *“Bei der Katze wars ja einfach, die Reihenfolge.”*
>
> RF: *“Nein, ich habs falsch gelegt, aber ich hab keine Beziehung zu Katzen. Ich bin mit einem Hund aufgewachsen.”*
>
> LR: *“Das war die Katze, da hab ich mir gedacht, die muss ich zuerst abfüttern, bevor ich mir einen Tee kochen kann.”*
>
> VM: *“Das irritiert mich, steuern kann ich es nicht, es ist ja vorgegeben. Die Reihenfolge der Karten ist vorgegeben, weil wenn ich es in einer anderen Reihenfolge lege, funktionierts nicht, also ich kann gar nichts steuern.”*

M: *"Bei der Katze konnte man steuern."*

VM: *"Achso."*

LR: *"Sie können aber nie einen Teekessel aufstellen, wenn die Katze hungrig ist. Das war mein Zugang. Ich hab die Katze zuerst zufrieden gestellt."*

VM: *"Also das kann man in einem auch reihen?"*

LR: *"Na warum denn nicht? Ich habs gemacht!" "Ich hab zuerst die Katze begrüßt, dann hab ich sie gestreichelt. Wenn die noch hungrig ist, dann lässt sie einem doch keine Ruh! Ich habe Prioritäten gesetzt."*

VM: *"Aber während das Teewasser kocht, kann ich ja einstweilen die Katze füttern."*

LR: *"Können sie machen, aber machen's das einmal in der Realität."*

HE: *"Ich habe zuerst den Tee gekocht und dann die Katze gefüttert."*

VM: *"Ich auch."*

LR: *"Schlechtes Gewissen soll sie verfolgen [laughing]!"*

These quotes show, that the participants had highly individual approaches to the interaction with the prototype. The sequence of doing the different use cases was influenced by experiences from real life. Some users intuitively first fed the cat, so they could afterwards make their tea without being disturbed by the hungry cat. The quotes also point out, that the order of the card placement was not clear for everyone. Some have wished for higher degrees of freedom.

In Station 2 of Iteration 2, the interaction sequence was mostly clear to the participants. However, one participant turned the sequence around, placing first the Personal Token and the Generic Token afterwards. Although it was not the planned order, she successfully completed the use case.

UP: [after she was presented with the first use case, she put the Personal Token on the scan area] "Das ist der Platz. Weil der Platz – anrufen ist da" [she put the Genric Token in the corresponding slot]

In Iteration 3, only one participant made the point, that she would change the interaction sequence. She would prefer to first use the Personal Token and then the Generic Token.

TW: *"Ich hätte das umgekehrt machen sollen. Das was zur Person gehört als erstes nehmen und dann… [pointed at Generic Token]"*

An accessible system with Tangible User Interface should therefore support planning and conducting individual interaction sequences. One solution could be to provide space or at least to consider the need for space for sorting the tangible interface elements. As a consequence, the system should also be able to react to individually different interaction sequences.

5.4 User Involvement

In this section we briefly describe the implications of our user-centred design process, focussing on the integration of elderly people throughout the whole design process. A detailed discussion of our findings can be found in our publication *kommTUi - A Design Process for a Tangible Communication Technology with Seniors* in Section 7.6. A carefully composed and well-organized user involvement is mandatory, especially when working with elderly users. The aim of our design process was to put maximum effort in creating a respectful and pleasant atmosphere in all our workshops. Due to our very limited resources (3 team members: project leader, designer, computer scientist), it was necessary to carefully plan the design process. This turned out to be a key success factor for the fruitful implementation of our three iterations for the development of our prototype.

For the analysis of these iterations, we designed a graphical analysis tool (Figure 5.20). This tool was used as a basis to better compare and understand the similarities and diversities of our workshops. Our graphical tool provides a visualization of our efforts the create a pleasant atmosphere for the participants and enables direct comparison of the three design iterations. The "tangible input" defines the core variable for each workshop year, influencing communication, interaction, design sessions, location and participants.

The three spheres describe the key trigger elements we were able to influence to create the right atmosphere for the different workshops. The first trigger element describes the *location* of our workshops and its relation to the participants. *Participants* represents the invited participants for each workshop setting and their relation to each other. *Communication* signifies the whole communication including initial contact, pre-information, pre-talks, interaction and the interactive design sessions. Together they formed a specific atmosphere, which we defined as playful, engaging and inviting from the very beginning of our research. We had to carefully spread the available resources on the different trigger elements. Hence, the analysis technique consists of **L**, **P** and **C** as trigger elements and the overall tangible input.

This graphical tool allowed us a specific analysis of our goal to achieve a respectful and pleasant atmosphere by relating specific components like location, participants and communication. We are able to visualize how we reduced our input in one trigger element when the other was getting bigger in consequence of the chosen workshop

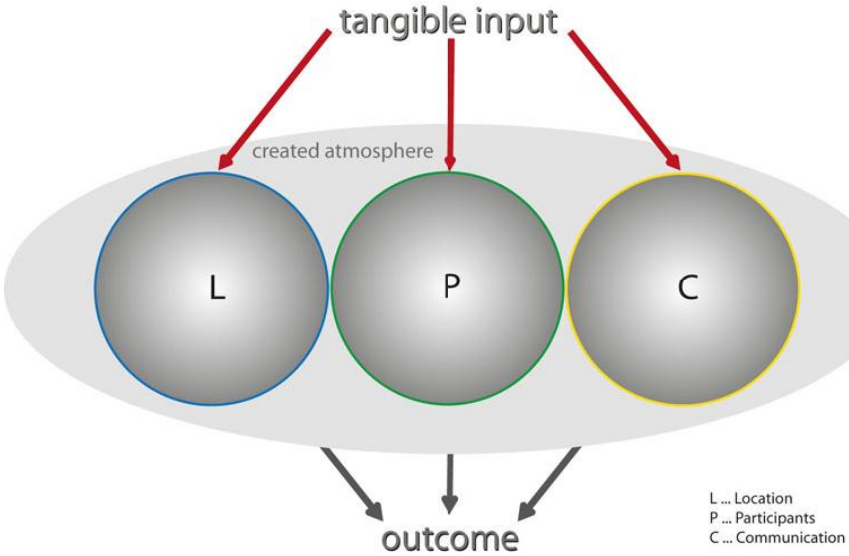


Figure 5.20: LPC analysis tool

structure. For example, we saw that we kept the effort regarding **P** constant, while **L** and **C** reversed from Iteration 1 to Iteration 3. The outstanding role of **P** is also underlined through the constant tangible input throughout all iterations. The findings of our analysis in the publication mentioned above indicates that when conducting a user-centred design process with elderly people, it is possible to create a similar positive atmosphere with different emphasis on the key elements of the workshops.

In this way, we were able to create a joyful and productive atmosphere at our workshops. In the reflection talks after the user interaction, the positive atmosphere was actively addressed and praised by the participants. A particularly helpful aspect was the involvement of reference persons in the process of recruiting and conducting the workshops. In Iteration 2 as well as especially in Iteration 3 the participants of the workshops were recruited via a central reference person. This person was searched in advance and then served as a proxy in the communication with the (possible) participants. The reference person was also present at the workshops, which was particularly important for the atmospheric situation at the individual workshops in Iteration 3. With this person we were able to discuss in advance what kind of gifts the participants would be happy to receive. Such small appreciations served as a thank-you for participating in our research activities, but also as an icebreaker at the beginning of the workshops.

5.5 Final Prototype

Based on the implications given in the last chapters, we will introduce the final version of our prototype in project *kommTUi*. It is a redesign of the prototype used in Iteration 3, further extended on the basis of the insights of the previous iterations.

Figure 5.21: Final prototype

Figure 5.21 shows the final prototype. There are some changes in the appearance of some parts of the prior version: The screw holes are covered by plastic parts, including the top right hole, where the on/off light used to be. The *Person* area has a rectangular shaped indentation to to enhance the visual guidance for the user. Additionally, a bulls eye symbol is placed in the middle of this area. This symbol can be found also on the self-adhesive kommTUi RFID-labels. When the RFID-label is sticked onto an personal object, the user gets an additional hint, that he or she has to place the object in a way, that the RFID-label touches the bulls eye symbol on the person-area. In addition, the GUI has been redesign according to the feedback of the user testings in 2012. In the final version, the letters *Aktion* or *Person* are blinking to guide the user interaction, not the whole side of the image (cf. Figure 4.35). This way, the graphical guidance is unified between the TUI and the GUI. In the following, a complete interaction cycle is described, from the installation of the necessary software to a finished interaction example.

Installation

Before using the prototype, the user has to install the corresponding software on his/her computer. This can be done via the enclosed installation CD or by downloading the software from online sources. The installation program creates the necessary database on the user's computer and sets up the USB connection. After the installation is finished, the program waits for an USB-connection.

Token Design

For the design of the generic and the personal tokens we propose to provide self-adhesive kommTUi RFID-labels. The labels for the generic tokens include the icons which were used most in Iteration 1 (see Figure 4.18). Additionally, blank labels will be provided to allow individual notes, pictures or icons on the generic tokens. There will be also self-adhesive labels for designing the personal tokens. For everyday objects without plain surfaces (like stuffed animals) we provide pins or collars with integrated RFID chip.

Initial State

When the user plugs the device into an USB slot, the *kommTUi* software initiates the USB connection with the hardware device. This is realized through a handshake protocol, which exchanges necessary data for the communication between *kommTUi* hardware and software. On the computer screen a window pops up, showing an image of the TUI.

Figure 5.22: Final prototype - initial state, *Aktion* blinking

In the initial state of the TUI, the *Aktion* letters are blinking, which signals the user, that he or she has to place the GT into the slot first (Figure 5.22). At the same time, the graphical guidance on the computer screen mirrors the visual feedback of the TUI:

Figure 5.23: Final prototype - GUI initial state, *Aktion* blinking

Just like on the hardware prototype, the *Aktion* letters are blinking, advising the user to choose the type of communication by placing the Generic Token. Additionally, the right side with the *Person*-area is darkened, to draw the user's attention to the Generic Token slot (see Figure 5.23).

Generic Token Interaction

When the user places the Generic Token into the slot, the *kommTUi* hardware transfers the ID of the token to the software. The software checks the ID whether it is registered to the user's system. If this is true, it signals the hardware to give a positive feedback. Thus, an auditive feedback confirms, that the interaction has been successful. As visual confirmation, the state of the *Aktion* letters changes from blinking to solid. If the ID of the Generic Tokens is not registered to the system, the software sends a signal to the hardware to provide a negative auditive feedback. In this case, the state of the *Aktion* letters is unchanged.

Personal Token Interaction

Figure 5.24 shows the prototype when the GT has been successfully placed in the GT-slot. The *Person* letters are now blinking. This signals the user to place the PT now. Accordingly, the image in the *kommTUi* screen window shows the left side darkened and the *Person* letters blinking. The bulls-eye symbol on the RFID-tag (see Figure 5.26) and the *Person*-area additionally leads the user in the interaction. If the user wants to undo his previous Generic Token selection, he/she can just remove the Generic Token. This

Figure 5.24: Final prototype - GT placed successfully, *Person* blinking

Figure 5.25: Final prototype - GUI GT placed successfully, *Person* blinking

resets the hardware device to the initial state (see Section 5.5). When the user places a Personal Token, a confirmation sound signals successful interaction and also the *Person* letters change from blinking to solid (see Figure 5.27). Again, if the ID of the Personal Tokens is not registered to the system or does not fit to the ID of the Generic Token, the software sends a signal to the hardware to provide a negative auditive feedback. The state of the *Person* letters is unchanged. The user now has to remove the Personal Token and try another one.

Figure 5.26: Personal token with RFID bulls eye sticker

Figure 5.27: Final prototype - interaction finished

Interaction Finished

After the Personal Token has been successfully placed on the *Person* area, the interaction is completed and the corresponding program is started on the computer (Skype, E-Mail client, etc.). Both the *Aktion* and the *Person* letters are solid. The user can now remove both tokens to start a completely new interaction or remove just the Personal Token to initiate the same type of communication with another communication recipient. If the user removes just the Generic Token, the *Person* letters change to blinking and the illumination of the *Aktion* letters is deactivated. Additionally, the slot for the Generic Token will not react to any placement of tokens until the Personal Token is removed.

5.6 Summary

To summarize and interrelate the results of our research, we propose the AMPTA model to visualize our approach for designing accessible technologies for elderly people. While the individual entities of our model have been described in detail in this chapter, the interplay between them is shown in Figure 5.28.

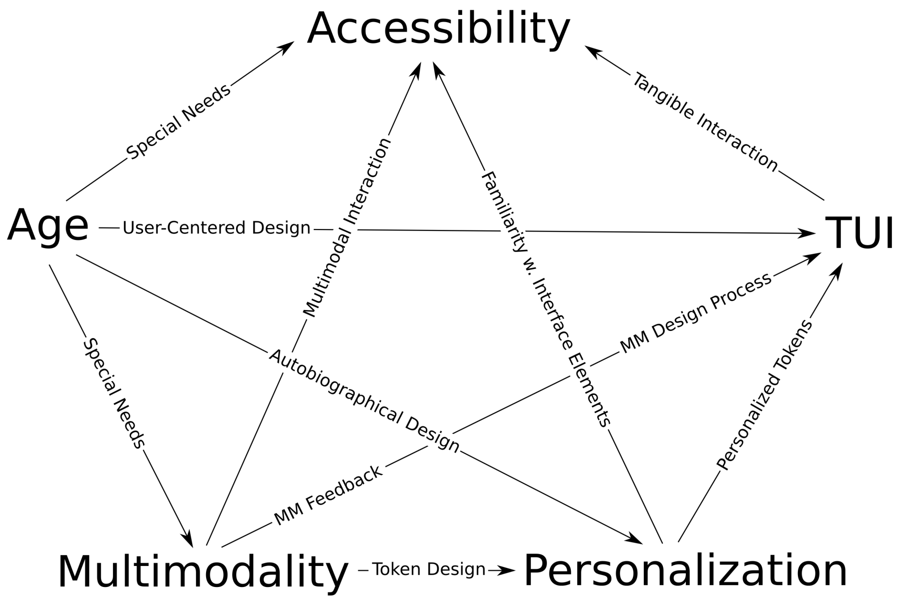


Figure 5.28: The AMPTA model

Each connection reflects the main insights of the conducted research. Since we aim the design of accessible technologies in our research, accessibility is affected by all other nodes in this model. Because our research focuses on the needs of older people, age has relations to all other nodes. Age-related changes raise special needs that affect accessibility. These specific needs can be addressed by the multi-modality of user interface and user interaction, the personalization of interface elements and the involvement of older users in the design process. The multimodality is connected to the node for Tangible User Interfaces via the multimodal feedback of the user interface and the multimodal dimension of the design process. Furthermore it enhances the personalization of the interface elements by the token design. Multimodal interaction is an essential factor for increasing accessibility. The personalization of the user interface is connected to the Tangible User Interface via the autobiographical design of the tokens, and supports accessibility through familiarity with the interface elements. Finally, Tangible User Interfaces support accessibility through tangible interaction.

Chapter 6

Conclusion

In this section we discuss limitations of this thesis and possible future research directions. We then conclude this thesis by summarizing the main contributions.

6.1 Limitations and Future Work

Our research focuses on the design of the Tangible User Interface, culminating in the presented final prototype design. It does not encompass the additional tasks necessary to run the system. This tasks include installing the Java service on the user's computer, configuring the Java service, e.g., assign service type and recipient contact information to the RFID serial numbers on the Generic and Personal Tokens and maintaining the hardware and the Java service. The setup and maintenance of related software like Skype is also not in the scope of this thesis. These tasks should be addressed at latest in the case of a concrete product development. A special focus should be placed on the involvement of relatives and caregivers.

The qualitative nature of our research design limits the generalizability of the results. A qualitative approach is chosen to get a deep insight into the quality of a design (see [48]). Since our research is dedicated to the user-centred design of a completely new Tangible User Interface for older people, we have focused on qualitative methods to directly inform the redesign process. Although this is a common approach in the research field of HCI, further user studies with the final prototype would be necessary to make a statistically significant statement about the usability of the system.

Especially the second and third iteration showed a gender difference in the participants' approach to our Tangible User Interface concepts. Female participants had fewer problems in designing the tokens. While male participants needed more guidance on how a generic token should be designed, female participants sometimes did not have enough space to stick everything on the generic token that they needed for a clearly recognizable interaction cue. It could also be observed in the interaction with the personal tokens that female participants were often able to interact very intuitively with them and clearly connected the associated information (recipient of the communication) with the personal tokens. Male participants often needed longer for the interaction and the connection between personal token and person was not always intuitively clear. In the accompanying discussions, the approach of using objects for interaction was also emphasized more clearly by female participants as potentially interesting. It would be desirable to invest further research effort in the investigation of possible gender differences.

In discussions with our participants, ideas for expanding the fields of application of our object-based approach came up several times. A particularly promising approach would be to use personalized items as personal identification objects. For example, a personal token or a combination of several personal tokens could be used as a password replacement, e.g., for financial applications. Zaim and Miesenberger have already presented a similar approach regarding ATMs [153]. It would be interesting to evaluate the possibilities of personal identification objects in the domestic environment.

In addition, possible technological enhancements would be a promising field for future research activities. Integration into existing or future smart home systems would be desirable. This could be achieved, for example, by integrating open interface technologies. The use of wireless technology such as Bluetooth or WiFi Direct would also be an option. This would require an analysis to determine whether the benefit of the degrees of freedom gained in the use of the device exceeds the increase in complexity in the setup.

6.2 Contributions

The contributions of this work consist of the answers to the research questions and the final prototype. The answers of the research questions are based on the findings of the discussion in Section 5. The final prototype is based on the redesign implications of our three research iterations and is described in Section 5.5.

Sub Question 1

Can tangible interface elements be used to support elderly users in the interaction with communication technologies?

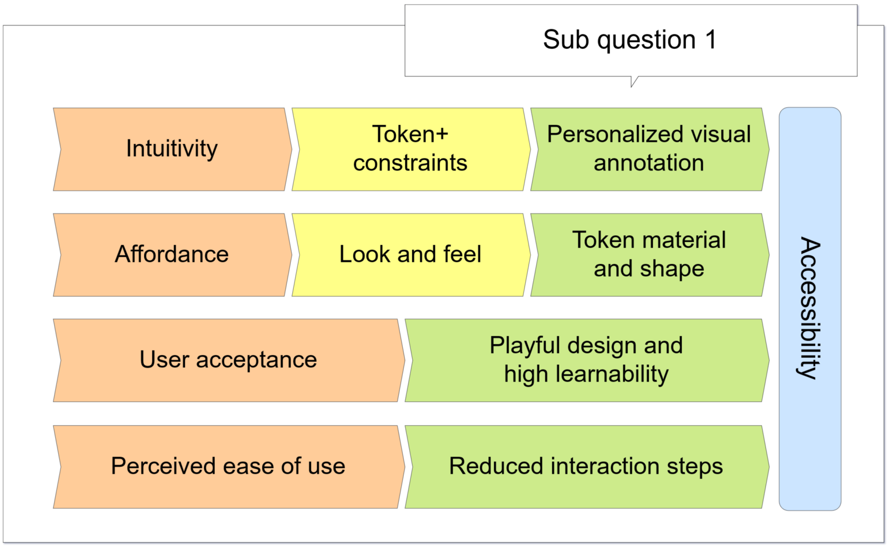


Figure 6.1: Contributions of sub question 1

Based on the results of the analysis of our research iterations, we claim that tangible interface elements can be used to support elderly users in the interaction with communication technologies. This statement is supported by numerous findings:

- By using tangibles as interface elements, a playful design can be created that breaks the initial barrier for older people to interact with new technologies.
- A high degree of intuitivity in user interaction can be achieved through a clear language of form in the design of interface elements. A distinct match of token and constraint creates a strong perceived affordance and therefore supports also older users efficiently in the interaction, independent of the previous experience in the use of modern information and communication technologies.
- The design and choice of material can make a decisive contribution to the pleasure of interaction. If the object invites the user to interact, it is also unconsciously adopted by the users. Furthermore, the choice of the external form can contribute to the creation of an affordance for the interface elements.
- The learnability of our interface and interaction design was high. Although some participants of our workshops had difficulties in the very first interaction with the

prototypes, the second run largely went without problems. A low learning effort contributes to the accessibility of a system.

- This learning aspect of accessibility is also supported by the reduction of interaction steps compared to working on a PC. Through the simple interaction process, first generic token then personal token, it is likely that our design is more accessible to the elderly through increasing the perceived ease of use.

Sub Question 2

Does the use of personalized and autobiographical elements improve the user interaction of elderly users with communication technologies?

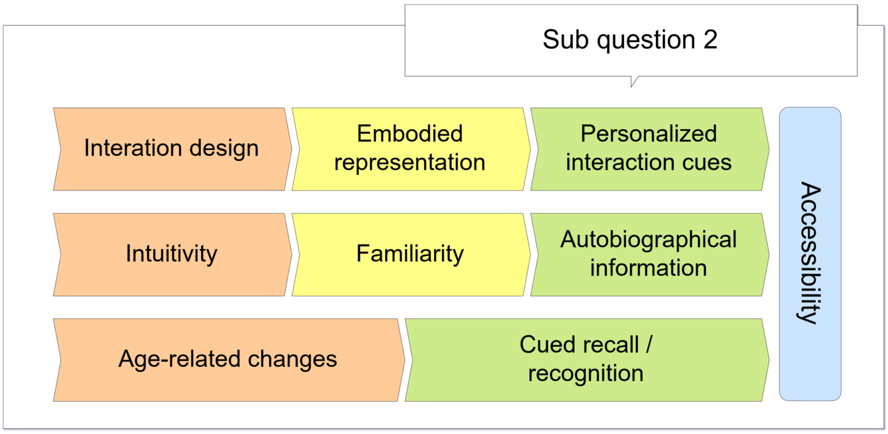


Figure 6.2: Contributions of sub question 2

Based on the findings of the literature research and the discussion, we were able to conclude that the use of personalized and autobiographical elements improve the user interaction of elderly users with communication technologies. The following points contribute to this insight:

- A major contribution of our research is the enhancement of the token+constraint approach through personalized interaction cues. While the interaction between token+contraint enables intuitive interaction for older users, the distinction between tokens and their functionality represents a further barrier. By involving users in the design of the Generic Tokens, we were able to meet the individual ideas of symbols and metaphors for the various functionalities. Our results showed that the differentiation between the Generic Tokens was clear for all participants, although some of the designs were quite unusual.

- Through the personalization of the Generic Tokens we enabled our elderly participants in the correct interpretation of graphic icons. The possibility of free annotation of the tokens also made it possible to include autobiographical information, e.g., drawing a curly telephone cord on the generic token for phone calls. In this way, a relationship is established with the object that is actually not familiar, which - in combination with the affordance of the object - also helps to facilitate a rapid first interaction.

- The personalisation of interface elements in regard to the Personal Tokens created a cognitive bridge between the personal objects as interface elements and the functionality that was associated with them. The findings of our research shows that our participants had very strong emotional ties with the objects they brought with them. They used their experience of life to design highly individualized tangible interface elements with unique autobiographical characteristics. In this way, the selection of the recipient was facilitated considerably for the participants.

- The inclusion of the concept of familiarity in the token design represents an environmental support for the recognition of functionalities. By providing contextual cues, older users are supported in remembering the connected digital information. This transforms the interpretation of the interface elements into a cued recall or even recognition memory task, which is not affected by age-related changes.

Sub Question 3

Can elderly users be successfully involved in the design and development of innovative and intuitive communication technologies?

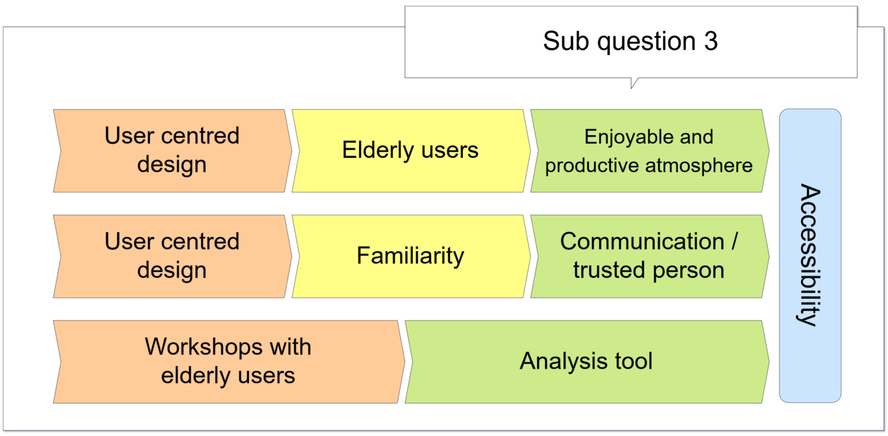


Figure 6.3: Contributions of sub question 3

Our research was based on the involvement of users to gather insights about their needs and requirements. There is limited literature about user-centred design of Tangible User Interfaces for and with older people. Based on our findings and the positive feedback of our participants, we answer the research question by providing recommendations to involve in the design and development of innovative and intuitive communication technologies:

- We involved our target group in the design process right from the beginning. The design process included three iterations that focused on interaction with prototypes of different maturity levels. We had a total of 35 participants, aged between 53 and 83, who participated in our design process.

- Our main focus when planning the workshops was on creating an enjoyable and productive atmosphere. This was a basic prerequisite for obtaining valuable insights from the workshops. The feedback from the participants and the achieved contributions were confirmation that we have achieved this goal successfully.

- We applied different strategies in the planning of the workshops. In the first iteration comprehensive information for and communication with the participants was in the foreground in order to compensate for the disadvantage of the unfamiliar environment. In the second and third iterations, trusted persons were used as proxies to the participants, thereby reducing direct communication. In contrast, familiarity with the chosen venue of the workshop became more relevant.

- For the atmosphere and the successful outcome of the participative workshops it is essential to break the ice as early as possible. For workshops with several participants it is therefore important to give them the feeling of being welcome on arrival and to provide them with a pleasant environment. In the case of individual sessions, it is indispensable to have a trusted person with you. This trusted person is not only particularly helpful in making the initial contact, but also helps to achieve better results, as the participants can act more relaxed through the presence of a trusted person. It has also proven helpful to provide a little gift, especially when the workshop is conducted with the participants.

- As a result, we provide a concrete analysis tool for user workshops in the area of Tangible User Interfaces design. It can be used for planning workshops by visualizing the relation of tangible input, location, participants and communication in order to create a successful workshop atmosphere. We identify the atmosphere as crucial for achieving valuable outcomes.

Sub Question 4

Can we use multimodality in the design of user interfaces and the user-centred design approach to create accessible communication technologies for elderly people?

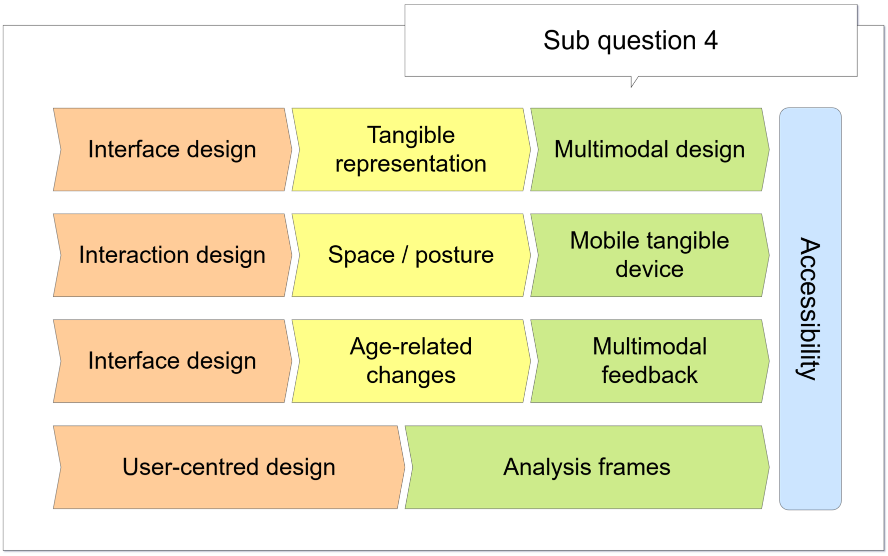


Figure 6.4: Contributions of sub question 4

In our research we embraced the multimodal nature of Tangible User Interfaces and enhanced it to provide an interaction design that addresses the special needs of older people. We applied multimodality not only in the area of user interface and interaction design, but also in the analysis of our user-centred workshops to create accessible communication technologies for elderly people:

- The multimodal design of our prototypes facilitated user interaction. For example, color marking together with textual hints and audio feedback guided the interaction with the personal tokens. The functionality of the Generic Tokens became completely recognizable by affordance of the object on the one hand and by visual design on the other hand.

- It is recommended to choose size, shape, and material of tangible interface elements to smoothly fit into the grasp hand of the users and therefore invite the user to interact and play around with it. This helps to overcome the initial barrier to interact with new technologies.

- Based on the findings from iteration 1, where participants adopted very different postures compared to the prototypes, and from iteration 2, where distance played a problematic role, a more mobile device was created in iteration 3, which could be positioned as desired. This solution also contributes to better use of the space around the device, which was utilized differently by the participants.

- The multimodal system feedback also supported the participants in their interaction. The provided audio and visual feedback was a valuable addition to the chosen token+constraint approach in the interaction with the Generic Tokens. Only through this additional information could the participants know whether the interaction had been completed. Participants also took the perceived audio feedback as an incentive, to rethink, or revise their decisions. Even though it was not always possible to clearly determine which modality was the decisive factor for a user interaction, it was always necessary to address several modalities, e.g., audio for a participant with impaired vision.

- As additional multimodal approach, we used the intangible representation of our Tangible User Interface to support the user interaction with the tangible control elements. In order to make it clear to the users which interaction step was the next one, we have displayed an additional visualization of the Tangible User Interface on the screen. This visualization supported the user by a blinking visual feedback in the interaction. At the same time, a blinking visual feedback was provided directly on the hardware. Thus a congruent guidance for the user could be achieved.

- Although older adults are often less technology-savvy and among our participants there were also many persons who have never interacted with a touchscreen before, one has to consider widespread interaction patterns in user interface design. Even participants without touchscreen experience experimented with touch or swipe gestures. When confronted, most said that they had observed them on other people. Therefore, such interactions must either be accepted by the user interfaces or, if they are not desired, prevented by the interface design. At the very least, the device must be able to withstand the mechanical stress caused by the use of such gestures.

- We also noticed that there are different preferences for the order of interaction. An accessible system with Tangible User Interface should therefore support either individual interaction sequences or provide clear guidance for the sequence of user interactions.

- As a tool for the analysis of our workshops we designed consistent, multimodal analysis-frames. When user interface and user interaction are designed to be multimodal, the analysis of the participative user workshops must also take account of this multimodality. We have designed our analysis frames to describe and analyse the relevant user interactions in their multimodality at a glance. Due to the clear structural specification of the frame, they are easily comparable and thus support the efficient identification of relevant points for a redesign.

Main Question

Main question: Can systems with Tangible User Interfaces help to provide accessible communication technologies for elderly people?

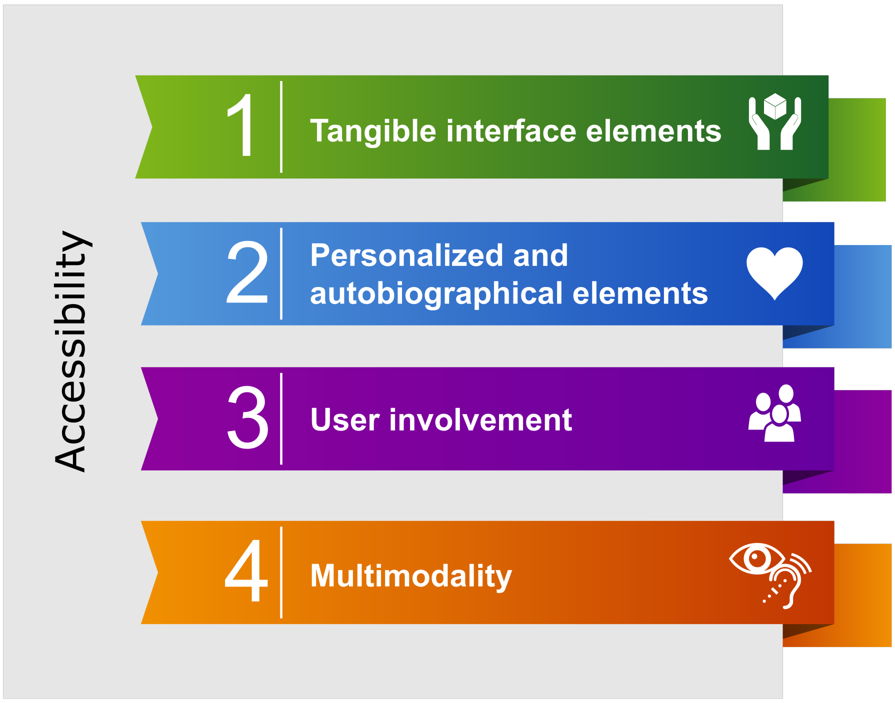


Figure 6.5: Overview of contributions

The main research question is answered by the combination of the four sub questions. By combining intuitive design of interface elements, the autobiographical nature of the tokens used, the involvement of users in a user-centred design process, and the multimodality of our Tangible User Interface, we were able to show how systems with Tangible User Interfaces improve the accessibility of modern communication technologies for older people. To conclude, we provide a summary of the findings of the four sub questions:

1. Tangible interface elements
    - A strong token+constrains relation supports elderly people in the user interaction.
    - The recognition of these relations is further improved by personalized visual annotations of interface elements.

- The right material and shape can help to achieve perceived affordances for interface elements.
- The user acceptance of a Tangible User Interface for elderly people can be enhanced by providing a design which is playful and easy to learn.
- A small number of necessary interaction steps can increase the perceived ease of use.

2. Personalized and autobiographical elements

   - Controls of Tangible User Interfaces embody a representation of digital data or an underlying functionality. The identification of this representation can be supported by involving the users in the creation of the interface elements and therefore reach a highly personalized interface design.
   - Using autobiographical information for the design of interface elements leads to a strong emotional tie between user and interface element and therefore supports intuitive use.
   - Providing contextual cues transforms the interpretation of the interface elements into a cued recall or even recognition memory task, which is not affected by age-related changes.

3. User involvement

   - We had a total of 35 participants, aged between 53 and 83, who participated in our design process.
   - A successful integration into the design process requires a enjoyable and productive atmosphere, especially for elderly people.
   - When conducting user workshops in an unfamiliar environment it is necessary to focus on comprehensive information and communication.
   - When working with elderly users in familiar settings (like their homes), a trusted person facilitates a positive atmosphere.
   - We provide a detailed analysis of our workshops regarding the relation of location, participants and communication.

4. Multimodality

   - The multimodal design of Tangible User Interfaces supports the recognition of the tangible representation of interface elements by elderly users, for example through providing a combination of visual and textual hints together with audio feedback.

- The usage of surrounding space can be crucial for the user interaction. Tabletop or desktop-based Tangible User Interface may cause postural difficulties for elderly users.
- Mobile tangible devices can be placed and arranged according to the needs of the users.
- Multimodal system feedback is necessary to guide elderly users in their interactions, regardless of possible age-related impairments.
- We provide multimodal analysis frames as a tool to describe and analyse the relevant user interactions in their multimodality at a glance.

By answering our research questions, we hope to have made a valuable contribution to the further development of the research field of accessible technologies for older people on the one hand and to have provided concrete inspiration for new design approaches for user interfaces of communication technologies on the other.

Chapter 7

Publications

7.1 Defining Multimodality for Tangible Interaction

Defining Multimodality for Tangible Interaction

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ABSTRACT
Multimodal interaction still is a young research field, challenged by its complexity. In this paper, we describe our qualitative approach towards multimodalities and present our selection and definition of modes. We show the design and set-up of *analysis-frames* as tools for qualitative analysis to deconstruct collected data from our workshops. By introducing this multimodal analysis with two real design cases, we provide empirical evidence to evaluate and improve our approach and to illustrate how further defining multimodality is essential for design practices to achieve usable and context-specific interfaces.

Author Keywords
Multimodal analysis, multimodal interaction, tangible user interface, participatory design.

ACM Classification Keywords
H.5.2. User Interfaces: Theory and methods.

INTRODUCTION

In current HCI research, different metrics are widely used to achieve a high quality (and highly rated) contribution. Especially the field of usability evaluation merely concentrates on quantitative empirical usability evaluations [1]. The number of mouse clicks, galvanic skin response or error rates: often the hard facts count.

In our research, we are focusing on participatory development of new systems with tangible user interfaces. When designing new technologies it is often necessary to go beyond quantitative measurements. Therefore we cannot restrict our analysis to the evaluation of single or combined input/output modalities like keyboard input and speech recognition or visual and haptic feedback. As Hassenzahl and Tractinsky [9] argue, it is essential to discuss empirical research and qualitative methods more, to further develop user experience and multimodality and their impact for interaction and interface development. We need to obtain a holistic view on the user interaction, to reach a deeper understanding of user's behaviors and needs. Especially when designing technologies with tangible user interface, we need to enhance our understanding of modalities. We need to better scrutinize how space is used and organized, and furthermore, how users interact with different types of objects.

RESEARCH

Our background and research interest is to develop tangible user interfaces (TUI) and explore on their potential as alternative to traditional input- and output devices. Our observations, methods and analysis presented in this paper are based on two cases: 1. *ColorTable* – a tangible tabletop interface providing an interactive and collaborative planning and discussion space set up in a tent directly on the site of the urban planning project. The interface was developed as part of IPCity (a research project founded in the 6th framework programme). 2. *kommTUi* – an ongoing national three-years human resource project. The aim of this project is to design and develop a tangible interface to support communication and social interaction among elderly people in a non-stigmatizing way.

The design process of both projects builds upon a high level of user integration through participatory workshops. We explored the user's expectations and needs using interviews, design sessions and playful interactions with technology probes. To gather the high amount of data we used video observation, photos, audio recordings and textual notes during our workshops.

METHOD

Multimodal analysis is a research area with input coming from multidisciplinary fields. Multimodal analysis was stimulated by the work of Kress and van Leeuwen [5] on semiotics of images. O'Toole scrutinized sculpture, architecture, and painting [6]. His analysis distinguished between "modal functions" (viewer's attention, thoughts, and emotions and their relation to an artifact), "representational functions" (illustrations), and "compositional functions" (organization of surrounding work space and use of colors, shapes, lines, etc.). Numerous projects focus on visual material e.g.: film, comics, or paintings, while acoustic modes (speech, music, sound) in their relation to images and tactile modes (haptic, materiality, surfaces, temperature, etc.) together with spatial issues like use of space are much less explored, hence challenge the design and design decisions [7].

In this section we present the structure of our *analysis-frames*, followed by the definition of the modalities and two example frames, showing the design and use of the frames.

Structure of Analysis-Frames

As a tool for our qualitative content analysis [2] we designed consistent, multimodal *analysis-frames*. These frames represent the principles of analysis of multimodal interaction by Norris [4] and were further developed in an accompanying PhD thesis [3]. Our multimodal analysis-frames consist of:

- Analytical category: Determines the criterion of selection for the distinct activity.
- Main modalities: Assignment of modes used during the activity.
- Visual frames: A collection of video stills of user workshops for a visual description of the activity.
- Context description of activity: In this section, the observed user interaction is described in a textual way.
- Audio/Visual analysis: Describes the auditive and visual impressions during the current activity, including statements and remarks of the workshop participants.
- Space analysis: Description of how the interaction space was used during the observed activity.
- Tactile analysis: Describes the haptical user interaction with the interface.

The above structure allows a congruent frame design and enables comparability between the analytical categories.

Definition of Multimodalities

We argue that user interactions are multimodal per se independently what type of devices they are interacting with. There are always audio, visual, and spatial elements in interaction. In the two cases *ColorTable* and *kommTUi*, which form our research base for multimodal analysis, users worked with tangible objects, used their full body to point and interact with objects and space and positioned themselves to objects, surrounding space and other people accordingly to their aim [8]. Therefore the modalities for the analysis are:

- Visual: Everything seeable (photos, drawings, visualizations, representations, sketches, collages, visual interaction feedback and guidance, etc.)
- Audio: Everything hearable (spoken words, noises, sounds, acoustic interaction feedback and guidance, etc.)
- Tactile: Everything tactile, haptic graspable and physical (shapes, materiality, material surfaces, three-dimensionality and physicality of artifacts and designed objects, collages, tactile interaction feedback and guidance, etc.).
- Gesture: How people work, point and move with their hands and interact with objects, artifacts and materials.
- Posture: How people posture their body and use their body in relation to the interface during interaction.
- Space: How people make use of the space and room around an interface, configure their body positions in relation to others and surrounding artifacts.

The first three are focusing on the senses, essential for peoples´ multisensory experience and strongly related to the design of artifacts. The second three modalities are looking at body movements, spatial and collaborative interaction, as well as body configurations in the use context. All are interwoven in a way so that ignoring one of it would mislead design and design decisions.

Example Frames

The figure below (see Figure 1) shows two examples of our multimodal analysis. As we take our analytical categories, select situations we want to analyze accordingly, we set-up multimodal frames, showing all relevant content from each category in one sight (on one or two sheets of paper). This makes it possible to compare the selected situations by spreading out the analysis frames on the table.

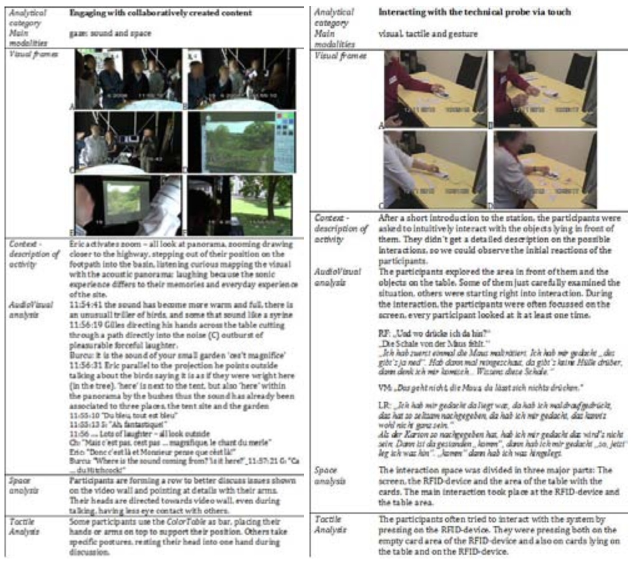

Figure 1. Two multimodal analysis frames showing selected scenes and observations from the two cases *ColorTable* (left) and *kommTUi* (right).

The categories for the analysis are drawn from the observation categories defined before the participatory workshops eg.: *workspace* which looks at usage of interface surrounding space and spatial arrangements, *workflow* focusing on participants organization of interface parts, interaction and communication or *tangible interaction*, scrutinizing token usage and the relation between user and artifacts.

CONCLUSION

Everyday life is multimodal in its nature, simple communication of two people uses spoken language, posture, gesture, body arrangement, head/arm movements and so forth. Therefore it is necessary to build – next to interaction – observation, analysis and development on the complexity of modalities. We showed in this paper a qualitative method based on empirical research to further define these and explore on qualities of use and user experience. We designed multimodal frames to enable analyzing key situations at one sight by describing and evaluating all modalities used. Every frame explains how each modality was used according to pre-defined analytical categories. Additionally, through congruent frame design, the frames are comparable and a valuable source for further development and impacts for redesign. Our future research therefore will look close at the potential of multimodal analysis frames for design and how findings of the analysis can be directly transformed for the next design-redesign cycle.

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7.2 Tokens: Generic or Personal? Basic design decisions for tangible objects

Tokens: Generic or Personal? Basic design decisions for tangible objects

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Abstract

One of the key concepts of Tangible User Interfaces (TUIs), as described in *Tangible Bits* (Ishii & Ullmer 1997), is the linkage of digital information with physical objects. Following the “token and constraints” approach by (Ullmer et al. 2005) we refer to these objects as tokens. The way users interact with the underlying system through tokens plays a decisive role in the design of TUIs and needs to be defined early in the design process. However, in this position paper we do not elaborate on tangible objects as containers for digital information, enabling user interaction and manipulation. We concentrate on one essential question arising during the design of tokens: What kind of tokens to choose and design - generic or personal tokens? In this regard, we distinct between individual, personalized artifacts and neutral objects and show the varying personal relations of users to tokens. We illustrate our statements with two interfaces (*ColorTable* and *kommTUi*), both with different complexities and requirements.

1 Introduction

Generic tokens are merely used in groupware- and collaborative interaction systems with complex TUIs. Based on simple and well-known geometric shapes like circles, rectangles, etc., the functionality and the content of generic tokens can be easily decoded by the users. Here the tangible objects represent digital containers, revealing their allocated digital information only in combination with the underlying system. Complex and collaborative interfaces often call for generic tokens due to workspace limitations. The *ColorTable* (Wagner et al. 2009) for example is a tangible tabletop supporting collaborative urban planning and the creation of urban future scenarios of a specific urban site. For the visualization of each urban planning setting a high amount of multimedia content is required. The representation of every single manifestation of an object (shape, material, color) through tokens would have led to spatial problems, so the decision of using generic shapes reduced the number of tokens needed significantly. Furthermore, the usage of generic objects strongly tied the users to the results of the collaborative interaction and the represented multimedia content, rather than to the tokens. Another and famous tangible interface based on user interaction through generic tokens is the Reactable (Jorda 2010), which also uses various basic shapes to distinguish between content groups on a Meta level.

In the first workshop series of our recent project *kommTUi* (Kommunikation via Tangible User Interface) we included user interaction with generic tokens to see how elderly users cope with tangible interaction and in which ways they interact with the tokens. A key factor for a successful interaction with the tokens was the design of form and shape. Through the affordance (Norman 1988) of the generic objects, many workshop participants were able to decode their functionality. Therefore, generic token design can take advantage of previous experience of users with similar formed objects. However, for many applications it would be desirable to have a connection between the users and the tokens on a more emotional level, providing a stronger link than just the affordance of the object. This can be reached by a more personalized design of the tokens, which aims for the users' personal history, memories and feelings.

As personalized tokens we define objects representing individual meaning to the user. They are linked to the user's biography, personal history and experience and can be created directly by the user: either by attaching a digital marker to an everyday object or by individualization/reshaping of generic objects provided by the designer. The experience and results from the earlier project *ColorTable* showed that a personal relation to artifacts is needed as soon it is used to represent a personal experience, an emotion or a specific statement. Participants enriched the generic tokens by placing individual photos or objects next to it or annotating directly on the tokens to make them more specific. Personalized tokens are not only containers, they transform into “keys”. They inhere a very personal, emotional metaphor, only understandable and decodable by the person who created the key. Therefore, personalized tokens are suitable for personalized systems like *Memodules* (Mugellini et al. 2007). *Memodules* includes personal objects (e.g. shell, stone, etc.) in the user interaction, which leads to a strong emotional tie with the tokens. This is done by attaching RFID tags to the objects and storing the specific user data on the tag through a RFID-writer device. The so-formed token represents the objectification of the user's memories and prior experiences. It can help to organize memories, as link to specific persons, situations, emotions, pictures, music, or feelings. In *kommTUi* we tried to figure out a proper mapping between the participant's communication behavior and everyday objects. Therefore, we asked the participants to bring personal items to the workshops, which best symbolize their everyday communication. The results will be the basis for the design of the *kommTUi* communication device, which allows the user to choose the recipients through highly personalized tokens. This integration of personalized objects in the user interaction leads to strong interface metaphors. Through the emotional and shape based guidance, attributes and functionality of personalized tokens can be recognized easier than generic tokens by the individual and provide an opportunity for user groups who have problems using traditional computer systems.

2 Discussion

Developing tangible interfaces calls for grounded design decisions: the context of use including the surrounding space, the amount of multimedia content presented, the number of tangibles for interaction and manipulation and the size of the interface itself. For most applications it is not enough to have a representation of user data, it's also necessary to provide representation of syntax, in which ways the users can manipulate the objects. The general idea to distinguish between generic and personalized tokens rose from numerous discussions during several design processes. Especially when a large number of tokens were used for interaction our observations and results in participatory workshops showed the need to personally annotate or mark the generic tokens. This made the tokens more individual and meaningful for the specific interaction or group creation. Depending on the complexity of a novel interface, designers should therefore consider their metaphor for the tangible design very carefully and decide early if generic or more personalized tokens suit best their interaction modes. If not generally decidable, it should be made clear, if individual annotations or manipulations of the objects itself are essential for an appropriate use. Physical objects vary in their physical characteristics like shape, color, weight, size, texture, temperature etc. Furthermore, tokens trigger different emotions and experience, depending on the meaning and representation for the individual user. In addition to this complexity, the personal relationship between users and tokens has to be further investigated and observed as it plays a role in the design of tokens for tangible user interfaces and feeds back directly into the choice of material, shape, color, size etc.

The personal perspective and the relation between user and object should be considered as design issue for tangible interfaces already during the early design process. This can influence understanding, manipulation and interaction by providing more insights into possible usage barriers, especially when designing interfaces for elderly. These impacts and results are still very preliminary but promising at this point of research, and will be included in our research questions for the next phase of *kommTUi*.

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7.3 Multimodality in Design of Tangible Systems

Hilda Tellioğlu, Lisa Ehrenstrasser, Wolfgang Spreicer

Multimodales Design

Multimodality in Design of Tangible Systems

Design_tangible interaction_multimodality_elderly.

Zusammenfassung. In diesem Beitrag präsentieren wir, wie wir Multimodalität beim Design von haptischen Systemen für ältere Menschen angewendet haben. Zunächst definieren wir sechs Eigenschaften der Multimodalität: akustisch, visuell, taktil, gestikuliert, posiert und räumlich. Wir untersuchen diese Kategorien in einem Designprozess und in der Generierung der Design-Artefakte. Wir illustrieren die Interaktion mit unseren Nutzern und Nutzerinnen bzw. stellen den Fokus der Multimodalität in so einem Designprojekt auch im Zusammenhang mit verwandten Ansätzen dar. Am Schluss fassen wir unsere Ergebnisse zusammen.

Summary. In this paper we present how we applied and analyzed multimodality in design of tangible communication systems for elderly. First we define six categories of multimodality (aural, visual, tactile, gesture, posture, and space), which we integrate in our design processes and design artifacts. We illustrate how user interaction has been established, especially when multimodality is central to our approach. We also discuss multimodal design in context of user experiences, user-centered design, and participatory design approaches. We show the added value and change of focus through multimodality in design processes. We analyze our findings before we conclude our paper.

1. Introduction

Considering users' skills and perspectives in a design process has a severe impact on the approach designers choose. User experience (UX) is individual and not social. It emerges from interacting with an artifact and includes emotional, affective, experiential, hedonic, and aesthetic variables of users (Hassenzahl & Tractinsky, 2006). How can we evoke user experiences out of anticipated use? How can we establish an environment for a cooperative evaluation of UX in early phases of a design process, i.e., without having a product or system already to experience with? How can we capture methodically and systematically UX during interaction with users? This paper presents how we managed to answer these questions in a design project for elderly. We based our design on UX and multimodality. We applied multimodal design methodologies, and defined multimodality with the categories aural, visual, haptic, gesture, posture, and space. In the next section, we present our multimodal design approach. With a case we illustrate how we can apply it in projects. We discuss our findings before we conclude our paper.

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2. Multimodal Design

Multimodal research is an emerging young research field. Besides well-known keyboard or computer mouse, human-to-human interaction in HCI includes user input via voice, gestures, or tangible objects. Accordingly, the output of a multimodal interface addresses various senses of the user, like visual, acoustic, or tactile feedback (Reeves et al., 2004). The focus of UX, especially in product design, is on the user interaction with the product, by pushing a button, by positioning certain objects in a specific way, by meaning and interpreting sounds provided by the system to react to system's behavior, by changing the course of interaction through involving the whole body, voice, activating or deactivating certain objects available for interaction, etc. As illustrated in our case, user interactions are multimodal independently what type of devices they are interacting with. There are aural, visual, and spatial elements in interaction. Especially use of space and spatial organizations challenges design and design decisions (Patten & Ishii, 2000). Based on the technique of multimodal analysis the relevant multimodalities needed for analysis and design were defined. Next to spoken language head and arm movements, body posture, etc., six categories originating from an accompanying PhD thesis (Ehrenstrasser, in progress) form our base to understand communication and interaction situations: Aural: Everything hearable like spoken words, noises, sounds, acoustic interaction feedback and guidance. Visual: Everything seeable like photos, drawings, visualizations, representations, sketches, collages, visual interaction feedback and guidance. Tactile: Everything tactile, haptic graspable and physical like shapes, materiality, material surfaces, three-dimensionality and physicality of artifacts and designed objects, collages, tactile interaction feedback and guidance. Gesture: How people work, point and move with their hands and interact with objects, artifacts, and materials. Posture: How people posture their body and use their body in relation to the interface during interaction. Space: How people make use of the space and room around an interface, configure their body positions in relation to others and surrounding artifacts. The categories are bidirectional, e.g., audio has always an impact on space and space to audio, gesture influences tactile experience and vice versa. In the next chapter, we present our case, in which we could investigate the multisensory experience of our users in different settings.

3. The Case and the Prototypes

Our case is about designing innovative ICT to support communication and social interaction among elderly people. In the research project kommTUi (funded by FFG, No: 823577), we developed several prototypes in three iterations with users. By means of video and audio recording, we gathered data during the workshops, which we analyzed multimodal. On the one hand, we were looking for non-stigmatizing ways of interaction for elderly. On the other, we investigated whether and how ICT with tangible user interfaces are more suitable for elderly and whether haptic interaction mechanisms improve the application and acceptance of ICTs by older people. In total, we had seven stations with different prototypes. In this paper we present only three.

3.1 The Board Game

We implemented a wooden board game based on Connect 4 (Figure 1).

Two players, sitting side by side, can play it having direct face-to-face communication. The game is multimodal: It can be played both by visual and tactile contact and also blindfolded (Figure 3).

We used 21 red and 21 white differently shaped figures to ensure a high visual contrast as well as a tactile distinction.

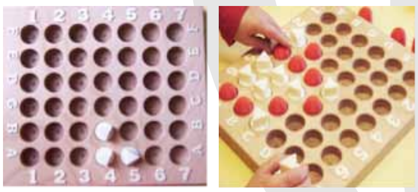

Figure 1: The Board Game.

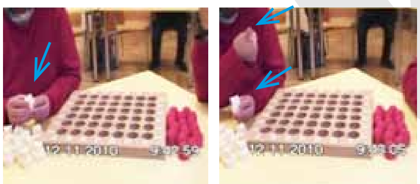

Figure 2: Example of unified and distributed cognition.

Figure 3: Example of material interaction when played blindfolded.

At the beginning, both players do not know how to start and play the game (Figure 2). Sitting side by side they talk about their experiences with this game if any and ways of playing it. Independently of what is being talked, one player grabs a figure and scans it with her both hands. This type of approaching the game is important to get familiar with it and its figures. Spoken exchange is an example of unified cognition, whereas sensing and scanning a game figure is distributed.

Two players decide to play the game blindfolded (Figure 3). After tying a scarf around the eyes, one player fingers the board with the marks and holes (2) and its borders (1). This is an example of haptic guidance and helps orientation before starting to play. During the player on the right side puts her red figure into the hole, the other player asks whether she has already played her figure and holds a white figure with her both hands (3). When it is her term, she tries with one hand to find the right hole and she holds the figure with the other. Then she puts the figure with both hands into the hole when her left hand arrives the target (4). This sequence is repeated through the whole game. Both players talk very briefly and only to guide and clarify things. Of course, fingering the board to decide what to play next becomes more complex and prolonged when the game is progressing. Here we observed material interaction and the restrictions when visual interaction is prohibited.

The Board Game combines all six categories of multimodality: Players talk to each other to clarify the rules or the status of the game, like who is next, who wins the game, whether they play another game, etc. The arrangement of the game board with letters and numbers and colored figures provide visual support. The status of the game can of course be observed the best visually. Orientation at the beginning and material interaction when played blindfolded are provided by tactile modality. Besides playing the figures, gesture around the board to support articulation or to show emotions is needed. This is connected to posture and space, like how players sit around the board, how and when they approach and move away, and body positions in relation to other player and to the board.

3.2 The Launchpad Game

We implemented a digital version of the board game by using a MIDI controller for interaction (Figure 4). We covered all predefined function descriptions and buttons of the device. We connected the Launchpad to a computer, for both to execute the game and to use audio and video connection via Skype (Figure 5).

Figure 4: The Novation Launchpad device (1), the Launchpad Game (2).

Two players sitting in different rooms play the Launchpad Game. They communicate with each other through an audio- and video channel. To play a figure, the player has to press one of the LED buttons in the column.

Figure 5: Audio and video communication via Skype during gaming.

Based on the observations of different sessions played during the workshops we can illustrate some interesting user interactions. Players differ in their perception which button they should push (Figure 6): the most upper one in the column (1) or the button showing the exact position of the figure they want to play (2). Players usually look at the Launchpad during the game. The communication with others occur in case of breakdowns or disruptions, to articulate or clarify misunderstanding of how to play the game or which button has which functionality to start a new game, cancel a game, or invite the other player to another game.

Figure 6: Different buttons pushed.

Sometimes players talk to themselves to think about their next move and gesticulate with their hands and fingers on the Launchpad to support their thinking loud (Figure 7).

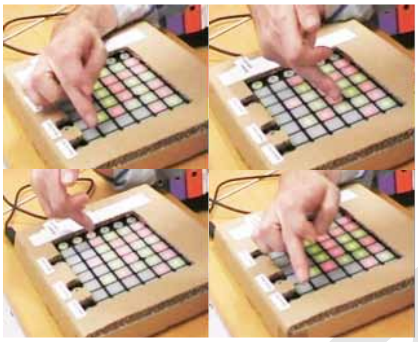

Figure 7: Gesticulating - thinking loud.

There are different ways how to position and use the device (Figure 8). Some use only one hand, some both (1+2); some use the space around the Launchpad to position their hands or arms to support concentration (3); some are bored and play with their fingers on the table (4); some play with their hands while waiting (5+6); bodies are positioned differently (closer or farther to the pad) depending on the success in the game.

In comparison to the Board Game, the Launchpad Game is much complicated to understand and use in many ways: If one starts a new game, the other player is automatically invited and must confirm the invitation by pressing the "invite a friend"-button on the right side of the pad. This button starts blinking on both pads. When the invited player pushes the blinking button, the game is started. Same happens when one wants to cancel or stop a running game and start a new one. This was not always clear to most of the players. One reason for this was the limited notification and feedback mechanism implemented on the Launchpad. Only using different colors or blinking a function button was not enough, we needed audio signals to alert situations or inform the players.

Figure 8: Positioning and dealing with the Launchpad.

After several tries players learned what optical signals meant and could use the pad with no delay. If the invitation was not confirmed, the system timed out after 30 sec. This happened a few times, which further confused the players because they could not understand why this happened and the blinking stopped. These observations show that visual and aural notifications are essential for interaction with a device, especially when the actions of other users must be made visible to all.

3.3 Sequencing Actions

The goal of this prototype was to achieve a deeper insight about possibilities and difficulties of tangible interaction based on RFID technology. Therefore, a RFID system was designed, which allows the manipulation of screen- and audio data by simply placing cards on a particular scan area (Figure 9). The system consists of a monitor with integrated speakers, an RFID reader integrated into a cardboard box (with a red rectangle at the top marking the scan area), the RFID cards (with red borders), and a standard PC for the program logic.

For the workshop, two use cases have been designed: interacting with a

Figure 9: Prototype for sequencing predefined actions using cards.

cat (petting and feeding the cat, the cat purrs and meows) and making tea (filling the kettle, putting it onto a stove, switching it on and off, boiling the water, pouring the boiled water). The sequence of actions for making tea is clearly defined by the application and the goal is to prepare warm water for tea. In other case, users can freely choose the order of doing things. Putting the particular start card onto the scan area starts the interactions. Each card causes a certain screen and audio output. An aural signal is used to alarm the user or give him/her a positive feedback.

This prototype focuses on space (body position in relation to interface, arrangement of cards), visual (object design, visual interaction feedback), aural (aural interaction feedback), and posture (toward interface) (Figure 9). The goal was to explore the ease of use of our tangible user interface for the elderly participants. Is the user interaction easier to learn when they can organize the interface elements (action cards) themselves? Are the interaction constraints strong enough for an effective interaction guidance of the participants?

The RFID system was located on a table, which stood in the middle of a room. We provided chairs on the long sides of the table, so the participants could choose to sit on one of the long sides of the table or just stand in front of it. The monitor was placed on the fourth side of the table, so the participants had a good line of sight to it. The RFID-reader covered in the cardboard box was mounted in front of the monitor, the RFID cards were grouped according to the use cases. It was up to the participants to use this predefined arrangement or change it according to their needs and requirements. The research question was to find out how the participants interact with this system, which they have never seen or used before and without having any information about how to use it. To support the interaction, the red rectangle on the cardboard box and on the cards were provided.

Most users positioned themselves on the right side of the table. The table was too long, the screen could not be seen easily and the scan area could not be easily used from this front end. Some of the male users changed their body position during the interaction, while female participants did not move from their original position.

One of the challenges at the beginning of the interaction was how to interact with the cardboard box and how to put the cards onto the scan area. This gives us information about the haptic interaction with the system. We could observe different ways of doing this (Figure 10): Some tried to push the scan area very hard to initiate action almost damaging it completely (1). They thought the box with the RFID reader is actually a mouse without a click button. Seeing its missing stability convinced them that pushing is the wrong way to interact with it. Some tried to wipe on the scan area (2), some to scroll like on a track pad (3). Some tried to start the interaction by using the MS Windows start button on the screen (the dock was still displayed on the bottom) by assuming it is a touch screen (4). Some tried to put two cards side by side (5) or on each other at the same time onto the scan area. Some put dependent cards in a sequence, like the cat meows and one feeds the cat (6), which unfortunately could not be read by the one port RFID reader. In all cases, the visual and aural feedback of

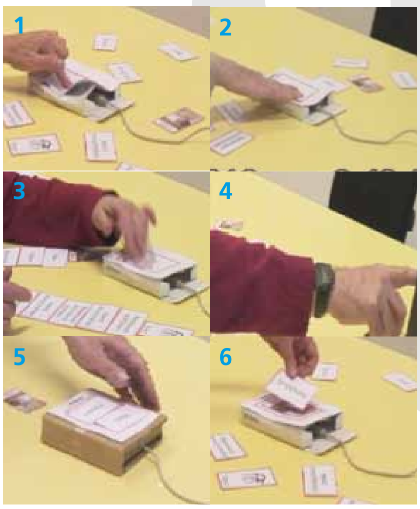

Figure 10: Different ways to interact.

the system helped users to understand and learn how to interact with the system. Due to the red rectangles almost to all it was clear in which direction and on which side they have to put the cards onto the scan area.

Users tried to sort out the cards before starting the interaction or during interacting with the system. They put them on the left or right side of the scan area in a certain order by separating the two use cases, so that they had an overview of the cards. They tried to sequence the cards on the table before interaction. Sometimes these sequences were not correct and they changed the order of the cards during interaction with the system. Though, some were confused and did not know how to proceed. Some solved the situation by starting again from the beginning. Only one user combined both use cases: first she fed the cat and then she made the tea. All others separated the use cases and did not see any connection between them.

4. Discussion

In compare to known HCI approaches with audio, visual, and haptic feedback modalities, and language, gesture, and mouse as input modalities, we analyzed the differences in the body language and body posture when playing the Board Game sitting side by side and playing the Launchpad Game sitting in two different rooms. For playing the Launchpad Game, the arrangement was necessary to ensure, that the players are located on the right side of the pads and can see and hear each other. For playing the Board Game, the players were sitting in close proximity and also their bodies were aligned to each other. They could touch each other when needed, e.g., to help when played blindfolded. At the same time we studied the haptic interaction with the game figures. Playing blindfolded was possible due to the special design of the game figures: The red ones had a round shape and the white ones had a triangular shape. With this design we achieved a visual and a haptic difference.

Gaming context increased the acceptance of the elderly to communication via Skype. It was part of the game. They could ignore it and focus on the game and use it when they wanted. It was their choice whether and when to use it.

Visual elements used in design are responsible for communication possibilities, limitations, and the state of interactions with the user. Users are informed about what they are seeing, and how it works. The design of visual elements enhanced with sound effects are in charge to transmit, on the one hand, the importance of the content and actions, and the relationships between them on the other. Sounds as ambient cues show changes in an application while users are otherwise occupied. Applications raise their voice if they need attention. Visual organization of colors, fonts, patterns, images, and visual elements shows the user how to deal with a system, how information is interrelated in the system, and what the hierarchy between interface elements is. How things are used, what material things users hold in their hands have, how users position themselves to the systems they use, how they interact with gestures to communicate with others, how the whole space is shaped and set up, become as further relevant modalities for design of systems.

When planning a workshop with older adults, it is necessary to consider the normative changes related with the aging process throughout the whole design process (Fisk et al., 2004). This is true not only for the design of different input and output modalities, but also for the workshop setup itself, e.g., wording in textual and oral descriptions, used icons, graphical guidance or arrangement of workshop rooms. As our workshops showed, considering these multimodal requirements leads to a pleasant atmosphere, which enhances the quality of the workshop results. The multimodal gaming situation described above was able to divert the elderly participants from their concerns of using new technologies. By sequencing actions, the possibility for the participants to rearrange the tangible interface elements to their own needs was very well accepted and extensively used. This helped the participants to familiarize with the interface. Beside the graphical and aural guidance, the haptic interaction with the interface elements supported the elderly participants in the initial contact with the prototype and led to easy to learn interactions.

Multimodality has impact on all types of decisions made in the process. While developing and re-designing the kommTUi prototypes, we noticed that each design decision we took implicated a high number of consequences related to other design decisions. It is not a coincidence that we could identify all categories in design settings, like the use and number of physical objects, their various materials and surfaces especially as tactile guidance and clues for usage; complex steps of interaction and chains of action; workflow and workspace organizations with the interface; the arrangement of devices, artifacts, and the use of space, etc. How we prepared our design workshops, how we carried out them, how we documented and analyzed data captured in these settings, were well designed in terms of multimodality. We argue that to design context and user aware systems all categories of multimodality are needed.

Furthermore, our users activated and deactivated the categories according to their relevance and use. Sometimes they looked at the screen; sometimes they only reacted to audio signals. We captured these changes and used them for design, even when our users were not present physically. We selected, combined, and composed these categories by analyzing the design issues they represent, before we used them in the redesign of our system. We integrated user attitudes in interaction in terms of multimodal categories into the design objects and we kept them there, like materiality and the shape of the tangible objects. So, we used multimodality as the guiding principle for our design practice.

As designers, we need approaches, process models, and guidelines to tackle all the challenges during the design of complex systems. First of all, multidisciplinary design teams are needed to facilitate multimodality in the design process. Second, the design setting must be multimodal. Besides systems we design, tools and technologies as well as room and space arrangements must be multimodal. Third, establishing a multimodal approach not only in the objects designed but also in the design process calls for user iterations and for capturing and maintaining multi-modal categories from iteration to iteration. The design must be concerned in all phases with users, with their use contexts and use experiences, and with all potential and concrete multimodal technologies.

In our case we had processes that leaded us to novel interfaces. We ended in creating intelligent objects, which are configurable and haptic. We were aware of differences of multimodal categories in the process, we used them differently in our design. But we used them all.

In sum, multimodal design serves as an approach to interaction and product design of novel interfaces. Some research questions need to be investigated in the future though: Is there a specific phase in the design process where multimodal design has more impact on the design? Does multimodal design look differently in software-only projects than in hardware-based design projects, e.g., based on embedded technologies?

5. Conclusions

In this paper, we showed how to design systems that provide richer interaction for elderly. We showed and discussed the categories embedded in multimodal design process (aural, visual, haptic, gesture, posture, and space) not only on a conceptual level, but also we presented empirical evidence illustrating how these categories can be identified and how multimodal design can be applied in real design processes. We addressed points for improvement in design processes to achieve better, user and use aware, context sensitive, and novel technologies. Users of systems need to be a real part of the whole design process. Furthermore, users should be present throughout design, interaction, and technology decisions. Designers need to consider multimodality in the design of artifacts, in user interaction, and in the whole design process, adding to the quality of design and use.

As a future research outcome we are interested to provide more detailed design rationale and patterns to make multimodal design applicable for designers.

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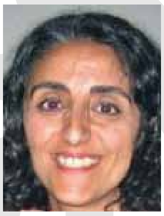

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7.4 Personal Interaction through Individual Artifacts

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München: Oldenbourg Verlag, 2012, S. 129-134

Personal Interaction through Individual Artifacts

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Abstract

Understanding and executing interactions with communication interfaces can be a bitter process, especially with basic or none technology knowledge. The paper gives insights in developing a tangible interface called *kommTUi,* a single user communication interface triggering interaction through a mixture of pre-produced, generic tokens and personal artifacts both serving as objects for defined interactions. We explore the importance of individualising tokens and personal relations between objects and users for interaction design and present findings from participatory design workshops.

1 Introduction

Recent discussions in the TEI community about future directions for the design of tangible systems suggest a shift away from creating seamless user interfaces to seamful mappings and a higher degree of appropriation by the user (Hornecker 2012). We want to contribute to this discussion by presenting our approach of designing personalized tangible interfaces. Referring to Tofflers term *prosumers* (Toffler 1980), we propose that users should participate in the design of products and interfaces. Recent developments underline the trend to dissolve strict distinction of producers and consumers. On the online platform NikeID[1], for example, users can customize and personalize their shoes before they purchase them. The product designers provide the basic form, the consumers/users appropriate it to their needs. In this paper, we describe how we facilitate interaction through personalized tangible objects. Our research aims are to scrutinize the role of personal artifacts for communication tools, observe how familiar objects support interaction and how this can influence design and set-up of a communication interface.

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[1] http://nikeid.nike.com (05.06.2012)

1.1 Background

In our previous paper, we scrutinized the differences of generic and personalized tokens for tangible interaction (Ehrenstrasser & Spreicer 2011). We have defined generic tokens as containers with well-known geometric shapes, predefined size and material. These tokens physically embody abstract digital data and can be easily integrated into a token+constraints set-up as a support for known chains of actions and shape patterns (Ullmer et al. 2005). On the other hand, we have defined personal tokens as individual objects with a special meaning to the user. These can be everyday or self-made objects, representing physical, autobiographical objects of memory, reminding the owner of special moments or friends (González 1995). Through the emotional linkage between the object and the user, personal tokens turn into *keys*, which can only be decoded by the owner of the object. While generic objects have been used since the first concepts of TUIs like the Marble Answering Machine (Poynor 1995), the usage of personalized tokens for user interaction came up within the last decade. The ME-MODULES project uses a combination of RFID-technology (Radio-Frequency Identification) and image recognition for creating „tangible shortcuts“ to ease the use of new technologies (Mugellini et al. 2009). The Alcatel Lucent venture *touchatag*[2] used RFID-stickers to link objects with different functionalities of traditional computer systems. Ishii et al. propose a different approach for personalized tangible objects in their vision for future tangible systems called *radical atoms*: pre-produced dynamic physical materials react and transform according to user input (Ishii et al. 2012). As van Hoven (Hoven, E. A. W. H. van den 2004) argues, the interplay between generic and personal tokens in the field of Tangible User Interfaces is still worth observing and scrutinizing further.

2 Design

To evaluate our approach, we conducted participatory workshops with a heterogeneous group of people between 55 and 70 years with different prior knowledge of ICTs (Fisk et al. 2009), based on the experience and findings from the workshops in 2010 (Ehrenstrasser & Spreicer 2011). We planned our second round of workshops with one group of participants, who have already attended in 2010 and one group with totally new participants. We used space, rooms and equipment to create a playful and harmonic workshop surrounding. Next to workshop design, our design work consisted of:

- Artifacts, mock-up and technical probe design: We provided a workshop package for each participant with three pre-produced, generic tokens, ready to be equipped and annotated in the design session at the beginning of each workshop. These generic tokens had a specially designed form and shape for our context of use (Fig. 1) to have a strong connection between the shape of the token and the corresponding slot. For annotating the tokens we provided stickers, icons, pen, paper, etc. Furthermore, we asked every participant to

[2] www.touchatag.com (04.06.2012)

bring an object, which reminds him or her on a very special friend or relative. These autobiographical objects were used to promote the linkage between the memory of a special person and the tangible element of the interaction (González 1995). The personal objects have been equipped with RFID tags to use them directly as *personal tokens* for the user interaction. The generic and personal tokens were part of our technical probe, which consists of a netbook embedded in a wooden case. On the top of the screen there are two areas, each equipped with a RFID reader, on which the users can place their tokens. The left area provides a slot, shaped like the bottom of the generic tokens. This similarity in shape should guide the user where and how to position the token on the probe. The personal tokens are placed on the right area, marked with a colored rectangle. Our token design is used to scrutinize the interplay between generic and personalized objects in our workshops.

- Interaction design: We introduced three use cases for user interaction with the technical probe – Starting a voice-over-IP call, sending a photo and sending a note. To start the interaction, the user had to choose the functionality by placing the particular generic token. After that, the user had to determine the recipient by placing the personal token. This interaction also started the call or the transmission. Each interaction was followed by acoustic feedback and visual feedback on the screen.

The design of the tokens is twofold, as we have our pre-produced generic tokens and the personal artifacts brought by participants. We argue that personal objects can embody specific stories, meanings known often only by the object owners. Therefore our definition of personal interaction is the usage of personal relations with artifacts triggering interaction, which is as well one of the essential design decisions to be explored in *kommTUi*. In the following section we will outline the conducted workshop and our categories of observation.

3 Observation and Analysis

- In the observations we focused on our argument of supporting interaction with personal objects. First of all, we scrutinized the equipping process of the generic tokens (e.g.: photos, symbols) during the design session. In addition, we examined whether this individualization extends generic objects to subjective objects in a way, that the emerging symbolic relation between the user and the object triggers the desired interaction (González 1995). Furthermore, we focused on how participants used interface and surrounding space and how the RFID interaction was perceived and used. Finally, we observed the use of generic and personal tokens – more detailed: the role of personal objects triggering interaction.

In the following section 3.1, we present examples of two participatory workshops, showing the importance of individual triggers supporting understandable interactions and specific relations of participants with their artifacts.

3.1 Examples

The workshops agenda consisted of a guided “design session” with all participants (station 1), followed by the specific interaction situations carried out individually (station 2) along *think aloud* and accompanying interviews (Fisk et al. 2009). The workshop ended with group discussion and reflection.

3.1.1 *Example 1 – use of generic tokens in the “design session”*

The generic tokens (each participant got 3 items, according to the type of communication) had to be equipped and personalized in the “design session”. The participants had to think about what kind of icon or annotation they would use to show the specific interaction - call, send note, send photo (Fig. 1). On the account of “personalizing interaction”, we added to the generic tokens the personal level – to make them individual and a personal key for the users and their communication interaction.

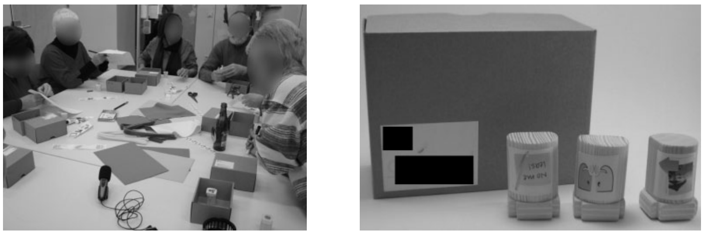

Figure 1: Generic tokens equipped with selected icons by our participants.

3.1.2 Example *2 – use of personal token*

The personal token (= artifact with personal history and meaning for a specific person, and a mounted RFID tag to trigger the technical interaction on a hidden place) helped to visualize the communication partner and served as “phidget”. The set-up of the technology probe provided the frame for the participants to try out to trigger interaction with the personalized generic tokens and individual artifacts (Fig. 2, left).

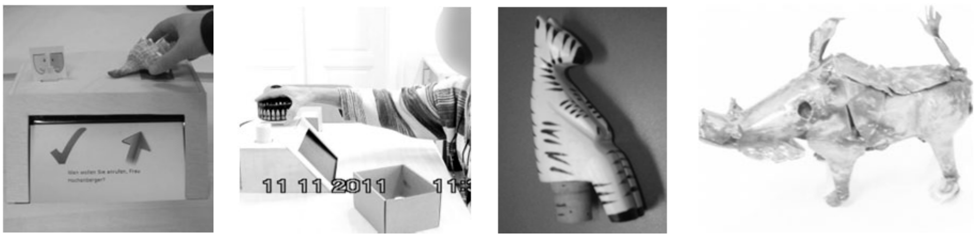

Figure 2: User interaction with personal tokens

- Each participant was asked to bring a personal item, which reminds him/her to a special friend or relative. Figure 2 (right) shows a metallic animal, reminding the participant of his wife. The item brings to him his wife in thoughts and is therefore the perfect artifact to serve as interaction token – triggering the digital communication by placing the animal to the defined spot on the prototype. The third photo (Fig. 3) shows a bottle cork in the form of a zebra, reminding one of our participants about her daughter. She told us, that if she hasn't talked to her daughter for a while, she turns the zebra so that the head is pointing away from her. If she feels close to her daughter, she turns the zebra so that the head is pointing towards her.

- The participants' approach towards the technical probe was very diverse: some were standing in a little distance, scrutinizing what laid in front of them, carefully not to touch it, needing strong invitations to start interacting. Others were happily jumping right into interacting with the technology probe.

4 Results

In the two workshops conducted in 2011 we explored a way of triggering interaction through a mixture of tokens: generic, but individually annotated and personal objects. Our focus in *kommTUi* lies on the design of tokens and the use of personal artifacts as interaction trigger. Therefore our token design is twofold: it is generic, since pre-produced by the development team itself, hence personal because of the individual annotation during the design session and the use of artifacts brought in by participants. Summarizing, our findings are:

- Time to start the very first interaction with the new RFID interface is very individual; hence the second round of interaction was carried out fast for every participant.
- The token+constraint relation of the generic tokens and the corresponding slot was understood well. The distinction of the different functionalities of the generic tokens worked out very well due to individual annotation.
- Personal artifacts adapted as tokens helped fostering the relation with communication partners and interaction itself. It "deepened" the communication aims through the selected objects with its own stories and embodied experiences.
- Simple interaction with the technical probe through personal and personalized artifacts was welcomed and especially perceived as useful even for very old age.
- The participants argued against purchasing an additional device for their homes.
- Our invitation to bring own objects and use them to trigger interaction enriched the communication, the experience with the interface and lowered the access barriers towards the interface. Participants were not shy to use their familiar objects.
- Through personal annotation and re-design of the pre-produced tokens the interplay between generic and personalized objects was successful.

The ad-hoc equipping (attaching RFID tags, annotating) made it possible to further explore the importance of familiar artifacts by reducing the barrier of interacting with a novel interface. Our findings show how personal objects can support interaction and reduce access or emotional barriers towards technology by using familiar artifacts with personal relation to the users. This can be helpful for further design and development of ICT products.

5 Conclusion

We argue that the use of personal artifacts supports interaction with novel interfaces. Personal objects "embody" a specific story known by its owner creating an individual relation to somebody or a situation. Therefore, they can link and support interaction, by equipping these objects with RFID tags and serving as tangibles for pre-defined interactions. Additionally, the role of users as co-designers enhances the advantages of generic tokens. Through individual annotations, generic tokens not only benefit from their affordances, but also from the personal relation to the users. Further development and design will be focused on the integration of our current technical setup into various common devices like: smart phones, tablets, home computers, notebooks. The major challenge here is to achieve the same interaction and functionality on different tools in order to further refine the RFID interaction with personal tokens as interaction key.

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7.5 kommTUi: Designing Communication for Elderly

kommTUi: Designing Communication for Elderly

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Abstract. Getting older does not mean being merely excluded from digital worlds. Elderly can at least use the current technology to communicate with their friends and family members without toiling, on contrary with joy and easiness. We know this is not true yet. With our research project *kommTUi* we do our part to get closer to this goal. In this paper we present our achievement so far. One of the outcomes is our approach to better design usable and user-sensitive interaction for elderly. We further show how four design workshops, carried out in two years, and tangible user interfaces we developed so far can generate and support playful environments with elderly. We finish our paper with the presentation of the final model of the new devices we are currently developing in our project.

Keywords: User centered design, technology for elderly, participatory design workshops, tangible user interface, interaction design.

1 Introduction

Two of the main reasons why elderly have problems to accept and use current ICT is the usability of the systems and their accessibility. To solve usability barriers user centred approach introduced to design [1]. This involves an early focus on users by empirically capturing users' needs, requirements, and performance, as well as on an iterative and participatory design [2] [3] [4]. The idea is to incorporate user requirements, goals, tasks, and experiences into the design process. Accessibility, on the other hand, is related to the development of HCI. After finishing the first wave of this development in system design which was large-scaled, rule-based, and pre-planned, the focus was on single individuals with different conditions [5]. Even having established pervasive technologies, augmented reality, small interfaces, or tangible interfaces around us, we still do not understand how these technologies change the nature of human-computer interaction [6]. Approaches like user-centred and participatory design help studying and even designing for single individuals – especially with special requirements like elderly – to connect them with others. So, it is about the combination of technology and process design supported by sophisticated approaches. We need grounded design

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decisions and ways for involving users from the beginning of the design process. In *kommTUi*, we applied exactly this approach what we present in this paper.

2 Project *kommTUi*

The focus in *kommTUi* is on design workshops to develop an intuitive communication tool for elderly. We conducted an evolutionary design process with participatory workshops, qualitative interviews, and multimodal [7] observation and analysis (Fig. 1).

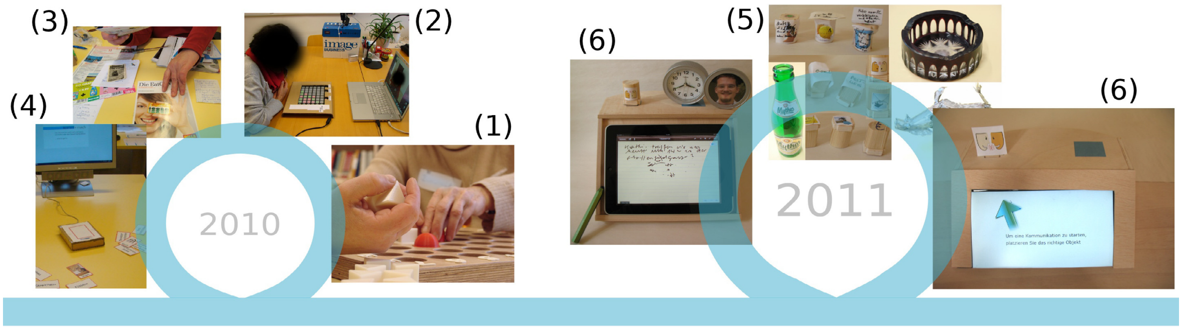

Fig. 1. The timeline of the evolutionary design process in *kommTUi*

In our multimodal workshop [8] series in 2010, we studied basic communication habits of participants and experimented with basic RFID interaction [9]. Our focus was on (Fig. 1): Playful interaction and communication via the popular game "Connect Four": one game equipped with a wooden board triggering multi sensory interactions when played blindfolded (1), one (electronic) game experimenting with playing and communicating remotely supported by a video and audio channel (2); qualitative interviews with each participant using physical artifacts (e.g., photos, personal items, cuddly toys, newspaper clippings, etc.) to unfold the individual communication network and habits (3); experiments with RFID interactions using a technology probe (4): Screen content could be changed by placing tokens on a specially marked device, supported by multi-sensoric feedback. Two use cases have been realized, one feeding a cat and the other making tea.

Based on the results from 2010, we defined the content and probes for the workshops in 2011. This time we focused on tangible interaction with communication devices, i.e., on the design of tokens, the use of personal artifacts as interaction triggers, and on the design of mock-ups. The hands-on set up included the following components: Collaborative design of pre-produced generic tokens (different for calling, sending photos, and sending notes) created by using various design materials and moderated by the research team (5); further definition of the idea of personalized tokens trying to use personal relations to artifacts with a special meaning [10]; each participant was invited to bring personal items to the workshop; these items were photographed and equipped with RFID tags for immediate use as personal tokens during the workshop (5); user interaction with a technology probe (Fig. 2) by triggering events through the previously designed generic tokens and the personal tokens (6); qualitative interviews with each participant during this interaction.

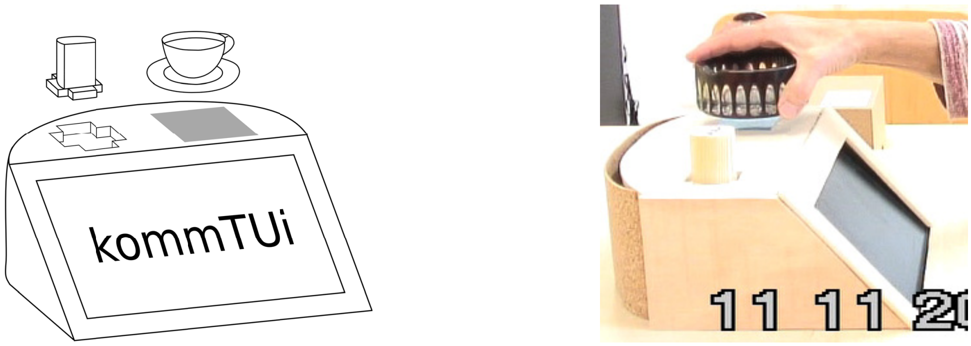

Fig. 2. The technical probe used in the 2011 workshop series

The technical probe presents a communication device based on tangible interactions. On the top of the screen there are two areas on which the users can place their tokens. Each area is equipped with an RFID reader, hidden beneath the wooden case. The left area provides a slot, shaped like the bottom of the generic tokens. The affordance of these tokens inform users where and how to position the token on the probe. With the generic tokens, the user can switch between different functionalities like sending a text note or picture, or starting a Skype call. The personal tokens are placed on the right area, marked with a colored rectangle. Due to differences in shape and size of the personal tokens used in our workshops, we decided to reduce the design of this area to a simple colored marking. The personal tokens both determine the recipient and start the communication. Token interactions are followed by visual and acoustic feedback. Throughout all workshops we had very positive reaction to the interaction with this technical probe. Especially the usage of the generic tokens proved to work without problems.

3 Conclusion

Besides the positive feedback of the users in our workshops, for many participants it is very important to keep the number of electronic devices in their households as small as possible. That is why, we in a next step translate the tangible functionality of the technical probe into a smaller device (Fig. 3), which can be connected to a standard PC or notebook. Additionally, the increasing availability of Near Field Communication technology can be used to interact with personalized tokens. Telephone numbers can be stored in personal objects equipped with RFID tags and than be accessed through reading the tag with the phone (e.g., the cup in Fig. 3). This way we link the *kommTUi* technology with devices that are already present in many households and increase accessibility of ICT for elderly, by using programs or functionalities like web browser, Skype calls, etc. through tangible objects.

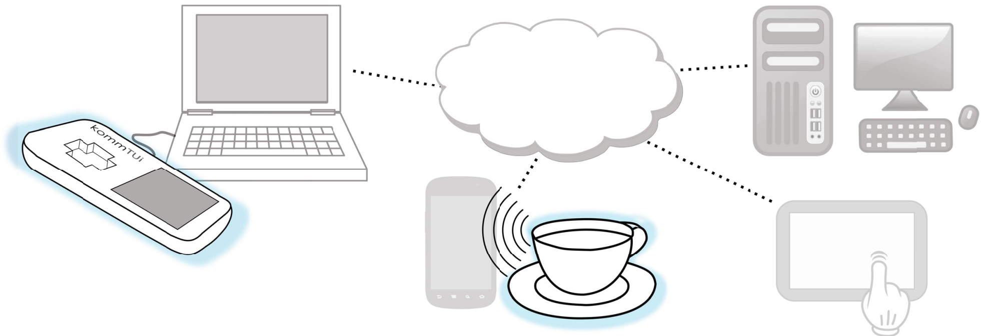

Fig. 3. The final model of the new devices in development [11] in *kommTUi*

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7.6 kommTUi - A Design Process for a Tangible Communication Technology with Seniors

kommTUi – A Design Process for a Tangible Communication Technology with Seniors

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Abstract. In this paper we present the analysis of the three years iterative design process of the research project *kommTUi*. In *kommTUi*, the goal was to design and develop an accessible communication system with tangible user interface to support digital inclusion of elderly people. We propose our qualitative approach for user involvement and identify the atmosphere as key factor for successful research outcome when working with older adults. Therefore, we introduce a graphical analysis tool for comparing the conducted workshops by means of different trigger elements like tangible input, location, participants and communication.

Keywords: user centered design, tangible user interface, design process, AAL.

1 Introduction

Efforts to support elderly people staying in their homes or in supported housing through assistive technologies (Ambient Assisted Living – AAL) have grown into a big research field with a lot of technological innovations in recent years. A large number of AAL research projects deal with topics like fall detection, health monitoring or smart homes, but also digital inclusion. A key requirement for all these technologies is accessibility, which means that they should be equally available to as many people as possible coming from diverse backgrounds with different technology knowledge. A lot of research has been done regarding user involvement and participation in this field [1-7]. However, there is little research on designing tangible user interfaces for and with elderly people. We describe our design approach for user involvement in the development process of a tangible communication tool. To achieve the goal of an accessible and senior-friendly system, our research project *kommTUi* focuses on a very high level of user integration and scrutinizes the possibilities of tangible user interfaces for user interaction. The integration of potential future users throughout the whole design process ensures early feedback on the interaction- and system design and therefore avoids possible design flaws from the very beginning of the development. We aim for an accessible information and communication technology (ICT) which is not only functional but is also accepted by elderly users and enables them to take an active part in the digital society [8]. In order to achieve this objective,

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we had to carefully plan our user-centered design process, with special focus on creating a respectful and pleasant atmosphere when working with elderly people.

2 Tangible Interfaces

Tangible User Interfaces combine digital data with physical objects. Through interacting with tangible elements it is possible to access or manipulate data linked to these elements. Unlike in Graphical User Interfaces there is not necessarily a clear separation between systems' input and output - it is also possible to have direct feedback at the input elements (Fig. 1) [9].

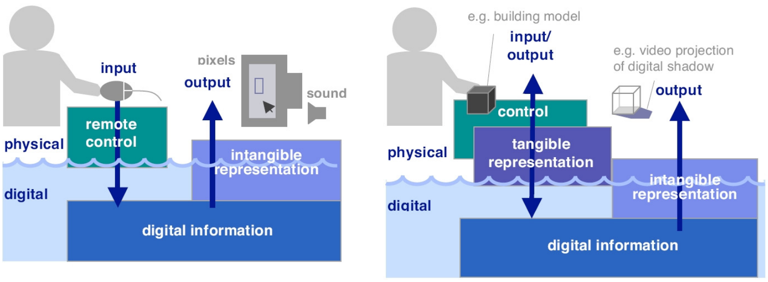

Fig. 1. Comparison of Graphical User Interface (left) and Tangible User Interface (right) [9]

In *kommTUi* we examine the possibilities of tangible interfaces to improve accessibility of ICTs. Accessible communication technologies can help elderly people to use applications and services of digital society and thereby avoid being confronted with (what Brandt et al. call) situated elderliness. Mainly we focus on the design of generic- and personal objects for user interaction. Well-known and often cited examples for tangible user interfaces, like the Marble Answering Machine [10] and the reacTable [11], are using generic objects with geometric shapes as interface elements i.e. marbles or cubes. The usage of generic objects like cubes supports users in the interaction through the natural affordances [12] of their shapes. There are several affordances of cubes, which are already learned in early childhood, i.e. rotate, roll, twist, turn, etc. [13]. They can also be easily included in a token+constraint setup to trigger well-known chains of actions and shape patterns [10]. While generic objects support the user through triggering simple interactions, personal objects can enrich user interfaces on a very individual and emotional level. Personal objects "can be everyday or self-made objects, representing physical, autobiographical objects of memory, reminding the owner of special moments or friends" [14]. They inhere an emotional linkage to the user, turning them into keys, which can only be decoded by the owner of the object. The MEMODULES project uses these relations to create "tangible shortcuts". Personal objects are recognized through a mixture of RFID tagging and image recognition, triggering special functionalities [15]. More recently, Samsung has released the Samsung TecTiles, attachable to every object and usable with every NFC-enabled Smartphone [16]. In kommTUi we scrutinize how tangible interfaces can be used by elderly people and could further improve accessibility of new communication. This has been realized in a user-centered design process, which will be introduced in the next section.

3 kommTUi Approach

From the very beginning of *kommTUi* we focused on the integration of elderly people in the design process. As previous research shows, user involvement has to be carefully composed and well-organized. This has been identified as especially important when working with elderly users: To overcome a potential lack of knowledge of and confidence in (new) technologies [1,4], to raise their motivation to engage in the design process although the benefit isn't immediately clear to them [2], to consider and react to age-related physiological impairments [5], to provide them a pleasant and welcome surrounding not reminding them on a “testing situation” [6], to support an inspiring collaboration in a very heterogeneous group of people [4] or to focus them on the given tasks in a respectful way [3].

Existing participatory user involvement strategies, like the *Future Workshop* format or the *say-do-make* framework, share the challenge of enabling unfamiliar people in an unfamiliar surroundings to produce a creative and successful outcome [17]. Therefore, it is crucial to put maximum effort in providing a respectful and pleasant atmosphere for successful user involvement. As we were confronted with very limited resources (3 team members: project leader, designer, computer scientist, cf. [18]), we had to carefully plan the design process. We defined three iterations for the development of our prototype, each containing user workshops, evaluation and redesign. The structure of the workshops was a mixture of qualitative methods for user-centered design [19]: design sessions, interviews, focus groups, usability testing and feedback rounds. For evaluation, we introduced multimodal analysis frames, a tool for qualitative content analysis with focus on multimodal interaction [20]. This formed the basis for the redesign phase, which completed the iteration. For an overall analysis of the workshops of all three iterations, we designed a graphical analysis tool (Fig. 2) to better compare and understand the similarities and diversities of the conducted workshops. The figure below is the basis of the analysis. As we developed a tangible

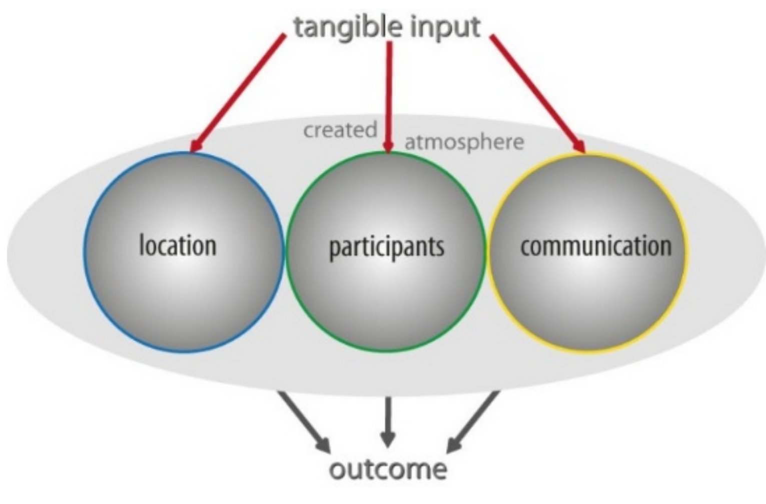

Fig. 2. Basic graphic as analysis tool for *kommTUi*

interface, the role of tangible objects and physicality was high. Therefore, "tangible input" stands for our core variable defined by the research team for each workshop year, influencing communication, interaction, design sessions, location and participants.

The graphic shows the structure of our analysis and enables direct comparison of the three workshops series conducted in 2010, 2011 and 2012. *location* ***l*** stands for the location of the conducted workshops and its relation to the participants. ***l*** can be supportive for the atmosphere when participants know the physical environment or challenging when they are unfamiliar with it [17, 21]. *Participants* ***p*** represents the invited participants for each workshop setting and their relation to each other. This trigger element can be modified by inviting participants, who share commonalities or are unfamiliar with each other, thus influencing group dynamic [21]. *Communication* ***c*** signifies the whole communication including initial contact, pre-information, pre-talks, interaction and the interactive design sessions. ***c*** changes through workshop design (exploratory or more focused on technology) and whether including a contact person known by the participants into the communication process [1]. These three elements form the basis to create a specific atmosphere, which we defined as playful, engaging and inviting from the start of *kommTUi* in 2010. More specific, the atmosphere has to enable openness for exchange, interaction and creativity and reduce barriers towards new technologies, especially when working with elderlies. Knowing the atmosphere we wanted to achieve for each workshop, we had to identify the trigger elements facilitating us to reduce or enhance them as needed. This was essential as we had fixed resources in time and person month for the project and wanted to realize similar quality in the workshops each year. Hence, the analysis technique consists of ***l***, ***p*** and ***c*** as trigger elements and the overall tangible input, which formulated the header of the development. For the workshop comparison we chose the perspective of our participants (user´s perspective), to scrutinize the effects of the conducted events and better understand user involvement and inclusion. In this way we visualize the impacts on planning and designing the *kommTUi* process to reach the specific inviting and playful atmosphere: our basis for successful workshops and research outcome.

3.1 Workshop Series in 2010

The focus of the workshops in 2010 was on exploration of communication habits of elderly people. Therefore, we provided several workshop stations with different kinds of playful user interaction. We had multisensory board game, an interactive board game played via video channel and a RFID station to try out tangible interaction. As we analyze the workshops from the user's perspective, the location in 2010 was totally new for our invited participants: *location* ***l*** was just a small part for the atmosphere to create, because our participants were uneasy about finding and getting along in the unknown surrounding. *Participants* ***p*** was bigger than ***l***: the fellow participants were familiar in the sense, that they all had the same interest group as background, but they did not know each other directly. As a consequence, *communication* ***c*** was important and had to be great, to balance the atmosphere to be achieved. In 2010 we invested a lot of time and resources to meet the interest group in one of their events, we wrote

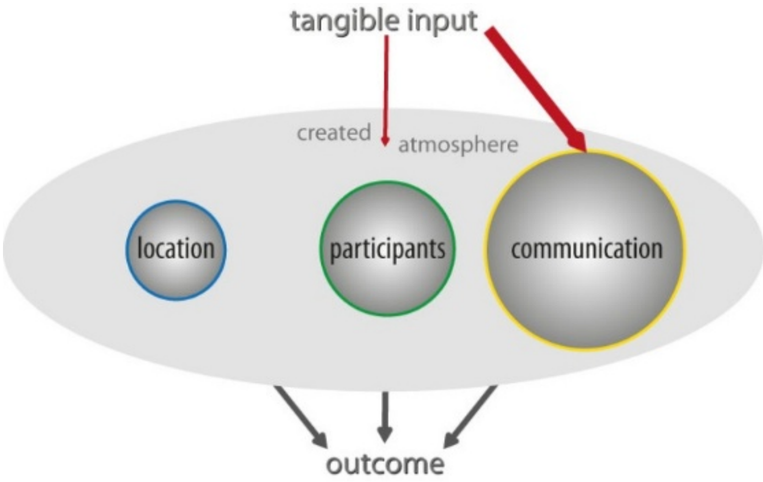

Fig. 3. Analysis of workshops in 2010

emails, designed and gave away cultural probes to each participant and phoned them to explain and getting to know each other. Before and after the workshops itself we conducted discussions and feedback rounds, during the workshops we interviewed each participant with the help of objects (like flyers, flowers, photos, lucky charms etc.,) as mediator to find out more about communication partners and content. Participants brought own flyers, photos etc. to explain topics of communication. *Effects: tangible input was only possible and defined for* ***c,*** *due to the early project phase. By having* ***c*** *as a mayor player,* ***l*** *and* ***p*** *could be less to create our specific atmosphere.*

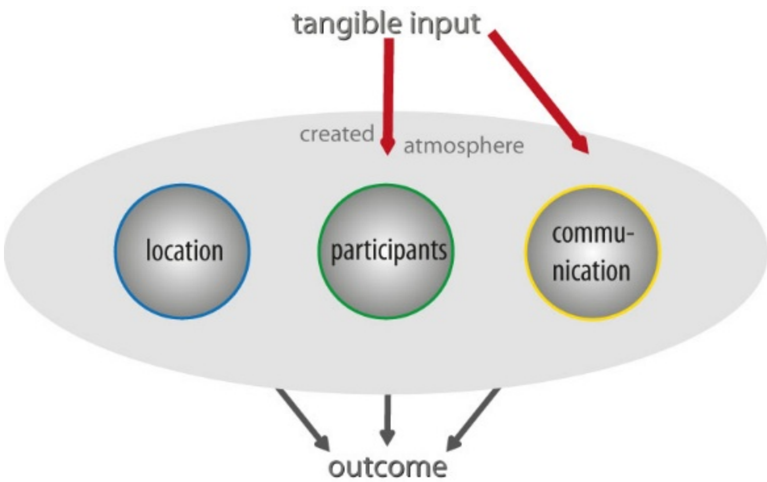

Fig. 4. Analysis of workshops in 2011

3.2 Workshop Series in 2011

In the workshops series of 2011, we focused on the interaction design. Based on the findings of the workshops in 2010, we developed different technology probes to examine basic tangible interactions with elderly people. For that reason, we introduced pre-produced, specially shaped objects made of wood, which we called "generic objects" [13]. Additionally, we asked the participants to bring a personal object to the workshop, reminding them on a special communication partner. This "personal token" was equipped with an RFID-chip during the design session and immediately used for user interaction. In 2011 the participants knew the location well. We were allowed to adopt the space, where they use to meet, exchange and arrange events, therefore ***l*** had a larger share of the defined atmosphere than in 2010: participants had no barriers or anxieties in any kind towards the selected location. *Participants* ***p*** increased too, because all participants knew one person – she was the initial person of the group and she helped us invite the others. ***p*** had the same amount of impact for the atmosphere as *location* ***l***. All participants had the same familiarity towards the others, as they were part of an elderly group of interests. As the two trigger elements ***l*** and ***p*** were more significant, this meant reducing *communication* ***c*** by achieving a similar atmosphere to 2010 was possible. For ***c*** we had a personal meeting with the initial person, we emailed and phoned again in advance to the workshops and gave away an information leaflets explaining our project and the workshop agenda. Tangible input was raised as we introduced personal objects into the interaction. Additionally the workshops started with a design session, where each participant equipped and designed the pre-produced generic tokens and described their personal object and the special relation it represents. *Effects: tangible input was increased by fostering participant's involvement in* **c** *and increasing it in* **p**. *By enhancing* **l** *and* **p**, *the effort for* **c** *could be reduced –* **l**, **p** *and* **c** *were equal in achieving the pre-defined atmosphere.*

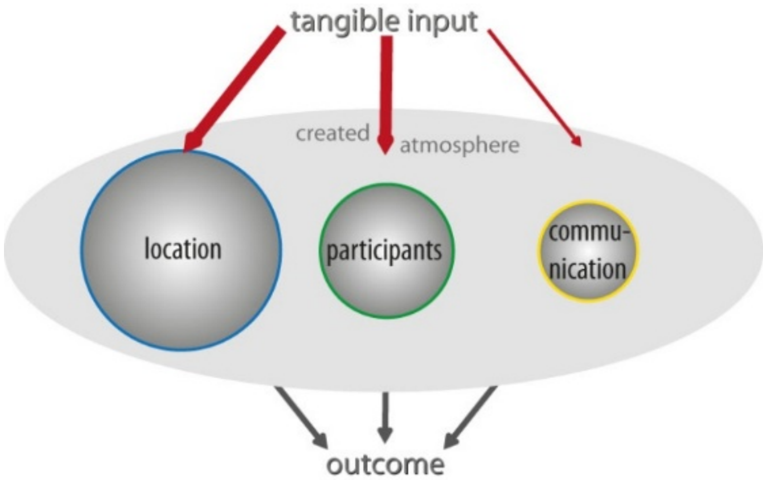

Fig. 5. Analysis of workshops in 2012

3.3 Workshop Series in 2012

The focus of the workshops in 2012 lied on evaluating the usability of the *kommTUi* prototype, which has been developed on the basis of the findings of the workshops in 2010 and 2011. The interaction design stayed basically the same, we had pre-produced generic tokens, which have been equipped and designed by participants, and personal tokens contributed by the participants. The *kommTUi* prototype has been extended to a USB pluggable device, to use it with a standard notebook or PC system. By placing the generic and personal tokens on the *kommTUi* device, the participants were able to use distinct functionalities like starting a Skype call or opening a website. In 2012 the location came to be the major player for the created atmosphere:

Each participant was visited at home - we moved the workshop in the domestic surrounding. From the user's perspective *location* ***l*** had a great influence in creating the defined atmosphere. *Participants* ***p*** stayed similar to 2011: They knew one person accompanying the research stuff. We had 2 different initial persons, hence one always was very well-known and liked by each participant. *Communication* ***c*** could be even smaller than in 2011, besides phone calls directly with the initial persons, we just fixed dates for the visits and talked to each participant shortly about what they had to expect. In 2012 we succeeded in introducing tangible input also in ***l*** and experienced once more the importance of involving known objects for interaction. The possibility of looking around in one's own home during personal objects selection was experienced as very homey and created an openness for telling relations and meanings of the selected objects. *Effects: tangible input was enabled in* ***l****,* ***p*** *and* ***c****. Participants got involved even stronger by enhancing the tangible input in* ***p*** *and* ***l****. The relation of* ***l****,* ***p*** *and* ***c*** *totally reversed compared to 2010:* ***l*** *was the major and* ***c*** *the minor player then.*

4 Conclusions

Our contribution lies in the specific analysis of our design process and our goal to achieve a respectful and pleasant atmosphere by relating specific components like location, participants and communication. Reflecting our analysis and the results, we were amazed by the fact, how clear the analysis tool showed insights in the relation of *tangible input*, *location*, *participants* and *communication* creating a successful workshop atmosphere. We set up the workshops in a way to create for each a similar atmosphere, realized how to increase or decrease each trigger element and how they relate. This was essential, since we had the same time and personal resources throughout all three years and could not increase certain parameters, without reducing others. We had to understand how we could reduce our input in time and effort in one trigger element, if the other was getting bigger in consequence of the chosen workshop structure. A good example for keeping this balance is the fact that the relation of *location* (***l***), *participants* (***p***) and *communication* (***c***) reversed from 2010 to 2012 (Fig. 2, 3, 4). We used different methods throughout the design process to keep ***p*** as an important factor for the atmosphere. This allowed us to increase/decrease ***l*** and ***c*** and still reach the desired atmosphere. The importance of ***p*** is also underscored by the constant *tangible input* throughout the whole design process. By integrating personal objects, the user involvement was getting even more intimate. This highly individualized interaction as part of our overall *tangible input* (Fig. 2) is able to reduce emotional barriers towards the interface and therefore increases the accessibility of the technology – a revelation for design and development of future communication products and an issue we found essential to scrutinize more. However, the high degree of personalization demands for a very sensible and respectful dealing with the elderly people, which underlines the importance of atmosphere for user involvement.

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