Physical Mobile Interactions: Mobile Devices as Pervasive Mediators for Interactions with the Real World

Dissertation
an der Fakultät für Mathematik, Informatik und Statistik
der Ludwig-Maximilians-Universität München

von
Enrico Rukzio

Tag der Einreichung: 19.12.2006

Berichterstatter:

Prof. Dr. Albrecht Schmidt
(Fraunhofer IAIS und
Rheinische Friedrich-Wilhelms-Universität Bonn)

Prof. Dr. Hans Gellersen
(Lancaster University, Großbritannien)

Prof. Dr. Heinrich Hußmann
(Ludwig-Maximilians-Universität München)

Tag des Rigorosums: 31.01.2007

Abstract

So far, mobile devices have mainly been used for interactions between the user, the device and the used service without considering the context of use. However, during the last years we have seen a huge interest in industry and academia in using mobile devices for interactions with things, places and people in the real world, termed *physical mobile interactions* in this thesis. Until now there has been no comprehensive analysis of these interaction techniques and no user studies have been conducted to analyze when which interaction technique is preferred by which users. Furthermore there is no comprehensive framework available which can be reused by application developers to integrate such interactions into their applications, and no specific methods and best practices have been reported that can be of use when developing physical mobile interactions and applications. This dissertation presents the first comprehensive analysis and classification of physical mobile interactions. Furthermore a mature framework was developed that provides various implementations of four different interaction techniques. These four physical mobile interaction techniques were then used in five different prototypes and analysed in five different user studies. The results concern the advantages and disadvantages of these interaction techniques as seen by potential users. This work also reports experiences, guidelines, methods and best practices that simplify the process of developing physical mobile interactions and applications. Furthermore this dissertation provides an analysis of privacy aspects in mobile interactions with public displays, presents the novel interaction technique *rotating compass* and the first concept of using the mobile device for direct touch-based interaction with dynamic displays.

Zusammenfassung

Mobile Endgeräte sind inzwischen zu einem alltäglichen Begleiter geworden und werden zunehmend für Interaktionen mit Dingen, Orten und Personen in der realen Welt eingesetzt, welche im Rahmen dieser Arbeit als physikalische mobile Interaktionen bezeichnet werden. Bisher gab es aber noch keine umfassende Analyse dieser Interaktionstechniken und keine Nutzerstudien, die erforscht haben wann welche Interaktionstechniken von wem bevorzugt werden. Weiterhin gibt es kein umfassendes Framework für die Integration dieser Interaktionstechniken in neue Anwendungen und keine Empfehlungen, die bei der Entwicklung solcher Interaktionstechniken und der darauf beruhenden Anwendungen verwendet werden können. Die vorliegende Arbeit enthält die erste umfangreiche Analyse und Klassifikation von physikalischen mobilen Interaktionen. Weiterhin wurde ein wieder verwendbares und ausgereiftes Framework entwickelt, welches verschiedene Implementierungen von vier dieser Interaktionstechniken zur Verfügung stellt. Diese vier physikalischen mobilen Interaktionen wurden in fünf verschiedenen Prototypen mit jeweils einer Nutzerstudie analysiert und verglichen. Das Ergebnis sind Erkenntnisse bezüglich der Wahrnehmung der Vor- und Nachteile dieser Interaktionstechniken seitens potentieller Nutzer. Diese Arbeit berichtet weiterhin von verschiedenen Erfahrungen, Richtlinien, Methoden und Erkenntnissen, die bei der Entwicklung von physikalischen mobilen Interaktionen und Anwendungen einbezogen werden können und somit diesen Prozeß erheblich erleichtern. Weiterhin wurden mobile Interaktionen mit öffentlichen Displays näher betrachtet, die Art der Informationen analysiert, die hierbei dargestellt werden können, und zwei neue Interaktionstechniken - der *rotierende Kompaß* und *die direkte Interaktion mit dynamischen Displays* - entwickelt.

Acknowledgements

First and foremost, I would like to thank my supervisor Albrecht Schmidt who had the greatest impact and influence of all on this thesis. I am extremely thankful for all the discussions, collaborations, hints, advice, tips, encouragement and inspiration. Furthermore, he gave me the unique opportunity to work within the Embedded Interaction research group and introduced me personally to many researchers that influenced my point of view, my work and my research in many different ways. I am especially thankful for all the independence and freedom I had, but also that he was ready and eager to help whenever necessary or asked.

My special thanks go to Heinrich Hußmann who also supervised my work in Munich and who gave me the opportunity to do research in many challenging and interesting projects, to work on my PhD and to teach in the Media Informatics Group. I am very thankful for all the guidance and important hints regarding my work in projects, research and teaching.

I am particularly grateful to all the fantastic students who did their practical courses, project and diploma theses within the scope of this work, but there are too many of them to enumerate all of them. The students who had the largest influence on this thesis were Jessica Aust, Gregor Broll, Oliver Falke, Karin Leichtenstern, Alexander De Luca, Friederike Otto, Dominik Schmidt, Sven Siorpaes, Sergej Wetzstein, Johannes Vetter and Eva Vodvarsky.

I would like to thank my colleagues of the Media Informatics group Richard Atterer, Sebastian Boring, Gregor Broll, Andreas Butz, Heiko Drewes, Rainer Fink, Otmar Hilliges, Paul Holleis, Matthias Kranz, Andreas Pleuß, Alexander De Luca, Lucia Terrenghi, Sybille Thomsen, Arnd Vitzthum, Martin Wagner and Siegfried Wagner for having a very inspiring and constructive working atmosphere and for being knowledgeable and constructive co-workers. I would like to especially thank Paul Holleis for his help when fighting with the English language, his cooperation in many student projects and his support when finalizing overdue tasks. I am also very thankful for the support Gregor Broll provided me in the last months which gave me more time to focus on writing this thesis.

A lot of the research described in this thesis was carried out in the context of the Simplicity project [@Simplicity] funded by the European Union, the Pervasive Service Interaction (Perci) project [@Perci] funded by NTT DoCoMo Euro-Labs and in cooperation with industrial research laboratories and companies. I have been lucky to meet many interesting people through these projects who had a high impact on my way of thinking and approach to research. I would like to thank Massimo Paolucci, Chie Noda and John Hamard from NTT DoCoMo Euro-Labs, Ulrich Dietz from Vodafone Group R&D, Robert Seidl from Siemens and all my friends and colleagues in the industry and academia I know from these projects, who have supported me and my work.

The passionate and fruitful discussions with the Pervasive Mobile Interaction Devices (PERMID) [@Permid] community, especially Rafael Ballagas (RWTH Aachen, Germany), Jonna Hakkila (Nokia, Finland), Derek Reilly (Dalhousie University, Canada), Christof Roduner (ETH Zurich, Switzerland), Michael Rohs (Deutsche Telekom Laboratories, Germany) and Pasi Välkkynen (VTT, Finland), were very important for many aspects and viewpoints mentioned within this thesis.

Vic Callaghan (University of Essex, UK) and Keith Cheverst (Lancaster University, UK) deserve my special gratitude for very rewarding cooperations and novel insights in doing research. Their input was vital to many aspects of my research.

I would also like to express my gratitude to Raimund Dachselt who taught me how to work in a structured way, what serious research means and how to write scientific publications even before I started with my work on mobile interactions.

Special thanks go to Paul Holleis, Gregor Broll, Derek Reilly and Andreas Pleuß who volunteered to proof-read parts of the thesis.

I would like to thank my parents and grandparents for their motivation, support, confidence and love throughout my whole live and especially during the years of my education.

Last but not least, I would like to express my deepest gratitude to my wife Yvonne. This thesis would have never happened without the love and understanding you have been giving to me for all these years.

Thanks to the numerous people who contributed to my life and work during the past years but whose names have not found their way into the acknowledgements.

Enrico Rukzio, December 2006, Munich.

A lot of the research presented in this thesis was funded by:

- IST *Secure, Internet-able, Mobile Platforms Leading Citizens Towards Simplicity* (*Simplicity*) project, European Union, [@Simplicity].

- *Pervasive Service Interaction (Perci)* project, funded by NTT DoCoMo Euro-Labs, [@Perci].

- IST *Simple Mobile Service (SMS)* project, European Union, [@SMS].

- IST *Discreet Service Provision in Smart Environments (Discreet)* project, European Union, [@Discreet].

Table of Contents

Figures

Tables

1 Introduction

1.1 Motivation

The often cited article by Mark Weiser *The Computer for the 21st Century*, published in 1991, laid the foundations of the research area *ubiquitous* or *pervasive computing* [Weiser 1991]. This vision is based on the idea that our environment and therefore our everyday lives become augmented with hidden computers in a way that objects and the environment become *intelligent*. The user can interact with the environment without being directly aware that the interaction takes place between the user and one or several computers. The possibility of augmenting the environment with different kinds of computers has been demonstrated in several application areas. The second goal, the invisibility of these computers, however, is in many cases still far from being possible and the user is aware (often necessarily) of the augmentation and needs to know how to interact with it.

An important step towards implementing the vision of ubiquitous computing is the use of mobile devices, which are the first pervasively available computer and interaction device. Most research and products so far mainly focus on the interaction between the user, the mobile device and the available services. The context of use is often not considered at all or only marginally. This does not conform to our everyday life and behaviour in which context plays a central role.

However, in the last few years, a huge interest in industry and academia in using the mobile device for interactions with people, places and things can be observed [Kindberg et al. 2002]. This thesis coins the term *physical mobile interactions* to describe interaction styles in which the user interacts with a mobile device and the mobile device interacts with objects in the real world. Such physical mobile interactions are the focus of this thesis. They enable the nearly ubiquitous use of mobile services that are connected with smart objects. In the terminology used, a smart object can be a real world object, a person or even a location. The usage of physical mobile interactions simplifies the discovery and use of mobile services, enables new kinds of object-, person- or location-based applications and removes several limitations of mobile devices. The most important physical mobile interaction techniques are identified to be *touching, pointing, scanning, user-mediated object selection* and *indirect remote controls*.

To date, there is no research that has identified which physical mobile interaction techniques exist, which implementations are available or are under development, for which applications areas they can be used and what their advantages and disadvantages are. Another open question is the context in which a given interaction technique is preferred by a user and the interaction techniques that are appropriate for specific applications and situations. The location of the object, the distance between object and user, the service related to the object, the capabilities of the mobile device and the preferences of the user are important factors that influence the selection of a specific type of interaction technique. Furthermore, the design, development and implementation of such techniques and the applications based on them are often time-consuming tasks. The reason for this is that, so far, very few techniques, methods or guidelines have been reported that can be of help when specifying requirements, designing, implementing and evaluating such applications or interaction techniques. Moreover, such systems are often built from scratch because only a few tools, APIs and frameworks exist that support physical mobile interactions.

Mobile interaction with remote displays is a physical mobile interaction technique that currently attracts the attention of many researchers because it is a very promising approach to overcome the limited output capabilities of mobile devices. This is also supported by the fact that displays rapidly become cheaper and grow in size and resolution while at the same time mobile devices provide more and more interfaces that can be used to interact with these displays. One further goal of this thesis is thus the development of novel interaction techniques in this area.

1.2 Contribution

The main focus of this thesis lies in physical mobile interactions, in which mobile devices are used as pervasive mediators for interactions with the real world. As discussed in the previous section, there currently is only very little research regarding the classification of such interaction techniques, their usage in mobile applications, their evaluation and their support in tools, frameworks or APIs. The goal of this thesis is to address these issues and to provide corresponding research results from which developers, designers and managers can ground their work and decisions when developing applications that use physical mobile interactions. In the rest of this thesis, such applications are referred to as *physical mobile applications*. The following list gives a very brief overview of the six most prominent contributions of this thesis.

- Definition of the term physical mobile interactions. Delimit its scope from similar research areas. Show application areas and a multitude of sample applications for such technologies.
- Classification and detailed description including characteristics, advantages, issues and implementations of physical mobile interactions.
- Presentation of a framework that can be used to quickly implement physical mobile applications.
- Study-based comparison of several types of physical mobile interaction techniques with the main focus on an evaluation of which type of interaction technique fits best under which situations, applications and scenarios.
- Guidelines and experiences for the design, architecture, creation and evaluation of different prototypes and applications using physical mobile interactions.
- An analysis of privacy aspects and novel interaction techniques in the field of mobile interaction with public displays.

The rest of this section explains these and several other contributions of the thesis in more detail. It also provides pointers into the corresponding chapters and sections.

The term physical mobile interaction is defined, taking the existing definitions for interaction, human computer interaction and mobile human computer interaction into account (section 2.1). Furthermore, the relationship and difference between physical mobile interactions and other research areas like ubiquitous computing, augmented reality, tangible user interfaces, context-aware mobile services, sensor techniques for mobile interaction, interaction design, mobile usability and mobile systems (section 2.2) is elaborated.

The thesis provides the first classification of physical mobile interactions (section 2.3). Every technique is described in a detailed way and both the most recent and the most relevant research which discusses this interaction technique is summarized. Different implementations are described and the advantages and disadvantages of touching, pointing, scanning, user-mediated object selection and indirect remote controls are analyzed comprehensively.

An overview of different application areas in which physical mobile interactions are already used to develop novel mobile services and applications is presented (section 2.4).

To support rapid development of physical mobile applications, the physical mobile interaction framework (PMIF) was developed (chapter 3). An important advantage of PMIF is the provision of a stream metaphor which the application developer can use to retrieve information from and write data to smart objects. The framework provides implementations of the interaction techniques touching using Near Field Communication (NFC) or Radio Frequency Identification (RFID), pointing using visual markers (visual codes or Semacodes) or a laser pointer, scanning using Bluetooth or GPS and user-mediated object selection. The maturity and the usefulness of this framework were validated through its usage in the development of seven prototypes.

The physical mobile interaction techniques touching, pointing, scanning and user-mediated object selection were thoroughly evaluated and compared (chapter 4). This is based on user studies analysing the interaction techniques in the context of mobile interaction in smart environments, a mobile tourist guide, a mobile museum guide, mobile interaction with advertisement posters and a cinema scenario. The results show that in a smart environment the distance between the user and the smart object is by far the most important factor for the preference of an interaction technique. If the object is within grasp, users prefer touching, if the user is too far away for touching but there is a line of sight, users prefer pointing, and in all other cases they prefer scanning. The reason for this is that people tend to be lazy and want to relax when being at home and therefore they try to avoid any physical effort which is needed to use a specific interaction technique. This is not true for the context of a mobile museum and tourist guide in which the user is interested in a nearby exhibit or sight anyway. Therefore, the distance between object and user does not play an important role. In this setting, factors like proactive behaviour of the application supported by scanning, simplicity and reliability provided by user-mediated object selection, innovativeness and fun aspects related with touching, pointing and scanning or simplicity provided by touching and user-mediated object selection can lead to user preference in a given context. The results presented here regarding the advantages and disadvantages seen by the users can be used by application designers when deciding which interaction technique(s) should be provided by their mobile application.

Existing techniques for specifying the context of use and its requirements were used for the development of physical mobile applications (section 5.1). This led to

- documented experiences and best practices for the costs, documentation, classification and quantitative results of field studies,
- a discussion of the costs, the reactions of observed people, documentation, ethical and legal issues of unobtrusive contextual observations and
- an analysis of the results, significance and needed effort for online surveys.

Best practices and experiences regarding the development of low fidelity prototypes to support the process of producing design solutions for physical mobile interactions and applications are reported (subsection 5.2.1 and 5.2.2). For example, different methods are presented for simulating physical mobile interactions when using paper- or HTML/Flash-based prototypes, and the trade-offs regarding the design of such simulated applications and interactions are explored.

It is shown that mobile phones can be used as a versatile platform for developing high-fidelity prototypes that make use of physical mobile interactions and other components connected via multiple interfaces (subsection 5.2.3).

The Physical User Interface Profile (PUIP) was developed which supports the design of important aspects of a physical mobile interaction or application using extensions to the Unified Markup Language (UML) (subsection 5.2.4). PUIP supports, for instance, the integration of aspects like the type of information presented at some point and how the real world context changes during an interaction.

Additionally, guidelines for the design of the architecture, a module pipeline and a process for module definition as well as a diagram for the visualization of context and policies that support the integration of context-aware functionalities in physical mobile interactions and applications were developed (subsection 5.2.5).

Best practices and experiences when evaluating the design of a physical mobile interaction or application using laboratory or field studies are reported (section 5.3).

Interaction with large public displays is a specific area of mobile physical interaction. Concentrating on this area, a matrix was developed which shows which kind of private information can be shown on a public display according to the number of people that see the display and the number that can interact with the display (section 6.1). It was also assessed how curious people are when passing such a display, and how this has to be considered and can be exploited for the development of applications which benefit from this inquisitiveness.

The numerous prototypes developed highlight the characteristics of specific interaction techniques in typical and novel application scenarios. In addition, new types of physical mobile interaction have been found. For instance, an innovative interaction technique for mobile navigation, the rotating compass, was developed (section 6.3). This research shows how synchronized public and private displays can be used in a physical mobile interaction. A corresponding study showed the advantages of this approach. Another example is the first system for direct touch-based interaction with dynamic displays which was designed, developed and successfully evaluated (section 6.4).

These contributions are meant to give people who design or develop applications using physical mobile interactions the means to quickly see which interaction techniques exist, what advantages and disadvantages they have and how they are judged by users within different contexts. After they have decided what type of interaction(s) to use, developers can use the proposed framework, best practices, methods and guidelines to implement the physical mobile applications and interactions of choice. In addition, new interaction techniques were developed that can be integrated into applications or can be the basis for the development of a different set of novel interaction techniques.

1.3 Outline

After introducing the topic and briefly describing the contributions of this thesis in chapter 1, chapter 2 analyzes the relationship between interaction, human computer interaction, mobile interaction and physical mobile interaction. This is followed by a discussion on connections between physical mobile interaction and other research areas. In the central part of this chapter, relevant physical mobile interaction techniques are analyzed and classified. This chapter closes by showing several application areas for physical mobile interactions.

Chapter 3 presents the architecture and implementation of the Physical Mobile Interaction Framework (PMIF). This framework supports the development of applications using various types of physical mobile interactions. Furthermore, instructions are given on how the framework can be used by an application developer and seven prototypes are presented that were developed using this framework.

Chapter 4 compares the interaction techniques touching, pointing, scanning and user-mediated object selection. This comparison is derived from the evaluation of five prototypes that were developed in the context of this thesis. Based on this, it is determined under which circumstances a specific interaction technique is preferred by a user, and when an interaction technique should be supported by a system.

Chapter 5 then presents methods and best practices for the development of physical mobile interactions and applications. This chapter is structured according to the user-centred design process and is subdivided into the three parts: specification of context of use and requirements, generation of design solutions, and evaluation of the systems.

Chapter 6 focuses on physical mobile interactions with public displays. First, aspects like privacy, curiosity and personalisation are discussed. Then two novel interaction techniques developed in the context of this thesis are presented: the rotating compass, an innovative interaction technique for mobile navigation, and a prototype that focuses on touch-based direct interactions with a dynamic public display.

The thesis is concluded in chapter 7 with a brief summary, a compact presentation of the main contributions and a discussion of possible future work.

Publications:

Excerpts of this thesis have been published in conference and workshop articles as well as patents: [Rukzio et al. 2004a], [Rukzio et al. 2004b], [Rukzio et al. 2004c], [Noda et al. 2005], [Rukzio et al. 2005a],[Rukzio et al. 2005b], [Rukzio et al. 2005c], [Rukzio et al. 2005d], [Rukzio et al. 2005e], [Schmidt et al. 2005a], [Schmidt et al. 2005b], [Broll et al. 2006a], [Broll et al. 2006b], [Falke et al. 2006b], [Falke et al. 2006a], [Holleis et al. 2006], [Leichtenstern et al. 2006], [Rukzio et al. 2006a], [Rukzio et al. 2006b], [Rukzio et al. 2006c], [Rukzio et al. 2006d], [Rukzio et al. 2006f], [Siorpaes et al. 2006] and [Broll et al. 2007] .

Several project and diploma theses as well as practical courses have been supervised by the author and served as basis for many results described in the thesis, most notably [@PEMS 2005, @PEMS 2006, @PME 2004, Alzetta 2006, Broll 2006, De Luca 2006, Falke 2005a, Falke 2005b, Leichtenstern 2006, Otto 2006, Ruseva 2006, Siorpaes 2004, Siorpaes 2006, Teuber 2006, Vetter 2006, Volkwein 2005, Wetzstein 2005].

Notes on Writing Style:

To increase readability, neutral persons will be referred to using the female pronoun only (*she* instead of, e.g., *she or he*) throughout this thesis. The parts of the thesis are named as follows: a single number X denotes a chapter, X.X is referred to as a section and all other parts like X.X.X or X.X.X.X are called subsections. If more than one paper is referenced at a specific position then these papers are listed in an alphabetical order.

2 Related Work and Classification

The concept of physical mobile interactions was developed within the context of this thesis. Therefore the first section of this chapter discusses this term and its relationship to the terms interaction, human computer interaction and mobile human computer interaction. The following section introduces and discusses related research areas like ubiquitous or pervasive computing, augmented reality, tangible user interfaces, context-aware mobile services, sensor techniques for mobile interactions, interaction design, mobile usability and mobile systems. Thereby the important research questions will be addressed and the differences or rather the relationship to physical mobile interactions will be depicted.

So far no classification of physical mobile interactions can be found in literature. Therefore existing classifications of related interaction techniques are analyzed in the following section and a taxonomy to distinguish interaction techniques is developed. This taxonomy is based on the sensed property, the number of supported dimensions, whether the interaction is direct or indirect and whether it is a relative or absolute interaction.

The following subsections present a classification of the interaction techniques touching, pointing, scanning, user-mediated object selection and indirect remote controls that were defined within the context of this thesis. The description of each interaction technique starts with a catchy name, a compact description of the usage and principles of the interaction technique and the classification according to a previously discussed taxonomy. This is followed by a discussion of the advantages and disadvantages of this particular interaction technique. Based on this, relevant implementations, prototypes and services will be discussed in detail to show the diversity of the existing technical solutions. The next section of this chapter then discusses different application areas for physical mobile interactions and in this way also shows their potential for novel mobile services and commercial applications.

2.1 From Interaction to Physical Mobile Interaction

The aim of this section is to discuss the definitions and relationships of the terms interaction, human computer interaction, mobile human computer interaction and physical mobile interaction based on previous work and findings of the author.

2.1.1 Interaction

The term *interaction* consists of the prefix *inter* and the word *action*. *Inter* literally means between or among, and the noun *action* has the basic meaning *the process of doing something to achieve an aim* [@AskOxford]. Other definitions found in Microsoft's Encarta are *communication between or joint activity involving two or more people* and *the combined or reciprocal action of two or more things that have an effect on each other and work together* [@MSNEncarta].

Basically all definitions focus on the relationships of at least two entities. If one of these entities is a computer and the other a human then we call this human computer interaction. Mobile human computer interaction addresses the interaction between a person and a mobile device. Physical mobile interaction focuses on the interaction of the three entities user, mobile device and smart object.

2.1.2 Human Computer Interaction

The following citations point out definitions for the term human computer interaction itself as well as direct and indirect human computer interaction.

> *By interaction we mean any communication between the user and a computer, be it direct or indirect. Direct interaction involves a dialog with feedback and control throughout performance of the task. Indirect Interaction may involve batch processing or intelligent sensors controlling the environment. The important thing is that the user is interacting with the computer in order to accomplish something.* [Dix et al. 2003]

The definition of [Dix et al. 2003] limits human computer interaction to situations in which the user explicitly wants to *accomplish something*. This definition thus excludes systems which adapt according to the behaviour of the user and where the user is not aware that she triggers this adaptation.

Beside the terms *direct* and *indirect interaction*, the terms *explicit* and *implicit interaction* can interchangeably be used instead as one can see in the following definition.

> *Explicit interactions include most of today's mouse and keyboard-based interaction models, where the user initiates a discrete action and expects a timely discrete response. Implicit interactions may use passive monitoring of the user over longer periods of time, and result in changing some aspect of the rest of the interaction.* [Wilson, Oliver 2005]

As both examples for the illustration of indirect and implicit interaction show, this kind of interaction has a strong relationship to the research area ubiquitous and pervasive computing. This also shows one of the goals that this research wants to achieve. It should be possible that the user interacts implicitly with the environment instead of always having to explicitly interact with a personal computer.

Another synonym for direct and explicit interaction is foreground interaction, with background interaction being the synonym for indirect and implicit interaction as one can derive from the following definition.

> *What we mean by Foreground are activities which are in the fore of human consciousness - intentional activities. […] By Background, we mean tasks that take place in the periphery - "behind" those in the foreground.* [Buxton 1995]

2.1.3 Mobile Human Computer Interaction

The following citation defines the term mobile human computer interaction and its relationship to human computer interaction.

> *[…] will be defined as the study of the relationship (interaction) between people and mobile computing systems and applications that they use on a daily basis. […] HCI is concerned with investigating the relationship between people and computer systems and applications. […] we are concerned with understanding the users, their various capabilities and expectations and how these can be taken into consideration in the mobile systems or application design.* [Love 2005]

In the context of this thesis the term mobile human computer interaction denotes in general an interaction between a person, her mobile device and the service she uses. Examples therefore include making phone calls, writing text messages, surfing the web or playing simple games. Research in the field of mobile human computer interaction focuses often on the input and output capabilities and techniques of mobile devices and how these can be designed or used to build effective user interfaces. Detailed information about the state of the art and trends in mobile human computer interaction can be found in [Jones, Marsden 2006, Lindholm et al. 2003, Love 2005, Weiss 2002].

The research area mobile human computer interaction (Mobile HCI) can be seen as a field of its own. This becomes obvious when looking at the identically named conference series which started as a workshop with 70 delegates in 1998 and which is in the meanwhile a matured conference with several hundred participants [@MobileHCI 2007].

2.1.4 Physical Mobile Interaction and Application

This thesis focuses on mobile interactions between a user, a mobile device, and a smart object in the real world. This specific mobile interaction technique is called *physical mobile interaction*. In this approach the user interacts with smart objects through the mobile device as she interacts with the mobile device and the mobile device interacts with the smart object. A *physical mobile application* is a mobile application that takes at least one physical mobile interaction into account.

Physical mobile interactions support the discovery and usage of services in a given context. This is one of the central issues that has to be addressed for creating innovative and useful mobile services [Rukzio et al. 2004b]. The generic term *smart objects* is used within the context of this thesis to summarize things, people and places with which the user can interact with [Kindberg et al. 2002]. The object is thereby often augmented to store and provide information used for the interaction. When talking about mobile devices in this thesis then those primarily refer to devices like mobile phones, smart phones and PDAs.

Mobile interaction with other *people* who also use a mobile device addresses applications like Bluetooth based exchange of multimedia data or mobile gaming applications. Interaction with *places* focuses mostly on location based mobile services in which one can interact with places whereby the location of the user and the object is used to start or to control an application. The mobile interaction with *things* like advertisement posters, public displays, objects within smart environments or other electronic devices is relatively new when compared with the other two options. Examples for this are the usage of the built-in camera of a mobile phone to take pictures of visual markers on advertisement posters which represent a URL, or touching an RFID-tag connected to a printer with a RFID-equipped mobile phones to print a file stored on the mobile phone.

An important difference between mobile interaction and physical mobile interaction is the distance between the entities involved in the interaction. A mobile interaction may happen between two entities that might be thousands of kilometres away from each other such as calling a friend on another continent. Physical mobile interaction instead requires the proximity of the entities involved in the interaction. This could for instance mean that the user has to be able to see the object, that it should be possible that the user can go nearby to the object or that the user can touch the object or point to it. A physical mobile interaction also presumes that a service related to the smart object exists, that the mobile device is capable to interact with the smart object and that the user can use the service via her mobile device.

The following Figure 1 shows the different parts of a physical mobile interaction. It depicts that mobile human computer interaction is based on the interaction of a user with her mobile device to use a mobile service which may be provided by an external server. In addition to that it is shown that a physical mobile interaction consists of a human computer interaction between the user and her mobile device, and a machine-machine interaction between the mobile device and smart objects in the physical world.

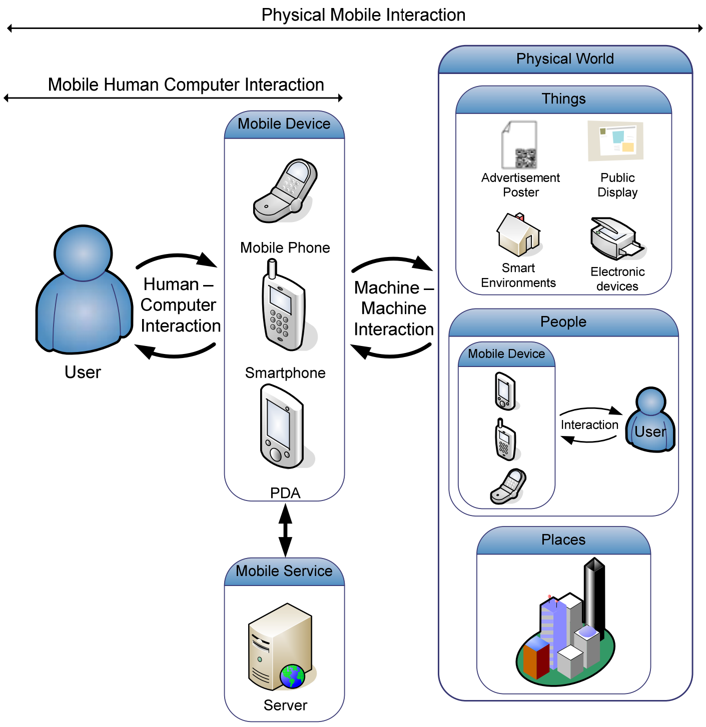


Figure 1: Elements of a physical mobile interaction.

The following Figure 2 is based on the analysis presented in the following sections and illustrates the most common communication channels between the user, the mobile device and the smart object. The arrows indicate the direction of the information flow. The focus of the classification discussed within this work is primarily the interaction between the mobile device and the smart object. The interface between the user and the mobile devices has been the focus of previous work as discussed in subsection 2.1.3 and will therefore be only briefly addressed whenever it is necessary.

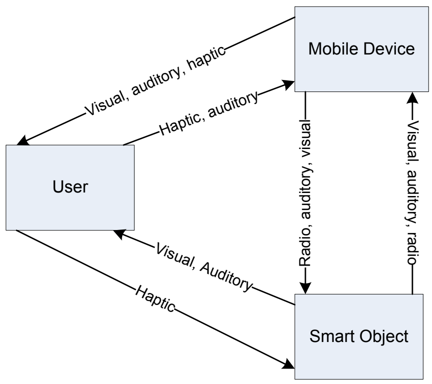


Figure 2: Communication channels between user, mobile device and smart object.

2.2 Related Research Areas

The aim of this section is the compact presentation of research areas that are related to the work presented within this thesis. Therefore in the following the relationships between physical mobile interactions and other high level interaction styles like augmented reality, virtual reality and ubiquitous computing are shown. Figure 3 gives an overview of different human computer interaction styles based on a classification of [Rekimoto, Nagao 1995] where the relationships between the real world, the computer (PC, mobile device, head mounted display, etc.) and the user are shown.

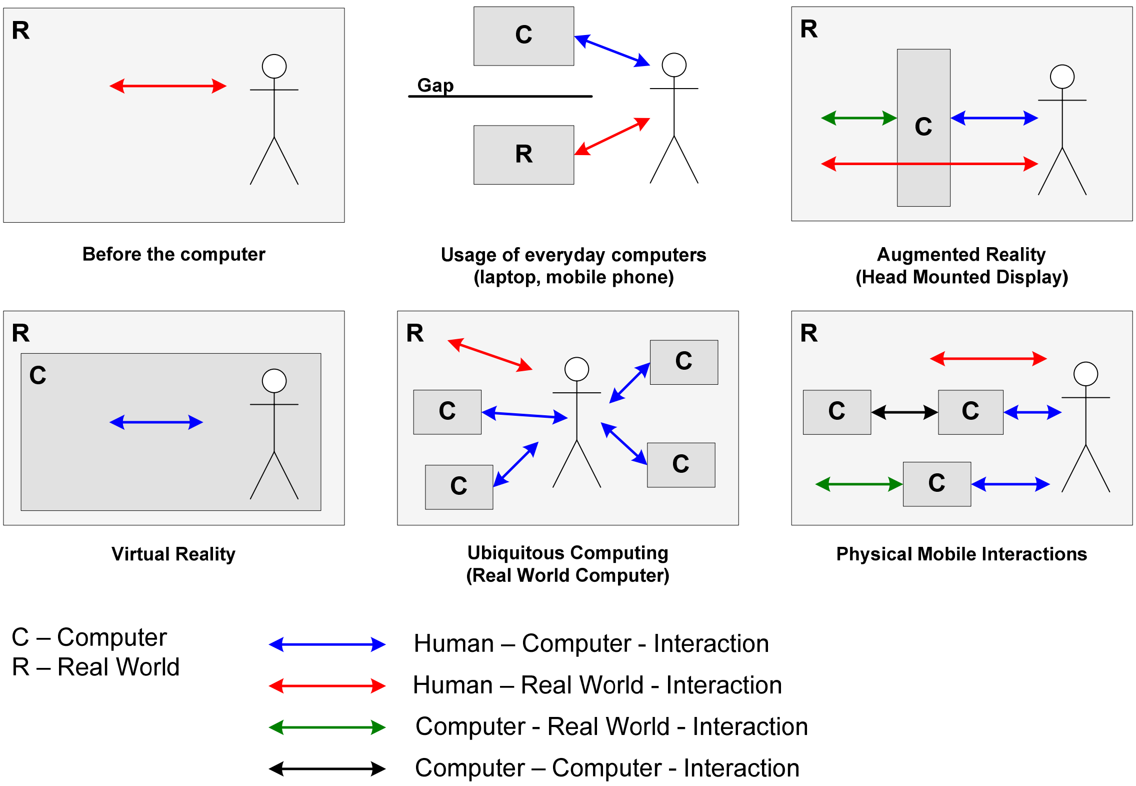


Figure 3: Comparison of HCI styles based on [Rekimoto, Nagao 1995].

The left top image of Figure 3 shows that we interact directly with the real world when not using a computer. When using everyday computers such as laptops or mobile phones then there is no interaction between the computer and the real world. This also includes conventional mobile human computer interactions in which the context of use is not considered. In this case there can only be indirect interactions with the environment in which the user acts as a mediator between the real world and the computer.

Physical mobile interactions in which a mobile device can be used for interactions with the real world or other computers (e.g. public display) are depicted in the upper right of Figure 3. This interaction technique is a special field in the area of ubiquitous computing that focuses on the interaction between a person, her computer (mobile device) and a potentially huge set of computers (smart objects) located in the real world. In addition to that it is possible that the mobile device interacts directly with the real world (real word – computer interaction).

The difference to virtual and augmented reality is that the mobile device in a physical mobile interaction is rarely used to augment the environment or to give the user the impression that she is in a virtual reality. The research field augmented reality will be discussed in subsection 2.2.2.

Apart from small changes, the differences with the classification of [Rekimoto, Nagao 1995] mainly concern the extension by computer - computer interaction, showing the interactions before using the computer and the illustration of physical mobile interaction.

There are different definitions for the previously mentioned human computer interaction styles that make it difficult to exactly define the differences. So it is sometimes not possibly to say that one interaction technique is just a representative of one HCI style. The NaviCam [Rekimoto, Nagao 1995] is for instance an example for a prototype which fits to augmented reality, ubiquitous computing and physical mobile interaction.

2.2.1 Ubiquitous or Pervasive Computing

Mark Weiser's oft-quoted article *The Computer for the 21st Century* [Weiser 1991] was the starting point of the research area ubiquitous computing or how it is also called pervasive computing. Weiser compares the way we interact with our environment and the way people interact with computers. At this time, more than today, people had to use special syntax or input devices to explicitly interact with communication technology or computers.

> *The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.* [Weiser 1991]

The above statement illustrates his vision of disappearing technology that is part of our everyday live and our environment. People use technology, invisible computers woven into the environment, without thinking about it. Mobile devices are seen by Weiser as just an intermediate step to his vision of pervasive computing. Satyanarayanan [Satyanarayanan 2001] supports this by saying that distributed systems are predecessors of mobile computing which itself is a predecessor of pervasive computing.

2.2.2 Augmented Reality

There is a strong relationship between physical mobile interaction and augmented reality as the following definition shows.

> *An Augmented Reality (AR) system supplements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the real world. […] we define an AR system to have the following properties: combines real and virtual objects in a real environment; runs interactively, and in real time; and registers (aligns) real and virtual objects with each other.* [Azuma et al. 2001]

The big difference as one can see when reading the section about the classification of physical mobile interactions (see section 2.3) lays in the visual augmentation. Most mobile augmented reality systems (e.g. [@KickReal, Azuma et al. 2001, Wagner et al. 2005]) are based on the see-through principle using the camera and the display of the mobile device. Most of the physical mobile interaction techniques are not restricted to this concept. One can interact with a real world object using a mobile device without any kind of visual augmentation. But when looking at some of the implementations of the physical mobile interaction technique pointing (see subsection 2.3.4) then there are also some augmented reality systems like the NaviCam [Rekimoto, Nagao 1995] these are also physical mobile interactions.

2.2.3 Tangible User Interfaces

The vision of tangible user interfaces and tangible bits was introduced by Hiroshi Ishii and Brygg Ullmer [Ishii, Ullmer 1997, Ullmer, Ishii 1997]. Thereby physical objects are linked with bits and the user can access the bits via interacting with these objects.

> *Tangible Bits allows users to “grasp and manipulate” bits in the centre of users attention by coupling the bits with everyday physical objects and architectural surfaces. […] The goal of Tangible Bits is to bridge the gaps between both cyberspace and the physical environment, as well as background and foreground human activities.* [Ishii, Ullmer 1997]

Physical mobile interactions and tangible user interfaces have in common that real world objects are augmented with digital information that can be used by a person through a specific type of interaction. The big difference is that there is not necessarily the need for a mobile device when interacting with a tangible user interface. Taking the statement of Satyanarayanan discussed in subsection 2.2.1 into account, one can view physical mobile interactions as an intermediate step to tangible user interfaces that fulfil one of the basic ideas of ubiquitous computing, which is that of disappearing technologies. But this vision of the disappeared ubiquitous computer is still far away. Furthermore there will always be places in which computers are not available and a mobile device is needed.

2.2.4 Context-aware Mobile Services

There is a very strong relationship between context-aware mobile services and physical mobile interactions. Physical mobile applications have to deal with different users that interact with different mobile devices with different smart objects in different real world contexts. Because of this, most systems that take this kind of interactions into account also have to be context-aware mobile services. Such services are seen as an enabling technology for physical mobile interactions.

A very important key component for the acceptance of new mobile services is their usability and simplicity. Most users are not willing to explicitly select a supported encoding and an appropriate resolution before watching a video on a mobile phone, to configure a huge set of parameters of the mobile device for accessing mobile services or to define which network operators they want to use for which service. Beside these technical aspects different users have different needs. If these are not satisfied, the user might stop using the service and refrain from using it again.

The field of context-aware mobile services addresses these issues whereby different types of context information are acquired and used to adapt to technical requirements and the user’s needs. Many academic and industrial projects were conducted that focused on the acquisition of context information; the composition of context to higher level context information; different levels of context; representation, structuring and managing of context; and reasoning based on context information for the development of adaptive and personalized mobile applications. See [Chen, Kotz 2000, Dey, Abowd 2000, Henricksen et al. 2002] for longer surveys about this subject.

2.2.5 Sensing Techniques for Mobile Interaction

In physical mobile interactions the mobile device interacts with a smart object. Therefore, the mobile device has to sense the real world in some way. This subsection briefly discusses the current state of sensor technology used for mobile interactions.

Sensor data is mostly used for the development of direct or indirect interactions and for the implementation of context-aware applications and services [Gellersen et al. 2002, Hinckley et al. 2000]. Furthermore one can distinguish between sensors that sense human interactions with the mobile device and sensors used for getting information about the environment or close objects. [Schmidt et al. 1999] used for instance light sensors, microphones, an accelerometer, a galvanic skin response and a temperature sensor to predict the user’s context. They combined the information they got from the different sensors to high-level context information such as *holding the phone in the hand* or *being in a meeting*. [Hinckley et al. 2000] used a proximity sensor, a touch sensitive sensor and a tilt sensor to develop sensing techniques for mobile phones and combined them for instance to recognize when the user picks up the mobile device. Furthermore they introduced the idea of sensor widgets with specific interfaces through which an application can access the sensor data or can be informed about changes in the sensor data in a contractually specified way.

The are also commercial mobile phones and services available that show that the integration of sensors can lead to new types of interactions and to user friendly context-aware services. The Nokia N70 which was introduced in 2005 includes for instance a light sensor which is used for adaptations according to the light conditions. In a dark environment the illumination of the keyboard is switched on and the brightness of the display is reduced. The Siemens CX70 Emoty is another example for a mobile phone with built-in sensors. It includes shake, press and stroke sensors to control avatars on the mobile phone. Such gestures are not seen as physical mobile interactions because in this case the mobile phone is not used to interact with smart objects in the real world.

Another application is sensing the surrounding world with the mobile phone. This can be done by sensors such as cameras, infrared sensors, barcode- or RFID-readers or microphones. These sensors are often used in conjunction with the physical mobile interaction techniques and are therefore explained in detail in the following section 2.3.

2.2.6 Interaction Design

As this thesis is focussed on physical mobile interactions, the interaction design during the development process is a very important aspect. There are many definitions of interaction design (a corresponding discussion can be found in [Jones, Marsden 2006]) and in the context of this thesis the following definition is used:

> *Interaction design creates a plan specifying the user needs in terms of required functionality, how this functionality is to be accessed and controlled, the presentation of content, system state, help and feedback information, and the way the system is to integrate with other resources in the user’s context.* [Jones, Marsden 2006]

The user interaction design should happen in parallel with the software development process and should supplement it from the beginning [Dix et al. 2003]. [Dykstra-Erickson et al. 2001] define an interaction design process to be consisting of the following five steps: find out about use, analyzing user data, generating ideas, designing systems and evaluation systems. Based on this, [Jones, Marsden 2006] show, especially for the field mobile interaction design, which techniques are useful in which phase of the process.

Chapter 5 of this thesis presents new findings and best practices that can be of use within the interaction design process when developing physical mobile interactions and applications.

2.2.7 Mobile Usability

The most important goal of interaction design and user-centred design is to develop usable products that satisfy the user's needs and to develop successful products and services. Nielsen defines the term usability as a *quality attribute that assesses how easy user interfaces are to use* [Nielsen 2003]. Furthermore he defines the quality attributes learnability, efficiency, memorability, errors and satisfaction. In addition to this, Dix states that *the ultimate test of a product's usability is based on measurements of user's experience with it* [Dix et al. 2003]. Jones and Marsden discuss the specific usability methods and techniques when developing usable mobile applications [Jones, Marsden 2006].

Mobile usability is an important focus of this thesis, too. Chapter 4 discusses the evaluation and comparison of different physical mobile interactions techniques and through this also analyzes their usability in different contexts. The following chapter 5 then presents different findings and best practices that can be of help within the user-centered design process whose goal is the development of usable mobile applications.

2.2.8 Mobile Systems and Architectures

Mobile applications and services are often distributed systems that are more difficult to develop when compared to conventional software which is not designed for mobile devices and wireless communication. The challenges of developing mobile systems and applications are the limited resources of the mobile device (e.g. memory and processing power), the limited communication capabilities of wireless networks (e.g. bandwidth or response time) and the required distribution of components via different devices and servers. A discussion of these issues and corresponding solutions can be found in [Linnhoff-Popien 2006, Roth 2005, Schiller 2003].

2.3 Classification of Physical Mobile Interactions

The aim of this classification of physical mobile interactions techniques is the provision of a comprehensive overview and the possibility to easily compare those techniques according to several properties. By means of this classification, a system designer, application developer or usability expert should be able to see which interaction techniques can be used under which circumstances and what the advantages and disadvantages are.

The first subsection of this section discusses previous classifications of mobile interaction techniques that influenced the classification scheme used for the comparison of physical mobile interactions in this thesis. Afterwards a taxonomy is discussed that was used to classify physical mobile interaction techniques and their different implementations.

In the following the interaction techniques touching, pointing, scanning, user-mediated object selection and indirect remote controls are discussed in detail. The textual description starts with the name of the interaction technique. One goal hereby is the provision of a distinctive and expressive name for the every interaction technique. At the beginning, the interaction technique is described from the user's point of view. The goal is that the reader gets to know what the user has to do and what the system does. Afterwards the advantages and disadvantages of the interaction technique will be discussed. Following this, technical realizations of the interaction technique will be described. When more than one implementation exists then those are compared showing the corresponding advantages and disadvantages. In addition to that additional information about the history, publications and products which were important for the development of the interaction technique is presented.

2.3.1 Existing Classifications

Before discussing the taxonomy and the different interaction techniques in detail, this subsection analyses existing methods for describing and comparing mobile interaction techniques. The classification of a specific area in a research field is always a very complex task especially because of the huge number of viewpoints one can have. First one can distinguish between the people who develop a new interaction technique, the people who use an existing interaction technique for building a prototype or a product and the people who use or test the product or prototype. When developing a new interaction technique or using an existing one for a new application, then for instance the user interface designer, the project manager, the software engineer and the customer or client have very probably a different perception and are interested in different aspects.

Iftode et al. [Iftode et al. 2004] defined four different interaction models when using a smart phone for interactions with the surrounding environment: universal remote control, dual connectivity, gateway connectivity and peer-to-peer. This classification focuses especially on the several kinds of technical connections between mobile devices and the environment. The dual connectivity model for instance addresses a mobile device with a short range (e.g. Bluetooth) as well as a long range (e.g. GPRS) network. Through this the mobile device can establish a link to a nearby object and can then access the internet for additional services. Satoh discusses in [Satoh 2004] different possible locations of the tag and the reader when using RFID technologies for physical mobile interactions. He discusses different possibilities for attaching the tag as well as the reader to a user or a fixed place. [Ailisto et al. 2003] presented a classification scheme for the comparison of different implementations of physical selection techniques based on visual codes, IrDA, RFID and Bluetooth.

The previous three classifications are focusing on the technical aspects of interaction techniques or technologies for their development. In the following, classifications will be analyzed that focus more on generic aspects of the interaction techniques and abstract from the concrete implementation.

[Buxton 1983] proposed a taxonomy that classifies input devices according to the sensed property (position, motion, pressure), whether a mechanical intermediary is used (e.g. stylus) or not (e.g. touch screen) and the dimensions (1, 2 or 3) of the interaction. [Foley et al. 1984] also presented a taxonomy of input devices that is based on subtasks like e.g. position, orient, select, path, quantify and text entry. [Card et al. 1991] developed another taxonomy for the classification of input devices which focuses on the one hand on the physical properties and on the other hand on the linear or rotary dimensions. The physical properties for the 3 linear dimensions (X, Y and Z) are position, movement, force and delta force. The physical properties for the 3 rotary dimensions (rX, rY and rZ) are angle, delta angle, torque and delta torque. In [Ballagas et al. 2004] the authors discuss several properties of interactions with large displays whereby they concentrate on the usage of personal devices as interaction devices. They analyze three different application domains of large displays: personal, semi-public, and public. Furthermore they discuss the following twelve design considerations when analyzing different interactions: serendipity, portability, sanitation, dexterity, multi-user, physical security, information security and privacy, social acceptability, interruptability, intentional vs. unintentional interaction and maintenance. In addition to that they use the input device taxonomy of Card [Card et al. 1991] to classify their mobile interaction prototype.

2.3.2 Taxonomy of Physical Mobile Interactions

The aim of this taxonomy is the classification of physical mobile interaction techniques regarding basic concepts like property sensed, number of dimensions, direct or indirect interaction and relative or absolute commands. Through this can be seen which interaction techniques are based on similar concepts and which differences exist. Furthermore indicate the empty cells the potential for novel physical mobile interaction techniques.

The taxonomy depicted by the following Table 1 is based on the taxonomy of input devices proposed by [Buxton 1983] and the classification of mobile phone interaction described in [Ballagas et al. 2006b]. The left vertical axis of Buxton's classification analyzes the sensed properties position, motion and pressure. This was adapted so that this axis now shows position, translation and rotation as the sensed properties. In addition to that it is depicted that sensing a position is just a discreet property. Furthermore, translation and rotation are continuous properties that can be sensed by the system. The advantage of using position, translation and rotation is that all positions and movements of the mobile device can be expressed through these properties. This concept is borrowed from the description of interactive 3D applications through languages like VRML or X3D.

The top horizontal axis shows, as in [Buxton 1983], the three dimensions that can be controlled by the user and sensed by the system during an interaction. As in [Ballagas et al. 2006b] an additional column labelled *N/A* is added for interactions in which objects are selected whereby the system can not sense any dimensional information.

The right vertical axis indicates whether the mobile phone interacts directly or indirectly with the smart object. Examples for direct interactions are for example when the mobile device is used to point at or touch a smart object. The usage of Bluetooth as an implementation of scanning or the usage of the mobile phone joystick to control the cursor on a remote display are typical examples for indirect interactions. The bottom horizontal axis shows whether the interaction with the mobile device results in an absolute or relative sensing of the users commands by the smart object. The numbers used within Table 1 are referring to the rows in Table 2 showing for each of the interaction techniques a descriptive name, a relevant reference and a link to the corresponding description in this chapter.

		Number of Dimensions									
		N/A		1		2		3			
Property Sensed	Position (Discreet)		(3), (18)				12, 13			Indirect	Interaction
		1, 2				5, 6, 7, 8		16		Direct	
	Translation (Continuous)				4		10, 13, 14, 15			Indirect	
						9, 6, 7, 8		16		Direct	
	Rotation (Continuous)				10	(17)			11	Indirect	
						9				Direct	
		Abs.	Rel.	Abs.	Rel.	Abs.	Rel.	Abs.	Rel.		
		Interaction									

Table 1: Classification of physical mobile interaction techniques inspired and adapted from Buxton's classification [Buxton 1983].

Nr.	Descriptive Name	Reference	Described in
1	Pointing	[Rekimoto, Nagao 1995, Rohs, Gfeller 2004]	2.3.4
2	Touching	[Want et al. 1999]	2.3.3
3	Speech	[Nichols et al. 2002]	2.3.7
4	Keypad	[@Blinkenlights]	2.3.7
5	Point & shoot	[Ballagas et al. 2005]	2.3.4
6	C-Blink	[Miyaoku et al. 2004]	2.3.4
7	Laser pointer	[Myers et al. 2002]	2.3.4
8	RFID/NFC Grid	[Reilly et al. 2006, Vetter 2006]	6.4
9	Camera tracking	[Madhavapeddy et al. 2004]	2.3.4
10	Sweep	[Ballagas et al. 2005]	2.3.7
11	Acceleration sensors	[Block et al. 2004]	2.3.7
12	Touchpad	[Myers et al. 1998]	2.3.7
13	Joystick	[Silfverberg et al. 2001]	2.3.7
14	Touchpad	[Enns, MacKenzie 1998, Myers et al. 1998]	2.3.7
15	Keypad	[Su et al. 2002]	2.3.7
16	Scanning (location based mobile service)	[Abowd et al. 1997]	2.3.5
17	Rotating Compass	[Rukzio et al. 2005a]	6.3
18	User-mediated object selection	[@BUGAbutler 2005]	2.3.6

Table 2: Interaction techniques referenced in Table 1.

2.3.3 Touching

By means of the interaction technique touching the user can select a real world object by touching it with a mobile device. According to the taxonomy described in subsection 2.3.2 touching is an absolute and direct interaction technique. For using touching the user must be first of all aware of the augmentation of the object. In the next step the user has to touch the object which is only possible when she is nearby to the object. Through this the mobile device knows exactly with which object the user wants to interact and presents related services.

This interaction technique is very natural because it conforms to one of our everyday physical interactions. We often touch objects with our hand or fingers while we speak about them to support the fact that we talk about this object and its attributes. One disadvantage when using this physical mobile interaction technique is that the user must be aware of the augmentation of the object and the provided services. Touching is convenient when the user is nearby the object and does not have to take a long walk to it. Sometimes it is even impossible to go nearby to an object, e.g. when it is on the other side of the motorway. Furthermore, sanitation might be a problem for some users because they have to touch a potentially dirty object with their mobile device.

[Want et al. 1999] were one of the first who presented a prototype for the interaction technique touching which incorporates Radio Frequency Identification (RFID) tags and an RFID reader connected to a mobile device, in this case a tablet computer. They used this prototype for instance to interact with augmented books, documents and business cards to establish links to corresponding services like ordering a book or picking up an email address. In [Tuomisto et al. 2005, Välkkynen et al. 2003] this interaction technique is called *TouchMe* which they realized via proximity sensors that sense the distance between the augmented object and the mobile device.

Typical technologies for implementing this interaction technique are short range RFID and Near Field Communication (NFC). When talking about the usage of RFID as an implementation of touching in the remainder of this thesis then always short range RFID is meant. When using RFID or NFC the objects do not have to be directly touched and depending on the used technology a distance of approximately 0-5 centimetres is sufficient for the selection. As described in [Falke 2005a] the needed dexterity can be also a problem for inexperienced users when they for instance do not know where the tag reader in the device is located and how they have to touch the object or, more precisely, the tag. A typical RFID system consists of an RFID tag or transponder and an RFID reader or writer [Finkenzeller 2003]. RFID tags can be very small and are inexpensive through which it is easily possible to tag objects. NFC is a short range data communication technology using the frequency band of 13.56 MHz. It is a combination of RFID contactless communication technology and wireless networking technology. NFC is a standardized through the Near Field Communication Interface and Protocol NFCIP 1/2 (ECMA-340, ECMA-352, ISO/IEC 18092) and is compatible to MIFARE (ISO/IEC 14443A), FeliCa (complies with ISO/IEC 18092) and ISO/IEC 15693.

The following Figure 4 illustrates the several interaction styles provided by NFC. The first one illustrates that the NFC chip can read information from and can write information to a tag. This is the functionality which is also provided by conventional RFID chips in mobile phones. The second one shows that the NFC chip can emulate an NFC tag, which is read by a reader of an interaction point like e.g. a turnstile in a train station. The last one illustrates that NFC also supports bidirectional communication between two devices which is comparable with very short range Bluetooth communication.

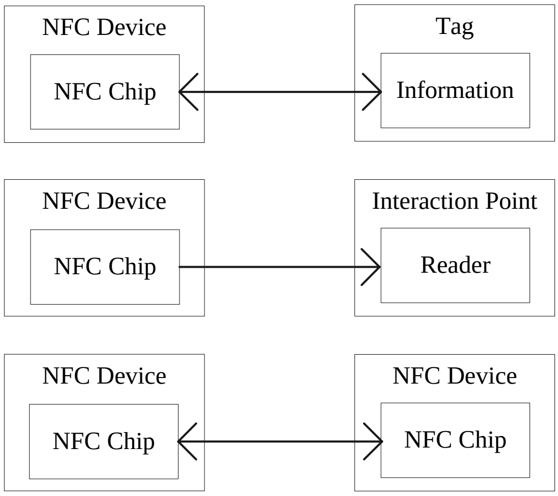


Figure 4: NFC interaction styles.

There are a lot of standards and proprietary solutions in the field of RFID and NFC based contactless short range communication. In the following, just the most important or innovate ones are mentioned.

MIFARE from Philips Semiconductors is a standard for contactless and dual interface smart cards which is fully compliant with ISO 14443A [@Mifare]. These tags were particularly designed for using them as electronic tickets in public transport and have memory capacities of up to 72 kilobytes. According to Philips there were 400 million cards issued and 2 million installed readers in 2003. FeliCa from Sony is a contactless IC card technology certified by ISO/IEC 18092 which is used for electronic ticketing, electronic wallets, identification, access control or e-Commerce [@SonyFelica]. Texas Instruments as another tag vendor offers among others 13.56 MHz and 134.2kHz RFID tags based on ISO/IEC 15693 and ISO/IEC 18000-3 [@TexasInstruments].

The following Table 3 shows some concrete examples of the mentioned RFID standards in combination with some technical details such as operating frequency and storage capacity.

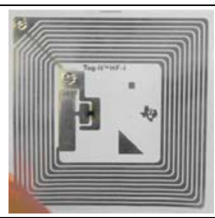
			
Name	MIFARE Standard contactless Smart Card [@Mifare]	Felica Contactless IC card RC-S833 [@SonyFelica]	Texas Instruments RI-I11-112A-03 RFID tag, [@TexasInstruments]
Standards	ISO/IEC 14443A	ISO/IEC 18092	ISO/IEC 15693 and ISO/IEC 18000-3
Facts	13.56 MHz, 1 Kbyte	13.56 MHz, 2 Kbyte	13.56 MHz, 2 Kbyte

Table 3: Tags for contactless short range communication.

The following Table 4 shows some examples of the usage of these standards within mobile devices. In principle it is possible that the RFID and NFC capabilities are provided by the mobile device itself or by an external device.

The Cathexis IDBlue pen [@IDBlue] is a typical example for the latter. It can be connected via Bluetooth to a mobile device through which a corresponding application can read and write tags. Beside this there exist several integrated solutions.

Nokia offers within its Field Force Solution product line the Nokia Mobile RFID Kit for the Nokia 5140/5140i and the Nokia NFC shell for the Nokia 3220 [@NokiaFieldForce].

From Benq-Siemens, there exists a similar prototype based on the Siemens CX70 Emoty [@SiemensNFC].

i-mode Felica is a service which is provided by NTT DoCoMo in Japan [@i-modeFelica, Boyd 2005]. Here mobile phones like the NTT DoCoMo SH506iC include a FeliCa chip to emulate Felica tags. The i-mode Felica service is already widespread in Japan and is currently used for transportation, ticket, membership card, key/ID and shopping applications.

				
Name	Cathexis IDBlue Bluetooth RFID pen [@IDBlue]	Nokia 3220 with Nokia NFC Shell [@NokiaNFCShell]	Benq-Siemens RFID / NFC Prototype [@SiemensNFC]	NTT DoCoMo SH506iC [@i-modeFelica]
Supported tag standards	ISO 15693-2, -3, Tag-it HF/HFI, Philips I-Code SLI	Philips MIFARE (Ultralight, Standard 1k / 4k)	Philips MIFARE Standard 1k	Sony Felica

Table 4: Mobile RFID or NFC devices.

The following Table 5 shows beside the advantages and disadvantages also the different properties of RFID and NFC. The different attributes are partly based on a classification discussed in [Ailisto et al. 2003].

As already mentioned the aim of this subsection was, beside the explanations regarding the interaction technique itself, the provision of a compact overview of techniques for the realisation of it. A comprehensive and detailed overview of short-range RFID and NFC, their usage in mobile applications and their differences, advantages and disadvantages can be found in [Falke 2005a, Falke et al. 2006b].

	RFID	NFC
Advantages	Unobtrusive tagging, simple, robustness, inexpensive, disposable, can be easily sensed	
		NFC device can emulate tags and supports the communication between two NFC devices
Disadvantages	No visual awareness, additional visual marker like the NFC logo is needed. Proposals for solving this problem can be found in [Riekki et al. 2006].	
	No emulation of tags possible	
Data transfer	Bidirectional (read / write)	
Data rate	212 kbps [@SonyFelica]	106, 212 or 424 kbits/s (ECMA-340, ISO/IEC 18092)
Latency	Ca. 1s [@IDBlue]	Ca. 1s [@NokiaNFCShell]
Operating Range	0 - 5 cm [@IDBlue]	0 - 3 cm [@NokiaNFCShell]
Data Storage Type	Fixed (read only tags), Dynamic (writeable tags)	
Data Storage Capacity	Most tags currently have a capacity of up to 5 Kbyte.	
	E.g. 2 Kbyte (Texas Instruments RI-I11-112A-03 RFID [@TexasInstruments])	E.g. 512 bit to 4 kbyte [@Mifare]
Unit costs	Depends heavily on the number of ordered tags and the standard of the tag. Examples: Expected 0,05 $ [Sarma 2001], 0,20 $ [Want et al. 1999], 1,75 € (order of 200 Philips MIFARE Standard 1k tags in 05/2006 from identmarket.de)	

Table 5: Comparison of RFID and NFC.

2.3.4 Pointing

By means of the interaction technique pointing the user can select or control a smart object by pointing at it with the mobile device. Therefore the user has to be aware that the smart object supports the interaction technique pointing. According to the classification described in subsection 2.3.2 pointing is an absolute direct interaction technique depending on its implementations described afterwards.

This interaction technique is very natural because it conforms to one of our everyday physical interactions. So we often point at objects with our index finger while we speak about them to support the fact that we talk about this object and its attributes.

Pointing can be realized by several technologies and interaction concepts which can be based on visual markers, image recognition, light beams or laser pointers, unidentified interaction or infrared technology as described below. [Fitzmaurice 1993] was one of the first who described the concept of using mobile devices for pointing based interactions with smart objects to interact with related services. He described a map on which the user can point to get information about a specific area and an augmented library as a potential application area for this interaction technology.

Tagging real world objects with visual markers and their interpretation has it is origins in the research fields computer vision and augmented reality. Rekimoto and Nagao who presented in 1995 the NaviCam were one of the first who presented a mobile device with an attached camera that interprets visual markers on physical objects [Rekimoto, Nagao

1995]. Their markers consist of a sequence of red and blue stripes. As one can see in Table 6 they used 4-bit visual colour codes which had a size of 3 cm x 5 cm. The NaviCam prototype worked at a distance of 30 cm – 50 cm between camera and marker. This prototype was for instance used to get additional information about pictures, for an active paper calendar and for an interactive door. Several projects focused in the last decade on the further development of visual markers and their interpretation on mobile devices. In the meanwhile there exist several visual markers techniques like for instance QR code [@QRCode], Semacode [@Semacode] or visual codes [Rohs, Gfeller 2004]. Most of them are two-dimensional codes which can store more information than one-dimensional codes like the EAN-13 bar codes attached to the products in a supermarket.

Through the availability of camera-equipped mobile phones with sufficient working memory and processing capabilities we currently see a big interest in using such phones for the interpretation of visual markers. NTT DoCoMo launched in 2003 a mobile phone of the 505i Series which had a preinstalled application for the interpretation of QR codes. Till May 2005 NTT DoCoMo sold about 20 million mobile phones which are capable to interpret QR codes [@QR_DoCoMo 2005, @QRCode_I-mode 2006]. A comprehensive overview of visual markers and their usage can be found in [Rohs 2005]. The following Table 6 shows some examples of visual markers and the corresponding references.

		
NaviCam [Rekimoto, Nagao 1995]	QR Codes [@QRCode]	Visual Codes [Rohs, Gfeller 2004]

Table 6: Several examples for visual markers.

One important factor for the usage of marker based approaches is the minimal and maximal distance between the mobile phone which can be used to interpret the marker. When taking a picture of a marker, the whole marker must be captured in a sufficient quality. Important parameters for the calculation of the possible distances are the minimal requirements of the used marker itself for a successful recognition, the size of the marker, the resolution of the camera, the viewing angle and an eventually existing optical zoom. When using a small marker and a low-resolution built in camera, the mobile phone has to have a distance of not more than just a few centimetres to be able to take a picture of the whole marker. On the other hand there already exist built-in mobile phone cameras with several mega pixel resolution that allow the user to take a picture of a distant marker. In addition to that the size of the marker can be very large like the 100 square meter big markers used within an advertisement campaign in Japan [Fowler 2005].

One disadvantage of those types of implementations is that smart objects need to be tagged with often visually disturbing markers. [Costanza, Leinss 2006] presented a concept which tries to solve this problem by proposing visually acceptable markers. A different approach also uses camera-equipped mobile devices for the implementation of the interaction technique pointing but employ an object recognition based approach instead of using visually augmented objects. Object recognition not only places high demands on the processing power of the mobile device, but the application on it must also be aware of the characteristics of the pointable objects. Furthermore there is no visual indication whether an object is pointable or not. [Fritz et al. 2004] presented a system for outdoor object recognition with camera equipped PDA whereby the analysis of the focused object is done by a server. The PhoneGuide [Föckler et al. 2005] is similar to this system but focuses primarily on the usage within an museum. This implementation is based on a mobile phone which is also responsible for the analysis of the image of the pointed object.

The advantage of the usage of visual markers or image recognition based approaches is that no power supply for the augmentation of the smart object is needed and it can be used with current mobile phones without additional hardware.

[Tuomisto et al. 2005, Välkkynen, Tuomisto 2005] implemented this interaction technique using light sensors attached to the object. The objects are illuminated by a laser beam which is generated by a laser pointer attached to the mobile device. The usage of the laser pointer has also the big advantage that the user gets feedback where she currently points to. This implementation allows easily selecting an object whereby the size of the light sensor, the diameter of the laser beam and the distance to the object play an important role for the complexity of the selection. This concept was extended by [Ma, Paradiso 2002] who showed how to use a modulated laser pointer to convey small amounts of data that can be used for identification. A more sophisticated approach are the RFIG (radio frequency and geometry) lamps in which visual information emitted by a mobile projector is sensed by photo sensors attached to RFID tags [Raskar et al. 2004].

The following Table 7 and Table 8 show an overview of six different implementations of the interaction technique pointing.

<table>
<tr><td>Principle</td><td>Visual marker</td><td>Image recognition</td><td>Light beam</td></tr>
<tr><td>Illustration</td><td>
</td><td></td><td></td></tr>
<tr><td>References</td><td>[Rekimoto, Nagao 1995, Rohs, Gfeller 2004]</td><td>[Föckler et al. 2005]</td><td>[Välkkynen et al. 2003].</td></tr>
<tr><td rowspan="2">Advantages</td><td>Makers are simple, inexpensive, disposable.</td><td>Smart objects do not need to be augmented.</td><td rowspan="2">Very intuitive interaction, Sensors can be small and unobtrusively embedded.</td></tr>
<tr><td colspan="2">No power supply on the smart object is needed.</td></tr>
<tr><td>Disadvantages</td><td>Visual obtrusiveness of the marker, limited information storage capabilities.</td><td>Great demands on image recognition capabilities and data model representing the smart object.</td><td>Smart object must be enhanced by a communication channel (RF, Bluetooth, etc.).</td></tr>
</table>

Table 7: Realizations of the interaction technique pointing – A.

Another realization of the interaction technique pointing which is depicted by Table 8 can be called unidentified interaction. Here the mobile device is just used to record and store image information without being aware of any other information like the identity or meaning of the objects within the picture. The recorded information is later processed by a person who is able to recognize the content of the image. An example for this realization is described in [Schmidt et al. 2005a] where the participants of a game have to take a predefined set of pictures of real world objects with their mobile phone. These pictures are at the end of the game uploaded to a web server and can then be rated by other users.

The usage of IrDA which is built into a lot of mobile devices can be seen as a further realization of the interaction technique pointing. IrDA theoretically supports a range of 0 to 1m between two devices [@IrDA]. Typical mobile devices support distances from 0 to 60 cm. This realization is for example used by the Mobipoint system [@Mobipoint] which is a commercial installation provided by the Deutsche Post to receive for instance codes from a poster that can be used for downloading ring tones for free from a webpage. When using a distance between 0 and 10 cm then the usage of IrDA can be almost seen as one possible realization of the interaction technique touching.

A further implementation of the interaction technique pointing is based on the recognition of the mobile device by the smart object or another mobile device. The Deutsche Bahn introduced for instance a mobile service for buying train tickets. At the end of the order the user gets the ticket in form of a visual marker included within an MMS. Another implementation is the C-Blink system [Miyaoku et al. 2004] which supports absolute direct interaction with a remote display. The mobile phone acts as a visible light source by dynamically changing its displayed information. This is sensed by a camera attached to the remote display through which the position and the movement of the mobile phone can be sensed.

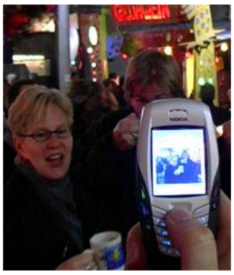
Principe	Unidentified interaction	Infrared / IrDA	Recognizing the mobile device
Illustration			
References	[Schmidt et al. 2005a]	[@Mobipoint, Ailisto et al. 2003]	[@BahnHandyTicket, Miyaoku et al. 2004]
Advantages	Smart objects do not need to be augmented nor identified.	IrDA is integrated in many mobile devices.	Handy possibility for identification (tickets, etc.)
Disadvantages	No computable information about the identity of the real world object is available.	Smart object must be enhanced by IrDA functionalities.	Code (e.g. paid ticket) can not be shown when phone is out of power.

Table 8: Realizations of the interaction technique pointing – B.

One disadvantage of the interaction technique pointing is the dexterity demanded from the user. When using a marker based approach the user must correctly focus to detect the whole marker or, when using a laser pointer based approach, the user has to point directly to the corresponding sensor on the smart object.

Beside the previously discussed implementations of the interaction technique pointing there also exist prototypes focusing on pointing based direct interaction with displays.

The SpotCode interface [@SpotCode, Madhavapeddy et al. 2004] is a direct absolute interaction technique and a camera- and marker-based approach for the interaction with public displays. Sliders and dials are augmented with visual markers through which the mobile phone can identify them and the user can interact with them. Through this it is possible to change the value of a slider by changing the position of the mobile phone in relation to the visual marker and it is possible to turn a dial by rotating the mobile phone.

Point & shoot [Ballagas et al. 2005] is an absolute direct interaction technique in which the mobile phone is used to select objects displayed on a remote screen. The camera and display of a mobile phone is used as a see-through device that augments the remote display with a cross-hair. After clicking the joystick on the mobile device the corresponding object is selected. The implementation of this interaction technique is based on visual codes [Rohs, Gfeller 2004] that are temporarily shown on the remote display to identify on which position the person has clicked using its mobile device.

A lot of work has been done in the field of using a laser pointer for interactions with remote displays. A discussion of such systems and the presentation of one that uses a PDA with an integrated laser pointer can be found in [Myers et al. 2002]. In many of these systems a camera is used to track the laser dot on the screen.

2.3.5 Scanning

The interaction technique scanning is in principle based on the proximity of mobile device and smart object which can be a real world object as well as a location in general. The mobile device scans the environment for nearby smart objects. This action can be triggered by the user or the environment is permanently scanned by the mobile device. The result is in both cases a list of nearby smart objects. Manually selecting one item of this list represents the selection of an object which may provide several services. On the other hand, the system automatically can monitor the location of a user in relation to several objects. In the case a predefined distance between user and object is sensed, a corresponding service is started which e.g. informs the user about the details of that object. The latter is very intuitive because it corresponds to our everyday behaviour. For example, we approach a person when we intend to talk with her or we approach an object to see it in detail.

The advantage of this interaction technique is the possibility to discover all nearby smart objects and the services they offer. The user does not need to be aware of the augmentation of a real world object nor needs this object be visually changed to draw the attraction of the user. One disadvantage of this interaction technique is that there is no direct link for the user between an item on the list of nearby smart objects and a concrete augmented object in the environment. The items in the list can be textual or visual. Based on this information, for example the word *lamp* or an image of it, the user has to find the nearby corresponding smart object. This might be simple when thinking about an augmented microwave but might be complicate when a room has for instance several lamps and just one is augmented or controllable.

The idea of using a mobile device for scanning the environment was first seen in the Star Trek television series (1966-1969). The tricorder, a handheld device equipped with several sensors, was used for scanning unknown environments, to diagnose a patient or for interactions with smart objects or computers [@WikipediaTricorder].

The usage of Bluetooth functionalities of mobile phones is a very popular implementation of user triggered scanning. Bluetooth [@Bluetooth] is a standard for personal area networks which operates in the unlicensed 2.4 GHz band. The Bluetooth version 1.2 which is currently used in mobile phones offers a maximal data transmission speed of 723 Kbit/s. The achievable ranges between the devices depend on the Bluetooth class whereby class 1 supports distances of up to 100 meters, class 2 which is used in most mobile devices supports distances up to 10 meters and class 3 supports distances up to 1 meter. Bluetooth is the first widely available technology for personal area networks but it has some disadvantages which make it not the perfect implementation of the interaction technique scanning: The paring procedure which consists of device selection, service selection and an optional password exchange is often a time consuming task. Especially the device inquiry and name discovery process which may excess 30 seconds does not support spontaneous interactions [David et al. 2005]. Because of this, several approaches have been developed which bypass this process using infrared [Woodings et al. 2002], RFID [Hall et al. 2002] or visual markers [David et al. 2005] to immediately establish a Bluetooth connection between two devices.

[Tuomisto et al. 2005] used SoapBoxes which communicate with each other via radio communication to implement this interaction technique. In this approach all nearby beacons that are attached to real world object are sensed.

Another widely used communication technique that is used for the implementation of user triggered scanning are wireless local networks (WLAN) such as WI-FI [@802.11]. WI-FI is mostly used for connecting mobile devices with a router to establish a voice or internet connection. It is also possible to connect two devices such as two laptops. But this is rarely used, especially because of the quite complicated pairing process.

In general we currently see a huge interest regarding the provision of location services which provide information about location of the user or any other object. Typical approaches are based on cell identification, the Global Positioning System (GPS), distance to near field networks such a Bluetooth or WLAN, RFID, infrared or ultrasound [Küpper 2005, LaMarca et al. 2005, Rao, Minakakis 2003, Want et al. 1992]. A very comprehensive overview of indoor and outdoor positioning techniques that can be used for user and system triggered scanning can be found in [Küpper 2005].

System triggered scanning is typically used by applications within the fields mobile gaming, mobile tourist guide systems and mobile advertisement. An example for such a system is the Buga Butler which was used during the Bundesgartenschau, the German national garden festival, in 2005 [@BUGAbutler 2005]. The Buga Butler is a PDA with a built-in GPS device. Based on the location of the user, the device presents information about points of interest. NTT DoCoMo launched in 2001 in Japan a location based service which is called i-area [@i-area]. Here cell information is used to get information about the restaurants nearby, about the location of the user on a map, about the local weather and information about the town. The research projects CyberGuide [Abowd et al. 1997] from Georgia Tech and the Lancaster Guide project [Cheverst et al. 2000] went a step further and used the location information for the provision of information about objects in mobile context-aware city or tourist guides.

2.3.6 User-Mediated Object Selection

By means of the interaction technique user-mediated object selection the user types in information provided by the object to establish a link between them. No special technology is needed to establish a link between the smart object and the mobile device because the user is in this case responsible for this. Examples for that are portable museum guides like PDAs where the visitor has to type in a number to get information about an exhibit or a URL printed on an advertisement poster to get access to the corresponding services. Common examples where this interaction technique is used can be seen in Table 9.

An important aspect for the usability of this interaction technique is the complexity of the information that the user has to type in. Looking at a mobile museum guide, it is mostly enough to type in a two to four digits number because a museum has a limited number of exhibits and often the museum guide focuses merely on the important ones. On the other hand, when looking at an advertisement poster with a URL then the user has to completely copy it. Furthermore, the mentioned URL is not specific to the poster and the user has to navigate within the provided mobile service to get the specific information related to that specific poster.

It can be said that user-mediated object selection is preferable only when the number of objects is limited and a simple mobile device without special technology supporting other physical mobile interaction techniques should be used. Typing in a URL is also possible when having a simple device and it is the one and only possibility to establish a link to a real world object.

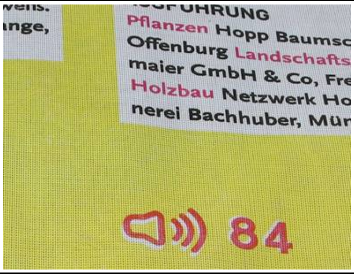
<table>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Typing in a number in a mobile guide [@BUGAbutler 2005]</td>
<td>Number or URL which can be typed into a mobile device.</td>
</tr>
</table>

Table 9: Realizations of the interaction technique user-mediated object selection.

2.3.7 Indirect Remote Controls

This subsection focuses on the usage of mobile devices as indirect remote controls for interactions with remote displays. These interaction techniques are discussed because they are physical mobile interaction techniques but they will not be analyzed in detail because of their indirectness or because they are just extensions of conventional mobile interaction techniques that are based on the usage of the touchpad, joystick or keypad.

Indirect relative interaction using a Touchpad: Position and Translation

[Enns, MacKenzie 1998] were one of the first who used a remote control equipped with a touchpad to control a remote display. With this prototype the user was able to control a television screen via unistroke commands entered on the touchpad. Within the Pebbles project, a PalmPilot (a PDA with stylus and a touch screen), is used as an input device for the interaction with a PC or a whiteboard [Myers et al. 1998]. The RemoteCommander application maps inputs made on the PDA to inputs of the PC through which the PDA replaces the mouse and the keyboard. The PebblesDraw application provides a shared whiteboard with which the users can interact via their PDA. Using the RemoteCommander the user can e.g. click on buttons to control the remote application and can draw e.g. lines using the PebblesDraw application.

Indirect relative interaction using a joystick: Position and Translation

Many of currently available mobile phones have a built-in joystick which can be used to control a cursor and perform clicks on a remote display. [Silfverberg et al. 2001] for instance analyzed the usage of an isometric joystick as a pointing device when interacting with remote displays. [Su et al. 2002] developed a software running on a mobile phone for remotely controlling a PC. At this the joystick of the mobile phone was used for controlling the cursor of the remotely controlled PC.

Indirect relative interaction using a keypad: Translation

Beside using the joystick of a mobile device for controlling a cursor or application on a remote display, the keypad can play a similar role. The keys 2 (up), 8 (down), 4 (left) and 6 (right) can for instance be used to indicate the direction of cursor movement. In addition to that, the key 5 can be used to select an object. Within the Rajicon prototype the keys 2, 4, 6 and 8 were used for indicating in which direction a screen should be scrolled [Su et al. 2002]. The Blinkenlights interactive installation consisted of a skyscraper used as a remote screen. Each of the 144 windows (18 windows per floor x 8 floors) of one front of the building could be highlighted by a lamp behind every window [@Blinkenlights]. It was possible to play a pong game on this remote display using a mobile phone (18 x 8 = 144 pixel). The key 5 moved the paddle up and the key 8 moved it down.

Indirect relative interaction using accelerometers: Rotation

[Block et al. 2004] developed a cube with built-in accelerates to control a remote home entertainment system through the rotation of the cube. There are several approaches to integrate acceleration sensors into mobile devices (e.g. [Bartlett 2000, Hinckley et al. 2000]) but so far the usage of this data for the control of a cursor on a remote display was not investigated. There are also mobile phones on the market which have already built-in acceleration sensors such as the Xpress-on Fun-Shell for the Nokia 3220 or the Samsung SCH-S310. Tilting the mobile device to the left could be for instance mapped to a mouse movement to the left on a public display.

Indirect relative interaction using optical flow: Translation

The *sweep* interaction technique [Ballagas et al. 2005] analyzes the optical flow of the camera of the mobile device to identify relative motions. Through this a mouse cursor on a remote display can be controlled by moving the mobile device.

Indirect relative interaction using speech

Beside these haptic input capabilities it is also possible to use speech recorded by a mobile device to control a remote system. Using for instance the Personal Universal Controller a user can speak the name of a command though which this is executed by the system [Nichols et al. 2002].

2.3.8 Overview of Physical Mobile Interaction Techniques

The aim of this subsection is to provide a compact overview of the previously discussed physical mobile interaction techniques. Every interaction technique in the following Table 10 is described by its name, a compact description, an image, the first or most important publications in alphabetical order, the technology used for the interaction between the mobile device and the smart object, the real world aspects of the interaction, the advantages and disadvantages and finally typical application areas.

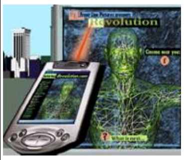
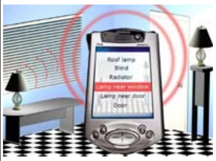
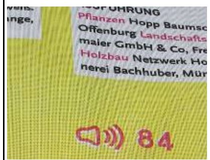
Name	Touching	Pointing	Scanning	User-mediated object selection	Indirect Remote Controls
Description	The user touches a smart object with a mobile device to establish a link.	The user points on a smart object with a mobile device to establish a link between them.	A link between mobile device and smart object is established because of their closeness.	The user types in information provided by the object to establish a link between them.	The user controls a remote display with a mobile device.
Illustration					
References	[@i-modeFelica, Boyd 2005, Want et al. 1999]	[Rekimoto, Nagao 1995, Välkkynen et al. 2003]	[Abowd et al. 1997, Cheverst et al. 2000, Välkkynen et al. 2003]	[@BUGAbutler 2005]	[Ballagas et al. 2005, Enns, MacKenzie 1998, Myers et al. 1998]
Device – Smart Object Interaction	Radio: RFID, NFC, proximity sensors	Visual: visual marker, light beam, IrDA	Location: Bluetooth, WLAN, GPS	No direct link.	Communication: Bluetooth, GPRS, data cable
Real world aspects	Distance object - mobile device: 0...10 cm, line of sight	Distance object - mobile device: 10 cm...10 m, line of sight	Distance object - mobile device: 10 m (Bluetooth), 45 m indoors / 90 m outdoors (WLAN)	Line of sight and readable	Line of sight, often indoors
Advantages	Natural way of interaction. Unambiguous selection of an object.	Natural way of interaction. Distance to the smart object.	Possible to discover all nearby objects, objects need not be visually augmented	No special device is needed.	Control a remote device, controlling a device which has no user interface.
Disadvantages	Proximity of user and object. User must be aware of the augmentation. Dexterity is needed.	Dexterity is needed.	No direct link between smart object and discovered item. Problematic localisation.	Inappropriate when typing in complex linking information (e.g. an long URL) is necessary	The interaction is intrinsically indirect.
Typical Application	Picking up a hyperlink represented by an advertisement	Getting information about a remote object.	Searching for nearby smart object to interact with them	Museum or city guide	Controlling an application on a remote screen within a meeting

Table 10: Overview of physical mobile interaction techniques.

2.4 Application Areas

The aim of this section is to discuss and analyze application areas for physical mobile interactions. Some of them have already been mentioned previously, but this section presents a structured overview of the most important ones independently of the interaction technique and used technology.

Active posters and advertising

Active posters and advertising is one of the most popular application areas for physical mobile interaction techniques. Posters, flyers and announces are widely used and already present the information that should be advertised. These objects need only be augmented and a person can request additional services by using a mobile device. This application area has a huge potential because every display, even road signs, newspapers or clothes can be augmented.

Active posters are for instance used to mediate the purchase of ring tones, wallpapers or music [@J-Ware 2006, @Mobipoint, @NFCCaen 2005, @PhilipsNFC]. Another example is the ToruCa service available in Japan [@ToruCa]. Here the user has to touch a ToruCa reader/writer with an Osaifu-Keitai phone, a mobile phone with NFC capabilities, to get a coupon or a flyer. Another example are augmented advertisements in magazines or augmented business cards [@BarCodeReader].

Tourist and museum guides

Mobile guides are a further popular application area that is already in use for some time using user-mediated object selection or scanning. The principle is that there are objects or areas that could be of interest and a user can use her mobile device to get more information about it. One could distinguish between indoor (e.g. a typical museum, exhibition or gallery) and outdoor guides (e.g. horticultural show, park or garden).

One example is the BUGA butler [@BUGAbutler 2005] used for a horticultural show that supports the interaction techniques user-mediated object selection and scanning. Further examples are a trial testing NFC technology to get information about landmarks in Caen [@NFCCaen 2005], the PhoneGuide [Föckler et al. 2005] used within a museum or Semapedia [@Semapedia] which links real world objects with Wikipedia articles.

Electronic key and ticketing

Using physical mobile interaction techniques the user is able to identify or to prove that she has a valid ticket allowing her to enter a building or a room. The advantage of these electronic identifiers or tickets is that they are easily transferable, they do not need additional space to carry them and they can be read by another electronic device.

Osaifu-Keitai phones are used in Japan for instance as electronic tickets, membership cards and airline tickets [@Osaifu-Keitai]. The mobile phone can also carry access codes [@PhilipsNFC] or public transport tickets [@BahnHandyTicket, @NFCRollout 2006].

Payment

The mobile device can be also used for payment acting as an electronic wallet or providing indirect access to the credit card or bank account. This approach is potentially more secure and provides more interaction capabilities than cash or an extra credit card.

Osaifu-Keitai phones can act as a credit card that can be used for buying any kind of goods [@Osaifu-Keitai]. Another example is using the mobile for paying parking fees [@NFCCaen 2005] or buying a soft drink at a vending machine [@cmode 2004].

Peer-to-Peer sharing

The peer-to-peer based interaction with other electronic devices is another application area for physical mobile interactions. It supports the simple exchange of data between two devices.

Examples include the peer-to-peer based exchange of images between a PDA and a TV or downloading a game from a laptop [@ECMA_NFC 2004]. The connection to another device can be also used for exchanging images, audio files or synchronizing address books [@PhilipsNFC]. Nokia Sensor is an application for peer-to-peer based social interactions between different mobile phone users [@NokiaSensor, Persson, Jung 2005]. A user can design her local homepage that can be read by others and should act as a starting point to get into contact.

Remote control and interaction with displays

Within this application area, which has a very strong relationship to the interaction technique indirect remote controls described in subsection 2.3.7, the mobile device is used to control a remote object. This can be for instance a display, a media server or the washing machine. The advantage of that approach is that one can control a remote device without walking to it or controlling a device which has no input capabilities or user interface.

Modern mobile phones provide support for Bluetooth profiles like the Audio/Video Remote Control Profile (AVRCP) to control devices like television or videocassette recorder, the Basic Imaging Profile (BIP) to send images to another device, the Basic Printing Profile (BPP) to print a document on an external printer and the Human Interface Device Profile (HID) to use the mobile phone as a keyboard or mouse when interacting with a PC [@BluetoothSpec].

Furthermore there are many projects like the Pebbles research project [Myers 2005], the T-Com House in Berlin [@T-ComHouse 2005] or the *Haus der Gegenwart* in Munich [@HausDerGegenwart] that focus on using the mobile device for remotely controlling objects and appliances in smart rooms and houses.

Using the mobile device as indirect remote control for a PC is another application area. Examples are Rajicon [Su et al. 2002] and the Ubiquitous Viewer from Toshiba [@UbiquitousViewer 2005]. [Greenberg et al. 1999] used mobile devices within a group meeting to collaborate with each other using a shared public display. The WebWall is a public screen, installed e.g. in a train station or an airport, with which the user can interact to participate in an auction or a public opinion poll [Ferscha et al. 2002, Vogl 2002]. Using the Hermes Photo Display, a person can use a mobile phone to interact with this public display to upload and view pictures [Cheverst et al. 2005].

There are also examples for using the mobile device as a direct interaction device for interactions with remote displays. [Reilly et al. 2006] and [Vetter 2006] use a mobile device for direct touch-based interactions with static and dynamic maps. Using the SpotCode Interfaces one can use pointing and different widgets to control an application on a remote screen [@SpotCode]. Through the interaction technique sweep and point &

shoot one can use a mobile phone to control the position of the mouse cursor on a remote screen and can also select an object [Ballagas et al. 2005].

Field force

The previous application areas focussed mainly on the typical consumers that are addressed by mobile network providers. This field force application area concentrates on mobile applications that support people within their daily work outside the office [@NokiaFieldForce].

All the services offered by the Nokia Field Force Solution are based on the concept that the system can track what each person did at what point in time. This is a very important source of information for improving the management and control of workflows and services. Security and guarding personnel can for instance confirm that they have been at a certain place by interacting with a marker attached to that place. Thus, the possibility to cheat can be drastically reduced and the management can track their activities. Facility management and home care companies can control when someone performs which tasks. Waste management companies can assure that special containers are checked in specific intervals.

2.5 Summary and Conclusion

This chapter described the way from the term interaction via human computer interaction and mobile human computer interaction finally to physical mobile interaction. The result of this analysis was the definition of the scope of this thesis and to clarify the different interactions within physical mobile interactions and the involved entities user, mobile device and smart object.

Based on this, the following section showed the relationship to the related research areas ubiquitous computing, augmented reality, tangible user interfaces, context-aware mobile services, sensing techniques for mobile interactions, interaction design, mobile usability and mobile systems. At this point, the similarities as well as the differences between physical mobile interaction and the previously mentioned research areas were analyzed in detail.

As the term physical mobile interactions was first defined within the context of this thesis and no other research has analyzed it before, a detailed classification of physical mobile interactions was presented in this chapter. Based on an analysis of related classifications and a taxonomy, the interaction techniques touching, pointing, scanning, user-mediated object selection and indirect remote controls were discussed in a very comprehensive way.

Finally, application areas for physical mobile interactions were discussed which especially showed the relevance of them for industry and academia. The mentioned examples show how these interactions can provide many benefits and advantages in areas like advertising, mobile guides, ticketing, payment, remote controls and field force.

This analysis has also shown that no comprehensive toolkits or frameworks are available that support easy development of prototypes and products based on physical mobile applications. The analyzed systems are often proprietary, support just one interaction technique or are limited to just one application. Therefore the Physical Mobile Interaction Framework was developed which will be presented in chapter 3.

When analyzing the different interaction techniques it was also recognized that very little research regarding their advantages and disadvantages in different contexts or applications areas exists. Very few previous research works were based on user studies showing the opinion of potential customers about an interaction technique and their problems or needs when using them. Because of this, different user studies based on prototypes developed within the context of this thesis were conducted. The results of this work are presented in chapter 4 and shows when and which users prefer in which context which interaction technique.

Because of the novelty of physical mobile interactions there is also very few research that has reported on best practices when specifying the requirements, when producing design solutions and when evaluating such systems. Therefore chapter 5 discusses corresponding results that are based on experiences gathered during the development of the prototypes and the physical mobile interaction framework discussed in chapters 4 and 3.

When analyzing existing research it was recognized that there are very interesting approaches based on using mobile devices for interactions with public displays because this is one solution to overcome the limited visual output capabilities of such devices. This lead to further research in this area described in chapter 6 which focuses on privacy and curiosity aspects, a novel interaction technique for mobile navigation and a new interaction technique for direct interaction with dynamic displays.

3 PMIF: A Framework for Physical Mobile Interactions

The previous chapter discussed and classified different physical mobile interaction techniques. Furthermore different implementations as well as their advantages and disadvantages were analyzed. This previous research has so far mostly focused on one specific interaction techniques, their implementation and applications developed on top of them. The development of such systems is currently mostly done from scratch and is therefore often a time consuming process. Currently only very few frameworks and toolkits exist that supports the implementation of applications that take physical mobile interactions into account.

For these reasons, the Physical Mobile Interaction Framework (PMIF) was developed to support the rapid development of mobile applications and services based on physical mobile interactions [Broll 2006, Rukzio et al. 2005c, Wetzstein 2005]. PMIF supports different implementations of the interaction techniques touching, pointing, scanning and user-mediated object selection. Furthermore it is possible to easily integrate new interaction techniques through a plug-and-play mechanism. In addition to that provides PMIF a simple and uniform stream metaphor to communicate with augmented objects.

The aim of this chapter is to give a compact overview of the framework without discussing details which are primarily of interest when starting to use the framework or when trying to extend the framework. The corresponding details can be found in [Wetzstein 2005], in a tutorial explaining the framework [@PEMS 2006], a tutorial how to install the framework, the documentation of the implemented prototypes, the Javadoc annotations and in the source code itself. The latter documents and code are not published but can be found on the CD accompanying this thesis.

This chapter is structured as follows. The next section relates PMIF to existing frameworks, APIs and toolkits. Afterwards sections 3.2 and 3.3 describe the architecture and implementation of the framework. Taking this into account the usage of the framework is discussed based on a concrete example. Following this, the prototypes which were realized with PMIF are presented in detail since many of them were used in the user studies discussed in chapter 4. This chapter is completed by a discussion of the framework.

3.1 Existing Frameworks and APIs

The development of mobile applications in general is in the meantime very well supported by specific tools, integrated development environments, user interface builders, frameworks, APIs, documentations, tutorials and literature. An corresponding overview for Java ME, Symbian and Pocket PC was for instance provided by the tutorial *Development of Interactive Applications for Mobile Devices* at MobileHCI 2005 [@DIAMD 2005, Rukzio et al. 2005b]. The aim of this section is the analysis of existing frameworks, APIs and toolkits which support the development of mobile applications that use physical mobile interactions.

When looking at the related work in this area, most publications and projects focus on the development and evaluation of novel interaction techniques or applications. The CoolTown project for example provides an architecture and implementation for an infrastructure for mobile interaction with people, places and things [Kindberg et al. 2002]. The WebWall system is an example for a platform that realizes mobile interaction with public displays [Ferscha et al. 2002].

There are several APIs available that support one single sensor type or one single interaction type. For example there is a huge set of APIs for the interpretation of visual markers sensed by a mobile phone camera - such as Visual Codes [Rohs, Gfeller 2004], Semacode [@Semacode] or QR-Code [@QRCode]. The core functionality of these APIs is the extraction of the information encrypted in visual markers.

The Contactless Communication API (JSR 257) is a Java Specification Request which got the status of a final release by 17 October 17, 2006 [@JSR257]. The PMIF framework is very similar to the JSR 257 but has the following advantages.

- It provides an implementation of the interaction technique pointing using a laser pointer based approach, of scanning using Bluetooth or GPS, and of user-mediated object selection in general.
- It provides a uniform abstraction layer for the development of applications that take physical mobile interactions into account. Without PMIF, different APIs such as JSR 257 (Contactless Communication API), JSR 179 (Location API for J2ME), JSR 135 (Mobile Media API) or JSR 82 (Java APIs for Bluetooth) have to be used in conjunction to develop an application that supports different physical mobile interaction techniques. The specifications of all JSRs can be found at jcp.org.
- It can already be used for the development of mobile applications like the ones that will be presented in section 3.5. Whereas it was not yet possible to use a fully-fledged implementation of JSR 257 within the context of this thesis.
- It provides support for the development of the user interface that is needed during a physical mobile interaction.
- It also provides components for the management of physical objects, the communication with object related services and the provision of mobile services.

So far there are two preliminary implementations of JSR 257 available. On the one hand the not officially released NFC Service Platform of BenQ-Siemens which is based on an early version of JSR 257 and which provides support for NFC [NFCSP 2005]. On the other hand there is the Semacode SDK for Java Phones that implements the public draft of JSR 257 [@Semacode].

The Nokia Field Force Solution consists of phones with built-in RFID/NFC functionality, the NFC & RFID SDK, the local interaction client and the local interaction server [@NokiaFieldForce]. This product supports, for example, field workers who just need to touch an electricity meter to get relevant information about it via their mobile phone. The NFC & RFID SDK is an API which can be used to develop Java ME applications that take the NFC/RFID capabilities of mobile phones into account. The local interaction server supports the management of users, tags and the actions that should be triggered when users interact with tags. In contrast to PMIF, the NFC & RFID SDK is a proprietary API that is only supported by Nokia NFC/RFID phones. But this API is currently the only publicly available NFC API providing functionalities for reading and writing tags and as well as the device-to-device communication via NFC. Furthermore, the local interaction server supports the integration into existing back-end solutions of companies and provides functionalities for the management of physical mobile interactions.

iStuff Mobile is a framework based on sensor enhanced mobile phones supporting the rapid prototyping of mobile interactions in interactive spaces [Ballagas et al. 2006a]. One advantage of the platform is the possibility to attach external hardware such as sensors or actuators to the mobile phone and use them within the implementation of the prototype. In contrast to that, PMIF focuses on physical mobile interactions, more on integrated sensors (e.g. a built-in camera or an NFC/RFID reader) and the usage of built-in communication facilities (Bluetooth, WLAN, GRPS) for the communication with external sensors.

3.2 Architecture of PMIF

In this section the architecture of the Physical Mobile Interaction Framework (PMIF) will be presented. First the requirements for the framework are discussed and based on this the architecture of the framework, divided into overall architecture, smart objects, mobile device and server, will be presented.

3.2.1 Requirements

After analysing existing frameworks, APIs and toolkits and before designing the architecture, the following requirements and goals for the PMIF framework were identified and defined. These requirements are also based on experiences gathered during the development of physical mobile interactions and applications that were implemented before the work on this framework had started.

- Support the development and implementation of systems that use physical mobile interactions.
- Support for many different physical mobile interaction techniques based on the different communication technologies between mobile devices and smart objects.
- Provision of abstractions for the programmer that hide the details of the communication technologies used for the communication between mobile devices and smart objects.
- Orientation on existing and evolving standards in this field like Java ME and the Contactless Communication API (JSR 257).
- Provision of interfaces for the integration of additional implementations for existing or novel physical mobile interaction techniques.
- Provision of lightweight components running on the mobile device which allows the easy development of applications that take the memory and processing constraints of mobile devices into account.

3.2.2 Overall Architecture

The following Figure 5 illustrates the overall architecture of PMIF. In this overview, all elements involved in the interaction are depicted: the mobile device, the smart object and related services running on a server. This figure also shows which interaction technique is implemented using which technologies.

Within a physical mobile interaction, the mobile device acts as a mediator between the physical and the digital world. The server represents the digital world which offers information and services related to the smart object. The latter represents the physical world and provides entry points into the digital world. Generally, it could be said that the smart object provides a link to corresponding services that are made available by a corresponding server.

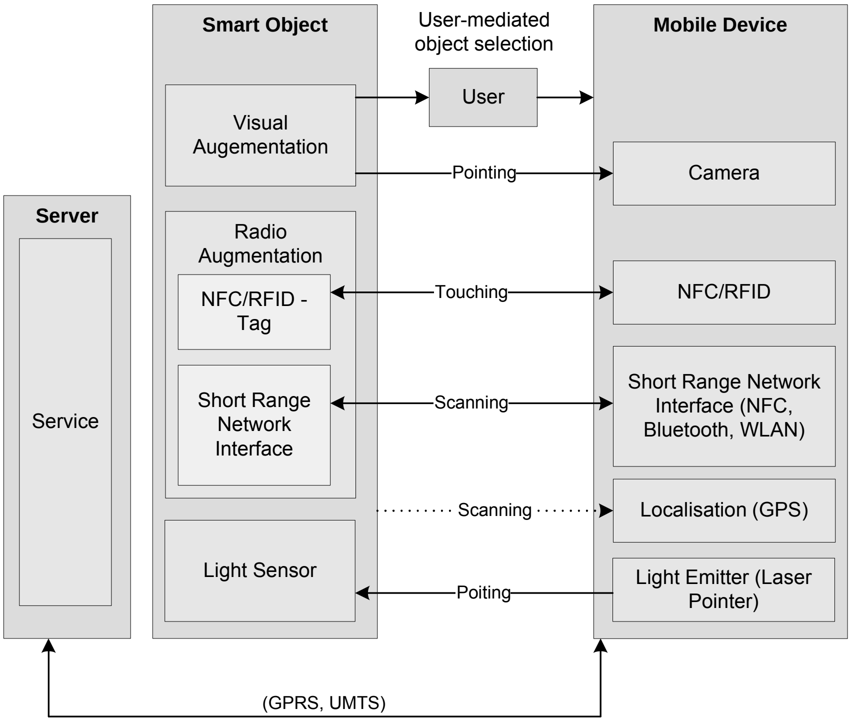


Figure 5: Generic architecture of PMIF.

The communication between the mobile device and the smart object can be based on different modalities: information provided by the smart object can be sensed by the mobile device (unidirectional arrow from smart object to mobile device in Figure 5), the mobile device can submit information to the smart object which senses it (unidirectional arrow from the mobile device to the smart object in Figure 5) or there can be a bidirectional communication between the mobile device and the smart object (bidirectional arrow between mobile device and smart object in Figure 5).

As depicted in Figure 5, PMIF supports visual and radio frequency based augmentation of smart objects. Visual augmentation is primarily done by visual markers attached to smart objects. The cameras of mobile devices take pictures of it and extract the identifier which is represented by the marker. PMIF also supports indirect user-mediated object selection in which the user acts as mediator between the smart object and the mobile device. For this, the smart object is augmented with a number or URL which has to be typed in by the user. Through this, the application running on the mobile device knows which services related to which smart object should be presented to the user.

Besides the marker based approach, PMIF also supports a second implementation of the interaction technique pointing. A laser pointer is attached to the mobile device and the smart object is equipped with a light sensor.

PMIF also supports the augmentation of smart object with technologies like NFC, RFID, Bluetooth and WLAN. The communication realized by these technologies can be distinguished as either unidirectional (e.g. read-only RFID tag attached to the physical object) or bidirectional communication (e.g. peer-to-peer communication based on Bluetooth). The interaction technique touching is supported by implementations based on NFC and RFID technology.

Another interaction technique supported by PMIF is scanning which uses location information to reason about the proximity of smart objects and mobile devices. The corresponding arrow between smart object and mobile device is dotted because only the information about the location of the object is required for the interaction but not the object itself. The implementations of PMIF for scanning are based on Bluetooth and GPS.

Based on this generic architecture and the used communication technologies, components of PMIF were defined which run on mobile devices and on the server which provides the services. Figure 6 illustrates the software components of the framework discussed in the following subsections in more detail.

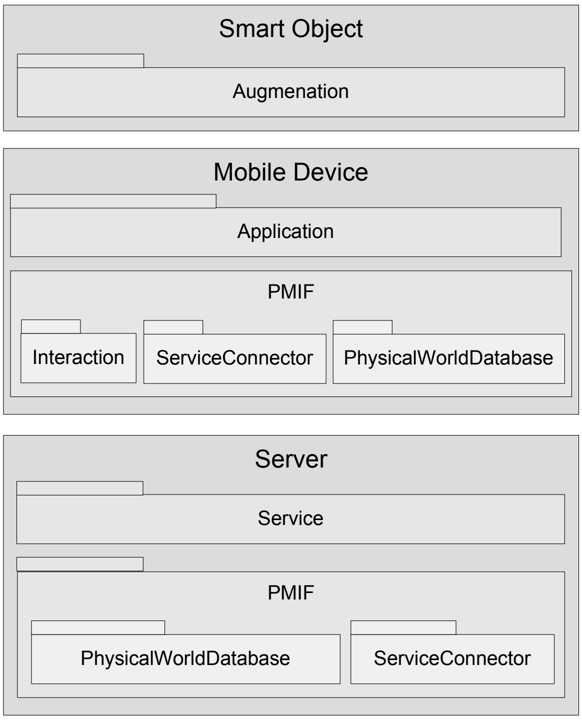


Figure 6: Architecture and main components of PMIF.

3.2.3 Smart Objects

As depicted by Figure 6 smart objects have to be augmented so that they can be sensed by mobile devices. So far PMIF supports no vision based approaches like the one discussed in subsection 2.3.4 in which no augmentation is needed. Typical examples for smart objects supported by PMIF are:

- advertisement posters augmented by visual markers,
- machines augmented by RFID/NFC tags to support up-to-date service information (e.g. when the item was last serviced and by whom) and

- public displays which are augmented by Bluetooth-based services through which the user can interact with it via a mobile device.

These examples also show the different kinds of smart objects that are addressed by the PMIF framework. A smart object can just be a location, a physical object augmented with a number, URL, NFC / RIFD tag or visual marker, another mobile device or a computer providing its services via Bluetooth to the mobile device.

This augmentation is only indirectly part of PMIF as the provided information is either static (e.g. visual marker or non-writeable RFID tags) or the service is provided by a server accessible via a network interface (Bluetooth).

In most cases the smart object provides an identifier which links to a service provided by a server. The complexity of such services can range from simple XHTML web pages to sophisticated Web Services.

3.2.4 Mobile Device

As mentioned before, the mobile device acts as a mediator between the physical and digital world. For this purpose, PMIF provides components for the communication with smart objects (*Interaction* component) as well as for the communication with a server (*ServiceConnector* component). These components and the *PhysicalWorldDatabase* are depicted by the box titled mobile device in Figure 6. They can be directly used by the application developer to implement applications that use physical mobile interactions. The components are independent from each other and can also be used individually.

The *Interaction* component provides an abstraction of the concrete technology (e.g. NFC or marker based) used for the communication between mobile phones and smart objects. This component handles every interaction with a smart object as a stream. The advantage of this solution is that the application developer who uses this component does not have to handle the details of each technology; she only needs to handle streams to and from a smart object. In practice there are two different kinds of streams: read-only streams in cases where the smart object provides static information (e.g. visual marker) and read/write streams in cases in which the smart object can also receive information (e.g. Bluetooth).

The following Figure 7 illustrates the different interaction techniques (green) currently provided by the *Interaction* component of PMIF (orange). Furthermore, the Java Specification Requests (JSR) and APIs are depicted which are used to implement an interaction technique or to show on which concepts the implementation is based on.

The main element of every interaction component is the *InteractionController* which is responsible for the communication with the smart object. The *InteractionController* is defined within *pmif.interaction* (orange) and then implemented according to the corresponding interaction technique (green).

Another component on the mobile device, the *ServiceConnector* component, provides a communication interface which abstracts from the concrete communication and transport protocol. That way, applications can be developed without the need to decide whether the communication should be based on HTTP, Web Services or SMS.

A service can be implemented using technologies like XHTML, i-mode, WAP, Web Services, OWL-S [Martin et al. 2004] or UPnP. The *ServiceConnector* handles the communication between the *Interaction* component and the service hosted on the server. It is, for instance, often important that the services on the server are informed about ongoing communication between mobile devices and smart objects. Furthermore, the *ServiceConnector* can be directly used for the presentation of the service if the service is realized with a direct renderable technology (e.g. HTML). If this is not possible, the information taken from the *ServiceConnector* (e.g. SOAP messages) have to be processed by the application before the presentation can be generated.

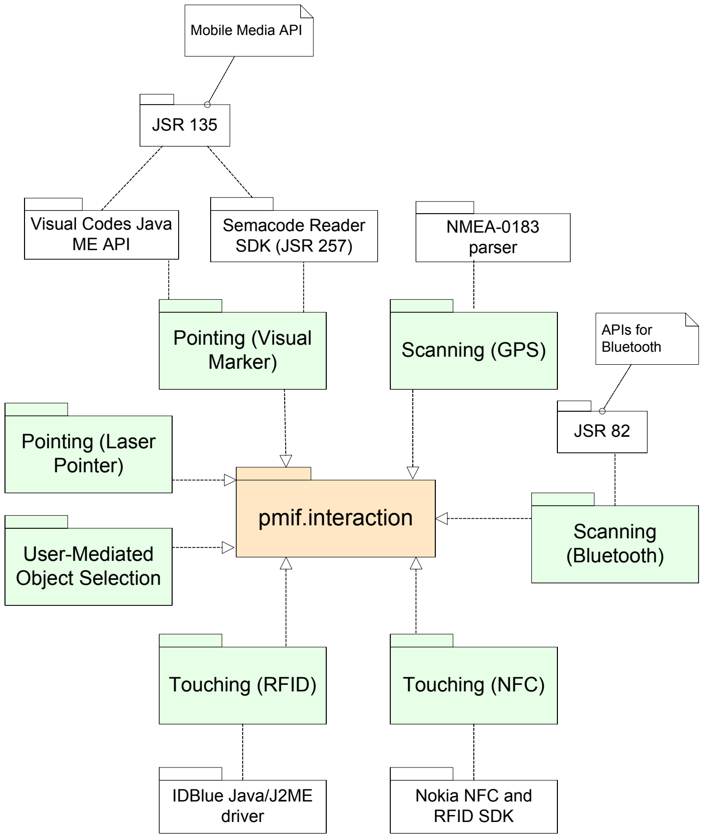


Figure 7: Interaction Component of PMIF.

Physical objects are managed by the *PhyiscialWorldDatabase* which can be located either on the mobile devices or on the server. This component can be used for the management of smart objects and the information regarding its identifiers, location, properties, related content (e.g. text, audio, images, video) and related services (e.g. a URL referring to a mobile service running on a server). Examples for identifiers are, e.g., a number represented by a visual marker, an identifier of an NFC or RFID tag, an identifier of a light sensor or a Bluetooth address.

In the case that one smart object supports different interaction techniques, all corresponding identifiers can be mapped to one smart object by using the physical world database. A feature of the *PhyiscialWorldDatabase* is the separation of data access through Java objects and the storage of the data. Thus, the data can be stored independently from the application in a database, in the file system, as an XML file or within a Java ME record store.

3.2.5 Server

Figure 6 also shows the components of PMIF on the server. It provides the *PhysicalWorldDatabase* and the *ServiceConnector* for the communication between the services on the server and the *ServiceConnector* on the mobile device. The server could be located in a remote destination or could even be an element of the smart object. An example for the latter case is a public display with a built-in computer.

The *PhysicalWorldDatabase* component is used by the *ServiceConnector* on the server to provide this information to the mobile device or by the services running on the server.

The *ServiceConnector* is on the one hand responsible for the communication between the mobile device and the server and on the other hand manages the relationships between the *PhysicalWorldDatabase* and the service.

3.3 Implementation of PMIF

It is in principle possible to implement the framework using an arbitrary server- or client-side technology. But it was decided to use the Java Micro Edition (Java ME) to implement the components on mobile devices and the Java Standard Edition (Java SE) for the implementation of the components running on the server. Platform independence, tool support, availability of open source APIs and widespread availability of these technologies were the most important reasons for that decision. The most critical part is the implementation of the components on the mobile phone since it is mostly not feasible to install another run-time environment or player. Therefore Java ME was chosen which is currently supported by circa 1 billion mobile devices [Hardy 2006]. Java ME is platform independent, and nearly all operating systems on mobile devices such as Symbian, Palm OS, Windows Mobile as well as most mobile phone vendor specific operation systems support it. The Java ME configurations CLDC 1.0/1.1, the MIDP 2.0 profile, some optional APIs (e.g. JSR 82, JSR 135 or JSR 257) and the generic connection framework are used for the implementation of the components running on mobile devices.

The Java Standard Edition (Java SE), the Servlet API, JDBC and MySQL are used for the implementation of the server side components. The service connector is realized as a Java Servlet running on a Tomcat server. The communication between the server and mobile devices can be based on HTTP or SOAP messages.

In the following, the implementations of the different interaction techniques are discussed. PMIF also provides simple example applications for each interaction technique that show how it can be used within an application. These example applications rarely do more than just pick up an identifier and show it to the user.

3.3.1 Touching

PMIF provides two implementations of the physical mobile interaction technique touching. One is based on Near Field Communication (NFC) and the other is based on Radio Frequency Identification (RFID). The smart objects are in this case augmented with NFC / RFID tags that can be sensed by mobile devices. Through this the application on a mobile device can read the information stored on the tag and can identify the touched object and the related services.

For NFC as well as RFID, the mobile device generates an RF field that powers the tag by inductive coupling and enables to send or receive data. A detailed overview and usage scenarios of these two technologies in mobile devices can be found in subsection 2.3.3.

The first implementation is based on a Nokia 3220 with an attached Nokia NFC shell [@NokiaNFCShell]. The reading range of this shell is about 3 centimetres whereby just one tag can be read at the same time. Mifare NFC tags with a storage capacity from 512 Bytes to 4 Kilobyte are supported. PMIF uses the Nokia NFC and RFID SDK 1.0 to access the NFC shell [@NokiaNFCSDK].

The second implementation is based on the IDBlue RFID pen which can be connected via Bluetooth with a mobile phone [@IDBlue]. This device supports the following RFID tag standards: ISO 15693-2/3, Tag-it HF/HFI and Philips I-Code SLI. The reading range is about 2-4 centimetres. PMIF uses the IDBlue Java/J2ME driver to access the RFID pen [@IDBlueDriver].

The following Figure 8 shows how the two devices are used to perform the interaction technique touching: a Nokia 3220 with NFC Shell (Figure 8a), an IDBlue RFID pen attached to a Nokia N70 (Figure 8b) and a user reading an RFID tag attached to a printer (Figure 8c).

a b c

Figure 8: Devices used for the implementation of touching [De Luca 2006].

3.3.2 Pointing

PMIF provides two implementations of the interaction technique pointing; one is based on visual markers and the other on a laser pointer.

The first implementation that is based on visual markers uses the built-in cameras of mobile phones to take pictures of visual markers. These are then analyzed and the deciphered information is used to establish a link to the object and the related services. PMIF supports two different kinds of visual markers: visual codes [Rohs, Gfeller 2004] and Semacodes [@Semacode]. For the implementation the visual codes for Java ME API and the Semacode Reader SDK for Java Phones 1.6 that implements the public draft of JSR 257 were used. Both APIs provide support for the generation and interpretation of visual markers. The Mobile Media API (JSR 135), already depicted by Figure 7, is used for accessing the camera and taking a picture.

The following Figure 9 shows the usage of the visual code based implementation of the interaction technique pointing.

Figure 9: Interaction technique pointing based on visual marker.

The second implementation is using a light beam from a laser pointer attached to a mobile phone that is recognised by light sensors attached to a smart object. The light sensors are attached to a micro-controller on which a recognition algorithm is implemented.

The Particle Computer platform was chosen as the micro-controller [Decker et al. 2005]. Particle Computers are small wireless sensor nodes. The node's hardware comprises a microcontroller, a radio transceiver (125 kbit/s, with a range of up to 50 meters), a real-time clock, a speaker for basic notification functionality, additional Flash memory and LEDs. For this prototype, off-the-shelf light sensors (FW 300) with an active area of about 0.77 square centimetres were added.

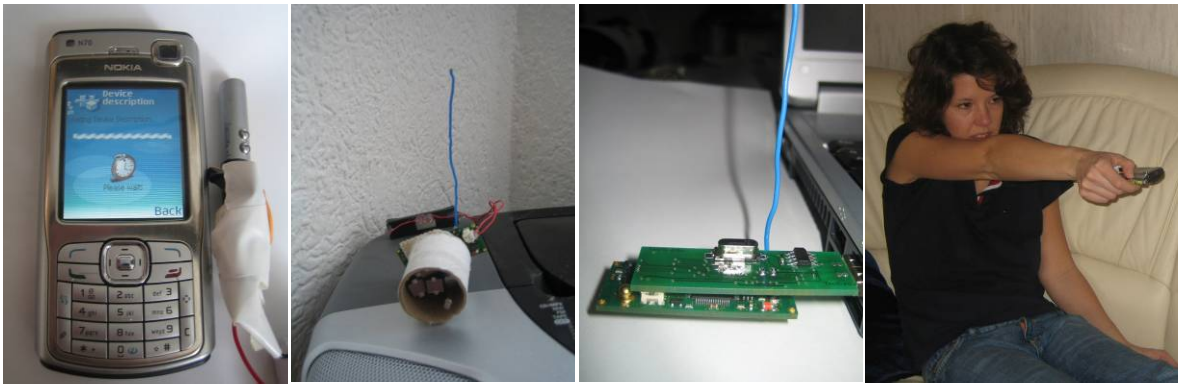
Each sensor for the pointing action consists of three such light sensors to achieve a larger active area (about 2.3 square centimetres). A small LED is added to provide basic feedback when the pointing action was successful. This setting is sufficient to detect whether or not a light source like a laser pointer is aimed at such a sensor.

However, a change in the ambient light can give exactly the same result, especially if the surroundings are rather dim and the main light is switched on. There is no way to distinguish these two cases by merely looking at the magnitude of the signal change. Therefore a chip was added to the laser pointer that makes the pointer pulse in a specific frequency. By hardware or – like in this prototype – software analysis directly on the Particle computer, it can be determined whether changes in the sensor values are caused by a pointer or by changes in ambient light.

This technique was also applied in [Ma, Paradiso 2002] where the authors showed that it is even possible to transmit an ID through the laser beam. After the Particle computer has detected that the laser pointer points to one of its sensors, a message is sent to a receiver connected to a USB port of a pointing recognizer server. This communication is performed using its radio frequency communication facility. The pointing recognizer on the server side retrieves the identifier of the smart object. Upon reception of such a message, this identifier is passed to a Java Servlet on the web server where it is stored in a database together with time information.

The moment the user starts the pointing technique mode on the mobile phone, it periodically sends requests to the web server. Whenever there is an identifier available in the database that is not older than a certain amount of time, this identifier is returned to the phone. Through this, the application on the mobile phone can identify the object which the person has pointed at and can start related services.

The following Figure 10 shows a Nokia N70 with an attached laser pointer (Figure 10a), a smart object with attached light sensor connected to a particle (Figure 10b), particle message receiver attached to a USB port (Figure 10c) and usage of the interaction technique pointing (Figure 10d).



a b c d

Figure 10: Used hardware for the implementation of pointing [Leichtenstern 2006].

3.3.3 Scanning

For the implementation of the interaction technique scanning, the built-in Bluetooth capabilities of mobile phones or external GPS devices are used.

PMIF uses the Java ME APIs for Bluetooth (JSR 82) to scan for and to connect to other devices. For that purpose, the Bluetooth Serial Port Profile (SPP) of JSR82 which is based on the Bluetooth protocol RFCOMM is used. This implementation of scanning was tested with external GPS devices (Royaltek BT GPS x-mini and the Blue GPS RBT-3000), external mobile printers (Brother MW-140BT) and remote PCs/Laptops. The latter were mostly using an Acer Bluetooth USB Dongle, e.g. the Acer BT-600.

The GPS-based implementation of scanning was tested with two external GPS devices - the BT GPS x-mini and the Blue GPS RBT-3000 from Royaltek - that can be connected to the mobile phone via Bluetooth. The Bluetooth serial port profile is used to communicate with the GPS device. PMIF provides the GPS data as NMEA-0183 data packets that can be used within the mobile application. Based on this implementation, two tutorials about connecting a GPS device with Java ME via Bluetooth to a mobile phone and about a Java ME NMEA parser were published [@TutorialHCILab]. Within a mobile application this location information can be used to analyze which smart objects are next to a person. If the distance is for instance below a specific threshold, the smart object is selected and the application can react on that.

3.3.4 User-Mediated Object Selection

The implementation of this interaction technique is very simple and already available in nearly every mobile phone. A URL printed on an advertisement poster which is typed in the browser of a mobile phone is already an implementation of this interaction technique. To support all relevant interaction techniques, PMIF also explicitly provides support for user-mediated object selection.

3.3.5 Used Hardware

The following Table 11 gives a compact overview of the implemented interaction techniques, the mobile devices and markers that were tested and used within prototypes developed with PMIF.

Interaction technique	Tested devices	Tested marker/technology
Touching (NFC)	Nokia 3220 + Nokia NFC shell	Mifare NFC tags (1 and 4 Kbyte)
Touching (RFID)	Nokia 6630 + IDBlue RFID pen	ISO 15693-3 tags (1 Kbyte)
Pointing (light beam)	Nokia N70/6630	light sensors (FW 300)
Pointing (visual marker)	Nokia 6600/6630/N70	Visual Codes [Rohs, Gfeller 2004], Semacode [@Semacode]
Scanning (Bluetooth)	Nokia 6600/6630/6230i/N70	Brother MW-140BT mobile Bluetooth printer, GPS - devices
Scanning (GPS)	Nokia 6600/6630 or Siemens S65 + Royaltek BT GPS x-mini or Blue GPS (RBT-3000)	N/A
User-mediated object selection	Nokia 6600/6630/N90/N70	N/A (e.g. printed numbers)

Table 11: Overview of which hardware (device, marker/technology) was used and tested within which interaction technique.

3.4 Programming with PMIF

This section shows - based on an example - how the *Interaction* component of PMIF can be used to develop a simple application using the physical mobile interaction technique touching.

The *InteractionManager* of the *pmif.interaction*-package (Figure 11) is the central class for implementing mobile interactions with smart objects. It hides the complex actions of setting up and initializing generic physical mobile interactions, manages their life-cycle (Figure 12) and provides methods that support the different *InteractionTypes* (which present different implementations of interaction technologies in the framework, like visual markers, Bluetooth or NFC).

Before starting the interaction with a physical object, an application has to register an *InteractionController* with the *InteractionManager*. Different *InteractionController*-objects set up connections with physical objects using the technologies behind different *InteractionTypes*. Applications never interact with *InteractionControllers* directly but only register them for the *InteractionType* they are interested in. The *InteractionManager* administrates the *InteractionControllers* and calls their methods in order to control the state of their life-cycle and to explicitly start physical interactions.

Figure 12 shows the different states and the possible state transitions of the *InteractionControllers.* The state *active* means that the user and the application are currently using the *InteractionController*. The *InteractionController* has to be initialized in advance (*InteractionControllerObject*) and can be paused if not needed.

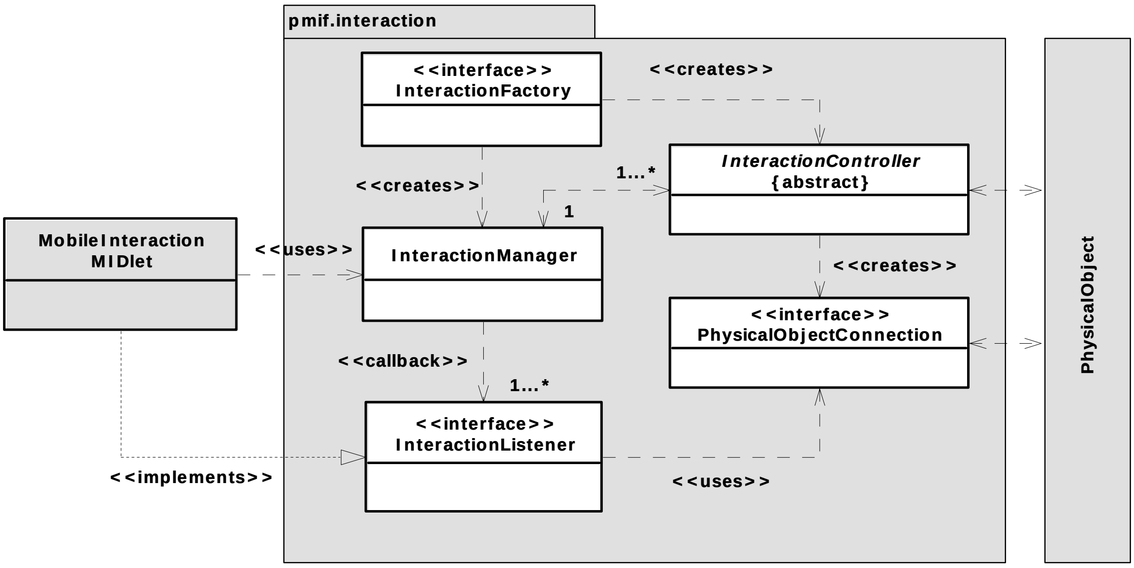


Figure 11: The *pmif.interaction*-package with its core components [Wetzstein 2005].

While registering an *InteractionController* with an *InteractionManager* only sets up a physical interaction, applications finally use objects that implement the *PhysicalObjectConnection*-interface for interaction. These objects created by the different *InteractionControllers* as the result of successfully establishing a connection with a physical object. A *PhysicalObjectConnection* can be seen as to provide a stream-metaphor which enables reading from and writing to physical objects using the technologies behind the corresponding *InteractionTypes*. They allow the communication with those objects, contain the data exchanged during interactions and provide methods to retrieve data.

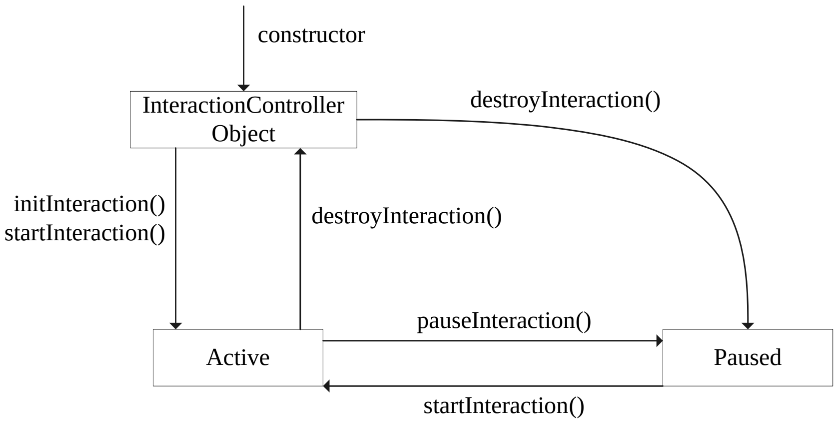


Figure 12: Life cycle of the *InteractionController* [Wetzstein 2005].

In order to use *PhysicalObjectConnections*, applications have to implement the *InteractionListener*-interface and register themselves with the *InteractionManager* for required *InteractionTypes*. As soon as an *InteractionController* that has been registered for a corresponding *InteractionType* has established a connection to a physical object, the created *PhysicalObjectConnection* is returned to the *InteractionListener* that has been registered for that very same *InteractionType*. The object that implements this interface can now use the data from the acquired *PhysicalObjectConnection* in order to implement its own event handling and functionalities.

The last component of this framework is the *InteractionFactory*-interface that can be used to create *InteractionManagers* and *InteractionControllers* as well as for the registration of the latter.

While these standardized classes and interfaces enable abstract and uniform connections and interactions with physical objects, they also provide the foundation of specialized components that implement particular technologies for physical mobile interactions. Due to the modular structure of PMIF, only the *InteractionController* and the *PhysicalObjectConnection* have to be sub-classed and re-implemented in order to extend the framework for new technologies, e.g. NFC-based data-exchange.

In order to include PMIF interaction techniques with mobile applications and take advantage of the corresponding technologies, developers only have to implement a small number of standardized steps. The following example illustrates these steps for NFC-based physical interaction. NFC is an RFID-related technology that allows the exchange of data simply by touching augmented physical objects. An NFC-enabled mobile phone could, for example, read data stored on NFC-tags attached to a poster and use this information as a parameter to invoke an associated web service.

As Figure 13 shows, the code for such an application is straightforward: At first, the *InteractionManager* is initialised (line 1) and a newly created *NFCInteractionController* – which is a subclass of the generic *InteractionController* – is registered for the NFC-*InteractionType* the application wants to use (line 2).

```
1	manager = InteractionManager.getInstance(this);
2	manager.register(new NFCInteractionController(), InteractionTypes.NFC);
3	manager.setInteractionListener(this, InteractionTypes.NFC);
4	manager.startInteraction(InteractionTypes.NFC);
5
6	...
7
8	public void connectionDetected(PhysicalObjectConnection conn, String type) {
9		if(conn instanceof NFCConnection){
10			nfcConn = (NFCConnection)conn;
11			nfcConn.startReading();
12		}
13	}
14
15	public void notifyTagRead(NTIPRecord[] records) {
16		//process data read from NFC-tags
17	}
18
19	public void notifyDeviceRead(NTIPRecord[] records) {
20		//process data read from NFC-devices
21	}
22
23	public void notifyStatusChanged(ContactlessEvent event) {
24		//handle events generated by the NFC-shell
25	}
```

Figure 13: Basic code excerpt for implementing the PMIF NFC functionality.

Next, the application registers itself as a listener for the same *InteractionType* (line 3) in order to be notified about the successful establishment of the corresponding *PhysicalObjectConnection*. For this reason, the application has to implement the *InteractionListener*-interface and its *connectionDetected*-method (line 8).

The *NFCInteractionController* uses this method to pass the established *NFC-PysicalObjectConnection* to the application.

After that, the physical interaction can be started by calling the *InteractionManger's startInteraction*-method (line 4) for the required *InteractionType*. Applications that want to support several types of physical interactions can repeat these steps for the different *InteractionTypes* using other specialized *InteractionControllers* and *PhysicalObject-Connections*.

The previous steps are the same for setting up and starting all physical interactions supported by the PMIF framework. Nevertheless, due to the properties of different interaction techniques and technologies some of PMIF's specialized components handle physical interactions differently, which is expressed by their individual implementations. In order to read data from NFC-tags and -devices, the application has to implement the *NFCListener*-interface with its methods *notifyTagRead* (line 15), *notifyDeviceRead* (line 19) and *notifyStatusChanged* (line 23). These methods are called if NFC-data has been read or if the status of the NFC-connection has changed. PMIF deliberately provides these methods as an interface so that applications can handle the received data individually.

3.5 Examples of Use

As already mentioned, PMIF provides a simple application for every interaction technique that shows how it can be used. This application mainly reads an identifier and presents it to the user. But for the development of a framework it is in general very important that it is used by several developers who build different systems. A framework can not be considered as usable, helpful and mature without the realization of prototypes or products based on it. Therefore, PMIF was and is used for the implementation of several prototypes using physical mobile interactions. Seven of them will be presented in the following subsections. Three of them were also used for the evaluations discussed in chapter 4. Therefore these prototypes, their architecture and functionality will be explained in more detail than the others. The usage of the framework for the development of these prototypes showed that it takes less time to develop such applications and that the integration of these interaction techniques can be done in a simple and structured way.

3.5.1 Mobile Tourist Guide: Mobile Petuelpark System (MOPS)

This prototype is a mobile guide application called MOPS (MObile Petuelpark System) in which the user can get information about smart objects, in this case about exhibits in a park. MOPS was developed mainly by 4 students, who had no previous experiences in developing mobile applications, within the practical course *development of media systems* in the summer term 2005 [@PEMS 2005, Rukzio et al. 2006e].

This prototype uses the physical mobile interaction technique pointing based on visual codes, scanning based on GPS and user-mediated object selection provided by the PMIF framework. The real world objects were augmented with information signs showing a number and a visual marker. With MOPS, users are able to use all these interaction techniques, walk through the park and get information about the exhibits. The prototype shows a screen presenting the name of the exhibit, a picture of it, some text about the artist and further information about the object. In addition to that, an audio file is played reading out the written information on display. In the following Figure 14, one can see two screenshots of MOPS. In the first one the user can select the desired interaction technique and in the second one the user sees and hears information about the selected object.

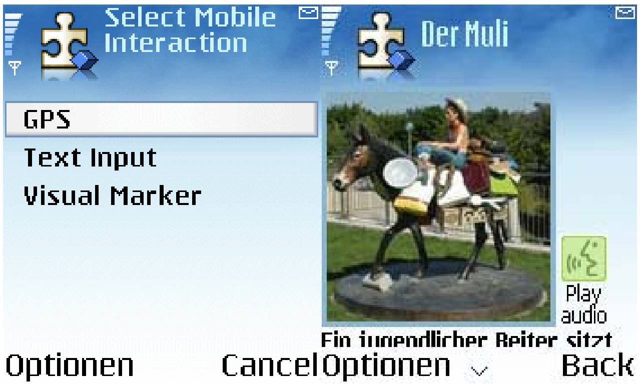


Figure 14: Screenshots of MOPS [@PEMS 2005].

MOPS was implemented using a Nokia 6630 and an external GPS device with a Bluetooth interface (RoyalTek BlueGPS RBT-3000) for the implementation of the physical mobile interaction technique scanning. Pointing was implemented using the visual code system that provides a tool for the generation of such codes and a Java ME implementation of the code recognition algorithm [Rohs, Gfeller 2004].

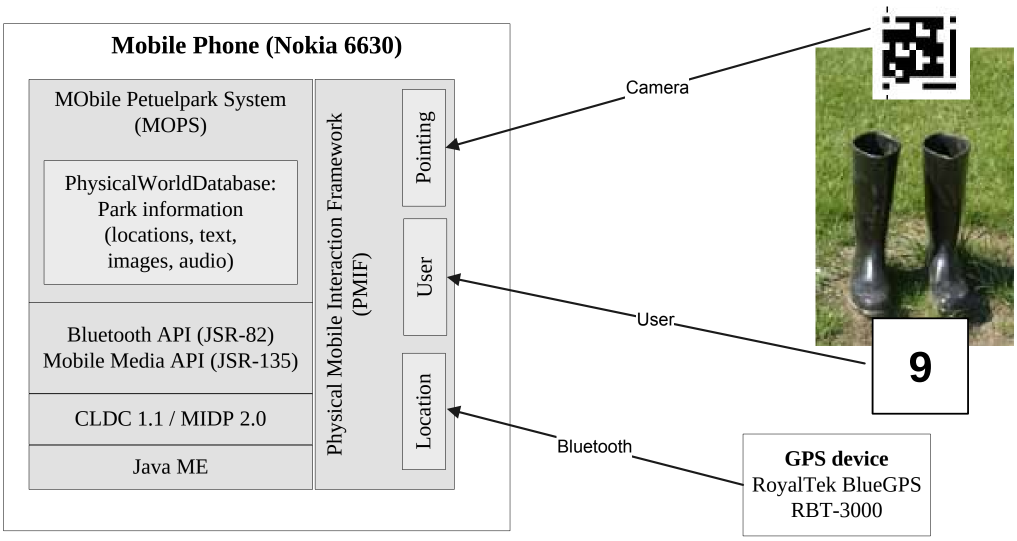


Figure 15: Architecture of the Mobile Petuelpark System (MOPS).

Figure 15 shows the architecture of MOPS consisting of an external GPS device, the mobile phone and the augmented exhibit. The application on the mobile phone is based on CLDC 1.1 / MIDP 2.0, uses the Bluetooth API to communicate with the external GPS device and uses the Mobile Media API to access the built-in camera of the mobile phone. Information about the Petuelpark like title, text or locations is provided by the *PhysicalWorldDatabase* of the PMIF framework running on the mobile device. An XML file that references images and audio comments is used to structure and store this data. This information is shown whenever the user is in a specified distance to the object, after she has typed in the number shown on the object or after a picture of the attached visual marker has been taken.

The prototype was evaluated in a two-day user study in which 17 persons took part. The results are discussed in section 4.3. For this study, an early version of MOPS was used that ran on a Nokia 6600. CLDC 1.0 and an additional server were used to interpret the visual codes. The mobile phone transmitted the picture via GPRS to the server and the server sent the included identifier back to the mobile phone. The reason for the latter was that at that time no Java ME version of the visual code system existed and the Semacode Reader SDK for Java Phones had not yet been released.

3.5.2 Mobile Museum Guide: Mobile Point of Interest System (MOPS++)

This prototype is called MOPS++ (MObile Point of interest System) and was developed within the practical course *development of media systems* in the winter term 2005/06 [@PEMS 2006]. This prototype is an enhancement of the MOPS discussed in the previous subsection but focuses on an indoor environment. Here the user is able to get information about objects within an exhibition. This prototype supports the interaction techniques pointing (visual codes), touching (RFID) and user-mediated object selection provided by the PMIF framework.

The prototype consists of several posters showing the name of the exhibit, a picture of it and some textual information in English and German. These posters are augmented with ISO 15693-3 RFID tags, visual codes and numbers. MOPS++ was implemented and evaluated using a Nokia N70 and an external RFID reader device with a Bluetooth interface (Cathexis IDBlue RFID-Pen) for the implementation of the interaction technique touching.

Figure 16 shows the architecture of MOPS++ consisting of the mobile phone, the external RFID reader and the augmented exhibit.

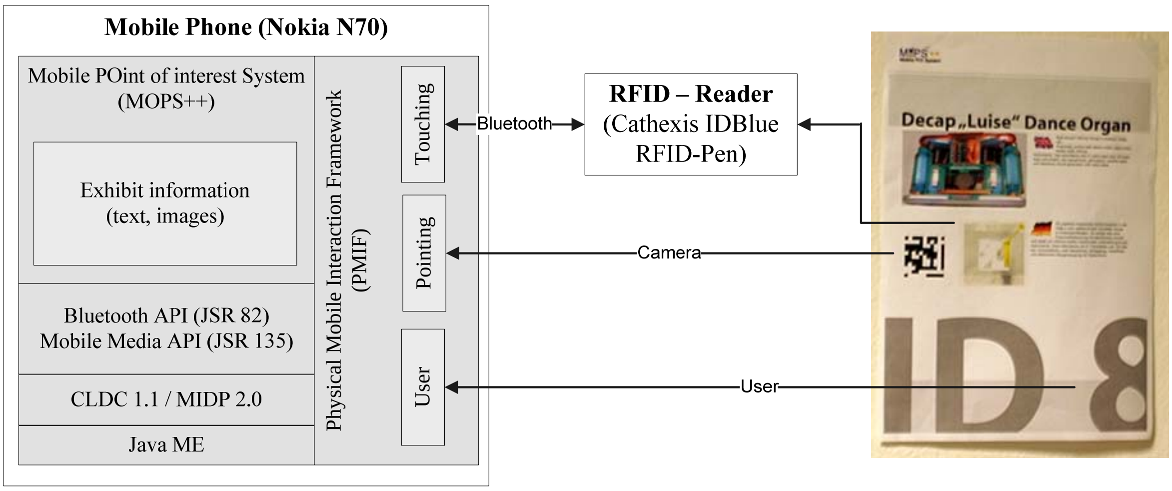


Figure 16: Architecture of the Mobile Point-of-Interest System (MOPS++).

The application on the mobile phone is based on CLDC 1.1 / MIDP 2.0, uses the Bluetooth API (JSR 82) to communicate with the external RFID reader and uses the Mobile Media API (JSR 135) to access the built-in camera of the mobile phone. Information about the exhibits like title or text is provided by an XML file that also references corresponding images. This information is shown after the user touches the RFID tag, after a picture of the attached visual marker is taken or after the user types in the number shown on the object.

The prototype was evaluated in user study in which 8 persons took part. The results are discussed in section 4.4.

3.5.3 Mobile Interaction with Advertisement Posters

This prototype for mobile interaction with advertisement posters was developed within the context of the Perci (Pervasive Service Interaction) framework and supports the interaction techniques touching, pointing and user-mediated object selection provided by the PMIF framework [@Perci, Broll 2006, Broll et al. 2006b, Broll et al. 2007, Rukzio et al. 2006c, Siorpaes et al. 2006, Siorpaes 2006].

The idea behind this prototype is similar to the previously discussed prototypes. The big difference is that a smart object is not just augmented with one link to one service. In this prototype, two posters, one for buying movie tickets and one for buying public transportation tickets, are augmented with multiple tags.

Figure 17 shows pictures of the posters. There is a visual code beside every NFC sign and on the position of every NFC sign there is a Mifare NFC tag attached to the back of the poster. The user can physically click on each of these markers by pointing to or touching them. To buy a movie ticket, for instance, the user has to select the movie, the cinema, the number of persons as well as the desired time slot.

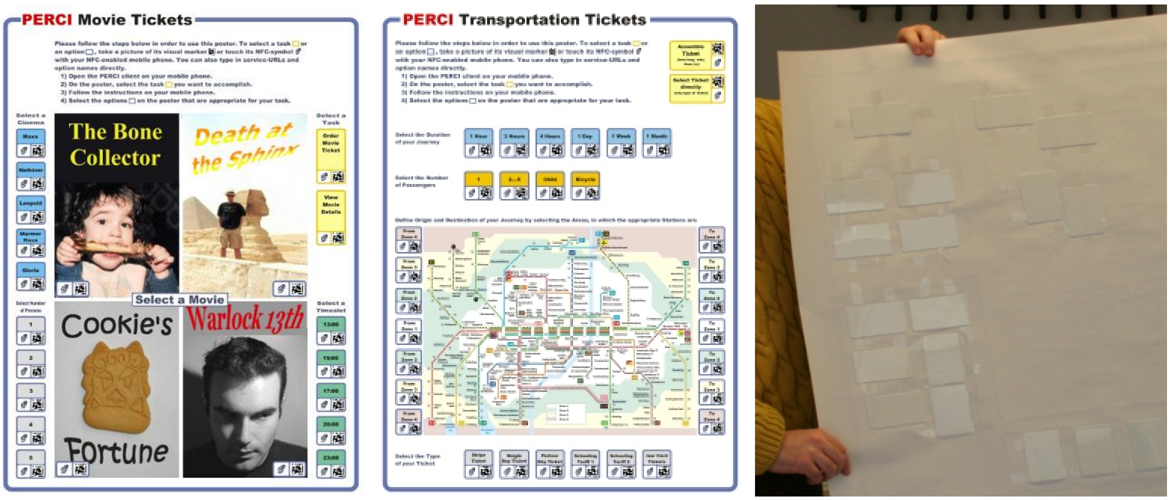


Figure 17: Left: posters for buying movie and transportation tickets. Right: the back of one of the posters [Broll 2006, Siorpaes 2006].

The way the interaction technique user-mediated object selection works is not as obvious as in the previous prototypes. After establishing a link to the related service by browsing to a URL printed on the poster, the user interface (XHTML or Java ME) of this service is downloaded to the mobile phone. The needed parameters, e.g. for buying a transportation ticket, can then be manually typed in. This can lead to a direct interaction mode with no connection to physical mobile interaction.

However, whenever a user looks at the poster to collect information or suggestions of how to proceed and then enters appropriate data into the form, it must be seen as a more complex version of user-mediated object selection.

Of course, all interactions can also be done by reading the NFC tags or taking pictures of the visual markers, thus incorporating the physical interaction techniques touching and pointing.

The following Figure 18 shows the architecture of this prototype and focuses primarily on its interaction aspects. The architecture consists of a service implementation, the service interface, the interaction proxy, the mobile device and the poster.

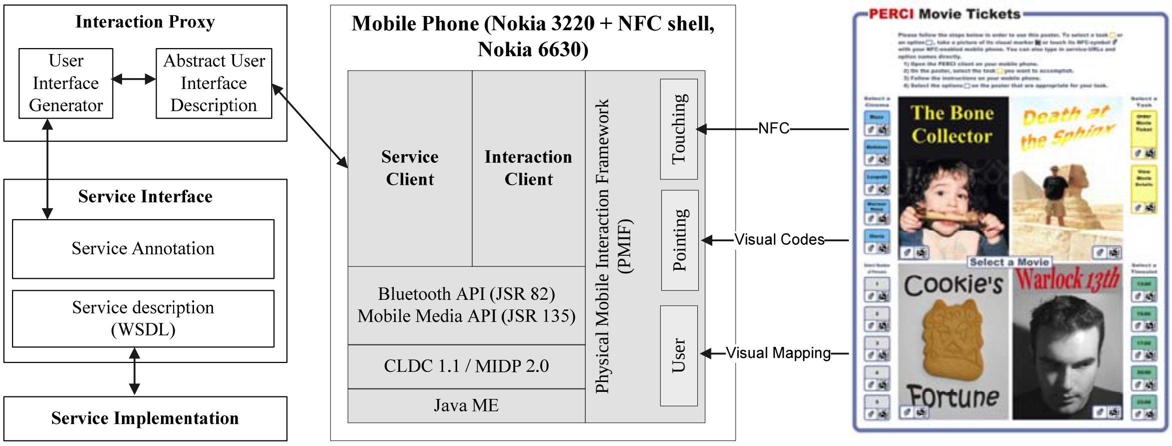


Figure 18: Architecture of the mobile interaction with advertisement posters.

One of the main ideas of the Perci project [@Perci] is that an arbitrary web service is augmented with additional semantic information and that a mobile user interface is automatically generated based on this information. Through this approach, it is easily possible to develop mobile applications that use mobile interactions based on existing web service descriptions.

An existing service is depicted by the box *service implementation*. For every such service, a corresponding *service description* based on WSDL and a *service annotation* exists. This is used by the User Interface Generator of the Interaction Proxy to generate an Abstract User Interface Description. This description is requested by the mobile device which converts it to a Java ME or XHTML based user interface. The latter is generated by the interaction proxy which converts the abstract user interface description into XHTML.

The shown architecture only shows the rendering with Java ME. The PMIF framework is then used to integrate the different interaction techniques into the prototype. For touching, a Nokia 3220 and the Nokia NFC shell are used. For the interaction technique pointing, the visual code system and a Nokia 6630 are used.

3.5.4 Additional Examples of Use

The following prototypes were also developed using the PMIF framework, but they were not used for the evaluation and comparison of physical mobile interactions techniques which will be discussed in chapter 4. Therefore these prototypes will just be discussed in a compact way.

3.5.4.1 Situated Mobile Commerce

A prototype for situated mobile commerce has also been realized. It can be employed by a user to get information about products in a store or supermarket [Alzetta 2006]. Furthermore, it is possible to compare products or to request related product tests.

The advantage of such a service is that the process of getting information about a product and buying the product in a shop can happen at the same time and place. This is a big advantage when compared to the current process where most people begin by gathering information about a product (e.g. a video recorder or TV set) at home and then go to a shop to buy it. In the shop, however, they see another similar product and have to go back home to their PC to inform themselves about the seen product.

This prototype supports the interaction techniques pointing based on visual codes and user-mediated object selection. A Nokia 6600 is used as the mobile device. The products are augmented with a sign containing a visual code tag and a number for user-mediated object selection. The information about the products is stored on a server and is requested on demand by the mobile device.

3.5.4.2 Mobile Learning

A mobile learning application for children was developed based on PMIF [Ruseva 2006]. Here, information signs in a zoo are augmented to provide links to information on the corresponding animals. Through this, children can select an animal and then they have to answer some questions about it before proceeding to the next one. This prototype employed user-mediated object selection on a Nokia 6630.

3.5.4.3 Mobile Peer-to-Peer File Sharing

Within this prototype, the interaction technique scanning implemented using Bluetooth is used to find other mobile devices which offer media data [Teuber 2006]. The concept underlying the prototype is that users can download media files (image, audio, video, etc.) from other mobile devices and that these files are then offered to other mobile users.

The interesting aspect of this prototype is that it implements a novel business model. The user pays for a media file when downloading it form a server and then she can subsequently earn money from other users when these download it from her. Two Nokia 6230i phones were used to implement and test the prototype.

3.5.4.4 Privacy Sensitive Ubiquitous Computing

This prototype analyzes typical privacy and security problems of mobile interactions with smart objects [De Luca 2006]. The user is able to interact with notes and a printer that are augmented with RFID tags. The prototype particularly analyzes the information that is exchanged between the mobile device and the smart object. The interaction technique touching is used within the prototype. A Nokia N70 connects an IDBlue RFID reader via Bluetooth to read the RFID tags attached to smart objects.

3.6 Summary and Conclusion

So far there was no framework, toolkit or API available which can be used to integrate different physical mobile interactions in an application in a structured and homogeneous way. Most of the available software just focuses on one implementation of one interaction technique and their usage within different applications.

The PMIF framework has been designed for the easy and straightforward development and implementation of applications that use physical mobile interactions. Its power and effectiveness is based on two aspects: On the one hand PMIF comprises several components that support the different physical interaction techniques touching, pointing, scanning and user-mediated object selection. On the other hand, PMIF also abstracts from specific techniques and technologies (e.g. Bluetooth, NFC, GPS, Laser pointer, visual marker, etc.) and provides a generic framework for the uniform integration and simple use of its specialized components. With PMIF, it is easy to use different communication technologies for the interaction between mobile devices and physical objects. Generally it could be said that using this framework makes it possible to integrate physical mobile interactions into an application in a time efficient, structured and simple way.

Another advantage of the framework is the possibility to integrate new implementations of physical mobile interaction techniques into the framework in an easy and structured way. For that purpose, the interfaces defined by the *pmif.interaction* component have to be used and implemented. The usage of a new implementation in an application is then similar to the usage of other implementations because of the abstractions provided by the PMIF framework.

This chapter has mainly focussed on the functionalities of PMIF that are directly involved in the interaction because this is the focus of this dissertation. The components *ServiceConnector*, *PhyiscalWorldDatabase* and *Service* were just discussed in a compact way but were especially used and showed their usefulness in the prototypes described in the subsections 3.5.1 Mobile Tourist Guide: Mobile Petuelpark System (MOPS), 3.5.4.1 Situated Mobile Commerce and 3.5.4.2 Mobile Learning.

Although the framework has not been evaluated in a formal way, the seven discussed prototypes show that the framework was already used within several projects and through this feedback it became a matured framework and many of the issues it had in the beginning could be removed.

PMIF was used in a practical course [@PEMS 2006], three diploma theses [Broll 2006, De Luca 2006, Siorpaes 2006] and three project theses [Alzetta 2006, Ruseva 2006, Teuber 2006] by students who often had no previous experiences with the development of mobile applications in general or the implementation of physical mobile applications. Especially the more matured versions of the framework allowed the computer science and media informatics students the easy and rapid integration of physical mobile interactions in their application without knowing how the interaction technique itself is implemented.

The PMIF framework is currently used within the Perci project in which the services related to a smart object are Web Services that are described by corresponding WSDL descriptions. The latter are augmented with additional semantic information to support the automatic generation of user interfaces presented by the mobile device [@Perci, Broll et al. 2006a, Rukzio et al. 2006c].

4 Evaluation and Comparison of Physical Mobile Interactions

Several projects have shown that mobile devices can be used to interact with smart objects but, to date, there has been no research analyzing in which context a given interaction technique is preferred by a user and which interaction techniques should be supported by smart objects. The type of application, the location of the object, the distance between object and user, the service related to the object, the capabilities of the mobile device and the preferences of the user are important factors for the selection of an interaction technique. The only comparable analysis of mobile interaction techniques was done by [Ballagas et al. 2006b]. Unlike our work, however, they focused on the classification of interaction techniques based on previous work and personal experience. They did not use questionnaires or user studies to compare the mobile interaction techniques under investigation. But this is very important for the evaluation of physical mobile interaction techniques because *the ultimate test of a product's usability is based on measurements of user's experience with it* [Dix et al. 2003].

Chapter 2 presented and classified different physical mobile interaction techniques, analyzed possible technical implementations and typical application areas. This chapter presents five different studies in which the physical mobile interaction techniques touching, pointing, scanning and user-mediated object selection have been evaluated. Indirect remote controls as discussed in subsection 2.3.7 have not been analyzed because the evaluations and comparisons described in this chapter focus on static displays and especially on interaction techniques that are used to select smart objects. Indirect remote controls are mainly used in combination with active displays and screens.

Based on the evaluation of these five prototypes, findings and experiences have been formulated that show the properties of each interaction technique and state in which context which technique is preferred by the user. The main goal was to identify typical situations and scenarios in which different techniques are useful and in which they are not. The analysis and the prototypes are based on mobile phones because most people own this special kind of a mobile device and already know how to interact with it.

The prototypical implementations of the following scenarios were either built using the framework presented in the previous chapter or, in case the framework did not exist at that point, contributed considerably to the shape and functions of that framework. In the first study the details of the design and engineering process are presented before reporting the results. In the further studies the focus only lies on the results.

4.1 Methodology

Each of the following five studies is different regarding the used prototype, the application scenarios and the interaction techniques that are supported and which were evaluated. But all of them consisted of three basic steps: a preliminary interview, the use of the prototype and a final interview. The interviews were designed to get as many quantitative results as possible. The advantage of such results (e.g. x percent of the participants preferred the interaction technique y if z applies) is their meaningfulness and the increased reusability for other researchers, application developers or designers. In addition to that, the participants were also observed during the study and they were asked to talk about their impressions and experiences while using the prototype. The latter is known as the Thinking Aloud method [Lewis, Rieman 1994]. Both interviews before and after the study were based on questionnaires including qualitative and quantitative questions. Questions that lead to qualitative results were mostly open questions asking for a general assessment of the interaction techniques or the prototypes itself. Quantitative results are based on predefined answers using a Likert scale [Likert 1932]. Some questions could also simply be answered with yes or no.

Most of the participants were people you often come across in a university building hosting a media informatics research and teaching unit: students who mostly study a technical subject, secretaries, technical staff and visitors. If another group of persons took part within a user study then this is mentioned within the text.

The following Table 12 shows which implementation of which interaction technique was analyzed in which of the user studies discussed in the following sections.

	Study 1: Mobile Interaction in Smart Environments	Study 2: Mobile Tourist Guide MOPS	Study 3: Mobile Museum Guide MOPS++	Study 4: Mobile Interaction with Advertisement Posters	Study 5: Cinema Scenario
Touching	NFC		RFID	NFC	NFC
Pointing	Laser pointer	Visual Marker	Visual Marker	Visual Marker	
Scanning	Bluetooth	GPS			
User-mediated object selection		Numbers	Numbers	Labels	

Table 12: Tested interaction techniques and the used implementations in the user studies.

4.2 Study 1: Mobile Interaction in Smart Environments

This section describes the implementation and evaluation of a prototype for mobile interaction in smart environments that is described in detail in [Leichtenstern 2006, Leichtenstern et al. 2006, Rukzio et al. 2006b] and which was developed in cooperation with the Intelligent Inhabited Environments Group of the University of Essex. The research presented in this section is mainly based on [Rukzio et al. 2006b].

This prototype focuses on the usage of mobile devices for interactions with objects in smart environments. A smart environment is an environment fitted with a variety of sensors and electronically operated devices which enable the occupants to customize the functionality of their living environment (e.g. a domestic home). Using such a system, it is possible to e.g. monitor light level, temperature, window and door statuses and who currently is in a house [Abramson et al. 2000]. Most current research related to smart environments focuses on context-aware systems which adapt according to contextual information. In [Shafer et al. 2001] the authors describe the Easy Living project providing an overview of interaction modalities in such context-aware smart environments. Such environments are usually equipped with a set of smart objects augmented by sensors or actuators to interact with their physical environment and which often provide a user interface. One issue is how to control and interact with these objects. One solution is to use mobile devices as remote controls. Examples include the Home Automation System [Tarrini et al. 2002] and the Pebbles research project [Myers 2005].

There are numerous scenarios in which mobile interaction in smart environments makes sense including the provision of additional services such as reading the manual of a microwave after touching it with the mobile device or requesting direct support for a specific device. Other examples are adding interaction functionalities for devices without an interface (e.g. information about power consumption of electronic devices) or remote control of objects (e.g. requesting the current status of the washing machine while watching TV). To address these and other questions, a comprehensive online survey was conducted, a paper prototype was developed and evaluated, the interaction techniques touching, pointing and scanning were implemented and this prototype was evaluated in a real world setting. This development process was based on user-centred design which means to focus on the user and retrieve as much user feedback as possible.

This section is organized as follows. The next subsection presents the results of the analysis which are based on an online survey with 134 participants. Afterwards, a paper prototype is discussed which was developed based on the findings of the analysis phase and which was evaluated in a small user study. Following this, the implementation and evaluation of the three interaction techniques and their usage in a demonstrator are presented.

4.2.1 Analysis

The goal of this phase was to analyze the needs of potential users and to deduce which services are useful when interacting via a mobile device with a smart object. Furthermore it was of interest in which locations and contexts potential users would interact with smart objects and which interaction techniques they preferred. A three step process of evaluation was used. The goal was to get an initial, unprejudiced user opinion via an online questionnaire which was then verified through the evaluation of low- and high-fidelity prototypes. Thus the known weakness of users not to be good at speculating about how they may or may not use systems was not a significant issue as the findings were tested using working prototypes.

The initial web based questionnaire was conducted in November 2005. 134 people participated, 40% of them were female. The participants were between 17 and 59 years old with an average age of 28 years. 41% of the participants had a university degree and 95% of them owned a mobile phone.

At the beginning of the questionnaire general explanations of intelligent environments were given and opinions about various aspects of such environments were gathered. The findings revealed that the respondents had high expectations concerning the benefits such environments could bring to their life. For example, they described a smart environment as an interesting, practical and comfortable way to live. In particular they saw the possibility to save time, energy and money. Many respondents mentioned benefits for older or handicapped people. In contrast to those opinions, some respondents were afraid of losing too much control. Several users mentioned a fear of a power blackout of the smart environment or were worried about the dependence on technology and a loss of human control.

The respondents were then asked about their general feelings regarding the usage of the mobile device to interact with objects in smart environments. The corresponding feedback was positive. It was pointed out that mobile phones were widespread and familiar. People mentioned the benefit of being able to interact with their smart environment even if they were away from home which provided a confident feeling of being able to regularly check the status of their homes during absence. Additionally, security issues were raised and it was apparent that there was no proper trust in the security of mobile phone technology.

The next section of the questionnaire presented three different application areas for mobile applications interaction with smart objects. The first one concerned getting information related to an object. Examples include getting online instructions for a device (e.g. a washing machine), opening a web page related to a device (e.g. a fridge), opening other websites related to the devices (e.g. recipes related to the microwave) or an online guide for the television or radio. The participants had mixed opinions about these application areas as one can see in the following Figure 19a.

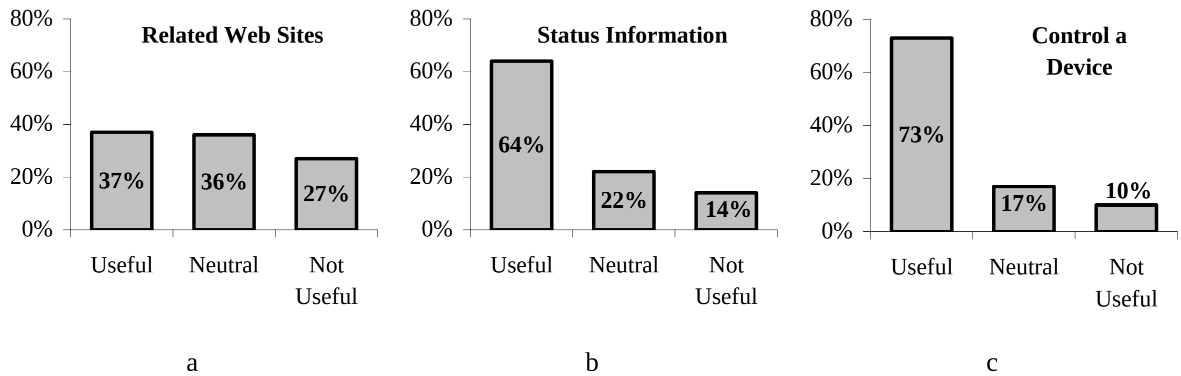


Figure 19: Results of the online survey regarding the usefulness of predefined application areas for mobile interactions with objects in smart environments.

37% rated retrieving information from related websites as useful whilst 27% thought it was not useful. The next application area was retrieving status information about physical appliances such as the status of the coffee machine (switched on/off) and the remaining time a washing machine needs to complete a wash (Figure 19b). Here 64% regarded such a service as useful. The last application enabled controlling a device such as the heating remotely (Figure 19c). Again this scored well with 73% of the participants considering such a service useful.

Subsequently the participants were asked when they would use the mobile phone for interactions with objects in smart environments. Figure 20 shows that the majority of the respondents (43%) would use such a system independently of their location. About a third of the respondents (34%) would use it only when not being at home. 13% would use it only when at home and 10% of the respondents would refuse to use such a system at all.

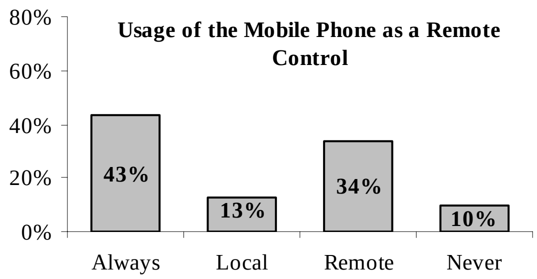


Figure 20: Preferred location of the user when interacting via the mobile phone with smart objects.

Next, the principle of each mobile interaction technique was explained and it was asked whether they would use touching, pointing or scanning when interacting with smart objects in various contexts. Figure 21 and Figure 22 summarise the overall findings and show that, in general, users preferred pointing and that they were almost equally split on the use of scanning, but generally disliked touching. From explanations given by the participants, it was possible to deduce that pointing performed best because many participants saw it as an intuitive interaction technique with little physical effort. Scanning was preferred in situations in which a physical distance existed between the user and the target object. Touching proved unpopular because most respondents did not see any added value; on the contrary, it was seen to cause more unnecessary physical effort. The only reported merit seemed to appear in situations where touching helped avoid ambiguity. The advantages of touching were seen in the accuracy and unambiguousness of the selection process especially when devices are small and close together. The most common complaint was the need for physical proximity to the device which requires a high level of user motivation to make the effort of approaching the device. The technique was rated as very intuitive and it was seen as the most secure and trustworthy approach.

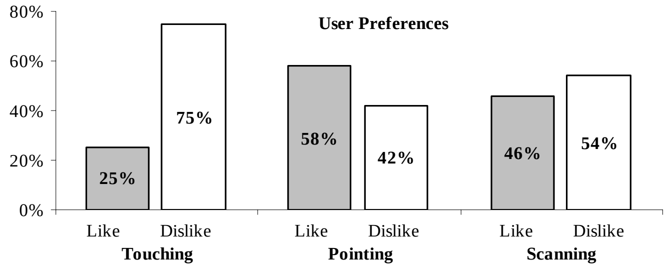


Figure 21: Preferences of the participants regarding the interaction techniques touching, pointing and scanning in general.

The benefits of pointing are seen as being natural, easy to use and quick for directly addressing the target device. In addition, the respondents mentioned that pointing avoids a complex user interface. However, ambiguities in the selection process are possible, especially if devices are close together or small.

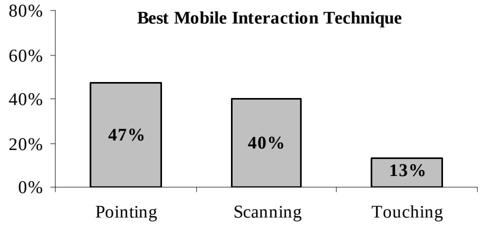


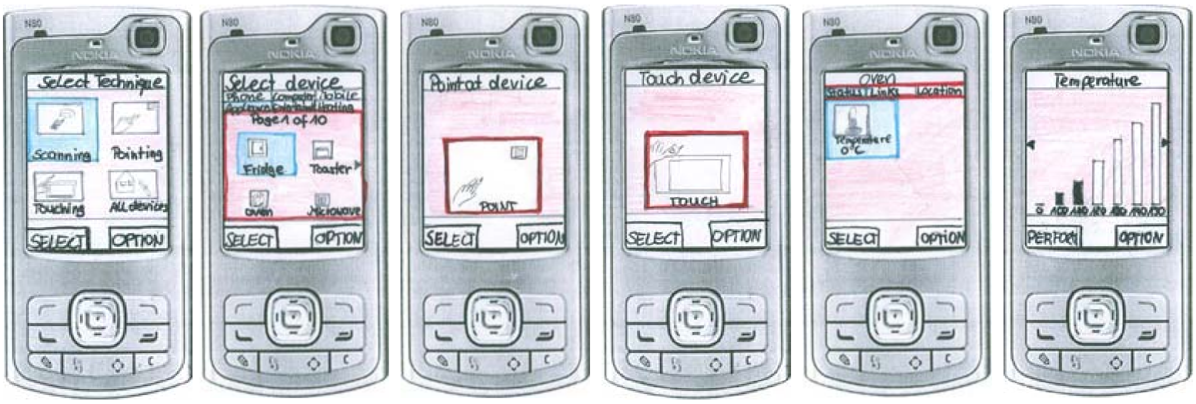
Figure 22: Direct comparison of touching, pointing and scanning.

A frequently mentioned benefit for scanning was that it operates at a distance and does not require proximity to the device and therefore requires less physical effort. Moreover, the listing of all available devices was seen as an advantage. Respondents mentioned that the mobile device becomes a mnemonic device for all available and usable smart objects. However, a drawback was that information might be displayed even if it is unimportant, although this might be more an implementation issue.

Whilst this survey allowed to get a feeling for the breadth of the issues to be investigated, by its nature there remained ambiguities that needed a more realistic context to resolve. Thus a low-fidelity and a high-fidelity prototype were developed to refine the findings and to evaluate the interaction techniques in a more practical context.

4.2.2 Low-Fidelity Prototype

The second phase of the user-centred design process consisted of the creation and evaluation of a low-fidelity paper prototype of the application. Figure 23 shows some samples of the paper prototype. It shows the screens for selecting a physical mobile interaction technique (Figure 23a), the interfaces after the selection of an interaction technique (Figure 23b - Figure 23d), a selected smart object (Figure 23e) and the usage of a service provided by the smart object (Figure 23f).



a b c d e f

Figure 23: Scans of the paper prototype [Leichtenstern 2006].

The test was conducted by eight people whereby everybody performed both tasks described below to verify the assumptions of the analysis phase.

Before each test, the participants were given explanations about paper prototyping in general. It was made clear that they should think aloud while interaction with the prototypes such that the operators could react and exchange the paper screens appropriately. The restrictions applying to the paper prototype were made clear and questions about the procedure were answered. Afterwards, it was explained how the interaction techniques work and how they could be used (taking into account it was a paper prototype).

In the first task the participants were asked to open a web page containing cooking recipes by selecting the fridge. In that situation the testers had line of sight to the fridge, but were too far away to perform touching. Six of the eight participants used pointing to select the fridge. They argued that, in the case of having a line of sight, scanning is too time-consuming. Furthermore, they were not motivated to actually go to the fridge to perform touching. They mentioned they would use touching if they were already close enough to the smart object. Just two of the testers used scanning but they realized during the selection process that scanning was more time-consuming than using pointing or touching.

In the second task the users were asked to set the timer of the microwave to 5 minutes. In this case several devices were close together and a selection via pointing could be ambiguous. Seven of the test people used pointing; as long as pointing was in any way possible they preferred it. They mentioned that if there was no line of-sight and pointing was impossible they would switch to scanning. Touching was only an option if they were already close enough to the device.

Next, the participants were asked which physical mobile interaction technique they would use if the smart object was in another room. All of them responded that they would use scanning. They did not show any motivation to move closer to perform pointing or touching.

Finally the users were asked which techniques they associate with the following features or attributes:

- **Security**: All eight users mentioned touching. They trusted this technique because they subconsciously think it is the most secure one. Due to the required close contact between phone and object, people tend to think that the communication between those is more reliable and that it is unlikely that it can be eavesdropped. They would use this technique if the smart object had some critical role in their life or in the current situation (e.g. a security observation camera or oven).
- **Intuitive:** Four persons mentioned pointing because they compared it to the TV remote control metaphor. The four others mentioned touching because they liked the easy selection process.
- **Speed:** Five of the participants mentioned touching because of the unambiguousness of the selection process. They thought that pointing needed more time because of the danger of selecting a wrong device and because of the pointing activity itself. The other three mentioned pointing because of the fact that they do not lose time getting closer. Furthermore, they all mentioned that the process of scanning for and selecting one device takes more time when compared with touching.
- **Least error-prone:** All mentioned touching because they associated this interaction technique with attributes like error resistance and security. It is also less likely to select a wrong device than when using pointing.
- **Highest cognitive effort:** Six participants mentioned scanning because they saw a high cognitive effort in finding the device and performing a mapping from name of the device to the device itself. Two mentioned pointing because they saw a cognitive effort in hitting the target. Touching was always seen as an easy action.
- **Highest physical effort:** All users mentioned touching because in all but the one case where the desired object is in direct reach, it requires more physical effort than the other interaction techniques.

4.2.3 High-Fidelity Prototype

After the analysis, the development of the low-fidelity prototype and its evaluation, the implementation of a high-fidelity prototype was started to evaluate the previous findings in a more practical context. For this a previously existing smart environment was used which is a domestic apartment that includes a range of smart objects which can be addressed via UPnP to receive and perform services.

Such a practical evaluation is very important for the analysis of these interaction techniques because several physical or technical constraints were difficult to simulate with a paper prototype or in an online questionnaire. Examples include the time needed for a scanning process, the time needed until the mobile device points exactly on an object or the correct touching of a smart object.

4.2.3.1 Architecture

This prototype does not use the PMIF framework because this was not yet in a matured state when the implementation of this high-fidelity prototype was needed.

Figure 24 gives an overview of the architecture of the high-fidelity prototype which consists of the following five components: The smart objects, the mobile phone, a web server, a pointing recognition server and a Universal Plug and Play (UPnP) server.

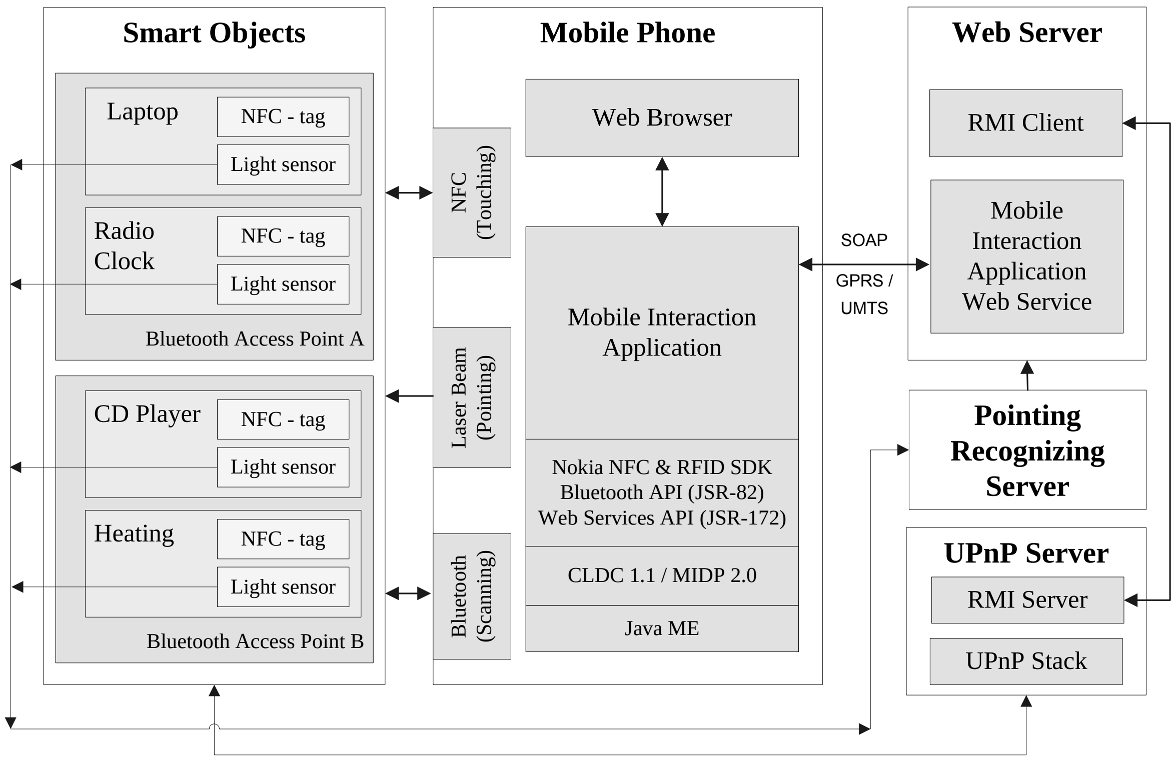


Figure 24: Architecture of the high-fidelity prototype including smart objects, mobile phone, web server, pointing recognizing server and UPnP server.

The smart objects and the services they offer can be accessed via UPnP. A heating system for instance could offer a service called *temperature*. Every service has a certain status which can be retrieved and changed via UPnP. Through this the mobile device is able to read the status of a smart object and to use a service provided by it. To identify an element in an UPnP network, a Unique Device Name (UDN) number is required to address the devices in such a network.

The physical mobile interaction techniques touching, pointing and scanning are used to select one of the UDNs through which a specific smart object is selected. For pointing, every smart object is augmented with a light sensor, which recognizes when the laser pointer attached to the mobile phone is pointing at it. For the implementation of touching, we used Near Field Communication (NFC) technology. The smart objects are augmented by Mifare NFC tags which can be sensed by the mobile phone. The physical mobile interaction technique scanning is implemented by using Bluetooth access points which provide information about nearby smart objects.

Thus, for every object to be identifiable by all three interaction techniques, it must be an element of the UPnP network, be represented by at least one Bluetooth access point and be augmented with a light sensor and an NFC tag.

The mobile phone application which is called Mobile Interaction Application (MobileIA) is implemented using Java ME and communicates via a web server running on top of a UPnP framework to retrieve information and to perform services in the smart environment. MobileIA uses the Nokia NFC & RFID SDK 1.0 [@NokiaNFCSDK], the Bluetooth API (JSR 82) and the Web Services API (JSR 172) and is based on CLDC 1.1 and MIDP 2.0.

Whenever there is a need for information, requests are sent to the Mobile Interaction Application Web Service (MobileIA Web Service). The MobileIA Web Service offers a WSDL interface to the mobile phone clients. The MobileIA uses the Web Services API to send a Remote Procedure Call (RPC) to the web server. The messages are sent using the SOAP protocol over GPRS/UMTS.

After the identifier of the smart object is known, the mobile phone client requests its description. This description includes all services provided by the object and the current status of the smart object with respect to those services.

From this, the mobile phone client generates a representation of the object. A user interface is generated that lists all available services, shows a graphical representation of the state and provides the means to invoke the service with parameters that can be specified. When the user changes the status of a device service, i.e. invokes the appropriate service, a request containing all relevant information is sent to the web server.

The web server gets the request and forwards it to the UPnP server. Since the web server and the UPnP server are separated, they communicate using Remote Method Invocation (RMI) from the RMI client (web server) to the RMI server (UPnP server). This RMI interface includes three operations and allows a request to be sent to all available devices. Thus, the web server can continuously update its list of available devices providing immediate feedback if devices drop out. Moreover, it allows a request to perform an action. The third method can be used to check if the status of a device has changed.

The UPnP server can then execute the service passed from the web server. The result of this service call can then be transferred back to the web server which can communicate it back to the mobile phone.

The UPnP service execution can be quite time consuming. To avoid a time-out during the communication between the mobile phone and the web server, the communication is closed after the service has been invoked. The result is stored in the database and can be queried by the mobile phone through the web server. This communication path can be used to send arbitrary results from the service back to the phone.

The following subsections discuss the implementation of touching, pointing and scanning in detail.

4.2.3.2 Touching

Touching is realized with NFC technology that was already described in subsection 2.3.3 Touching and 3.3.1 Touching.

If users want to use the touching technique, they first initiate the corresponding interaction mode. The NFC reader then starts looking for available tags within its scope. When the mobile phone is in the proximity of a smart object, the NFC shell establishes an electromagnetic field to create a radio frequency connection. It can then read data from the tag. An UDN identifier can be extracted form this data.

The following Figure 25 shows the Nokia 3220 with integrated NFC chip (Figure 25a), usage of the NFC phone for reading a Mifare NFC tag (Figure 25b), a Mifare NFC tag attached to an smart object (Figure 25c) and a user who is using the NFC phone to touch the NFC tag (Figure 25d).

a b c d

Figure 25: Implementation of the interaction technique touching and used hardware [Leichtenstern 2006].

To get the device identifier (UDN) from the Mifare NFC tag, the MobileIA uses the Nokia NFC & RFID SDK 1.0 [@NokiaNFCSDK]. Once the user has moved the mobile phone close enough to the Mifare NFC tag, the SDK triggers an event and notifies the MobileIA of an available data packet. The UDN stored in the packet can then be read. As described above, the device description is retrieved through the infrastructure and can be used by the application running on the phone.

4.2.3.3 Pointing

Pointing is realized with a light beam from a laser pointer attached to a Nokia N70 that is sensed by light sensors on the smart object. This basic implementation was later adapted and integrated into the PMIF framework and was therefore already described in subsection 3.3.2. The information described in subsection 3.3.2 is essential for the understanding of this subsection.

After the Particle computer attached to the light sensor has detected that the laser pointer points at one of its sensors, a message is sent to a receiver connected to a USB port of the pointing recognizer server. This communication is performed using its radio frequency communication facility. On the pointing recognizer server side, the UDN sent with the message is retrieved. Upon reception of such a message, the UDN is passed to a Java Servlet on the web server where it is stored in a database together with time information.

The moment the user starts the pointing technique mode on the mobile phone, it periodically sends requests to the web server. Whenever there is an UDN available in the database that is not older than a specified time, this UDN is returned to the phone. As described earlier, the device description is then requested.

The light sensor had a diameter of about 2.5 centimetres. For recognition, the sensor must be hit for about 1 second. Selecting a target with the laser pointer which is about 3 meters away is fairly easy.

Figure 10 on page 45 shows the used hardware, a Nokia N70 with attached modified laser pointer (Figure 10a), smart object with an attached light sensor connected to a Particle computer (Figure 10b), Particle message receiver attached to a USB port (Figure 10c) and sample usage of the interaction technique pointing (Figure 10d).

4.2.3.4 Scanning

Scanning is realized using Bluetooth access points which provide information about smart objects in their proximity. To implement this technique, a Nokia N70 phone was used since it provides Bluetooth support. The mobile phone user first chooses the scanning mode on the mobile phone. Then the user explicitly starts a Bluetooth scan for all available Bluetooth enabled devices that can connect to the phone and subsequently selects one of them. This includes all access points in the user’s proximity. The list of found access points can be used to get an approximation of the location of the user which could potentially be used to reduce the number of devices listed. The mobile phone sends the list of access points to the web server. A description in the infrastructure maps each access point to devices that are located close to it. From that description, the web server retrieves all available devices. The UDN and a human-readable name of each of the devices are sent back to the phone. The mobile phone application generates an appropriate graphical representation for each of the devices and displays it. For unknown devices, a standard representation including the name is chosen. Now the user can select one of the smart objects from the list and its device description is retrieved in the same way as with the other two techniques.

4.2.3.5 User Study

The experiment based on the prototypes described above was conducted with 20 participants. The users were aged 9 to 52 with an average age of 28 years. 35% of the participants were male and 70% had an academic education. 55% of the participants did not have a technical background in their job or field of study. In the first part of the experiment, the users had to perform different tasks using the high-fidelity prototype. The tasks had to be performed at different positions and activities. In all of the following scenarios the participants were located in a living room. All scenarios were subdivided into the three activities sitting, lying and standing to cover most casual activities. It was assumed that lying is related to activities like relaxing or lazing around, sitting is related to talking or writing, and standing is related to working and hurrying. All participants performed all tasks of the four scenarios while sitting. Afterwards they were asked about their behaviour and preferences when lying or standing.

In the first scenario the participants had to select the CD player and then had to turn it on. There was a distance of three meters between the participant and the device. The users had free line of sight to the smart object. 95% of all participants used pointing to select the CD player. This decision was independent of their activity. Just one person used scanning.

In the second scenario the participants had to open a website related to a radio show. This link was available through the radio which was standing close to the participant. All participants used touching in that situation. The decision was independent of the activity. The users mentioned that in that situation touching is the best and fastest technique because they do not need to spend physical effort because they were already in touching range.

In the third scenario of the experiment the participants had to select the heating of the bathroom, switch it on and set it to 25 degrees. 100% of the participants used scanning to select the smart object. There were no differences when lying, sitting or standing. No participant was motivated to move to the other room and to use pointing or touching.

In the last scenario the participants had to select the laptop to access a Wikipedia link which was stored on it. The testers were not able to point at the laptop because there was no line of sight to it at the given position. The users had to move about one meter for pointing and about four meters for touching. Unlike the first three scenarios, the activity of the user (sitting, lying or standing) was an important factor for the selection of an interaction technique in this scenario. When the users were lying or sitting, all participants used scanning to select the smart device. In contrast to that, in the case where the users were standing, just one person used scanning, 25% pointing and 65% touching. They refused to use scanning since this interaction technique takes more time than the other two. The reason for the high acceptance of touching was that the participants thought that if they are already standing they could move the short distance to the touching range as well.

4.2.4 Summary

Based on the research described in the previous subsections, the following basic guidelines for the usage of physical mobile interactions in smart environments were formulated:

- Users tend to switch to a specific physical mobile interaction technique dependent on **location**, **activity** and **motivation**.
- The **current location** of the user is the most important criterion for the selection of a physical mobile interaction technique.
- The user’s motivation to make any **physical effort** is generally low.

Next, the most important factors for the selection of an interaction technique will be discussed.

Location: In general the following three different situations appear.

- The smart object is within reach of the user. In this case users prefer touching because in this context it is more intuitive and faster than the others techniques.
- The smart object and its tags can be seen by the user but it is not in close reach. In this situation users mostly prefer pointing because they would have to expend physical effort to use touching. In addition, they avoid scanning because it is more time consuming and complex.

- The smart object is in scanning and pointing range, but there is no line of sight between the user and the smart object. In this situation users mostly prefer scanning because they would have to spend physical effort to use touching and pointing.

Activity: Besides location, current activity is another factor influencing the selection of a physical mobile interaction technique. The following three different activities were considered: lying, sitting and standing. The results of the user tests showed that in the context of lying or sitting, the location context is much more important than the activity context. Yet, the situation when the user is standing is completely different. In this situation the motivation to move and to use touching or pointing is much higher. Another aspect of activity is the kind of occupation. If the user wants to relax, she does not want to make any physical effort, whereas she is more motivated to move when she is busy.

Motivation: Basically, the user is not willing to make any physical effort and chooses a physical mobile interaction technique mainly according to the location and activity context. Nevertheless, the motivation to approach a smart device can be increased. In particular the following aspects increase the motivation to move:

- Security Issues: Users are willing to make a physical effort when they are highly motivated, e.g. when the smart device plays some critical role in their life. In these cases, users are ready to get closer to perform a selection via touching. Examples include interaction with the security system of a smart environment or the oven. The reason is that users are convinced that this interaction technique is more secure because of the short distance between the mobile device and the smart object. It is thought to be not possible to interrupt or eavesdrop on the connection or to manipulate the transferred information. Furthermore, they see that the risk of selecting the wrong device is very low.
- Speed: In some cases, the selection process must be performed very quickly. Here, the motivation is increased to move closer to use a fast direct interaction technique. An example for this is the control of the lights in the room. In this case the users are not willing to use a time-consuming scanning procedure, they prefer to point to or touch the object to quickly switch it on or off.
- Intuitiveness: The intuitiveness of the direct interaction techniques can increase the motivation to approach an object for interaction. Older people in particular who are not used to mobile phones are more motivated to make a physical effort to prevent a more complex and time consuming indirect selection technique.
- Maximum Physical Effort: The previously mentioned aspects to increase the motivation are only appropriate if the required physical effort is not too high, e.g. implies movement of up to 10 meters. The further the smart devices are away the less important are the motivation aspects.

4.2.5 Conclusion

A comprehensive analysis of the physical mobile interaction techniques touching, pointing and scanning within the context of smart environments has been presented in section 4.2. First an online questionnaire was conducted asking the participants about their opinion with regard to mobile interactions in smart environments in general, and in particular which services they would use. Additionally, they were asked about their preferences regarding the three interaction techniques. Following this, a low-fidelity and a high-fidelity prototype were developed and evaluated that supported touching, pointing and scanning.

The influence of the user's location, her activity and her motivation on the preference for a physical mobile interaction technique was analyzed. It was observed that location is by far the most important factor for the selection of touching, pointing or scanning within a given context. In addition to this, it was examined how the activity of the user (standing, sitting, lying) related to the same decision. Generally, it can be said that if the user is sitting or lying, she prefers an interaction technique which is possible without changing the location, even if the interaction might take more time. Furthermore, it was inferred that factors such as security issues, speed and intuitiveness can also influence the preference for an interaction technique within a given context.

Put in a nutshell, people prefer to touch things that are near. If they are not near, and there is a free line of sight, they prefer pointing. Only if all else fails, they prefer scanning.

4.3 Study 2: Mobile Tourist Guide MOPS

This section describes the evaluation of the mobile tourist guide called MOPS (Mobile Petuel Park System) [@PEMS 2005] whose functionality and implementation was already discussed in subsection 3.5.1. This prototype supports the interaction techniques pointing, scanning and user-mediated object selection for the selection of points of interests. User-mediated selection and scanning are interaction techniques that are often used by mobile outdoor guides like the BUGA Butler [@BUGAbutler 2005]. Therefore, the prototype supports these two interaction techniques as well. In addition to those, pointing as a novel interaction technique that requires a short distance to the exhibit is integrated. The implementation of scanning is based on an external GPS device and the implementation of pointing is based on the visual code system. When using scanning then the user gets automatically informed about a nearby object when the distance between object and user falls below a specified distance.

MOPS and the supported interaction techniques were evaluated within a user study conducted in the Petuelpark [@Petuelpark] in Munich. This context was selected since there are many modern art objects within this park and many visitors have no idea about the idea and message of these exhibits. Because of this, potential testers or users might be more interested in using a mobile guide in general. Another reason for selecting the Petuelpark was, that much information about the exhibits was readily available. Furthermore, it was possible to use a GPS-based implementation of the interaction technique scanning because relatively few disturbing objects like high buildings or trees are within or nearby the park.

The two day user study (see Figure 26), in which 17 persons participated, was conducted in the Petuelpark [@Petuelpark] in November 2005. Besides the evaluation of the interaction techniques, the evaluation of the concept of such a mobile guide and the current implementation in general was one of the goals of the test. The following text focuses primarily on the evaluation of the three supported interaction techniques.

Figure 26: Evaluation of the prototype for the Mobile Tourist Guide MOPS.

The user study was divided into three phases. In the first phase demographical information about the participants (age, profession, sex, etc.) were collected and they were asked questions regarding the usage of their mobile phone and their prior experiences with mobile guides.

13 participants (77%) were male, 4 female. The participants were between 19 and 29 years old with an average age of 24 years. All participants owned a mobile phone with 13 (77%) of them having a built-in camera and 9 (53%) of them Bluetooth support. 7 (41%) of the participants had already used a mobile guide provided by a museum or an exhibition. 6 of the those 7 previously used mobile guides were without a display that presented audio information related to an object or the exhibition.

Afterwards, the idea underlying MOPS was explained and questions regarding the supported interaction techniques were asked. The following Figure 27 shows the result of the question *Which interaction technique is in your opinion the best one for such a mobile guide?*.

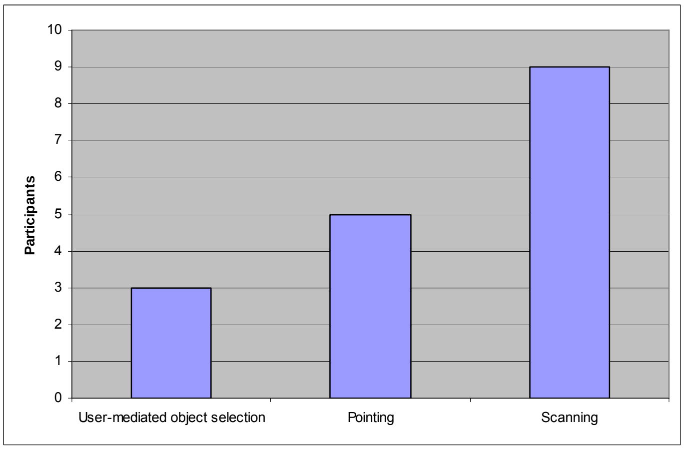


Figure 27: Preferences of the participants before using the prototype.

As one can see most (9 of 17; 53%) of the participants preferred scanning whereby just 5 (29%) preferred pointing and only 3 (18%) supported user-mediated object selection.

Within the second phase of the user study the participants had time to test the MOPS prototype. The fact that mostly two participants used the prototype at the same time should simulate the more realistic situation that a small group or a couple is jointly walking through a park and not just a single person by its own. The two participants were asked to interact with 6 sights whereby the prototype was given to the other person after every interaction.

Every participant had to test every interaction technique but it was their own decision in which sequence they tested the different techniques. The following Figure 28 shows that the majority of the participants (14 participants, 82%) started with the physical mobile interaction technique pointing. Scanning (GPS) was most often used as second type of interaction (11 participants, 65%) and in the last step user-mediated object selection was chosen by 14 participants, 82%.

The reason for this sequence is that most participants were curious about the interaction technique pointing because most of them had never seen something like this before. In contrast to that, some of them had already heard about location based guides but never used one which can explain why this interaction technique was so often selected as the second one. Most of them could imagine how user-mediated object selection works. Since it was not seen as a very innovative interaction technique, this was selected as the last one to try.

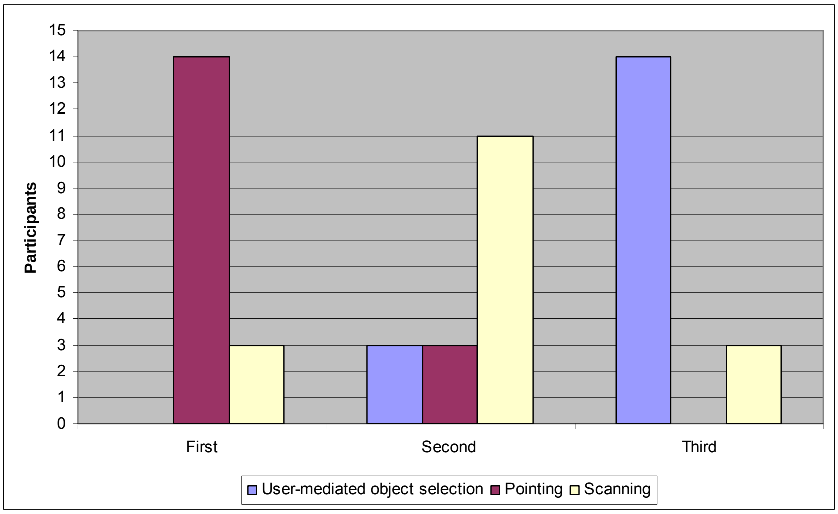


Figure 28: Sequence in which the different interaction techniques were selected by the participants.

After every interaction with an object, the participant who used the prototype in this moment was asked why she or he selected this particular interaction technique. Furthermore, the participants were asked to rate this interaction technique regarding their simplicity of use, the fun factor and how innovative and reliable the interaction technique for them seems.

Possible answers were defined and encoded by the following Likert scale: completely agree (4), partly agree (3), do not know (2), partly disagree (1) and disagree (0).

As depicted by Figure 29, the participants did not see a big difference regarding the simplicity of the different interaction techniques, but user-mediated object selection was seen as the simplest one.

The participants saw pointing and scanning as the funniest interaction techniques whereas user-mediated object selection with an average rating of 1.3 was seen as the least funny one. This also corresponds to the results regarding the innovativeness of the interaction techniques where the participants equally preferred scanning and pointing to user-mediated object selection.

When looking at the results of the reliability of the interaction techniques then it can be seen that the participants preferred user-mediated object selection over pointing and scanning. The reliability results may have been influenced by the problems the participants had with the usage of the implementations of scanning and pointing. The external GPS device had sometimes problems to receive sufficient satellite signals and the accuracy of the identified position of the user was also sometimes not satisfying.

When using pointing, some participants had problems to have the marker completely focussed with the built-in camera. Therefore, some of them needed more than one try to successfully use this interaction technique.

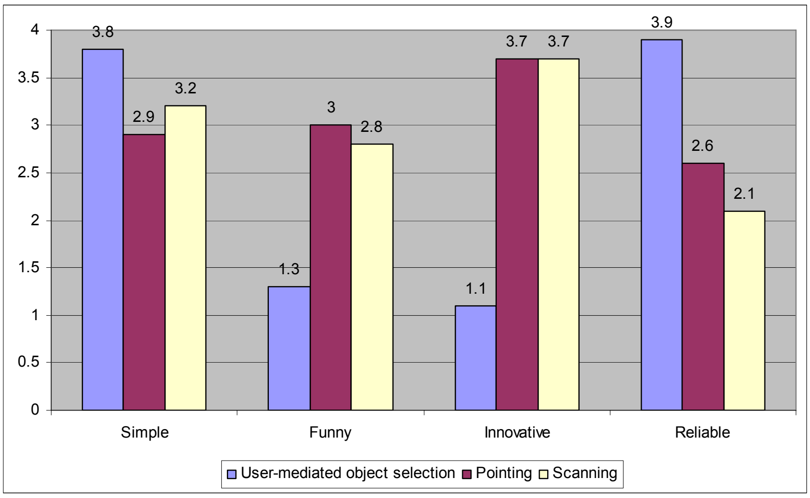


Figure 29: Average ratings of the interaction techniques.

In the third phase, after the usage of the prototype, general questions about MOPS and which interaction technique they preferred most were asked. It was also of interest to find out which one they would continuously use and which one they judged to be the most reliable, innovative and funny ones. The corresponding results are depicted in Figure 30.

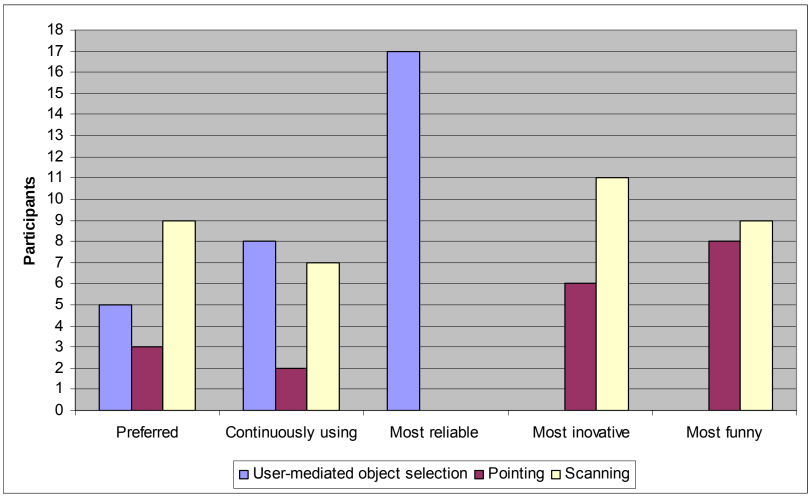


Figure 30: Final ratings of the interaction techniques.

9 of 17 (53%) favoured scanning over user-mediated object selection (5 of 17, 29%) and pointing (3 of 17, 18%). When comparing these results with the results depicted by Figure 27 that showed the preferences before using the prototype, then one can see that before and also afterwards 53% preferred scanning. When looking at pointing, then the number decreased from 5 (29%) to just 3 of 17 (18%). With user-mediated object selection, it is the other way around.

These results change a little bit when asking about the interaction technique they would continuously use. Here, user-mediated and location based object selection were preferred most often whereas pointing was just mentioned by 2 participants. User-mediated object selection was unanimously mentioned to be the most reliable technology when comparing it to the others. Scanning and user-mediated object selection were seen as innovative and funny interaction techniques whereas none of the participants connected these attributes with user-mediated object selection.

At the end the participants were asked whether they would use such a guide or not. 10 (59%) said yes, three were undecided and four answered with no. While giving this answer, some mentioned without being specifically asked that the price for such an application or service is crucial for the decision whether they would use it or not.

4.4 Study 3: Mobile Museum Guide MOPS++

This section describes the evaluation of the mobile museum guide MOPS++ (Mobile Point of Interest System) [@PEMS 2006] whose functionality and implementation was already discussed in subsection 3.5.2. This prototype supports the interaction techniques touching, pointing and user-mediated object selection to choose an exhibit in a museum. User-mediated object selection is the most typical interaction technique used in such guide and is therefore also supported by this prototype. In addition to this touching and pointing are integrated as novel interaction techniques that require a shorter distance to the exhibit. The implementation of touching is based on an external RFID reader attached to the mobile phone and the implementation of pointing is based on the visual code system.

MOPS++ was tested in May 2006 by 8 persons within a university building in which part of a train museum was simulated. There were no real exhibits, but posters showing a picture and a description of it in English and German were set up instead. Each poster was augmented with an RFID-tag (1 Kbyte, ISO 15693-3), a visual marker and a number to support all three interaction techniques. This section describes a user study for testing and comparing these three supported interaction techniques.

The following Figure 31 shows the usage of these interaction techniques during the user study. Figure 31a shows how the mobile device is used to read an RFID tag (touching), Figure 31b shows the reading of a visual marker (pointing) and Figure 31c shows the direct number input.

a b c

Figure 31: Usage of the three interactions techniques taken during the study.

The user study was split into three phases. In the first phase we collected demographical information about the participants (age, profession, sex, etc.) and asked questions regarding the usage of their mobile phone and their prior experiences with mobile guides as well as their opinion about the three supported interaction techniques. In the second phase every participant used each interaction technique twice whereby the sequence of the used interaction techniques was uniformly distributed. 7 participants were male, 1 female. The participants were between 23 and 45 years old with an average age of 28 years. We explained the idea behind MOPS++ and again asked questions regarding the supported interaction techniques. The following Figure 32 shows the results of the question *What is the best and what is the fastest interaction technique?*.

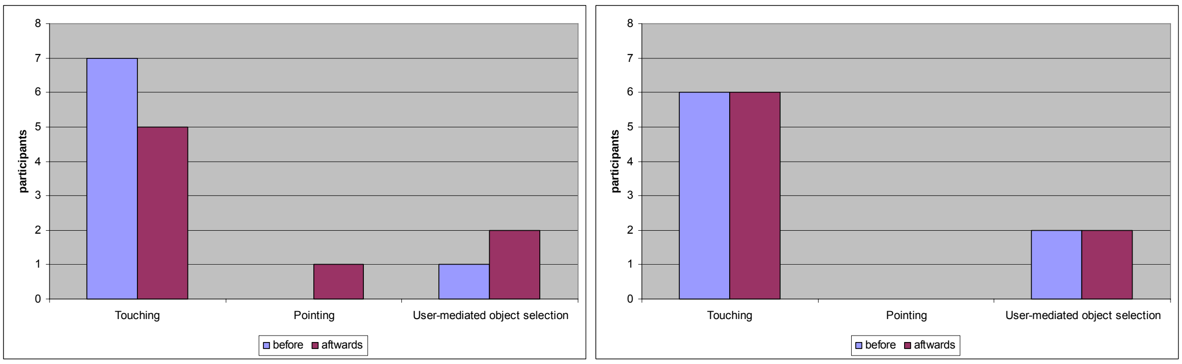


Figure 32: Best (left) and fastest (right) interaction techniques before and after the study.

The results show that before and after using the prototype, most participants preferred touching and some of them user-mediated object selection. Nearly nobody mentioned that she or he thought that pointing would be the best or fastest interaction technique. The reason for that is that a person in a museum is already close to an object to perform touching. The most noticeable disadvantage of touching, that the user must be nearby the object, has no impact in this context.

Furthermore, we asked the participants after having used the prototype to rate the interaction techniques regarding the attributes funny, innovative, reliable and simple. At this they could choose between the following possible answers according a Likert scale:

completely agree (4), partly agree (3), do not know (2), partly disagree (1) and disagree (0). The corresponding results are depicted in the following Figure 33.

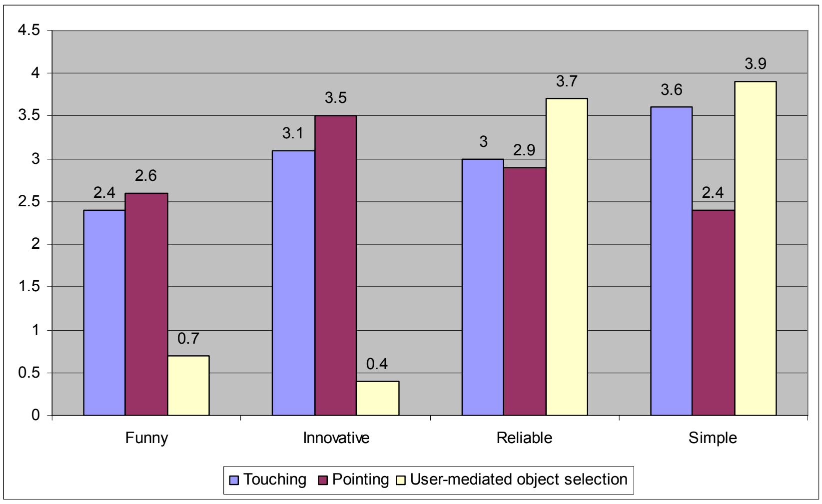


Figure 33: Average rating regarding the adjectives funny, innovative, reliable and simple.

In addition to that, we asked the users what they would rate to be the funniest, innovative and reliable interaction technique. Furthermore, we asked them which interaction technique they would continuously use. The corresponding results are depicted in the following Figure 34.

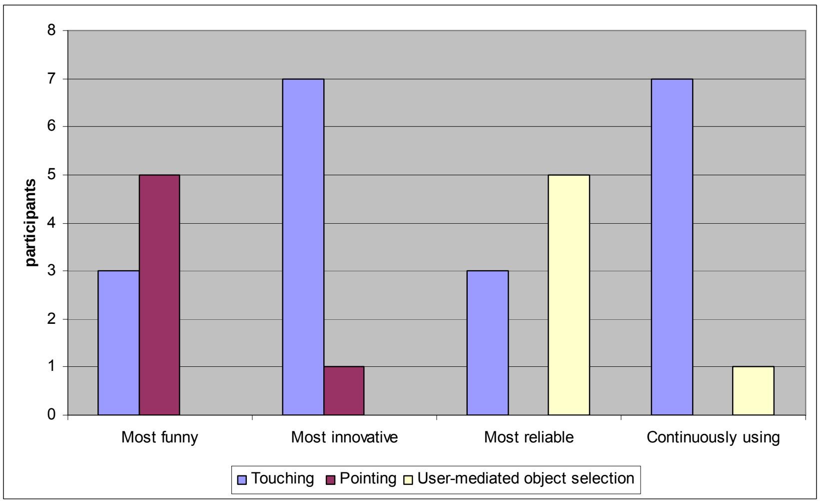


Figure 34: Rating regarding fun factor, innovativeness reliability and usage.

As one can see when looking at the previous two figures, touching and pointing are seen as funny and innovative interaction techniques. In contrast to that, user-mediated object selection and touching are seen as reliable interaction techniques whereby this is not the case when looking at the results of pointing. The reason for this is again, as it was in the previous study, the complexity of taking a picture of the complete marker in a sufficient resolution. This is also one of the reasons why pointing is not seen as a simple interaction technique whereas touching and user-mediated object selection got good results regarding this question. Furthermore, most participants would prefer the interaction technique touching when continuously using such a system.

Even if the context of a museum was just simulated and due to the fact that just 8 participants took part, this study shows the preference of people for touching, their interest in pointing and their trust in user-mediated object selection.

4.5 Study 4: Mobile Interaction with Advertisement Posters

This section describes the evaluation of an application of mobile interaction with advertisement posters described in detail in subsection 3.5.3 [@Perci]. This prototype supports, like the mobile museum guide application discussed in the previous section, the physical mobile interaction techniques touching, pointing and user-mediated object selection. This prototype supports a specific kind of user-mediated object selection which is called direct input. With direct input, the user does not need to look on the smart object to see the available options because they are presented on the mobile device, e.g. via a drop down menu. The same options are also shown on the smart object and can be used to support the interaction on the mobile phone. Examples are the four movie posters (see following Figure 35) that show the available movies. When looking at the poster this can help the user in the decision for one specific movie, e.g. because she likes the design of a specific poster.

The interactive poster that supports the purchasing process (see following Figure 35) provides action tags and parameters tags. After an action tag was selected, several parameter tags have to be used. The action tags offer the functionality for getting information about an advertised movie and for buying tickets. Through the parameter tags, a specific movie, a cinema in which the user wants to go, the number of persons for whom a ticket should be bought and a preferred timeslot can be selected.

Touching	Pointing	User-mediated object selection

Figure 35: Usage of the three interactions techniques taken during the study [Broll 2006, Siorpaes 2006].

Every option is accessible through an augmentation by an NFC Mifare tag (touching) as well as through a visual marker (pointing). The layout of the poster does not define an explicit sequence for the interaction with the poster reflecting the implementation which also does not prescribe a predefined sequence. Thus all physical parameter tags can be clicked in an arbitrary order after the corresponding action tag for buying a cinema ticket has been selected. This allows the user to proceed in the way she thinks is most appropriate.

In June 2006 a user study was conducted to evaluate this prototype and to compare the three supported interaction techniques touching, pointing, and user-mediated object selection. The goal of the study was, besides the evaluation of the interaction techniques, the evaluation of the concept of such a mobile ticketing application and its current implementation. The following text just concentrates on the evaluation of the three supported interaction techniques. 17 participants took part in the user study, aged from 23 to 46 years. The average age was 29 years. 4 testers were female and the other 13 male.

After the preliminary interview, the participants had to fulfil a predefined task with each of the supported physical mobile interaction techniques. The task was to buy a cinema ticket using predefined settings for movie, cinema, number of persons and timeslot. The sequence of the usage of the interaction techniques was alternated from user to user to avoid undesired side effects.

Many participants could, in the beginning, not imagine possible workflows for the interaction with the poster. A common statement was *How do I start?* Many people are used to explicit workflows such as starting at the top and continuing to the bottom when filling out a form. Another example for a known workflow is opening the SMS application on the phone, writing the text, selecting the recipients and sending the message. The participants in this user study were confused by the fact that there was no predefined sequence to select movie, cinema, time slot and number of tickets. This problem was partly already identified in a preliminary study based on a paper prototype that is described in [Broll et al. 2006b]. Because of this, the poster as well as the mobile phone application provided different hints of how to use the prototype. But as previous work has already shown and as it was proved again in this user study, people often ignore and do not appreciate such explanations.

As already mentioned, the poster had been augmented with action and parameter tags. The user had first to select the action she wants to perform (e.g. order a movie ticket) and then had to select the corresponding parameter tags like movie title or time slot. Many people did not understand this distinction without a corresponding explanation or reading the instructions carefully.

After the usage of the prototype we asked the testers how easy it is to handle each of the interaction techniques and how funny, innovative and reliable they are. The possible answers were: completely applies (4), somewhat applies (3), do not know (2), somewhat not applies (1) and not applies at all (0). The average of the given answers is depicted by the following Figure 36.

Touching followed by user-mediated object selection were seen as easy to handle. The result for user-mediated object selection is negatively influenced by the fact that two participants had serious problems with using the HTML browser on the mobile phone used for the implementation of this interaction technique. Pointing was not seen as easy to handle because the testers had problems to take a picture of the entire visual code in a sufficient resolution. This result probably improves when using a real time recognition implementation of the visual code system.

Many testers said that touching is a funny interaction technique. They primarily answered *do not know* or *somewhat not applies* when thinking about pointing and fun. User-mediated object selection was not seen to be funny at all.

Most testers saw touching as an innovative interaction technique, were often undecided when thinking about pointing and saw user-mediated object selection not as an innovative interaction technique.

Touching and user-mediated object selection were seen as reliable interaction techniques whereby they were undecided when thinking about pointing.

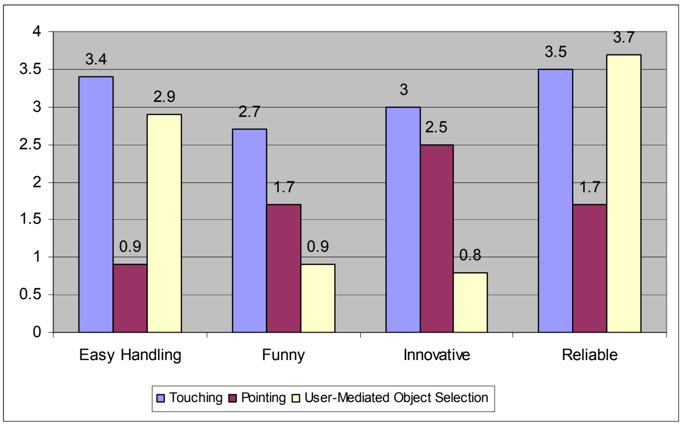


Figure 36: Rating of touching, pointing and user-mediated object selection.

Most testers said that user-mediated object selection is not a funny or innovative interaction technique. This is probably because people already knew and have already used this interaction technique.

The results for pointing were in general negatively affected by its implementation that needs a few seconds till the user knows whether she has successfully captured the visual code or not.

Before and after the user study the participants were asked which interaction technique they preferred and which of the three was the fastest. Before the study, 13 testers preferred the interaction technique touching whereby one preferred user-mediated object selection and one participant was undecided. 2 participants did not answer this question. After the user test, 13 participants preferred touching and 4 user-mediated object selection.

Before the study, 14 testers said that touching and 1 participant said that pointing is the fastest interaction technique. 2 participants did not answer this question. After the user study, 12 persons mentioned that touching was the fastest technique whereas 5 mentioned user-mediated object selection.

When looking at the overall result, touching is seen as the best interaction technique when taking the four analyzed attributes and the questions regarding the preferred and fastest interaction technique into account. Touching was highly ranked in all questions regarding the four attributes easy handling, funny, innovative and reliable. User-mediated object selection is seen as a reliable interaction technique that is easy to handle but is not innovative or funny. Pointing received the worst marks but is seen as more innovative and funny than user-mediated object selection.

4.6 Study 5: Cinema Scenario

This section describes the results of the evaluation of a prototype based on a cinema scenario using the physical mobile interaction technique touching [Falke 2005a, Falke et al. 2006b, Falke et al. 2006a]. In this scenario a person first comes across a poster of a cinema movie and touches this poster to buy a cinema ticket. In the evening, the person enters the cinema and touches the turnstile which reads the tickets stored on the mobile phone and the user is able to pass. In the cinema, the person touches a vending machine with her mobile phone to buy a drink. After watching the movie the person touches a poster of a taxi company to call a taxi.

The primary goal of the development and evaluation of this prototype was the analysis of security aspects, how people would like to control the functionality related to the touching capabilities of the mobile phone and how much time they needed until they have learned how to correctly touch objects with their mobile phone.

The prototype was implemented using a Siemens CX70 with an NFC sensor board attached to the mobile phone’s back cover. The application running on the mobile phone was implemented using CLDC 1.1 and MIDP 2.0 of Java ME. The Siemens NFC API was used to read the MIFARE 1K smart cards that were attached to the posters [@SiemensNFC]. The application on the mobile phone communicates via SOAP messages with a server providing the application logic and additional information.

20 persons participated in the user study conducted in autumn 2005. 12 were female and 8 male. Their average age was 26 years; most of them were students of computer science. The testers were asked to use the prototype with regard to the previously discussed scenario. In the user study, the turnstile and the vending machine were simulated by corresponding posters.

The following Table 13 shows the statements which the participants had to judge and Figure 37 shows the average results for these statements. They could be answered with applies completely (4), applies (3), may apply / may not apply (2), does not really apply (1) and does not apply at all (0).

18 of 20 testers (90%) mentioned that they would have no problems (*applies* or *completely applies*) with touching a smart object in public (statement 1). The participants were aware that somebody else could see what they did. Many of them mentioned that they did not see a big difference compared to making a phone call in public when thinking about the privacy aspects of these interactions.

19 participants (95%) assured that they wished to confirm the transmission of personal data like name, address or credit card information (statement 2). They had a split opinion when non-personal data like a ticket is read (statement 3).

Through the next two statements, existing preferences concerning the need for confirmation of actions when paying should be analyzed. The results indicate that if the electronic wallet is used, most were undecided (statement 4). 10 participants would want to confirm (*applies* and *totally applies*) and for 6 it would be acceptable (*does not apply at all* and *does not apply*) not to confirm before paying. In the case that the bank account, credit card or phone bill was involved (statement 5), then 19 testers would like to have the chance to confirm or cancel the process (*completely applies*) before actually paying.

Nr.	Question
1)	I have no problem with using touching in public.
2)	I wish to confirm the transmission of personal data.
3)	I wish to confirm the transmission of non-personal data.
4)	I wish to confirm any deductions made to the electronic wallet, even if I hold it to a reader device.
5)	I wish to confirm any deductions from my bank account, credit card or phone bill.
6)	I would rather use touching then enter an address by hand.
7)	I would use mobile services like this on my own phone.
8)	I would use mobile services more often when touching was possible.

Table 13: Statements which the participants had to judge.

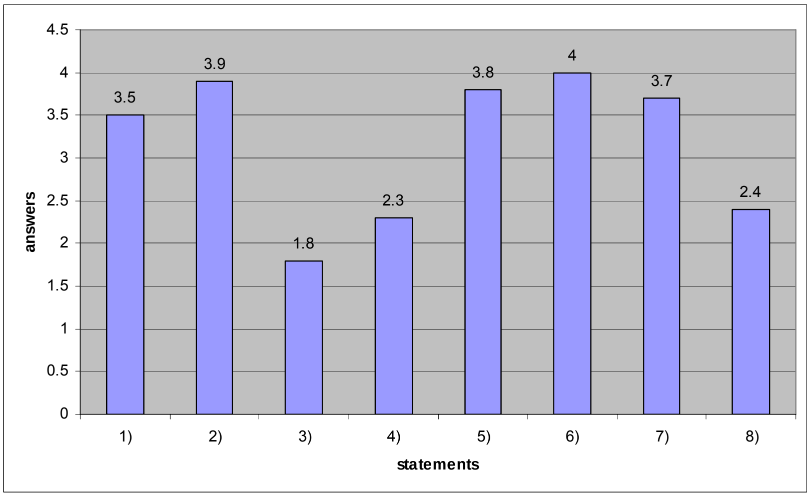


Figure 37: Answers of the participants regarding the statements depicted by Table 13.

All 20 participants clearly indicated that they would prefer touching when comparing it to user-mediated object selection (statement 6). When using the latter interaction technique, the user would have to type in an internet address by hand. 19 persons would use (*applies and totally applies*) a mobile service like the one tested on their own phone (statement 7) and 11 testers (55%) would use mobile services more often (applies and totally applies) when the interaction technique touching can be used (statement 8).

In further questions, 16 participants (80%) answered that the mobile phone should only scan for tags after they explicitly started such a scan, whereas 4 answered in the negative. 14 mentioned that the phone should emulate tags all the time, 1 was undecided and 5 would want to explicitly define when a tag should be emulated. A further functionality of the NFC-based implementation is that it is possible that many NFC tags can be emulated by the phone in parallel. 17 testers would use this functionality; just 3 would explicitly want to define which tag is currently emulated.

Within the user study, the participants had to interact with 4 different posters. The following Figure 38 shows how many attempts they needed on average until the tag was successfully read by the mobile phone.

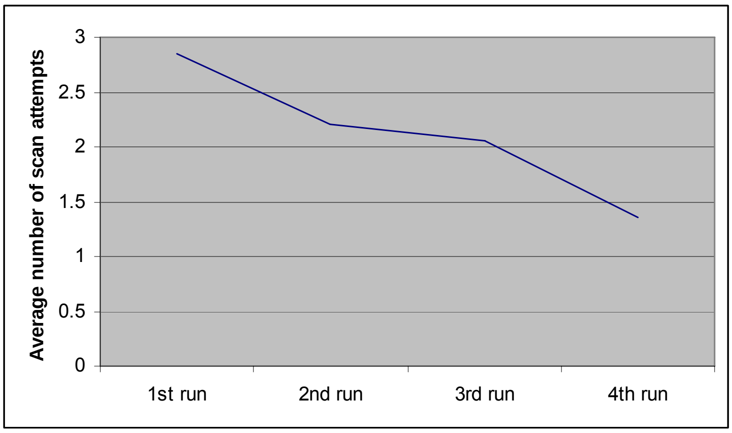


Figure 38: Number of scanning attempts within the four runs [Falke 2005a].

In the beginning, the participants needed almost 3 attempts whereas during the fourth run most of them needed just one attempt. The reasons for failures include the fact that the participants did at first not know where the NFC sensor was located, they did not know what the maximum scanning range is and they were not aware of the time that is needed for scanning a tag.

4.7 Discussion and Comparison

This section summarises the results of the five studies described in the previous sections of chapter 4. These results can help application designers and developers when deciding which physical mobile interaction technique should be supported within their application. In the following, the properties of each interaction technique under evaluation are recapitulated and a set of findings is derived suggesting the use of specific techniques under specific circumstances.

4.7.1 Touching

Touching is regarded as an intuitive, very quick, funny, reliable, unambiguous, innovative, simple, easy to handle, reliable and secure interaction technique which potentially requires physical effort but requires only little cognitive load.

It is seen as seen as an intuitive interaction technique because of its directness and the similarity to real world activities such as pressing a button on the microwave.

It is a very quick interaction technique because the user needs only perform a computer - real world interaction and very few human - computer interactions. The interaction consists mostly of touching the smart object, waiting for feedback that the touching was successful and recognising the feedback provided by the mobile device.

This interaction technique is also very error resistant and unambiguous when compared to pointing or scanning. The studies have shown that people can learn touching very fast and that they make very few errors after they are used to it. It would be an error, for instance, if the NFC tag is touched too briefly so that the mobile device can not read it. It is also an unambiguous interaction technique because first of all, it is technically impossible to read two tags at the same time and second, because of the directness it is hardly possible to select a wrong tag or smart object.

It is also seen as a secure interaction technique as the results of study 1 (section 4.2) show. One reason for that is that especially non-technical people think that it is hard to intercept or modify the communication between the smart object and the mobile device because these two objects are so close together.

Touching is typically preferred when the smart device is in reach of the user. Touching often requires the users' motivation to approach the smart device. But people try to avoid this physical effort, especially when being at home. This motivation increases if the benefits of touching outweigh the required physical effort. The user studies based on prototypes of a mobile museum guide (see section 4.4) and mobile interaction with advertisement posters (see section 4.5) shows that in these cases touching is the preferred interaction technique. In these situations the user is anyway interested in being near the smart object and in this situation many of them prefer touching because of the previously mentioned advantages.

4.7.2 Pointing

Pointing is seen as an innovative, funny and intuitive technique that requires some cognitive effort to point at the smart device and needs line of sight. It is typically preferred when the smart device and its tag are in line of sight of the user and the smart device cannot be accessed directly by the user. In the users' minds, pointing makes most sense because it combines an intuitive interaction with less physical effort (no need to actually approach the object in question).

It is also seen as an intuitive interaction technique, because it corresponds to our everyday behaviour to point at things when talking about them. Furthermore, it is an example of direct interaction techniques; these are generally seen as simpler as indirect interaction techniques.

When being at interaction distance, pointing is seen as the quicker interaction technique when comparing it to scanning but it is considered to be slower than touching. Fastness, error resistance and required physical effort of the interaction technique pointing depend heavily on its implementation. Both implementations discussed in the chapter have in common that they require some dexterity to correctly point at the light sensor or the visual marker.

When using a laser pointer as described in section 4.2, it can be seen as a fast and simple type of interaction that consists only of the pointing task, waiting for the confirmation of the interaction and getting feedback about how this changed the used application. The error resistance of this implementation is also high because the user gets direct feedback whether the selection was recognized and whether the correct object was selected.

In all other studies, described in sections 4.3, 4.4 and 4.5, an implementation based on visual markers was used. Here the testers did not get a rapid feedback. First they had to take a picture of the marker, then this has to be analyzed by the visual code software and then the user gets a feedback about its success or failure. Because of this, it takes several seconds until the user knows whether the visual code was recognized or not. Therefore, this implementation of the interaction technique pointing is not fast and also not error resistant. The latter especially results from the delay between taking a picture and getting the information that the image of the marker was not recognized.

Furthermore the used mobile phones and the size of the used marker also limited the distance in which an interaction was possible. This will change in the future, as mobile phones will have cameras with a high resolution and an optical zoom. The allowed distance is also based on the size of visual markers which was relatively small in presented prototypes. The example of the usage of big markers, like the 100 square meter big QR codes [Fowler 2005] used for an advertisement in Japan, shows that it is also possible to use marker based implementations of pointing in which the user can be far away from the smart object.

A disadvantage of this interaction technique is the coordinative effort and cognitive load to point the mobile device to the marker or light sensor on the smart object. Pointing with the laser on a sensor and taking a picture of a visual marker needs considerable concentration and physical skills, especially from inexperienced users.

4.7.3 Scanning

Scanning is seen as an innovative, somewhat funny and very technical interaction technique which is more complex to use because of its indirectness. Therefore the indirect mobile interaction technique scanning is avoided in many cases. If there is line of sight, the user normally switches to a direct mobile interaction technique such as touching or pointing.

Indirect interaction is mainly used to bridge a physical distance and to avoid physical effort. Scanning is seen as the technique with the least physical effort. Users tend to switch to scanning if a movement would be necessary to use a direct interaction technique.

A disadvantage is, that the user has to select the intended device when using for instance a Bluetooth based implementation of this interaction technique; this process is more time-consuming than directly interacting when standing close to a smart object. Furthermore the cognitive effort is higher compared to pointing or touching. It is typically used when the smart device and its tag can not be seen by the user and when the smart device is in scanning range.

A further advantage of scanning is the possibility to get a list of all smart objects in the vicinity. Thus it can be avoided to miss one. Additionally, no visual augmentation to attract the attention of the user is needed.

A disadvantage of this is, that the user has to establish the mapping between an item on the list or map presented by the mobile device and the objects in the environment for which a high cognitive effort is required. This might sometimes lead to frustration or the selection of the wrong object.

The study 2 (section 4.3) showed, that many testers saw the interaction technique scanning as a technique which they would prefer when using a mobile tourist guide. One important reason for this was, that they like to get proactively informed when a sight is nearby.

The presented studies were conducted using on two different implementations of the interaction technique. One was based on Bluetooth and one on GPS. When using Bluetooth then the users did not like the time which is needed to show a list of nearby object. The disadvantage of GPS - which was seen by the testers – was, that the GPS device had sometimes problems to deliver the exact position on time.

4.7.4 User-mediated Object Selection

User-mediated object selection is seen as a very reliable and simple interaction technique. The user has to establish a link between a smart object and a mobile service. In the previously discussed user studies (e.g. section 4.3 and 4.4) this merely meant typing in a simple number.

This view on simplicity and reliability might change when the user has to copy a URL using T9. This is much more cumbersome and the possibility of typing in a wrong URL is much higher. The performance of this interaction technique depends also on length of the information which has to be typed in. User-mediated object selection is relative fast when the user has to type in for instance a three digit number and is relative slow when the user has to type in a long URL.

User-mediated object selection is well known because it is, in contrast to the others, already used in mobile guides and many people already have experiences with its usage. Mainly because of this it is not seen as a funny or innovative interaction technique.

4.7.5 Summary

The following Table 14 shows based on the findings discussed in the previous subsections the advantages and disadvantages of the analyzed physical mobile interaction techniques. This table also discusses attributes like fun factor or innovativeness which might be a reason for a potential customer to buy or use a mobile service or application.

	Touching	Pointing	Scanning	User-mediated object selection
Rating: good, average, bad				
Felt error resistance, reliability	Good	Good (laser pointer) – Bad (visual marker)	Average	Good (short number) – Average (long number)
Performance, speed (within interaction distance)	Good	Average	Bad (Bluetooth) – Good (GPS)	Average (short number) – Bad (long number)
Simplicity, Intuitiveness	Good	Good (laser pointer) – Bad (visual marker)	Good (GPS) – Average (Bluetooth)	Good (short number) – Average (long number)
Rating: high, medium, low				
Cognitive load	Low	Medium (laser pointer) – High (visual marker)	High (Bluetooth) – Medium (GPS)	Medium (short number) – High (long number)
Physical effort	High	Medium	Low	Low
Fun factor	High	High	High (GPS) – Medium (Bluetooth)	Low
Innovativeness	High	High	High	Low

Table 14: Comparison of properties of the touching, pointing and scanning.

4.8 Further Findings

This section presents findings from the presented studies that are not specific to one type of interaction technique as have been the results shown in the previous section. This includes design aspects of the smart objects, characteristics that all the interaction types have in common as well as additional parameters that have been found important for such interactions.

4.8.1 Interface Design of the Smart Object

Most smart objects in the presented studies provided just a simple interface design that showed all provided interaction possibilities. Every smart object provided one marker for the supported interaction techniques and every marker represented a link to the same digital information or service. In the Mobile Museum Guide, discussed in section 4.4, for example, every poster was augmented with an RFID-tag, a visual marker and a number that lead to the same information shown on the mobile phone.

This principle of a smart object that is augmented with exactly one link to one service is used by most projects in that field. The physical mobile interaction is just used to establish a link between the smart object and the mobile device. All the interactions before and afterwards are conventional mobile interactions without using any further physical mobile interactions.

In contrast to that, the poster in the mobile interaction with advertisement posters prototype discussed in section 4.5 provides many different NFC tags or visual markers that represent different links. As the corresponding study showed, the participants were irritated by the fact that there were many tags and that they were not able to see a predefined interaction sequence. But there are in principle three different approaches to solve this problem that are visualized by Figure 39.

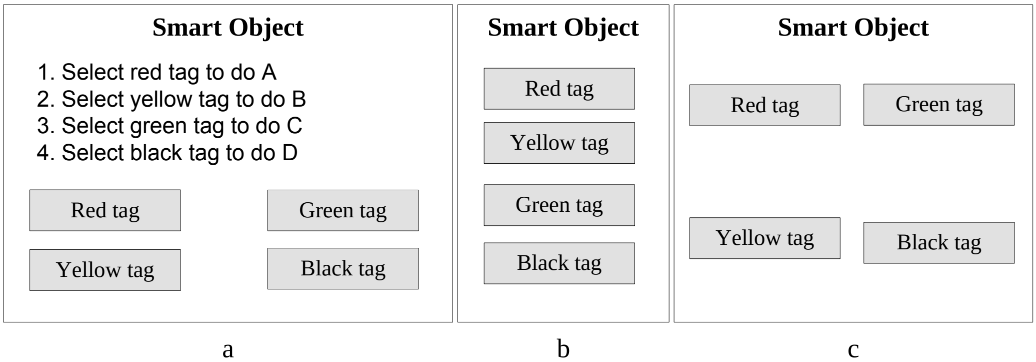


Figure 39: Approaches for designing the markers on the smart object.

Explicitly defined interaction sequence (see Figure 39a): The smart object visualizes explicitly, e.g. through numbering, a predefined interaction sequence as for instance known from some vending machines. The advantage is that everybody who wants can read this description and can thus use the system. Unfortunately, this also raises the complexity of the user interface because of the required text explaining the interaction sequence.

Implicitly defined interaction sequence (see Figure 39b): In this approach the smart object implicitly visualizes one possible interaction sequence through its design. The arrangement of the tags can for instance visualize the desired interaction sequence. This can be achieved through grouping of tags or their horizontal or vertical alignment. In contrast to the previous solution, the complexity of the interface needs not be raised. But some users might miss these implicit hints and do not know in the first place how to use the prototype. In addition, such a layout might not be appropriate or generate misunderstandings with other cultures that, e.g., read from right to left.

No defined interaction sequence (see Figure 39c): In this case the sequence of the actual physical mobile interactions plays no role as in the mobile interaction with advertisement posters prototype. The advantage is that there is no defined sequence and it is up to the user how she proceeds. Unfortunately most people are used to sequential workflows and therefore first need to get used to the fact, that every interaction sequence is allowed. In addition to that it depends on the application itself whether a prescribed interaction sequence is needed or not.

Furthermore, the interface on the mobile device should provide visual hints instead of textual descriptions to help the user while interacting with the smart object. An image of an RFID tag on the mobile phone indicates better than a corresponding text that the user could touch such a tag with her device. The presented prototypes did not focus on or analyze the visual design of the tags and the related services or functions. Only little research has been done in this field so far, the most important being [Arnall 2006, Riekki et al. 2006, Välkkynen et al. 2006].

4.8.2 Feedback

One of the most important features of the interaction paradigm direct manipulation is rapid feedback on all actions [Dix et al. 2003]. This is also true for physical mobile interactions. The user must get rapid feedback after every action. She should be informed what has happened and how this influences the used application. An example is that the user gets notified by a vibration of the mobile phone that she has successfully touched an NFC tag and that the mobile phone display shows how this interaction affects the application.

4.8.3 Novelty and Fun as a Design Criteria

One of the most important selling factors for new mobile applications is the acceptance of it by the potential user. There are many reasons why people would use and pay for a novel service. One is that many people are curious and interested in novel devices and technologies. The previous studies have shown that this is also true for physical mobile interaction techniques. Within the evaluation of the mobile tourist guide MOPS discussed in section 4.3 for instance, the participants could decide in which sequence they used the three supported interaction techniques. Most of them first selected pointing, then location based object selection and at the end user-mediated object selection. This study also showed that the first two interaction techniques were seen as much more innovative and funny than the third one. Taking these results into account, it can be argued, that the integration of novel and playful interaction techniques render a mobile application or service more attractive for potential users or customers.

4.8.4 Reliability

The reliability of an interaction technique is more important than attributes like being innovative or funny when using an application over a longer period of time. Most participants said that user-mediated object selection is the most reliable interaction technique because no technical problems like insufficient contact to satellites (for GPS based implementation of scanning) or inaccurate focus of the mobile phone camera on visual markers (for pointing) could interfere with the interaction with an object.

4.8.5 Number of Selectable Objects

If the number of selectable objects is small, the user prefers user-mediated object selection when compared to pointing. After the practical usage of the prototype in study 2, only 3 of the 17 participants (18%) said that they preferred pointing and just 2 of 17 (12%) would use it continuously with such a prototype. One reason for this is the limited number of objects in a museum or park like in the Petuel Park. The user only needs to type in a short number to identify an object. Even though pointing is not too laborious either, the required cognitive and physical effort is still less when using user-mediated object selection. The results are very probably different when complete and complex URLs have to be typed in.

4.8.6 Privacy and Security

As the studies, especially the ones presented in sections 4.6 and 4.2 have shown security and privacy are important issues for potential users. They would like to control which information is sent and received by the mobile device. People are afraid of scenarios like when standing in a crowd, a person nearby is empties her electronic wallet. One possible solution could be a firewall-like application on the mobile phone that manages these aspects. Such applications are analyzed in [De Luca 2006] or [Aust 2006] which were conducted within the context of this thesis but which are not discussed in this document.

4.9 Summary and Conclusion

At the beginning of this chapter, five different studies were discussed which analyzed the appropriateness of touching, pointing, scanning and user-mediated object selection in different application areas. Based on this the advantages and disadvantages of these interaction techniques were summarized in section 4.7 and further findings were discussed in section 4.8. These results are supposed to help future application designers in developing systems that use physical mobile interactions. When looking at the results, it must be remembered that no long term studies were conducted. However, based on these results developers should be able to decide better which interaction techniques should be provided in which context.

One disadvantage of the direct interaction techniques and the required low distance between the smart object and the user are their public visibility. It is easy to see the connection between a particular user and the object she interacts with. Some testers did not like the fact that other people could see or guess what they were currently doing and that others could eventually spy onto them.

Furthermore, the described studies showed that potential users see benefits for mobile interactions with smart objects in smart environments, with sights using a mobile tourist guide, with exhibits using a museum and with advertisement posters. This again demonstrates the potential of these interaction techniques for novel mobile applications and services.

Another important aspect that has to be considered when considering which interaction techniques should be supported in an application are the capabilities of the mobile devices currently owned by potential customers. In Europe, for instance, extremely few mobile phones are currently available that provide NFC functionalities and just a few mobile phones provide localisation functionalities like GPS which can be used for the interaction technique scanning. On the other hand, many mobile phones have a built-in camera that can be used for the marker based implementation of pointing, have a Bluetooth interface that can be used for the implementation of scanning and provide the functionalities needed for user-mediated object selection. These aspects were not considered in the previous sections because the goal was to focus on the properties of the interaction techniques in general and not on the current market situation of available mobile phones and their capabilities which can change very rapidly.

The distance between the user and the smart object was only in the first study the most important aspect for the preference of a specific interaction technique. The activity *standing* of the first user study can be compared with the situation of the user when using a mobile tourist guide or a mobile museum guide as discussed in studies 2 and 3. In these cases, the user is also standing and is interested in the nearby sights and exhibits. Therefore the motivation to move closer to use touching, pointing or user-mediated object selection exists. This is also true for the studies 4 (mobile interaction with advertisement posters) and 5 (cinema scenario). Here the user has to read the information on the posters and therefore she has to be nearby anyway.

After discussing the related work in chapter 2, presenting the PMIF framework in chapter 3 and the evaluation of physical mobile interaction techniques in this chapter, the following chapter discusses novel findings regarding the development of physical mobile applications.

5 Development Process of Physical Mobile Applications

When looking into the literature about software development in general (e.g. [Sommerville 2004]), about human computer interaction (e.g. [Dix et al. 2003, Shneiderman, Plaisant 2004]) or about mobile human computer interaction (e.g. [Jones, Marsden 2006, Love 2005, Weiss 2002], one can find a diverse set of information regarding the development of applications. Not surprisingly, most of them discuss processes to develop systems, requirements engineering, software or system design, software development methods, guidelines, principles, evaluation, theories, models, user interface design, interaction design, prototyping, information architectures or usability testing.

It is not the aim of this chapter to present a completely new methodology for the development of physical mobile applications. Most aspects discussed in these previously mentioned books can also be used for such applications because they are in the end just mobile applications which are a specific kind of conventional software systems and applications.

The aim of this chapter is to report experience, best practices, guidelines, methods and lessons learned that can be of use for other interaction and software designers, programmers and project managers. Most of the presented information is based on practical experiences gathered during the requirement analysis, design, development and evaluation of physical mobile applications. Many of these results can be also used for the development of conventional mobile applications.

When thinking about software engineering in general, the waterfall model is probably the first published and accepted software development process [Royce 1970, Sommerville 2004]. It consists of the five phases requirements definition, software and system design, implementation and unit testing, integration and system testing, and operation and maintenance. Furthermore and based on this, there exist other processes like extensions of the waterfall model, evolutionary and component based software development, formal system development, the spiral model and extreme programming.

As already discussed in subsection 2.2.6 the interaction design should play a very important role when developing mobile applications and services. It was also mentioned that [Dykstra-Erickson et al. 2001] defined an interaction design process to be consisting of the following five steps: find out about use, analyzing user data, generating ideas, designing systems and evaluation systems. John and Marsden discuss in [Jones, Marsden 2006] which techniques are useful in which phase of the process, especially for the field mobile interaction design.

The following Table 15 illustrates three of these five phases and shows the new findings and techniques that are discussed within this chapter. There is a strong relationship and overlapping between the interaction design process and the user-centred design approach [@UCD]. Therefore, the left column shows the relationship between the user-centred design process and the interaction design phases defined in [@UCD] and [Dykstra-Erickson et al. 2001].

The techniques for specifying context of use and requirements, development of low-fidelity prototypes and evaluation of designs depicted by Table 15 were used within the context of this thesis. This chapter reports lessons learned and best practices that are of help when using them for the development of physical mobile interaction and applications. Besides the additional information regarding these well-know techniques three new techniques for the development of high-fidelity prototype were defined as shown by Table 15.

User-centered design process phase (interaction design phase)	Technique		Discussion of technique	
			in literature	in this thesis (subsection / page)
Specify context of use and requirements (finding out about use)	Field studies		[Jones, Marsden 2006, Shneiderman, Plaisant 2004]	5.1.1 / 91
	Unobtrusive contextual observation		[Jones, Marsden 2006]	5.1.2 / 94
	Online survey		[Jones, Marsden 2006, Wright 2005]	5.1.3 / 96
Produce design solutions (designing systems)	Low-fidelity prototypes	Paper prototyping	[Weiss 2002]	5.2.1 / 100
		HTML/Flash prototyping	[Weiss 2002]	5.2.2 / 102
	High-fidelity prototypes	Using mobile phones for domain specific information appliances	n.a.	5.2.3 / 104
		The Physical User Interface Profile (PUIP)	n.a.	5.2.4 / 107
		Development of context-aware mobile systems	n.a.	5.2.5 / 117
Evaluate designs (evaluating systems)	Laboratory studies		[Dix et al. 2003, Jones, Marsden 2006]	5.3.1 / 124
	Field studies		[Dix et al. 2003, Jones, Marsden 2006]	5.3.2 / 126

Table 15: Phases and techniques considered within this chapter.

The following sections discuss experiences, best practices, guidelines, methods and lessons learned that can be used for the specification of the context of use and requirements, for producing design solutions and for the evaluation of designs. Often one or more case studies are presented and based on this the lessons learned and best practices are discussed.

5.1 Specify Context of Use and Requirements

One of the first steps when building a new system is the specification of requirements. This process is defined by [Sommerville 2004] as follows:

> *Requirements engineering is concerned with establishing what the system should do, it's desired and essential emergent properties; and the constraints on system operation and the software development process. You can therefore think of requirements engineering as the communication process between the software consumers and users and the software developers.* [Sommerville 2004]

5.1.1 Field studies: What can our environment tell us?

When thinking about a new idea for a physical mobile application, one of the first steps should be an analysis of the environment. This is different from the development of most conventional mobile systems because they do often not take the context of use or the physical world into account. Most published methods within the analysis phase like contextual enquiries, questionnaires or focus groups are focusing on the user of the system. But when developing physical mobile applications, one of the first steps before the involvement of users could be a field study analysing the prerequisites, the current real world situation. For this cheap and fast process, a person needs only to go to the places of interest, has to document and to classify it. Based on this information, the interaction designer knows more about the real world situation and can use this for the next steps. Furthermore, the results can show whether the real world situation fits to the first idea or whether these results can lead to new ideas for new applications.

5.1.1.1 Case Studies

The motivation for the **first case study** described in this subsection was the idea that people can use their mobile phone for interactions with public posters. The following explanations regarding this case study are mainly based on [Rukzio et al. 2004b]. An example for this could be a movie poster augmented with visual tags that can be used to order tickets using the mobile device. The goal was to analyze where posters and adverts are located. To capture this, various public places were examined and the properties of these places were analyzed. Therefore the author walked through the city of Munich and took photos of public posters taking their context into account. The result was that, in general, posters and paper based adverts can be found in nearly any public place. In many cases the information of the posters relates in some way to the place where it is posted. Especially in locations for public transport systems like airports, railway stations and bus/tram/subway stops, a lot of advertisement posters can be found. The posters are mostly attached to the building walls of the airport or the stop. Inside or near these locations, advertising columns and notice boards can also be found. In addition, posters are encountered at places where people spend some of their time. These include restaurants, cinemas, house walls near streets, crossings, or show windows.

Another result was that in order to use such information displays as gateways for access to mobile services, the most important attribute of a poster, with respect to its location, is the distance between a potential user and the poster. This distance limits and defines possible interactions.

In general, two main locations can be distinguished. First, there are posters a user can approach very closely. Examples are posters at a bus stop where the potential user is waiting, or an advertising column on the pavement. The user can potentially come very close to them and touch them. Second, there are posters that are out of reach because they are attached in such a way that they can only be viewed from a distance. Usually these posters are larger and the user can not physically get very close. Examples are posters on the ceiling, attached high up on buildings or behind a street or railway track.

In terms of dynamic aspects two categories should be considered. First, there are places where people can stand for whatever amount of time they want. If they are interested in particular information they can decide to stay in front of a poster and read it carefully. Typical examples are posters in the street. Second, there are locations where users are only passing. In this instance, the time the user can spend in front of a particular poster is not determined by the user. Typical examples are large posters on the motorway or close to the railway and posters along an escalator.

In general, four different categories can be distinguished as shown in the following matrix. There are further dimensions such as frequency of change and type of content but they are not central to the system investigated. See the following Table 16 for examples.

<table>
<tr><td></td><td></td><td colspan="2">Viewing time</td></tr>
<tr><td></td><td></td><td>user chosen</td><td>determined by circumstance</td></tr>
<tr><td rowspan="2">Physical accessibility</td><td>approachable</td><td>
</td><td>
</td></tr>
<tr><td>distant</td><td>
</td><td></td></tr>
</table>

Table 16: Categories of poster displays.

These results were then used to identify which physical mobile interaction technique should be preferred in which context (viewing time, physical accessibility). Taking this into account, a contextual observation was conducted (see subsection 5.1.2) and a prototype for pointing-based interaction with an advertising column (see [Rukzio et al. 2004b] for details) was developed.

A **second case study** described in detail in [Otto 2006] was conducted based on the result of the first case study. The goal of this field study was to analyze which kind of public displays exist, who provides this information and how many dynamic displays already exist. For the field study, a typical path between the home and the workplace of a person was chosen. This consisted of 12 minutes of walking and a 5 minutes subway trip. A camera was used to take pictures of all displays that were visible during this route. All in all, 172 different public displays were recorded and were categorized into three different categories: static information posted by an individual, static information posted by an organization and dynamic information posted by an organization. Dynamic information means that, e.g., a monitor was used to show information that change over time. There was no dynamic information posted by an individual. The following Table 17 (+ positive, 0 neutral, - negative) shows the different categories of information displays illustrated by some visual examples.

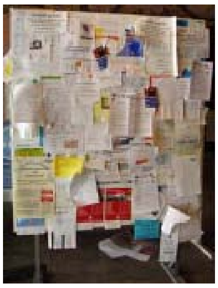
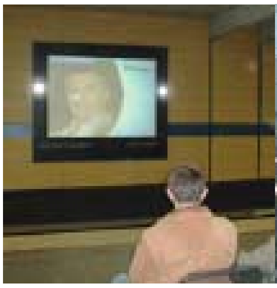
Categories	Potential for mobile interaction	Up to date	Frequency
Information posted by an individual			
 	+	-	~ 16%
Static information posted by an organization or company			
 	+	0	~ 81%
Static information posted by an organization or company			
 	+	+	~ 3%

Table 17: Categories of information displays [Otto 2006].

During the classification of the information displays it was also analyzed whether a mobile interaction with the display could be seen as a valuable service. Furthermore, it was analyzed whether the presented information is up to date and how often this kind of information display appeared within the 172 recorded displays.

The results were used to generate new ideas for mobile interaction with information displays. Two different application scenarios were developed whereby one was evaluated through a paper prototype (see subsection 5.2.1) and another through a high-fidelity prototype (see subsection 6.2.2).

5.1.1.2 Lessons Learned and Best Practices

A field study analyzing the potential context of use should be considered as one of the first steps when designing and developing a new physical mobile application.

Costs: The costs for such a field study are mostly very low and the results are quickly available.

Documentation: A photo or video camera or a microphone can easily be used to record information about the real world context. Furthermore, notes and sketches are another possibility to record information during a field study. This information can then be used to classify and to illustrate the different real world contexts.

Classification: The visual or audio information can be easily classified according to the needs of the considered concept. Images are also a good basis to communicate with the different stakeholders involved in the development process.

Quantitative results: When analyzing a real world situation within defined conditions (time, route, etc.), quantitative results can be generated in addition to the qualitative results. An example for this is the following: *While walking a typical route from home to work, in our case 12 minutes walking and a 5 minutes subway trip, the person saw 172 different information displays.*

5.1.2 Unobtrusive Contextual Observation

Contextual observation is one important method to gather information about the current behaviour of potential users or they way they use a system now [Dix et al. 2003, Jones, Marsden 2006]. The following subsection reports a case study of an unobtrusive contextual observation in which the observed persons were not informed about the observation.

5.1.2.1 Case study

This case study is based on the first field study described in subsection 5.1.1.1 in which was examined where posters and adverts are located [Rukzio et al. 2004b]. The goal of the unobtrusive contextual observation was to analyze how people interact in these spaces, in particular, at bus stops and railway stations.

In order to gain insight into the time available for mobile interaction with public displays, people and their behaviour were observed while waiting for public transport. One goal was to find out how long the passengers are waiting on average in relation to the frequency of busses and trams. How many of them come just in time and how many of them do not think about departure times when they go to a stop? Furthermore, their activities during such waiting periods were analyzed. All in all 230 passengers at three different locations were observed.

This was done by three different observers that used the same forms for noting their observations. For every passenger a description was noted that identifies her (e.g. young woman with a red t-shirt), arrival and departure time, what the person holds in the hands, activities of the person and if this person is part of a group.

In the first sample, 100 passengers were observed at a bus stop in Munich between 6.45 and 8.15 am on Wednesday, June 9, 2004, a workday. A bus stop in a residential area was chosen to analyze the behaviour of people on their way to work. Most people are using the public transport system for driving from home to work in the morning and back in the evening. Therefore these two situations were analyzed in particular. Thus it was possible to observe a fairly broad range of people who might all be potential users.

The intervals between two busses were 1, 5, 4 and 10 minutes. The average waiting time of the passengers was 3 minutes and 13 seconds. As one can see in Figure 40, nearly 1/3 of all passengers may not have enough time to use a mobile service that is connected with a poster because they just wait between 0 and 60 seconds. The reason for this is that most people prepare themselves in the last seconds for the arrival of the bus, tram or train. They often look in the direction from which the bus will arrive and will possibly not use this short time for looking at and interacting with any posters. On the other hand, 44% of the passengers were waiting for more than 3 minutes.

In the second sample, a total of 100 passengers at two opposite tram stops between 3.40 and 4.55 pm on the same day were observed. A bus stop in a business area was chosen to concentrate on the behaviour of people who drive back from work to home. The interval between two trams in every direction was 10 minutes. The average waiting time of the passengers was 4 minutes and 37 seconds.

The following Figure 40 presents the distribution of the different waiting times in the first two spot checks.

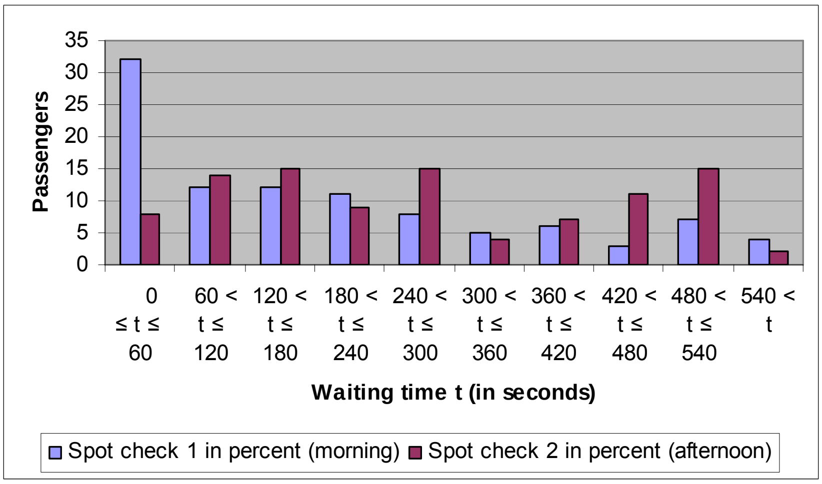


Figure 40: Waiting times of passengers.

At the spot check in the afternoon it was recognized that there were more groups and thus about 20% of the people were talking to each other. During the spot check in the morning nobody made a call, whereas 8% of passengers did that in the afternoon.

For public transport with a high frequency (e.g. the time between subsequent trains or buses is at most 10 minutes), the observations indicate that people arrive at the stop without prior knowledge of the timetables and therefore, on average, wait about half of the duration between two busses or trams.

A further observation at an S-Train station (metropolitan train, June 15, 2004) with an interval of 20 minutes between trains showed that people mainly arrive in the last 10 minutes before the train leaves. Here an average waiting time of about 5 minutes was observed as well. Furthermore, it was interesting to see that people who changed their mode of transportation (switching from bus to train) had to wait - even if they had perfectly planned their journey.

Furthermore it was seen that many of those people who expected to wait carried something to read (mainly newspapers and books). People with waiting times shorter than 4 minutes did not read during their waiting period.

From these observations it was concluded that a key requirement is that the access to a mobile service of interest to the user is established in a short time; typically this should be less than a minute. Furthermore, the system should also support an operation where the user can move on after the initial link using the poster is made.

In general, it was recognized that most of the people with short waiting times actually did not do anything. This was seen as a really promising basis for the usage of mobile information services as a time killer. Mobile services might be particularly welcome at places and during the time where people actually do nothing. As has already been described in [Nielsen 2000], killing time is a killer application. It was also seen that people with short waiting times looked quite often at information displays or picked up advertisements and read them on the train. In some trains there are boxes with flyers - and people read them very often whereas in other circumstances they would not have looked at them.

5.1.2.2 Lessons Learned and Best Practices

An unobtrusive contextual observation should be considered as one of the first steps when designing and developing a new physical mobile application.

Costs: The costs for such an unobtrusive contextual observation are mostly very low and the results are quickly available. Furthermore there is not need to get in direct contact with the observed persons and therefore less time is needed when compared with a user study in which the testers are asked direct question.

Observed people: A lot of people recognize it when they are observed by another person. Within the first observation described above the observer looked from the opposite street side to the stop which was ca. 25 meters away. Even in that case people recognized the observation because they saw a person who looked at them and made notes.

Documentation: In the case study described above it was sometimes difficult to observe all the people at a stop and note everything using a pen. A solution for this would be the usage of a video camera but this would probably irritate the observed persons.

Ethical and legal issues: As already described in [Jones, Marsden 2006] such aspects should be considered when conducting an observation. For instance different countries have different laws regarding recording, storage and processing of private data.

5.1.3 Online Survey

Online surveys are a cheap and fast method to question people, for instance, about their current opinion or behaviour, how they like ideas for novel mobile applications and what they think about mobile interaction techniques. A compact introduction and a discussion of the advantages and disadvantages of online surveys can be found in [Wright 2005]. The aim of this subsection is to report about experiences when using online surveys in the context of physical mobile interactions and new mobile applications.

5.1.3.1 Case Study

In May/June 2004, an online survey was conducted to figure out which mobile services potential users might connect with an advertisement or active poster as described in subsection 3.5.3. The research presented in this subsection is mainly based on [Rukzio et al. 2004b]. The survey consisted of three different forms that had to be answered by the participants.

At the beginning, the participant of the survey was told to imagine that she lives two years later, has a modern mobile phone with a colour, high resolution display and a contract with a mobile operator that includes a flat rate for unlimited internet use.

Afterwards, an example was outlined which showed possible mobile services which might be connected with a poster advertising a motion picture. In the first form, eight different posters (e.g. poster from a hotel chain) with a corresponding description (e.g. *this is a poster from a hotel chain*) were shown to the participant and for each of them a corresponding text input area was offered. The participants were asked to enter which mobile services could be of interest regarding the current poster. In the next form the same posters were presented, but this time the potential user was asked to rate (scale between 1 – *absolutely irrelevant* to 10 – *I would immediately use that*) different proposed services regarding these posters (e.g. book a room in a hotel). In the last form, the participants were asked about demographic data like gender, age, highest school exam and occupation.

The first form was completed by 38 persons, the second by 39 and the third by 34 persons. It is of great interest that there is a convergence in what services people would expect to be linked to a particular poster. Usually a small number of mobile services (e.g. 2 to 5) have been identified as the most-wanted ones.

Through the last form it was figured out that 82% of the participants were male, most of them (68%) were between 20 and 29 years old and had a university-entrance diploma (94%). In addition, 32% of the participants were students, 21% were clerks, 6% were entrepreneurs and the rest had a different profession. The survey was distributed via email to colleagues and students in Austria, Switzerland, and Germany with a request to further forward this email. Thus, people were asked who use email and have a relationship to computer science because they are colleagues or students. This means that, as a starting point, persons were addressed who, because of their technical affinity, tend to be easier to convince to try new technical prototypes.

The eight different posters in the forms advertised: a concert of a pop star, a discount of a car rental company, a home entertainment distributor, a hotel chain, a car of a carmaker, a fashion boutique, a speech of a politician and special offers from a flight distributor. This selection has been inspired by posters commonly seen in the city representing typical categories.

The next three tables depict the most important results of the first three posters because most participants of the web based interview gave more detailed answers for the first posters. The first part of every table shows the results of the first form and the second section shows the results of the second form whereby answers given most often and highest ratings are shown first.

Proposed services by the potential user	Mentioned by
Download song fragments, play current song.	28 (74%)
Order or book tickets.	26 (68%)
Download information regarding the artist/concert.	24 (63%)
How do I get to the concert?	9 (24%)
Download tour information.	9 (24%)
Rating of the predetermined services	Rated (1-10)
Order tickets for the next concert.	5,9
Download current album or song and play it.	5,9
See tour dates.	5,5
See information about the pop star.	4,4
Send information to a friend.	4,4

Table 18: Poster advertises a concert of a pop star.

Proposed services by the potential user	Mentioned by
Information regarding specials offers and prices.	32 (84%)
Show me the closest rental station.	24 (63%)
Which cars are available? Detailed information about the cars (description, picture).	23 (61%)
Book a hired car.	16 (42%)
Rating of the predetermined services	Rated (1-10)
Show me the closest rental station.	7,7
Get actual prices/offers.	7,6
Calculate price for my desired car/route.	7,4
Rent a car.	5,6

Table 19: Poster advertises a discount of a car rental company.

Proposed services by the potential user	Mentioned by
Show me the closest store.	22 (58%)
Get detailed technical information (pictures, videos, 3d-animations) of the products.	21 (55%)
Check prices.	13 (34%)
Show me all products (online product catalogue).	10 (26%)
Where to buy in the internet?	5 (13%)
Rating of the predetermined services	Rated (1-10)
Where is the closest store?	6,0
Get information about the actual products.	5,5
Order/buy a product.	3,3

Table 20: Poster advertises a home entertainment distributor.

Based on the first form in the survey it was concluded that people are potentially very interested in the usage of mobile services. It was recognized that the participants could imagine a large set of different services that might be connected with different posters. The most interesting service for the users was to get more information about the specific area of the advertisement. For example, looking at the poster advertising a discount of a car rental company, 84% of the participants wanted more information regarding special offers and prices (see Table 19) and at the poster promoting a home entertainment distributor, 55% of the participants wanted to get more technical information (see Table 20).

In particular, potential users are really interested in buying products or services that are only for sale in a limited amount. For instance, 68% of the users could imagine to order or book tickets for a concert (see Table 18). Especially while looking at the poster advertising special offers from a flight distributor, nearly all users (87 %) were interested in looking for and booking available flights, special prices and last minute flights. Furthermore, the participants of the survey were interested in location based services. 24% were interested in how to reach the concert or where it’s located (see Table 18), 63% were interested in the location of the closest car rental station (see Table 19) and 58% were interested in the location of the closest store where they can buy special home entertainment devices (see Table 20). Other innovative services have been mentioned like *bring the hired car to my current location* by several participants.

A further interesting point is that the participants were interested in information and services that are not directly related to the services offered by the advertiser. For instance, in connection to the poster of a hotel chain, 7 of 38 participants (18%) mentioned that they are interested in tourist information of the city. Moreover, the participants were interested in aspects that are related to the whole line of business like price comparisons and products of competitors. From the survey it was reasoned that if the right services are provided and easy access is given, people will be keen to use them. It was also very interesting to see that given a specific advertisement or information poster people came up with very specific ideas for related mobile services.

Further online surveys that were conducted in the context of this thesis are reported in subsection 4.2.1 and [Alzetta 2006].

5.1.3.2 Lessons Learned and Best Practices

An online survey should be considered as an easy and fast method to get a rough idea about the opinion of people and potential users. Based on already reported advantages and disadvantages (see [Wright 2005]) the following lessons were learned.

Too positive results: When using an online questionnaire, the asked people are mostly familiar with the WWW and can use a web browser. Therefore primarily technically interested and young people participate, especially when submitting the online survey to colleagues and friends. These people tend to be early adopters and therefore often give positive answers when asking about novel services and interaction techniques. Examples are the very positive results in previously discussed cased study. These results of this online survey were presented twice to researchers in this field and the audience always questioned the positive numbers.

Pretest: An online survey should be seen as a pretest to get a first idea on how people and potential users think. If such a survey fails completely, e.g. when the product or service concept is not seen as useful, then one can review or reject it before developing a prototype. But it is important to validate the results by other methods like prototypical evaluation, focus groups or field studies. Study 1: Mobile Interaction in Smart Environments presented in section 4.2 shows that an online survey can be used to compare different options and to get a general feedback which can then be concretized by the evaluation of a low- and a high-fidelity prototype.

Imaginativeness of the participants: Especially when presenting new ideas, it is questionable whether the participants who fill out the online questionnaire can understand everything. A lot of people do not carefully read the online survey and tend to have little time to fill in the answers. Furthermore, they are mostly not able to ask questions when they did not understand an explanation or question and they do not see or are able to use a prototype of the system or application. These aspects have to be taken into account when analyzing and interpreting the results of an online survey.

Time and effort: Relatively little time and effort is needed when having the knowledge and the infrastructure for setting up an online survey. Technically, just some web space, a scripting language and maybe a database are needed to implement it. There are also software solutions available that can be reused, see [Wright 2005] for an overview. The evaluation of the results is also very easy because the answers are already electronically available and can be imported in a program for interpreting the data.

5.2 Produce Design Solutions

The process of designing systems or producing design solutions is described in detail in [@UCD, Dix et al. 2003, Jones, Marsden 2006]. This section focuses primarily on the development of low- and high-fidelity prototypes. In general, it can be said that a high-fidelity prototype already resembles the final product whereas a low-fidelity prototype does not. When thinking about the iterative software development, a low-fidelity prototype is done at the beginning and a high-fidelity prototype at the end of an interaction.

The purposes of both prototypes are very similar. They can be used by the development team itself to generate new ideas, to identify important challenges and to discover the different aspects of the system. These prototypes can also be used to communicate with the clients and other persons involved.

A very important aspect is the possibility to evaluate these prototypes within user studies or focus groups. Especially low-fidelity prototypes can hardly be used to prove that the concept of the system will be successful but it is easily possible to identify if the concept or the prototype makes no sense at all as well as to identify potential issues.

The following subsections focus on techniques for the development of high- and low-fidelity prototypes.

5.2.1 Low-fidelity Prototyping: Paper Prototypes

Paper prototyping is a cheap, quick and easy method to evaluate the concept and interaction design of a mobile application [Weiss 2002]. This subsection discusses case studies using paper prototypes as well as lessons learned and best practices based on usability tests taking these prototypes into account.

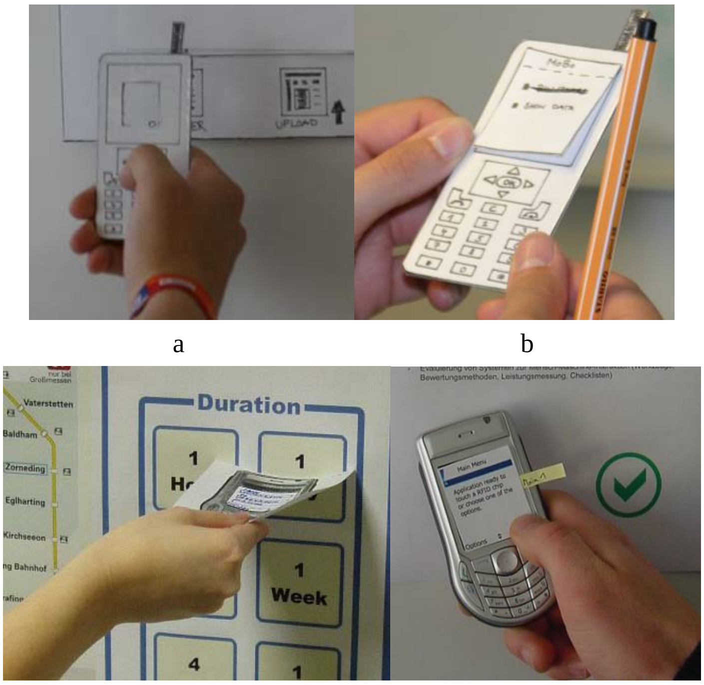
5.2.1.1 Case Studies

This subsection merely consists of references to studies described elsewhere in the document: The first case study which is discussed in this thesis analyzes mobile interactions in smart environments and was already described in subsection 4.2.2. The second case study focuses on the evaluation of privacy aspects when using mobile devices for interactions with remote displays and is in detail discussed in subsection 6.2.1.

5.2.1.2 Lessons Learned and Best Practices

Simulation of physical mobile interactions: Because of the novelty of physical mobile interactions, only very few paper prototypes have so far focused on this area. The challenges of such a prototype are the simulation of the direct interactions with smart objects. Figure 41a shows an interesting solution for a visual marker based realization of the interaction technique pointing. A conventional paper prototype (Figure 41b) of a mobile application can be used. But the display area of the paper phone is cut out. Thus, it is possible to see through the paper phone and to emulate the view finder of a mobile phone. Figure 41a shows how such a paper phone can be used to focus on a visual marker.

But it is in general not possible to simulate real world interactions. So it is very complicate to assure that a picture of a whole marker was taken and that an NFC tag was touched in a sufficient way. Figure 41c shows, for instance, how users in a user study focusing on NFC based interaction with advertisement posters used the paper phone to touch a tag. Such an interaction would fail when using a real mobile phone. It is therefore important to not only conduct low-fidelity prototypes but to also develop high-fidelity prototypes which take the physical and time constraints into account.



a b

c d

Figure 41: Examples for paper prototypes for physical mobile interactions [Broll 2006, De Luca 2006, Otto 2006].

Augmenting a real mobile phone. Figure 41b shows a paper prototype as is used in many projects. The development of the paper phone itself is very cheep and can be done in a few minutes. But the usage of a real mobile phone with a paper screen attached to the real screen seems to be the better solution. If the paper screen of Figure 41d would not have the shown yellow label it would look like a real application running on the mobile phone. Furthermore, this solution has the advantage that such a paper prototype already has the right form factor (e.g. weight and right size).

Realistic vs. quick and dirty screens. The display of a paper prototype is usually designed using just pen und paper (Figure 41b). One important advantage of this is that new user interfaces can be created on demand, e.g. because the user did an unexpected action. On the other hand it is also possible to design the user interface using an image editing program like Adobe Photoshop. Through this it is possible to design quick, cheap and realistically looking paper prototypes. But the effort for doing this is higher when compared to the usage of pen and paper. It should also be considered whether it was not better to develop an HTML- or Flash-based low-fidelity prototype in this case.

5.2.2 Low-fidelity prototyping: HTML / Flash prototypes

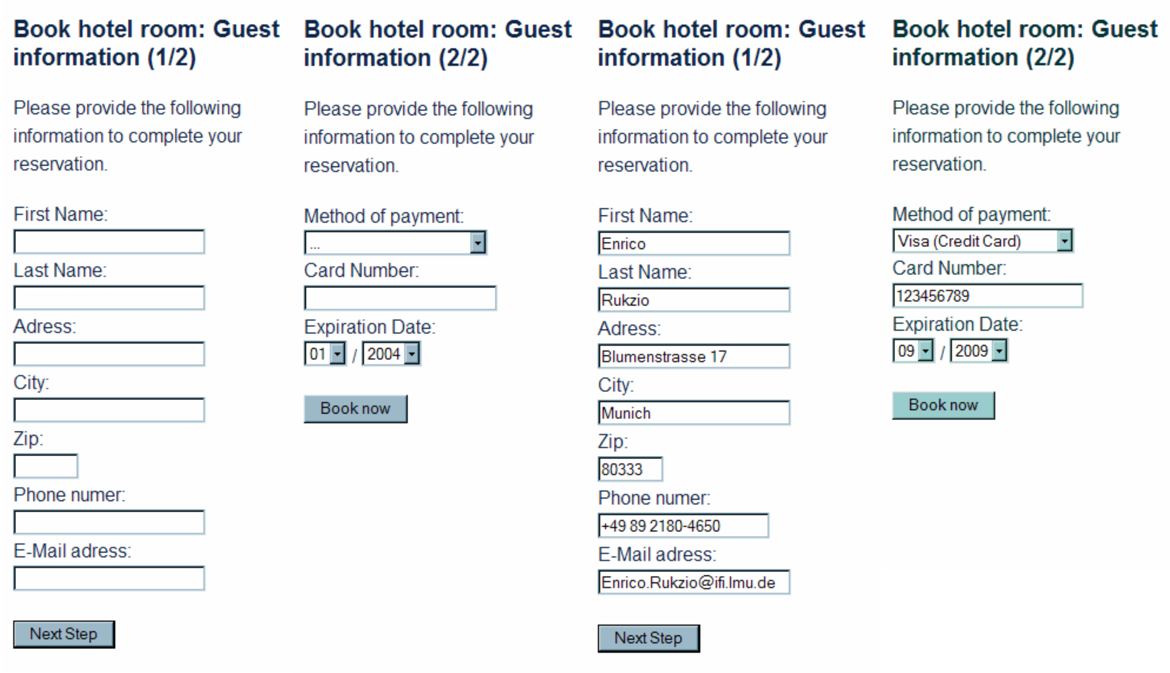
This subsection discusses a case study based on a HTML-prototype and lessons learned from the usage of such prototypes. HTML or Flash low-fidelity prototypes are similar to the previously discussed paper prototypes, but they show a realistic interface that can run on a real mobile device. This subsection focuses on very simple prototypes that merely show different screens that are linked via hyperlinks.

5.2.2.1 Case Study

This HTML prototype represented an application for automatic form filling on mobile devices [Rukzio et al. 2004c]. The goal was to figure out whether people like such an application that automatically fills in forms with their personal data like name, address and city. A Sony Ericsson P800 with the internet browser Opera for Smartphone/PDA was used. In addition, two versions of a HTML-based hotel reservation service were developed. In the first version (see Figure 42a and Figure 42b) the user has to fill in every form field by herself whereby in the other version (see Figure 42c and Figure 42d) the fields where already filled out with user data.

In the second version, two errors were integrated (wrong address and credit card number) that the tester had to identify and to correct. In both versions, the first name, last name, address, city, ZIP, phone number, e-mail address, method of payment, card number and expiration date have to be filled in, accepted or corrected.

The HTML prototype was tested by 8 users (colleagues from the department) whereby all where familiar with web forms and the concept of mobile services but all of them used a Sony Ericsson P800 for the first time.



a b c d

Figure 42: Screenshots of the HTML prototype.

The following Figure 43 shows the durations for filling in the data in the empty forms and the completion time for pre-filled forms. Additionally, it shows the average times the testers needed in a first, second and third run.

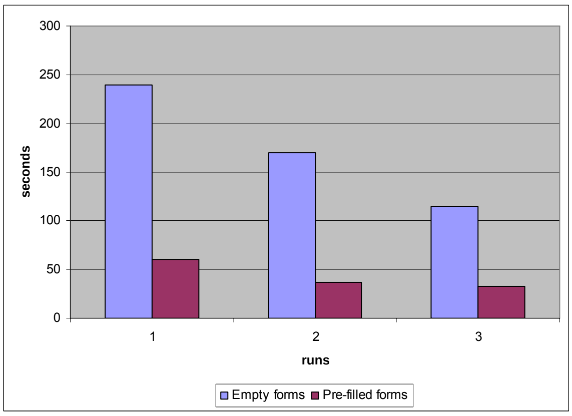


Figure 43: Average input times over all users. The users were asked to perform several runs.

The most important result was that the testers needed about four times longer to fill the empty form compared to the pre-filled form which needed corrections. Furthermore it was recognized that the testers learned quit fast to use the virtual keyboard and the styles of the Sony Ericsson P800. But still, the factor four exists after three runs. From this it was concluded that a form filling application would be extremely helpful and would if intensively used, support the further dissemination of mobile services.

Beside these numeric results it was recognized that most users where frustrated when they used the stylus of the smart phone for inserting text. It was thus concluded that it is very important that the user has to type in as few text as possible.

At the beginning of every test the tester were told the intention of the different forms. Furthermore they were told that in the second version there is an intelligent assistant which tries to fill out all fields based on the user data stored on the mobile phone. After this explanation many testers said they do not want to give their personal data away. From this the requirement was derived that all data has to be stored on a physical device that is owned by the user herself. The users liked to be in control and wanted to see what data is filled in the different fields such that she has the possibility to delete or change the automatically inserted data. This approach provides the user an overview where and when data is transmitted and what data is given to which service.

5.2.2.2 Lessons Learned and Best Practices

Realistic user experience: The big advantage of a low-fidelity prototype developed with HTML or Flash is its realism. Many testers using such a prototype might think that they use matured product. Therefore the experience of the users and their feedback is much better when comparing it with a user study based on a paper prototype. Furthermore the testers have to imagine how some aspects look like when using a paper prototype which is not the case when using such a realistic prototype.

Quick and easy: Such prototypes can be built easily and in a quick way when having the knowledge to implement HTML pages or Flash applications. One needs only design the screens and define the hyperlinks between them.

Limited functionality: When using a paper prototype, new functions can be added on demand by creating a new paper based interface. This is not possible when using an HTML or Flash based prototype because it takes some time till a new screen is defined. Although this might be done in 5-10 minutes, this is a too long a break within the evaluation of the prototype by a user. Such a prototype also only has limited interactivity, so it is hard to simulate interactions which react on written user input or to show personalized pages. One solution for the latter problem is to define what the users have to type in and by this it is also possible to simulate interactive applications.

Unrealistic physical mobile interactions: The physicality of physical mobile interactions can not be expressed by such prototypes. It not possible to access the camera or to react to NFC events. Such functionality can only be added by Wizard of Oz methods [Dahlbäck et al. 1993] or through the support of a person who supervises the test. This person can say things like *you did not touch the NFC tag correctly* or *the processing of this action will now take 3 seconds.*

5.2.3 High-fidelity Prototypes: Mobile Phones – a Versatile Platform

This subsection discusses how mobile phones can be used as the basis for the development of high-fidelity prototypes or mobile applications that take external sensors or devices into account [@PME 2004]. This subsection is mainly based on [Schmidt et al. 2005b].

A wide variety of powerful mobile phones have become very low priced. Devices are available to suit different tastes and to accommodate different user needs. Even devices for specific domains are available, e.g. the rugged phone Nokia 5140. Many of these devices offer extensive multimedia functionality including a camera for still images and movies, sound recording and playback abilities, and extensive storage capability. Additionally, as the devices are mobile phones they offer voice and data connectivity over mobile networks. Some phones even include sensors, e.g. the Samsung SCH-S310, or separate sensing modules are provided as add-on components.

Using Bluetooth connectivity, mobile phones can be extended with various additional devices. Mobile wireless printers or GPS-receivers are typical examples. Similarly, short range communication can also be used to communicate with other mobile phone based appliances or stationary computers.

The functionality included can be programmed by third party developers. These developments can be based on C/C++ (Symbian OS or BRED), Java ME or Python for Series 60 phones. Most phones offer a wide variety of APIs to access the basic input/output, multimedia, and network communication (short range and long range) functionality.

Given these technical capabilities, it is possible to use mobile phones as a platform for the development of domain specific high-fidelity prototypes and applications that take internal sensors and devices into account.

The afterwards presented case study analyzes the domain of policing inner city parking. A prototype based on a camera-equipped mobile phone was developed to be used in this context. In this case study the advantages and shortcomings of the use of mobile are highlighted.

5.2.3.1 Case Study: Information Appliance for a Traffic Warden

Mobile workers use in many areas specifically designed handheld information appliances. Such appliances are developed to be highly suitable for the task that has to be performed. However, the development of such appliances is fairly expensive and only makes sense for settings where there are large numbers of mobile workers doing similar tasks.

In different domains where mobile workers access or create information, mobile information appliances are in use. Typical examples are handheld devices for conductors on trains, facility management, security personnel, delivery personnel of parcel services, traffic wardens and parking police. These devices are often custom made and designed to suit the particular need of the application area. Besides processing power and storage space, such devices may include screens for output, mechanisms for user input, printing facilities, additional input mechanisms (e.g. card reader), network access and synchronisation.

In many areas of mobile work, paper and pens are still used since the development of specific appliances is not economic due to high costs of the implementation. In domains where such appliances are used they are often combined with paper solutions (e.g. a customer receives a delivery slip).

The basic design criterion was that the information appliance lets persons do what they are good at (like judging a situation) and let the system do where human errors are likely to be introduced (like when specifying the location, documentation of the case and writing the ticket). Some sources of errors are already eliminated by the mobile devices they use: the date and time are automatically set by the device and the ticket is printed. However, describing the location is at some places problematic and often inexact. Documenting the situation by taking pictures is very helpful in later legal disputes.

After analyzing the current work practice of traffic wardens, the following workflow for the application was designed. After the warden spots a situation she selects a violation from a predefined list containing, e.g., ignored parking prohibition. Then she takes a photo of the overall situation and of the number plate. The latter is used to analyze the information on the licence plate by the server. To check if the quality is sufficient for extracting the information of the picture, it is immediately transmitted to the OCR module on the server.

Afterwards the traffic warden can record an audio comment for describing the situation. During the whole process the position is gathered, e.g. by using GPS or PlaceLab [LaMarca et al. 2005]. After closing the case, all data is transmitted to the server and stored in a database. The GPS information is converted into a symbolic location representation (street name and house number) using a geographical dataset. Furthermore a mobile printer is used to print the parking ticket.

Figure 44 depicts the architecture and implementation details of the prototype. The mobile unit of the system consists of a mobile phone with a camera, a GPS device and the mobile printer. All three devices are connected over Bluetooth. Alternatively, a mobile phone with integrated GPS could be used. The phone communicates via GPRS with a server.

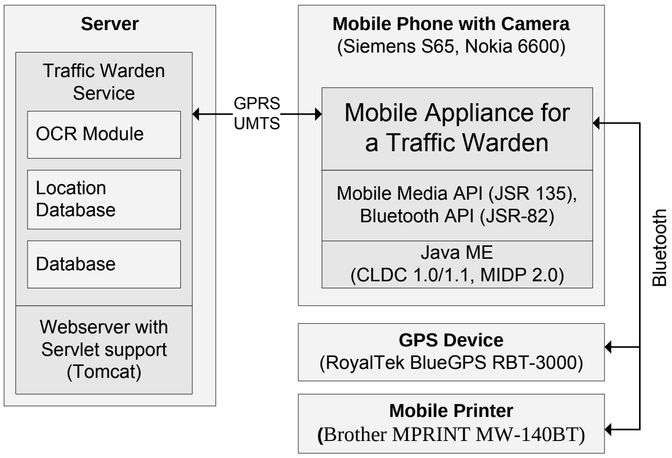


Figure 44: Architecture and prototype.

The prototype was built to explore the concept and to show that the implementation of such an information appliance is already possible with today's hardware and software platforms. As depicted in Figure 44, two different mobile phones (Siemens S65, Nokia 6600) were used, the GPS device RoyalTek BlueGPS RBT-3000 and the mobile printer Brother MPRINT MV-140BT. The drivers and software for the mobile printer and the GPS device that were developed in this context are Open Source and can be found at [@eitutorial].

Figure 45: Screenshots of the prototype [@PME 2004].

Figure 45 shows three screenshots of the prototype that illustrates the workflow: selecting the violation, taking photos of the license plate and the overall setting of the case before transmitting it to the server.

5.2.3.2 Lessons Learned and Best Practices

The advantages of using standard mobile phones to implement high-fidelity prototypes or products of information appliances are: variety of form factors, low price, user's familiarity, and good usability with respect to the hardware.

Additionally, the available development environments, the development support, and the provided APIs are suitable for quickly developing custom software for specific use. The built-in support for short and long range network communication are very convenient for many application areas.

Depending on the mobile device and the additional components used, the battery time may be shorter than with specific devices. For certain applications the available form factor (button and display size) may not be optimal. A further issue is that users may want to use the device with their basic phone functionality instead of using it in the appliance mode.

An important issue is the selection of the device or the set of devices that constitute the hardware platform for development. A great variety of devices is available.

Making use of the capabilities to link the real world efficiently with the virtual world is a further important issue. In many cases this can significantly accelerate the workflow and it can help to prevent human errors. Typical technologies for that are based on the camera of the mobile phone, GPS, visual markers or RFID / NFC.

When designing an information appliance on a generic platform like a mobile phone, it is important to restrict the functionality to support the task in an optimal way. Even if it is technically easily possible developers should not get lured into adding generic functionality to the device.

This subsection showed that mobile phones have become a versatile platform that can be used for the development of sophisticated high-fidelity prototypes or products that can take different external devices (e.g. external GPS device or mobile printer) and communication with different servers into account.

5.2.4 High-fidelity Prototypes: The Physical User Interface Profile (PUIP)

The generation and use of user interface descriptions in general finds its justification in the need to identify and communicate patterns that simplify the complexity of phenomena and support people in discerning meaning. The need to understand that complexity makes it vital to think visually and systematically: furthermore, visual thinking supports the communication of abstract ideas. This is the main motivation for graphical models, which enable people to see systems as whole entities, show relationships among elements, and recognize patterns. Different graphical languages have been developed within different fields (e.g. electronics, mechanics, mathematics) to support the expression and communication of abstract concepts. Within software design, there are several examples of graphical system representations: some important modelling issues remain unsolved though, that prevent universally adopting user interface descriptions. The emergence of physical mobile interaction techniques augments the complexity of interaction phenomena to be modelled.

A core state-of-the-art technique for communication, planning and design of software systems is object-oriented modelling. The Unified Modelling Language (UML) is the current de-facto standard for this purpose being widely accepted in industry and supported by an extensive number of tools [@UML 2006]. The current version, UML 2.0, provides 13 different diagram types to describe the static structure and the behaviour of software systems. UML 2.0 focuses more on technical properties of the system, whereas task and user interface modelling is not well supported. However, the UML 2.0 provides built-in mechanisms which can be used to extend the language for this purpose.

So far the field of model based user interface development has focused mostly on the usage of one device, such as a Personal Computer, by one person. This subsection focuses on the issue to define a user interface description that supports the design and development of physical mobile interactions and on the specific modelling challenges that such interactions imply. Here several devices or physical elements are used for input and output. These new settings require description models to support the analysis, design and implementation of high-fidelity prototypes and final applications that take such interaction techniques into account.

Therefore the new UML 2.0 Physical User Interface Profile (PUIP) was developed that is based on the UML 2.0 Profile for Context-Sensitive User Interface (CUP) [Bergh, Coninx 2005] to support the modelling of physical mobile interactions. The feasibility of this approach is shown within this thesis through the modelling and discussion of an existing physical mobile interaction technique. PUIP was also used for the modelling of eight further physical mobile interaction techniques, the corresponding diagrams and explanations can be found in [Volkwein 2005]. This research presented in this subsection is mainly based on [Rukzio et al. 2005d].

Another consideration that motivates PUIP is that the HCI community, especially within mobile and ubiquitous computing scenarios, has been engaging more and more interdisciplinary teams lately. Bringing computing out of the traditional location constraints of situated, individual interaction with the personal desktop system has widened the spectrum of stakeholders engaged in the design and development of new interactive products. Product and interaction designers, service providers, hardware manufacturers, marketing and sociology experts, as well as ethnographers are just some of the professional profiles that assume new roles and relevance in the team. This requires suitable communication tools in order to foster understanding among stakeholders and provide the possibility to contribute to the design of the system from different perspectives.

5.2.4.1 Design Goals and Specific Issues of Physical Mobile Interaction

The following goals were focused while searching for an appropriate representation model for physical mobile interaction techniques:

- *Support classification and comparison of the existing interaction techniques.* We currently assist to a growing interest in physical mobile interactions, both in industry and research, which leads to new interaction techniques and corresponding prototypes. Therefore a user interface description technique is needed to classify and compare them.

- *Support evaluation of interaction techniques*. The user interface description should support the evaluation of existing and new physical mobile interactions. For instance the number and kind of physical interactions (e.g. move, focus, touch, etc.) and of the involved information displays are important criteria for the usability and complexity of the user interface: such aspects should be presented and detectable in the model.

- *Support of all phases of the development process.* Interactions are relevant in every phase of a mobile system development process, which typically consists of analysis, design, implementation, test and maintenance: the description of the interfaces should support all of them directly or indirectly.
- *Support communication between stakeholders.* The user interface description should support the communication between the persons that are involved in the development process such as the software engineer, user interface designer, customer, analyst, programmer and tester. Therefore an important requirement for the interface description is understandability.
- *Adopt a description which is oriented or based on standards and tool support.* The user interface description should be based on a widespread and matured standard because this supports its acceptance. Furthermore there is a high probability that existing tools supporting this standard can be used for the new user interface description.

Physical mobile interaction techniques raise new issues in terms of modelling in comparison to traditional desktop-based human-computer interaction, due to the augmented complexity of the context. In particular:

- *The physical constraints*: The user interface description should be able to integrate the physical aspects of mobile interactions with the real world. Examples are that the user has to be in a specific distance to a physical object before starting the interaction, or that the mobile device touches another object.
- *The device features*: e.g. different screen sizes; different modalities of interaction supported. Many physical mobile interactions use several communication channels. Therefore the interface description should integrate this aspect.
- *The temporal context*: e.g. simultaneous vs. asynchronous presence of multiple users in front of an interactive display; duration of interaction between a user and a display.
- *The social context*: e.g. presence of multiple users in front of a display, wireless user-user communication via mobile devices.

The next subsection analyses the related work in order to assess whether and how these issues are covered by existing methods.

5.2.4.2 Related Work

On the other hand, during the 1990's a number of languages for user interface modelling were developed. A substantial goal of them was to build a bridge between the UI designer's and the software engineer's perspective on the UI (for details see, e.g., [Trætteberg 2002]). Usually they base on a task model (e.g. ConcurTaskTrees [Paterno et al. 1997]) provided by the UI designer and an application model (e.g. UML class diagrams) from the software developer. Both models are used to derive an abstract presentation model – describing the structure of the UI in abstract terms – and a dialog model which covers the UI behaviour. The last step in the UI development process is the concrete presentation model, which is often derived (semi-)automatically from the preceding models. Since the late 1990's, several approaches have emerged that propose extensions for the UML to integrate UI modelling, e.g. UMLi [Silva, Paton 2000] or the UML Profile for Interaction [Nunes, Cunha 2000].

Today there is a growing demand for approaches integrating additional and complex requirements of current advanced UIs, e.g. integration of media objects, multimodality, context-awareness, or physical interaction. There are some proposals available (e.g. [Bergh, Coninx 2005, Paterno 2004, Pleuss 2005]) which address several of these issues. But there is currently a lack of an adequate modelling approach for physical mobile interactions. One contribution comes from the strongly related domain of augmented reality applications: ASUR++ [Dubois et al. 2003] also focuses on the modelling of physical mobile interactions. This notation is not based on an existing modelling language like UML and therefore probably neither tool support nor a big community which is familiar with the syntax exists.

This subsection aims to model physical mobile interactions based on existing and UML-related approaches. Therefore the UML Profile for Context-Sensitive User Interfaces (CUP) [Bergh, Coninx 2005] is used, an approach based on UMLi for modelling context-sensitive UIs. CUP is defined as a UML 2.0 Profile, i.e. it uses the built-in extension mechanisms of UML 2.0. Besides, CUP proposes some improvements on UMLi and also updates to UML 2.0 (while UMLi is based on UML 1.4). The most important extension mechanism of UML 2.0 is the Stereotype. A Stereotype (notated in «») extends and adapts an existing model element for a specific purpose. It can add additional properties as well as a customized graphical notation. Further details about CUP are given within the corresponding subsection (where required) in the description of the concrete example.

5.2.4.3 Physical User Interface Profile (PUIP)

The comparison of existing approaches lead to the result that CUP is the most suitable existing approach for the defined goals: on the one hand it is based on UML 2.0 and considers the results of earlier UML-based approaches; on the other hand it supports modelling context, which can be used for describing the context of use of physical mobile interactions. In the following paragraph, a complete example is shown of how to model physical mobile interactions based on CUP. Thereby the decisions on how to apply the given modelling constructs are discussed. It turns out that CUP is a helpful and powerful base for context modelling. However, for some aspects additional extensions or adaptations of CUP are required. Thus, a new Profile based on CUP, called PUIP (Physical User Interface Profile) is proposed which encloses CUP elements and necessary extensions which are required specifically for modelling physical mobile interactions.

This subsection is structured as follows: first one implementation of the interaction technique pointing is discussed. This is then used to discuss the CUP diagrams: abstract presentation, context model, and task/dialog model. Each model is augmented where necessary with extensions for modelling physical mobile interactions.

As already discussed in subsection 2.3.4, different implementations of the interaction technique pointing exist. The following subsections focus on the implementation based on visual markers that are attached to a smart object. The user has a mobile device with an integrated camera and a preinstalled program interpreting the marker. After the user got aware of a visual marker (e.g. on an advertisement poster) she has to approach it. Then she has to focus the camera of the mobile device on the marker, the marker is interpreted and a webpage related to the advertisement poster is shown on the mobile device.

5.2.4.3.1 Modelling Presentation

The presentation model in CUP presents the user interface in terms of abstract user interface elements. It describes the user interface in a platform- and modality-independent way. In a later development step, the concrete user interface presentation is derived from the abstract presentation model. The concrete presentation realizes the abstract elements (e.g. using a standard widget toolkit) and specifies additional properties of a concrete user interface implementation, like layout and adornments. Often, the concrete presentation is created directly in user interface building tools, thus this is not mentioned in this subsection.

CUP provides four different user interface elements and introduces icons for them. *inputComponent* allows the user to input or edit some data in the system. *outputComponent* presents some information to the user without the possibility of editing. *actionComponent* allows the user to invoke some action of the system without additional data input. *groupComponents* are used to structure the other three types of elements (like e.g. a window on a graphical user interface). The following Figure 46 depicts the elements *inputComponent*, *outputComponent* and *actionComponent*.

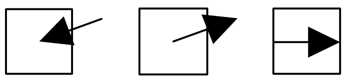


Figure 46: inputComponent, outputComponent and actionComponent.

The provided model elements are sufficient for physical mobile interaction. However, it must be kept in mind that here they can also be realized by real world objects in addition to conventional user interface devices.

Figure 48 shows the abstract presentation of the interaction technique pointing using the notation provided by CUP. For example the *groupComponent FocusAndBrowse* includes the *outputComponent FocusOfTheCamera* and the *actionComponent StartMarker-Interpretation*.

As mentioned above, an important characteristic of physical mobile interaction is the realization of the user interface elements on different devices or real world objects. Thus, this should be specified within the presentation model. CUP does not offer a specific modelling construct for this purpose. However, deployment diagrams from standard UML 2.0 can be used for this purpose, as they describe where to deploy an artefact of the implementation (e.g. on which device).

When modelling physical mobile interactions, deployment diagrams would then map the abstract user interface elements to the different devices and objects. However, the relationship to the device is one of the core characteristics of the user interface elements. In experiments it was found out that it is not suitable to search for this information within a separated diagram. Thus, a new relationship (extending the UML 2.0 association) *renderedBy* was introduced which connects a group component and element of the context diagram. The following Figure 47 shows an example of the introduced association. The *groupComponent InitialDisplay* is rendered by a mobile device.

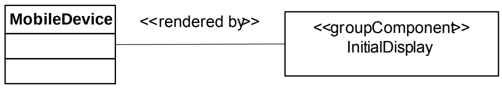


Figure 47: Example for a rendered by association.

There are two different displays involved in the implementation of the interaction pointing. The display of the mobile device and the advertisement poster with the visual marker which is also a display.

Figure 48 shows which interface components are rendered by which device. The mobile device presents three different screens during the usage of the interaction technique pointing. The display, which is an abstraction of the advertisement poster, is static and therefore presents only one screen during the interaction technique. The classes *MobileDevice* and *Display* are essential elements of the context of use which is modelled afterwards in the context diagram.

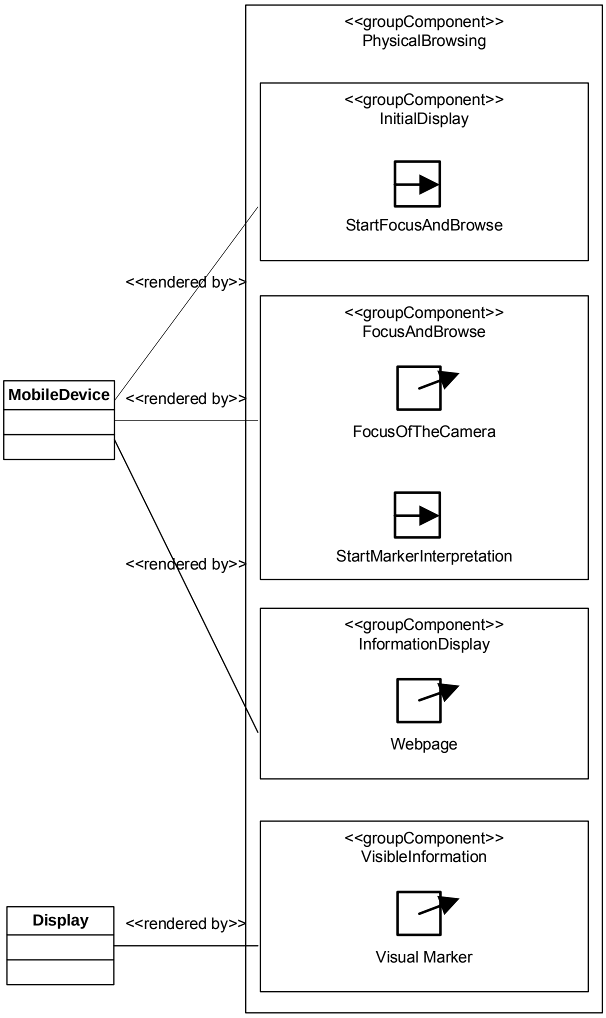


Figure 48: Abstract presentation specification.

5.2.4.3.2 Modeling Context

The CUP uses UML 2.0 class and package diagrams for the description of which context information is used for the adaptation of the user interface and the application itself. Furthermore, it introduces Stereotypes to consider how the context information is gathered.

In contrast to that, PUIP focuses on the context of use which is required for an interaction technique. Here it is described which properties the involved entities should have and which physical constraints for the interaction exist. The notation provided by CUP is suitable for this purpose.

The following class diagram in Figure 49 depicts the generic context that is valid for the whole pointing interaction. The classes *User*, *MobileDevice* and *Display* are introduced which are all special *InteractionElements* with a corresponding location. The relationship classes *U_MD_Relationship*, *MD_D_Relationship* and *U_D_Relationship* (U = User, MD = Mobile Device, D = Display) express the physical relationships between the interaction elements.

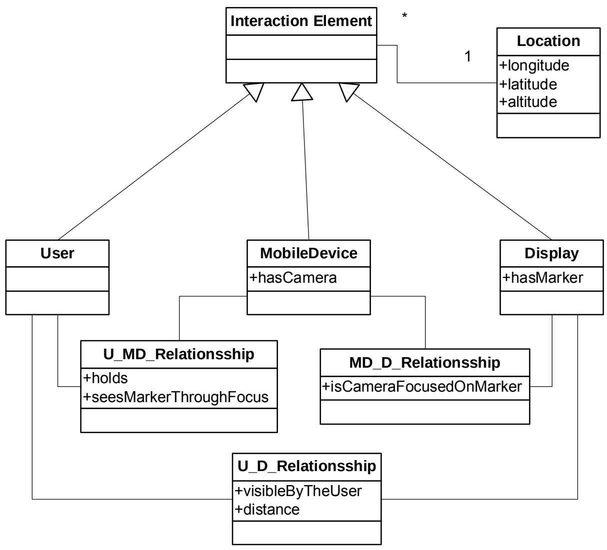


Figure 49: Interaction elements and relationships.

An important aspect is the dynamic change of the concrete context during the interaction. To specify the context for a specific point in time during the interaction, the use of UML 2.0 object diagrams is proposed. In analogy to conventional classes and objects in UML 2.0, a concrete context information at runtime is an instance (i.e. object in the object diagram) of the general context description in the class diagram.

The following Figure 50a depicts the concrete context of use before starting the interaction and at the end of the interaction. Both object diagrams state that the

- Mobile Device has a camera (*MobileDevice*),
- Display has a visual marker (*Display*),
- User holds the mobile device (*U_MD_Relationship*) and that the
- Display is visible for the user (*U_D_Relationsship*).

At the end of the interaction (Figure 50b) the user also has a specific distance to the display (*U_D_Relationsship*), the camera of the mobile device is focused on the marker on the display (*MD_D_Relationsship*) and the users see the marker through the focus of the camera (*U_MD_Relationsship*).

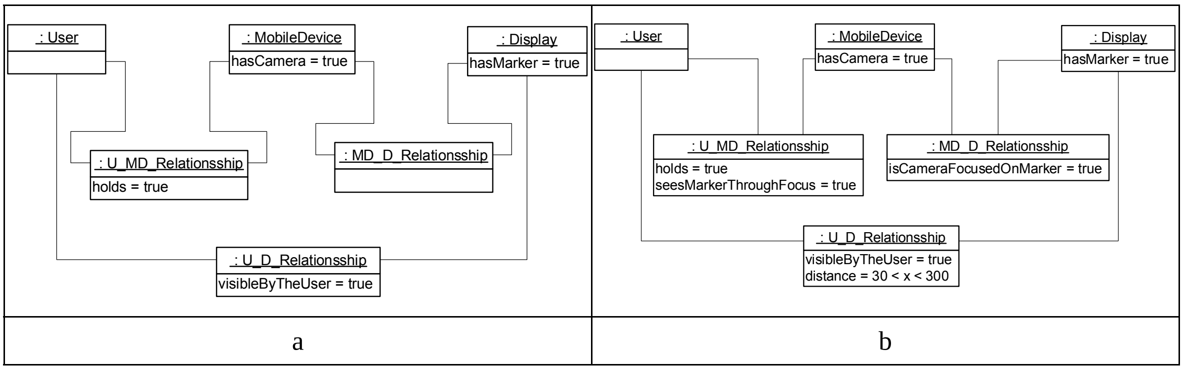


Figure 50: Context of use before (a, left) and at the end (b, right) of the interaction.

5.2.4.3.3 Modelling Tasks and Dialogs

CUP uses UML 2.0 activity diagrams to model tasks based on the concepts used in ConcurTaskTrees [Paterno et al. 1997]. Tasks are represented by actions, which are extended by the Stereotypes user, system, and interaction to specify user tasks, system tasks, and interaction tasks analogous to [Paterno et al. 1997]. In addition, as they describe context-sensitive applications, they introduce a stereotype environment to specify tasks performed by an entity in the physical environment that is neither the system nor the user. Temporal relationships between the tasks are specified using the various modelling constructs provided in standard UML 2.0 activity diagrams.

In PUIP, nearly all actions in the activity model are interactions between the user, the mobile devices and the smart object. Thus, to achieve more expressive power, the semantics of the Stereotypes is slightly modified: the Stereotypes *user*, *mobiledevice* and *smartobject* are used to describe which entity involved in the interaction starts a specific action in the activity model.

Based on the task model represented by the actions in the activity diagram, a dialog model is specified. It shows the relationships of tasks (i.e. UML actions) to abstract user interface elements and to contextual information. CUP uses the standard UML object flows as the modelling construct to denote these relationships. Object flows represent the flow of data from or to an action, analogous to input or output parameters of an operation.

The relationships between user interface elements and actions specify that some information is sent to, or gathered from the user interface element. For example in Figure 51, the action *StartApplication* depends on the user interface element *StartFocus-AndBrowse*. Object flows do not exactly fit to this semantics, and therefore UML dependencies are used instead to express these relationships.

For the user interface elements themselves, it is important to see their relationship to a device or smart object. As explained above, the presentation model specifies these relationships. Thus, one has to refer to the presentation model to find out which device or smart object is related to an action (as the action is related with user interface elements).

To achieve better usable models, it is, with PUIP, optionally possible to annotate the instances of user interface elements in the dialog model with a textual value showing the related device or smart object. In the same way, user interface elements can be annotated with the name of the group component they belong to. PUIP uses a notation similar to attribute values below the icon of the user interface element as part of the customized graphical representation of the Stereotypes *inputComponent*, *outputComponent*, and *actionComponent*. In Figure 51, e.g., the user interface element *StartFocusAndBrowse* is annotated with property values showing that the element is part of the group component *InitialDisplay* and rendered by the device *MobileDevice*.

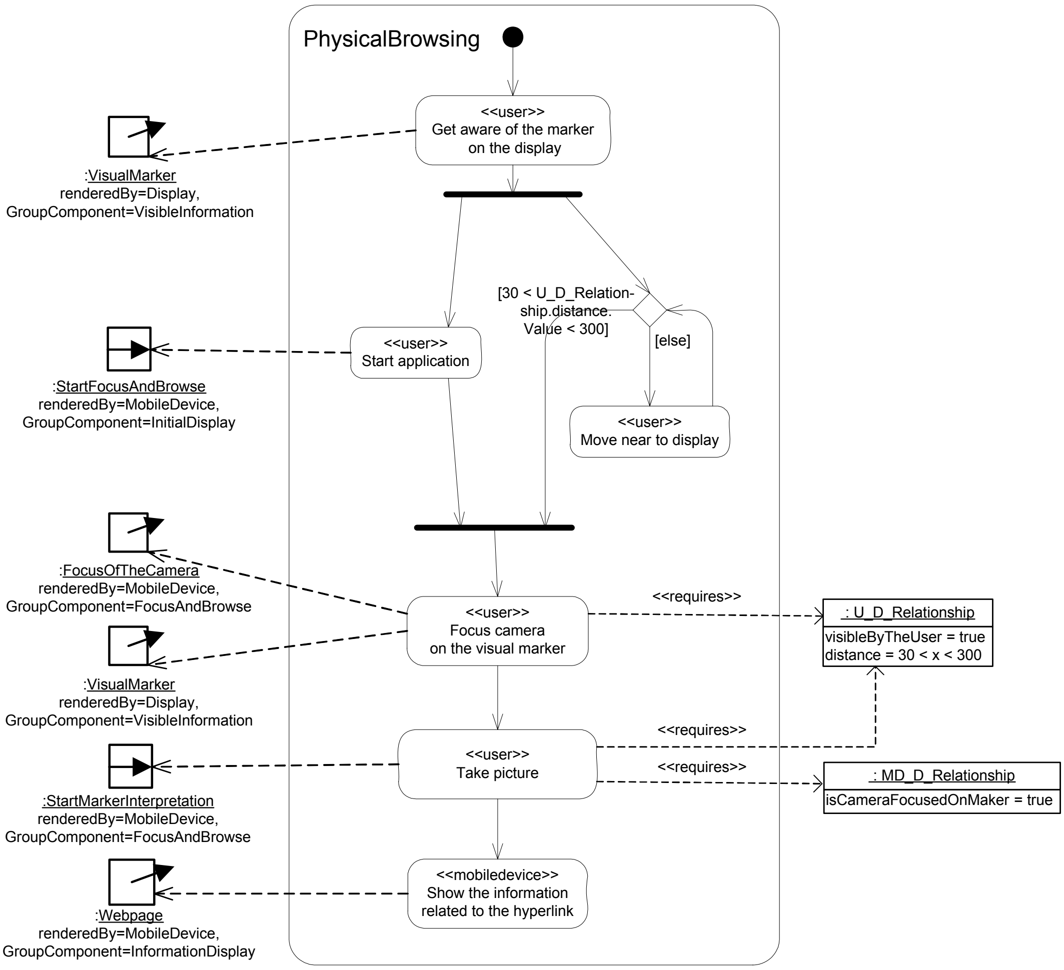


Figure 51: Dialog model for pointing.

CUP uses relationships between actions and context collectors, to show which contextual information is involved within the action. However, as described above, it is important to specify the contextual situation required for an action within the physical mobile interaction. As introduced with the contextual model, context objects are used to describe a concrete runtime instance of context information. These constructs also fit well for this context here: context objects are used to describe the required concrete context instance, required for an action. A Stereotype *requires* is introduced which represents a dependency between an action and a context object with the meaning that this context is required to execute the action. For example in Figure 51, the action *Focus camera* on the visual marker requires that the user sees the device and is in an appropriate distance to the display. This is specified by the values of *U_D_Relationship*.

In addition, conventional UML guards can be used to express constraints on control flows, like 30 < *U_D_Relationship.distance.value* < 300 in Figure 51.

In the following the complete interaction technique pointing depicted in Figure 51 using the proposed modelling constructs of PUIP is explained. The first action is started by the user (*«user»*). At the beginning of the interaction technique the user has to get aware of the marker on the display. This interaction of the user and the user interface element *VisualMarker* is depicted by a corresponding UML dependency. By inspecting the abstract presentation specification (Figure 48) or the annotation one can find out that *VisualMarker* is part of the *groupComponent VisibleInformation* which is rendered by a display (e.g. an advertisement poster). The interaction is done without using the software of the system: it is exclusively a cognitive and physical action. This first interaction is very important for the interaction technique pointing. In this way, a person who reads this specification knows that there should be a visual attraction on the display, which calls the attention of a potential user. In this sense not only the design of the software and hardware components are important for the development of such a system. The specification of the physical environment, in this case the design of the display, plays an important role for the usability and acceptance of such an interaction technique.

In the next step the user can execute two actions in parallel: start the application *FocusAndBrowse* on the mobile device and approach the display. The latter action is essential for the interaction because the marker must have a specific size in the image taken by the camera of the mobile device. Therefore the user and her mobile device have to be in an assumed distance of 30 to 300 centimetres. A physical constraint is expressed which is essential for the usage and evaluation of the interaction technique. If for instance someone plans to use this interaction technique in an airport where a lot of posters are attached to high walls then this kind of pointing is probably not feasible because the user is not able to get close enough.

The next action is again triggered by the user after the two previous actions have been performed. Here the user has to focus the camera of the mobile device on the visual marker of the display. This is a typical example of modelling a multi display interaction because the display of the mobile device and another display are involved. This is indirectly depicted by the related user interface components *FocusOfTheCamera* and *VisualMarker*. This interaction fulfils the requirement stated by the object *MD_D_Relationship* on the right hand side of Figure 51 which is an important precondition of the following actions.

Afterwards, the user has to take a picture of the marker on the display; the system processes this picture and shows the information related to the physical hyperlink on the display of the mobile device.

5.2.4.4 Conclusion and Discussion

In this subsection the issues of modelling physical mobile interaction techniques are discussed. By reviewing existing modelling techniques, the suitability of the UML 2.0 Profile for Context-Sensitive User Interface for the interface description was validated. The feasibility of using this method for modelling physical mobile interactions was verified and the Physical User Interface Profile (PUIP) was proposed. This is an extension of the CUP to fit the specific issues raised by physical mobile interactions. The most important differences to CUP can be found in the model of the abstract presentation and the dialog model because PUIP introduces new approaches for the integration of physical and multimodal aspects of the interaction.

PUIP was, as already mentioned, used for the modelling of a further eight physical mobile interactions [Volkwein 2005]. This can be also seen as a first evaluation of PUIP. In general it could be said that these examples show both, the feasibility and the added value of this approach when comparing it with previous ones. An important issue is the abstraction level which is modelled using PUIP. If every aspect of a physical mobile interaction is expressed then the different diagrams tend to be very large and become more difficult to understand.

While supporting the suitability of such an approach as a standardized tool, its limits in terms of a communication tool were recognized, which is one of the design goals that was stated at the beginning. This consideration arises from direct experience with the people who were involved in the development of PUIP, which also included interaction designers. Even though such a model is relatively easy to understand even for people with limited or no programming skills, the model runs short in performing as real working tool for designers. One of the main constraints appears to be the fact that the model accommodates requirements and functional issues, but provides little insight into how the interface should actually look like. Furthermore, the elements that constitute this graphical representation are neither extremely diverse nor self-explanatory, thus providing only limited support to pattern recognition and visual thinking. Possible further extensions of the model might include pictograms of physical actions or pictograms of displays for more immediate recognition of the interaction type and flow. Thereby the trade-off between the level of abstraction and the detail of context/interaction description must be considered. Further improvements of PUIP should also consider the integration of goals like the support for modelling multi user interactions and expressing the social context of an interaction.

5.2.5 High-fidelity prototypes: Development of Context-Aware Systems

When developing applications which take physical mobile interactions into account, the context of use plays a very important role. Examples for this context information within the scope of this thesis are especially the device capabilities in general, the interaction techniques supported by the device, the smart object, the rendering capabilities of the mobile device, the service and the user. The consideration of context information and the adaptation of services and applications based on them has been a research focus in the area of mobile computing in the last years (see subsection 2.2.4 Context-aware Mobile Services).

This subsection focuses on a case study about a context-aware mobile cinema information service and the lessons learned during its development. The most important results are guidelines regarding the architecture and implementation of such systems, a process for the definition of the adaptations, a diagram for the visualization of context and policies and a module pipeline for structuring policies and context information. The research presented in this subsection is mainly based on [Rukzio et al. 2005e]. Further details about this research and the case study discussed afterwards can be found in [Falke 2005b, Siorpaes 2004].

Two other context-aware mobile applications were developed in the context of this thesis but are not discussed in this document. The first prototype is an application for automatic form filling on mobile devices where personal information about the user and web forms are considered as context information [Noda et al. 2005, Rukzio et al. 2004c, Rukzio et al. 2006a]. The second prototype focuses on physical mobile interaction with advertisement posters that supports different interaction techniques and was already discussed in subsection 3.5.3. Despite the fact that these two systems are not discussed here, the experiences when developing them influence this subsection and support also the results in the lessons learned subsection.

5.2.5.1 Case Study

In this subsection, first a scenario for and then the implementation of a context-aware mobile cinema information service are discussed. The core concept of the scenario is based on a user who is standing in front of the cinema. She is not sure which movie is the most interesting one. For these situations, the cinema offers a mobile service which can be used to get information about the current program using her own mobile phone. As a special feature, the user can download movie trailers. Especially for the download or streaming of videos many different context information should or have to be taken into account. The most important parties involved in this process are the user, the device of the user, the offered videos and the available networks.

The user can define three different preferences. For every preference a weighting factor between 1 (*this is not important for me*) and 10 (*this is very important for me*) can be defined. With the first preference *quality*, the user can indirectly influence the visual quality of the video which is based on parameters like resolution or encoding. Via the parameter *speed*, the duration of the transfer of the video from the server to the mobile phone can be defined, which is for instance based on the selected network type or the amount of data of the video. Adjusting the parameter *cost*, the user can define preferences regarding the costs for viewing the trailer. This aspect can for instance be influenced by the selection of the network provider.

The mobile device of the user has a specific screen resolution and it is assumed that it is possible to play videos with this resolution and also videos that have a smaller resolution. Furthermore, the mobile device is characterized by a set of supported network types and a set of supported video encodings.

The different trailers for the movies that are currently shown at the cinema are available in different video encodings (e.g. MPEG-4, Real Media, H.263), resolutions and storage sizes. The user does not need to pay a fee to the cinema for the information service including the download of trailers. The user has only to pay the fees to the network provider for the transmission of data.

The user can easily switch between different network providers who have different pricing models and offer different network types. Every network type (e.g. GPRS, UMTS, WLAN) is characterized by its transmission speed. Regarding the price, there is no difference for using e.g. GPRS or WLAN. The user only pays a fixed price per transmitted amount of data which is defined by the network provider.

In this scenario, for the download of the video, the context-aware application has to define which video (e.g. resolution, encoding, size), which network provider and network type (e.g. GPRS, UMTS, WLAN) should be selected based on the capabilities of the mobile device (e.g. supported network types, resolution, encoding) and the preferences (quality, speed, cost) of the user.

A prototype was developed based on an architecture described in detail in [Rukzio et al. 2005e] to evaluate technologies and methods for the development of such systems. The W3C recommendation Resource Description Framework (RDF) was utilized as an interoperable representation of context information that can be used by different systems and which can be processed by most inference systems. Policies are used which can be seen as sophisticated conditional rules for the definition of the adaptive behaviour of the system. The Java Expert System Shell (Jess) was used as the policy language as well as the policy decision point respective inference engine [Friedman-Hill 2003]. The Java Agent Development Framework (Jade), an agent based middleware that supports mobile devices, was used as the middleware of the system [Bellifemine et al. 2003].

The following Figure 52 depicts the architecture of the prototype that is divided into the network side and the user side.

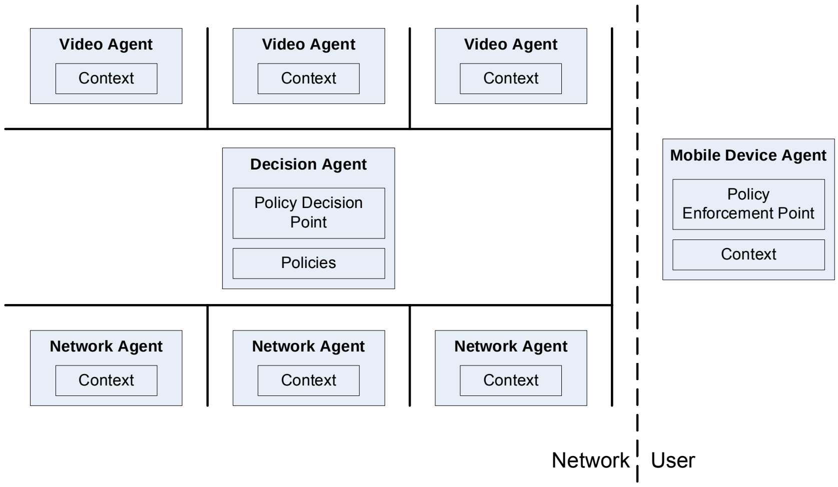


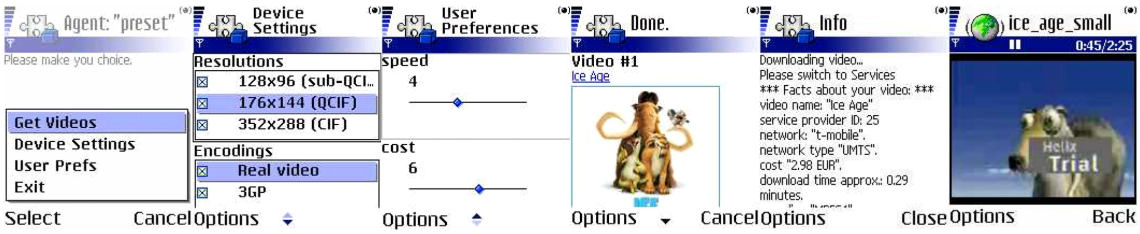
Figure 52: Architecture of the prototype.

The network side includes the video provider agents, the network provider agents and a decision agent. The user side includes the mobile phone agent which represents the device as well as the preferences of the user. The video and network provider agents provide only context information. The decision agent consists of a policy decision point and provides policies. The mobile device provides context information and acts as a policy enforcement point.

All context information is described in RDF and translated in the policy decision point by XSL transformations into the Jess syntax for describing knowledge since the Jess library is not capable of directly processing RDF content. All agents are realized as Jade/Leap agents. Leap (the Lightweight Extensible Agent Platform) is an extension of the Jade platform which allows developing applications for mobile devices that support the Java ME. As mobile devices, a Siemens S65 as well as a Nokia 6600 were used that support CLDC 1.0/1.1, MIDP 2.0 and the Mobile Media API. All agents in the network ran on a single PC but because of the Jade middleware it is no problem to distribute the different agents to different servers or different mobile devices.

As depicted by the screenshots of the prototype in the following Figure 53, the user can do four different tasks (three of them are shown in Figure 53a). First it is possible to change the settings of the device to simulate different mobile devices (Figure 53b). Here it is possible to define the screen resolution as well as the supported video encodings and network interfaces. Moreover, the user can define her preferences (Figure 53c) regarding quality, speed and cost on a scale between 1 (not important) to 10 (very important).

After the user selects the option Get Videos (Figure 53a) she sees a list of available videos each represented by a title, image and description (Figure 53d). This information was requested by the mobile device agent from the video agents that represent the different videos. After the user selects a specific video by clicking on it, the decision agent calculates, based on the policies and different context information, the best combination of video (resolution, encoding, size), network (e.g. UMTS, WLAN or Bluetooth) and network provider based on the user preferences and device capabilities. This information is shown to the user of the prototype (Figure 53e). Afterwards, the mobile device agent requests the video and the user can watch the trailer of the movie with the built-in browser of the mobile phone (Figure 53f). This sequence can be repeated several times whereby the user can change the device capabilities and preferences which lead to other decisions by the decision agent.



a b c d e f

Figure 53: Screenshots of the interface of the mobile device agent [Falke 2005a].

5.2.5.2 Lessons Learned and Best Practices

This subsection describes lessons learned, best practices and guidelines usable for the design of context-aware mobile applications and their implementation. As already mentioned, physical mobile applications are also often context-aware mobile applications. Thus, the results reported in this subsection can also be applied to the development of physical mobile interactions.

At the beginning, guidelines for the design and implementation that can be considered when developing context-aware mobile applications are discussed. A further problem when building such systems is the lack of methodology for the definition of context information and policies. A corresponding process is defined afterwards. Furthermore, an extended UML diagram notation for the development and documentation of the adaptation process as well as a concept of a module pipeline for defining and structuring policies is introduced. Many technologies of the described context-aware mobile cinema information service, the architecture and the methodology described afterwards were later on successfully used in prototypes developed within the IST-project Simplicity [@Simplicity, Salsano, Martire 2005]. Examples include the Simplicity prototypes Multimedia Messaging and Simplicity Aware Service Environment. This supports the argument of the usefulness and reusability of the used technologies and methodology.

Architectural and Implementation Aspects

When developing an architecture for a context-aware mobile system, one should consider these four guidelines:

- *Uniformity in the different adaptation areas.* The elements of such an architecture are often distributed over different servers (e.g. for service provisioning, billing, network provider) and different mobile devices. For the flexibility, compatibility, extensibility and adaptability it is very important that the representation of context information, the definition of policies and the reasoning take places in a uniform way.
- *Separation of context, policies, policy decision point and policy enforcement point.* In some systems the mentioned elements are woven into a single adaptation application. This could lead to unintentional adaptations and hysteresis effects if two applications run in a single system and do not share common context information or make fully independent decisions. Through the separation of the different elements it is possible to build systems that act consistently in a global way. Additionally, it is easily possible to change the context information, to modify policies and to integrate new adaptations.
- *Policy language should be generic regarding the range of adapted services.* The policy language should not be specialized for a specific adaptation area. This allows the integration of arbitrary adaptations or decisions requested by different entities. Through this it is also possible to support a system wide adaptation process.
- *Reuse and adaptation of existing and matured standards.* Especially in research projects we often see the development of new context representations, policy languages and policy decision points. But the development of stable, generic and reusable versions of such systems often needs a huge amount of work and time. Therefore it is often better to reuse and adapt existing languages, standards, APIs and frameworks.

Defining Context and Policies

After the design of the architecture one further important task is the definition of context information and the policies needed for the policy-based adaptation process. For this complicated and time-consuming task there is so far no easy and practical methodology or visualization available. In this subsection a process which supports the developer during this step is described. Like other software development processes, this methodology is iterative because not all requirements, the desired result and the intermediate steps can be recognized at the beginning. Five different steps are defined which are needed for the definition of context and policies that are explained afterwards. Their processing sequence is visualized in Figure 54.

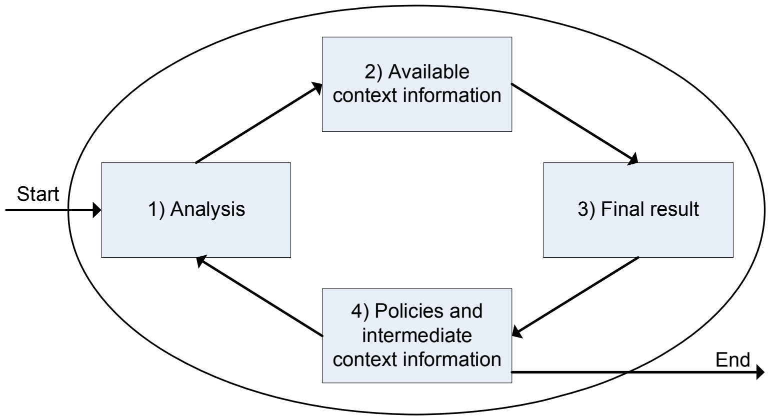


Figure 54: Different steps for the definition of context and polices.

Different steps for the definition of context and policies:

- 1) Analysis of the requirements of the specific adaptation like in any other software development project.
- 2) Definition of the available context information (knowledge engineering)

  The developer should collect all available context information that might be useful for the desired decision process und she should also define the corresponding data structure. At the end of this step it is already possible to define concrete example data for instance as RDF Schema and RDF documents.
- 3) Definition of the desired final result

  In this step, the developer should specify the desired result which is also a piece of new context information generated by policies. As in step 2, it is also possible to define the context information for example in RDF and RDF Schema.
- 4) Definition of the policies and intermediate context information

  4.1) Gradual development of policies based on existing context information until the definition of the desired final result has been reached.

  4.2) Iterative development of new preliminary context and rules on the basis of available context information and preliminary results

  4.3) Separation of context information and policies into modules which leads to a module pipeline
- If all context information, the final result as well as the intermediate context information have been defined, this process is either finished or the next iteration should be started.

A Diagram for the Visualization of Context and Policies

To support the proposed process of the definition of context information and policies, a specialized diagram was developed which helps the developer in the different steps and is also very suitable for documentation purposes. The diagram is based on the UML class diagram and integrates static (structure of the context information) as well as dynamic information (execution of policies). It shows the available and intermediate context information, the final result, the modules, the processing order of the modules (module pipeline) and indirectly the execution of policies.

Figure 55 shows the core elements of the diagram and the depicted example is afterwards used for the explanation of this visualization. Modules are separated by vertical dashed lines and their names are depicted like a state in a UML state diagram inside a rounded rectangle on the top. The context information is visualized like a class in a UML class diagram. This should look familiar for people who are already used to this type of diagram. Figure 55 shows the different resources (*Resource A - F*) and their properties (*property*).

The arrows between two modules go from left to right and show the processing order of the modules. In Figure 55, first Module I, then Module II and at the end Module III is processed. Module I shows the information that is available at the beginning of the decision process and is therefore the result of step 2 of the definition process introduced before. Module II is a result of step 4 and represents the preliminary information resulting from the combination of the information present in Module I. Module III shows the final result which was defined in step 3 and which is used for the concrete adaptation done by the policy enforcement point.

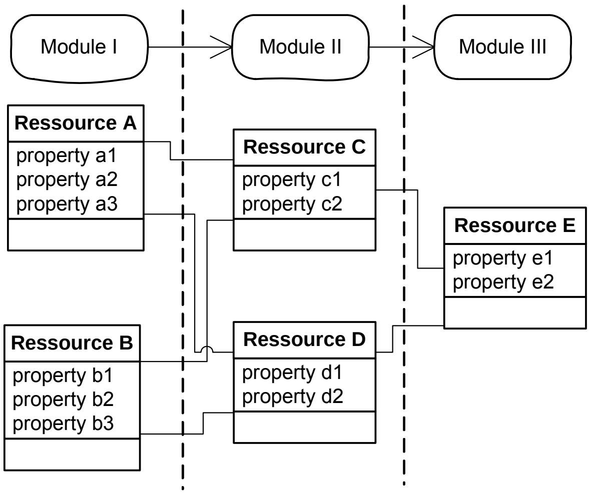


Figure 55: Core elements of the diagram.

Policies calculate new context information based on existing information. This is indirectly visualized by the lines which connect resources of different modules. All lines that connect resources in a left module to a resource in a right module visualize policies that use the resources in the left module to calculate the information that is represented in the right module.

Module Pipeline

Common problems of policy based adaptive systems are computability, conflict detection and resolution, complexity and performance. Some of these issues can be addressed through the usage of a new module concept. Basically it provides the developer with an opportunity to structure a potentially large set of policies into modules. Through this divide and conquer strategy it is possible to concentrate on only a few policies within a specific time frame.

One other very important problem are possible cycles during the execution of policies. If for instance the policies A and B react on a change of the resource C and both policies change this resource then A and B run infinitely. This effect is usually undesired and needs a lot of processing power. This problem can be solved using modules that define an execution order. If for instance the two modules I and II are defined then first all policies in module I must be fired before a policy in module II can be fired. The disadvantage of this is that the parallelism of the execution of policies is restricted. But it is still possible that all policies in one module can be executed in parallel.

Often a policy should only be fired if a specific set of information is available. If, for instance, a policy has to select the minimal duration for a data transmission then all possibilities for the data transmission and their duration have to be calculated first in a previous module.

5.2.5.3 Conclusion

This subsection first of all discussed the need for context-awareness when developing mobile applications, especially those that are based on physical mobile interactions. Following this, a case study of a context-aware mobile cinema information service was introduced that was implemented by a corresponding prototype. In particular, four guidelines for the development of architectures for such systems were discussed. Based on this, a process for the definition of context and policies that is supported by a novel diagram and the concept of the module pipeline were introduced.

5.3 Evaluate Designs

Within the context of this thesis many designs and prototypes were evaluated by testers, most of them were students, colleagues and friends. Existing literature already discusses the advantages and disadvantages of different evaluation techniques [Dix et al. 2003, Jones, Marsden 2006, Shneiderman, Plaisant 2004]. The aim of this section is the report of relevant experiences and best practices when conducting laboratory studies that are not described with this focus in literature or which should be stressed because of its importance.

5.3.1 Laboratory Studies

A typical laboratory study as conducted in the context of this work consists of five important steps: preparing the study, a preliminary interview, usage of a low- or high-fidelity prototype by a tester, final interview and evaluation of the study. Examples for such studies were discussed in chapter 4 Evaluation (sections 4.2, 4.4, 4.5 and 4.6), in chapter 6 (subsections 6.3.3 and 6.4.2) and for example in a study which evaluated whether the uncertainty in a context-aware mobile applications should be visualized or not [Rukzio et al. 2006f].

Testers should not fill in the questionnaire: It is very important that another person than the tester fills in the questionnaire. Most people do not like to fill in forms and to write text. Therefore especially answers to open questions tend to be very brief when filled in by the tester itself. If another person takes the notes, the participant has also more time to think about the question since taking notes takes much more time than just saying the answer. Another interesting technique is to write very slowly after the tester has given an answer. This period of time is uncomfortable for the tester and therefore she talks about further ideas and answers that can be of interest.

Quantitative instead of qualitative results: Quantitative questions and results should always be preferred in a user study in which testers are interviewed one after each other. Results like *X of Y persons liked Z* has more significance then *some persons said that they like Z.*

Generic versus prototype specific results: Especially in research, a prototype is often just a representation or implementation of a generic concept or research question. Therefore it is desirable to also get generic results besides the evaluation of the tested prototype. One can for instance ask for other application areas of the prototype or the advantages and disadvantages of the implemented application area (not just the prototype).

Detailed documentation: A laboratory study should not just be documented by the memories of the person who conduct the study and the results noted in the questionnaire. Taking pictures of the people using the prototype is a very cheap way to document how people hold the prototype, how they look (e.g. confused or happy) and how the test settings were. Such pictures can then be used to support the communication with colleagues, clients or the management. This is also true for videos taken during the study. They can also be used for the evaluation of the study, e.g. for measuring the time a participant needed for a specific task. One disadvantage of taking pictures and recording videos is that a further person is needed and that some testers do not like it.

Realistic test situation: Laboratory studies are often somewhat unrealistic because they do not happen in the right context or situation intended for the application, like at home, at a specific public place or during a sight seeing tour. Therefore one should try to make the test situation appear as much realistic as possible. An example is the evaluation of the mobile museum guide described in subsection 4.4. Putting all the labels used for the augmentation of the exhibits on a table would not lead to a realistic situation and therefore the test might produce suboptimal results. Therefore the labels were attached to the wall with a realistic distance between the different labels to simulate a typical situation in a museum. But there are also more sophisticated approaches in which real world situation are simulated in a laboratory to conduct more realistic user studies like [Singh et al. 2006].

Do not explain the prototype: The prototype should not be explained in detail before the participants test it. The persons should just know how the prototype works in principle or what the aim of it is. This simulates the case that someone is using a product for the first time without reading a manual or getting instructions from another person. Too detailed explanations can cover problems that might appear in practice.

Carefully designed questionnaires: When having no experiences with studies, existing literature has to be considered because there are many mistakes one can do when creating a questionnaire. It must be clear what the goal of the study is and which open questions exist that should be answered by the prototype. Furthermore, it is important to design the questions in such a way that the answers are easy to evaluate statistically. It is also important for the evaluation that every participant gives answers to all questions and that sometimes they have to decide for one given answer.

Ask for ideas before presenting existing ones: The tester should be asked for own ideas before presenting existing ideas using questions or prototypes. This could lead to new ideas that are not based on concepts known before.

Cover implementation issues: Some prototype implementations especially when looking at low-fidelity prototypes, have technical problems or do not provide some functionality in a matured way. In this case the user tends to criticise the implementation and might not see the advantages of the overall concept. Therefore the tester should be told in these situations that this function works in the desired way when having a matured prototype.

5.3.2 Field Studies

A field study is very similar to a laboratory study; the difference is the real world context of the study and the better possibility to recruit people from the street. The experiences or best practices reported in this subsection are based on the field study already described in section 4.3 and a cancelled field study aimed to evaluate an application for mobile interaction with an advertising column [Rukzio et al. 2004b]. Most aspects previously mentioned for laboratory studies are also true for field studies.

Different context and transportation issues: Conducting a study in a real world context can lead to a huge set of undesired problems, even after careful preparation. Examples include another network infrastructure, missing power sockets or no mobile network coverage. Before inviting or recruiting people, everything should be tested in the real world context in advance. Other issues that should be considered are weather conditions or other events that can happen simultaneously like a street party or a tour of a group of tourists.

Study in context: The big advantage of such a study is that it happens in the desired real world context. This leads to a realistic situation that influences the value of the given answers in very positive way. Moreover, this context supports and stimulates the imagination of the participants.

A calm place for the interviews: As already mentioned it is often chosen to interview the participants before and after the usage of the prototype. For this situation it is important to find a calm and comfortable place where the tester can ideally sit down and relax. This is a much better situation than when asking the tester questions while standing on a crowed place.

5.4 Summary and Conclusion

This section reported new best practices, lessons learned and guidelines that can be re-used by other application developers, software architects, managers and designers when developing physical mobile interactions and applications.

In the first part, new findings regarding field studies, unobtrusive contextual observations and online surveys are discussed that can be used when defining the context of use or the requirements of a new application or service.

The next part focused on new techniques for the development of low-fidelity prototypes and high-fidelity prototypes. New findings regarding the development of paper prototypes and HTML/Flash prototypes were discussed.

Following this, the usage of the usage of mobile phones as a versatile platform for the development of mobile applications, the Physical User Interface Profile and methods for the development of context-aware mobile systems were discussed.

Afterwards best practices are presented that should be considered when conducting laboratory or field studies that take prototypes using physical mobile interactions into account.

All the presented results are based on practical experiences that were gathered when analysing, designing, developing and evaluating physical mobile applications.

After discussing new results regarding the development of physical mobile applications the following chapter focuses on one specific field within the research area physical mobile interaction. Mobile interactions with public displays can be seen as a subset of using mobile devices as indirect remote controls as discussed in subsection 2.3.7.

Chapter 6 will focus on aspects like privacy, personalization and curiosity within such interactions. Furthermore two novel interaction techniques, their implementation and their evaluation will be discussed.

6 Mobile Interaction with Public Displays

As already discussed, mobile devices such as mobile phones, smart phones and PDAs have become very popular in the last years. Furthermore, processing power, quality of display (e.g. resolution, size, etc.) and the set of available network interfaces (e.g. GSM, GPRS, UMTS, WLAN or Bluetooth) is drastically on the increase. But the input and output capabilities of these devices is still far from the simplicity and speed of common desktop PC’s. Beside this we have seen a remarkable improvement of large screen displays, in particular increased size and resolution, falling prices, and availability of different display technologies in the last few years. Because of this, such displays can be seen in more and more public places such as airports, train stations, subways or house walls. They mostly present advertisements, news, weather information or information related to the places where they are located. Therefore, the usage of mobile devices which interact with these public screens to overcome the limited visual output capabilities is seen as a very promising interaction technique.

A first introduction of the research area mobile interaction with public displays was already given in subsection 2.3.7 Indirect Remote Controls. Generally it could be said that the usage of ubiquitous displays has up to now often focused on scenarios located in indoor environments (e.g. office, home) where specific groups (e.g. working teams, families) interact with these displays [Vogl 2002]. But beside this there are also several research projects and commercial applications that use mobile devices for interactions with public displays. An example for that is the WebWall that provides functionalities for public polls, auctions, browsing, photo slide shows or personal ads [Ferscha et al. 2002, Vogl 2002]. The Yahoo! Billboard was a car racing game introduced in 2004 and used a big display at the Times Square [@YahooBillboard 2004]. Persons close to the video screen were able to use their mobile phone to participate in the game shown at the display and to control a car. A similar installation was the NikeID Billboard in which a sports shoe could be designed using the mobile phone [@NikeID 2005].

This chapter presents new findings and novel interaction techniques within the research field mobile interaction with public displays. The first section focuses on the issue that the public displays can be seen by a group of people. At this the relationship between the number of persons and the information shown on the public display is analyzed. Based on this, the following section focuses again on these privacy aspects and also analyzes based on the evaluation of two prototypes the curiosity of people who pass a public display.

The next section focuses on the rotating compass, a novel interaction technique for mobile navigation taking the separation of personal and public data into account. This is based on a public display that cycles through a set of different directions and a synchronized private device which indicates which direction depicted by the public display should be considered by the user. The advantage of this approach is that no indoor location system is needed and that the conducted studies show that people like and understand this interaction technique.

Section 6.4 focuses on a new interaction technique for direct mobile interaction with public displays. This is the first interaction technique in which the mobile device can be used as a first class direct input device. After showing the advantages of the interaction technique, a corresponding implementation and a user study evaluating the prototype and interaction technique is discussed.

6.1 Privacy and Personalization

This section is based on [Rukzio et al. 2004a] and analyzes and classifies privacy and personalization aspects of mobile interactions with public displays. A matrix is presented which relates the number of persons that can see the display to the number of people that can interact with the display. This illustrates the different cases in which personalization of services on public displays is useful and in which not.

[Huang, Mynatt 2003] analyzed existing applications for displays and present a matrix which relates the group size for which they are designed to the type of space in which they are viewed. In contrast to this analysis, this section focuses primarily on personalization and privacy aspects of displays that can be found in public spaces.

In principle it is possible to personalize a service for one specific person, a couple or for a specific group with or without common interests and preferences. If personalization is aimed at all people using a system, no real adaptation can be performed and the service is somehow static.

In addition to that, the three following levels of personalization can be distinguished:

A: Personalized information that must not be shown in public (e.g. automatic form filling of a form for ordering a book which shows address and bank account).

B: Personalized information that can be shown in public (e.g. visualization of weather information of the home town of a person and the wind conditions of the persons favourite lake because she loves windsurfing).

C: Personalized information that can be shown in public if no link to the initiator can be drawn. This assumes a large number of people potentially interacting with the display (e.g. you request a special song to be played; it will be played in public but it is not indicated who requested it).

Levels B and C are very interesting from perspective of the display owners and service providers because a lot of people are curious to see what others are doing or viewing.

To personalize a special service, some knowledge is needed about the people involved. Generally this information can be made available through a profile of the user or through the observation of a user during a session.

As shown in the following Figure 56, there are 16 different possibilities regarding the relationship between the number of people that can see the display and the number of people that can interact with the display.

Both axes are subdivided in 1, 2, group and X persons. The number 2 represents a pair of users which might have a mutual trust. A group might be a number of about 10 people which could be somehow related, e.g. through a common interest in the place where the display is located (e.g. people travelling together). X people represent a larger number of people (e.g. more than 20) who are not related to each other. Group and X may overlap in size but the clear distinction is that people in a group are related to each other where this is not the case in X. These four different subsections are abstractions whereas also mixed cases might exist.

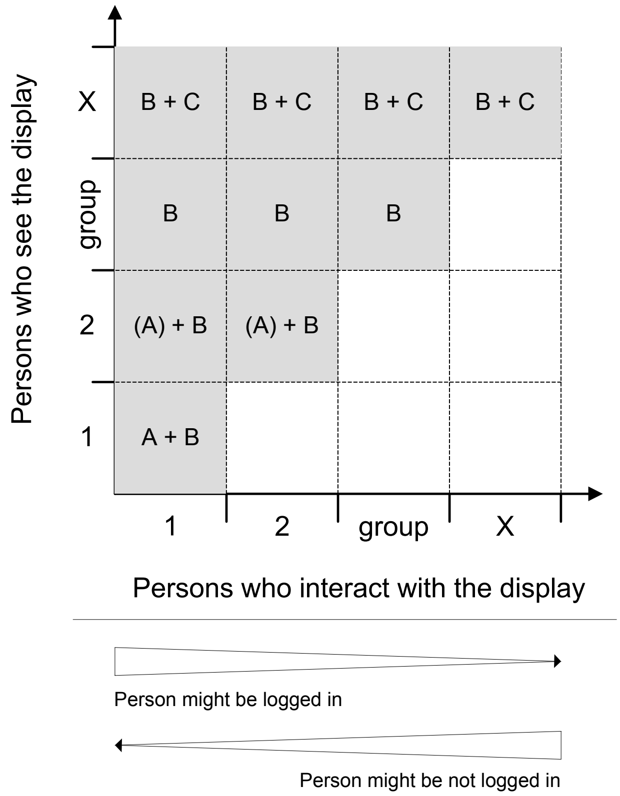


Figure 56: Relationship between the number of people who see the display, those that can interact with the display and the level of personalization.

A public display which can be seen by 1-2 persons might for instance be an ATM, a ticket machine, or a terminal at a station or airport. A display box (like a phone box) is also imaginable. The privacy of these private-public displays is limited because it is possible that someone observes the person while she is interacting with the display. If we think of a display at a bus station, then this is seen by a group of people that might all be related to this place because a lot of them are living near that bus station. At an airport or a concert there are displays that can be seen by a large number (X) of people.

When only one or two people interact with the public display they are probably logged in or have authenticated themselves (as when withdrawing cash from an ATM). If a lot of people interact with the public display it is less likely that they are logged in (e.g. the flight schedule board at the airport).

Figure 56 shows that there are only few cases where adaptations of level A are suitable, but this is not surprising because we are thinking about personalized interactions with pervasive public displays. The level A might be restricted (depicted by (A)) when the two persons who see the display do not trust each other. But the levels B and C show that limited adaptations are reasonable for public displays. Cases where people interact with the display without seeing it (fields which are not grey) are not considered. This might for instance happen when people can interact indirectly or remotely with the display (e.g. they are sitting far away on a desktop PC and have access to the content on the public display).

After discussing the privacy and personalization aspects from a theoretical point of view the following section will analyze these and other aspects based on the evaluation of two prototypes in a more practical context.

6.2 Privacy and Curiosity

Mobile interaction with public displays is gaining more and more interest, especially in application areas like advertisements, gaming, exchanging multimedia data or leaving notes. But so far no research exists looking at privacy concerns of users when interacting with public displays in a practical context. In the following, two user studies are presented that were conducted to take a closer look at these issues. The first one showed that users would not use an application that displays personal information on a public display. Most participants were afraid that other people could see their private information. To prove this argument, a second test was performed that showed that nearly every second person looked at the person and the display with which this person interacts. But this curiosity could be an advantage for applications that advertise something that needs the interest of the people passing by. Therefore, the second test was extended with an interaction technique that is based on mobile phone gestures. Here nearly 70% of the people who passed by looked at the public screen. The research presented in this section is based on [Holleis et al. 2006, Otto 2006].

Everyone can potentially see information presented on a public display leading to ambiguous implications. Especially for advertisements or for applications that are designed for a group of people such as a public auction or poll, it is seen as an advantage. But what about private or semi-private data showed on such a display? The WebWall, for instance, provides functionalities for an image gallery that might be used to display private pictures [Ferscha et al. 2002]. Would people use a public display to see their own pictures and accept that other people can see them as well?

The previous section already analyzed the relationship between the number of persons who can see a display, the number of persons who interact with the display and which kind of information is appropriate to be shown on a display. But these are just assumptions that are not based on experiments. To verify these with practical observations, two user studies were conducted. In the first one, an application was designed in which a public display could be used to exchange pictures stored on the mobile phone of the people interacting with it. A corresponding paper prototype was developed and evaluated to figure out whether people would use such a system and how important they judged occurring privacy issues. The result was that privacy is a very important issue for the testers and because of that none of the participants would actually use such a system. All participants in the test said that they expected most people who pass by to be curious about what happens on the display.

Because of this argument a second experiment was conducted to analyze how much people are interested when passing a person who interacts with a public display. The result showed that nearly every second person (49%) looked at the display and that the fears of the participants of the first study proved true. But this disadvantage for an application taking private information into account can be exploited by applications that require attention. Because of this, the prototype was extended to analyze in a further user study how the curiosity of people could be raised. Therefore the interaction technique SWEEP [Ballagas et al. 2005] based on gestures to control a game was used. These dynamic motions of the user amplified curiosity and more people than before looked at the display. Furthermore, more participants even stopped and some ended up playing the game themselves.

The next subsection discusses the first user study in which the privacy awareness of users was tested. Afterwards the realization and results of the second user study that evaluated the curiosity and interest of people in the interaction of another person using a public display is described.

6.2.1 Private Information on Public Displays

To gather insight on how people are thinking about using public displays for their own, possibly private purposes, a small user study using the following scenario was conducted. 6 persons took part in this compact user study; most of them were in their twenties. The reason for not involving more persons was that the results were already unambiguous after these six persons.

Mobile phones are increasingly used as storage device for data like pictures, music or movies. Phone owners also often want to share or present such data to other people. The numerous limitations of small phone displays can be overcome by large public displays. The used scenario was presented to the testers by using short comic strips as shown by Figure 57.

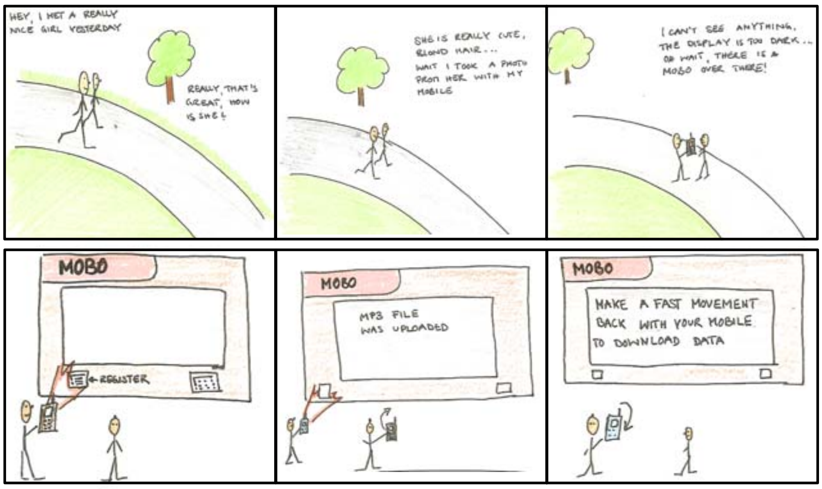


Figure 57: Some of the sketches used to explain the given scenario to participants in the user study [Otto 2006].

The following description was used to explain the scenario to the testers: Ben wants to show a picture of his new girlfriend to Dave. Unfortunately, the phone's display is very small, has low resolution, and is hard to see in the sun. They approach a large public display (called 'MoBo') to which Ben wants to upload the picture. He quickly registers at the display, browses through the menu by tilting and nodding with the phone. With a quick gesture, he throws the picture to the display. Additionally he uploads a ring tone he composed himself for sharing it with his friend. Dave browses through a list of ring tones that have been uploaded and initiates a download with a quick waving movement of his phone.

Most of the actions necessary to interact with the public display were designed to be done by gestures. This should help to make the interaction more intuitive, increase the memorability of the actions and make it more intriguing to use in general. It can be implemented using various methods like built-in accelerometers or using the optical flow of the camera of the mobile phone.

In order to evaluate the idea in an early state of development, a paper prototype with which the whole system could be emulated was developed. A magnetic billboard was used as public large display with paper screens that could be easily replaced. Mobile phones were built from carton and paper with replaceable sticky screens.

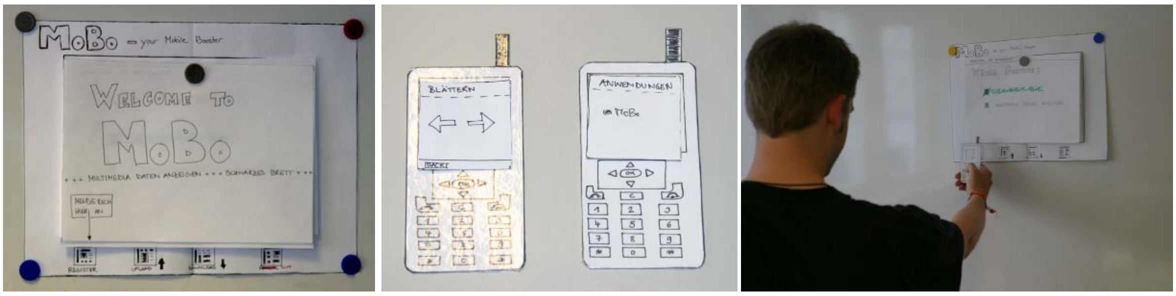


Figure 58: Paper prototypes of public display, mobile phones and a user interacting with the system [Otto 2006].

They had an average size and form factor, a see-through display to simulate the camera output, and a standard button and joystick layout (see Figure 58 and Figure 41a at page 101). Large and small screens for all possible states of the system and the phones were prepared in advance. Two persons assisted during the tests. One was monitoring the actions of each user and exchanged the screens appropriately. The other person videotaped the whole process and took notes of questions, unclarities and errors that appeared during the process.

After a quick introduction to paper prototyping, the testers were asked to read the scenario, then the idea was explained to them in more detail and questions were answered if they had any. According to the scenario, they were then given specific tasks to accomplish. One of those tasks was to upload a picture stored on the mobile device to the public display. This included a registering process, browsing the menu and initiating the correct gestures. Intentionally no detailed instructions on how to solve the tasks were given to be able to judge whether or not the necessary steps are easy and obvious enough.

After each person successfully finished the task (Figure 59), we had informal discussions and distributed a small questionnaire to gather additional feedback from the users.

Because of the monitoring in general and evaluation of the questionnaires in particular, it was concluded that all participants quickly understood and grasped the setting and scenario. Menu navigation and gesture interactions did not pose any problems; most actions were immediately done correctly using only the short description given on the public display (e.g., *tilt phone to the right to …*). They also stated that it was an interesting idea to use public displays in such a way and even suggested several additional application scenarios (billboards, games, etc.).

However, every participant expressed huge doubts regarding privacy issues. No one wanted to have private content presented on a publicly visible display even if there was no one standing close by in that very moment. Besides feeling uneasy about what is done with the data, users were convinced that passers-by would be attracted by their activities in front of the display and could see their private pictures, etc. In informal discussions it was found out that it was rarely thought that people would maliciously spy on them but that curiosity attracted them and made them watch.

Figure 59: Pictures from the paper prototyping user study: Mobile phone, interaction and replacement of screens [Otto 2006].

This opinion was given independently and unanimously by all participants and therefore it was conjectured that applications handling delicate information on public displays will hardly be accepted by potential users. However, one of the major current uses of public displays (passive, active or interactive) is advertisement. In contrast to the scenario presented above, such displays are the more valuable the more people look at it. Thus, the curiosity of people can be utilized for the application area of advertisements which led to the study described next.

6.2.2 Curiosity of People

As has been shown in the previous subsection, people are worried about having private data shown on a display which could potentially be seen by every passer-by who is curious enough. Of course, raising curiosity can be an important factor for other purposes like multi-player games and advertisements.

Therefore it was analyzed with another user study whether or not people really are curious and how much they show interest in what other people do in public places. A gaming application was implemented where an item on the public display can be controlled by gesturing with the user’s phone. The idea was that such interactions catch people’s attention and encourage them to play by themselves.

6.2.2.1 Prototype

Since several people who participated in the first user study mentioned interactive games as another possible type of intriguing application, a game using the SWEEP technique was implemented [Ballagas et al. 2005]. The iStuff Toolkit was used which encapsulates many implementation details [Ballagas et al. 2003]. A Symbian application on the mobile phone tracks the phone’s movement by exploiting the mobile phone’s camera images. Events are generated and sent via Bluetooth to a specific port on the public display server machine. There they are transferred to the Event Heap, a tuple space in which data is passed between applications through the generation and consumption of tuples of data through a shared data space. A Java application catches the events and transfers them into x/y coordinates. Additionally these coordinates are passed to a Java package which can directly map them to corresponding cursor keys on the public display controller. This allows using every available game that uses the standard set of keys as controlling input without needing to manipulate the source code of that game. This architecture can be seen in Figure 60.

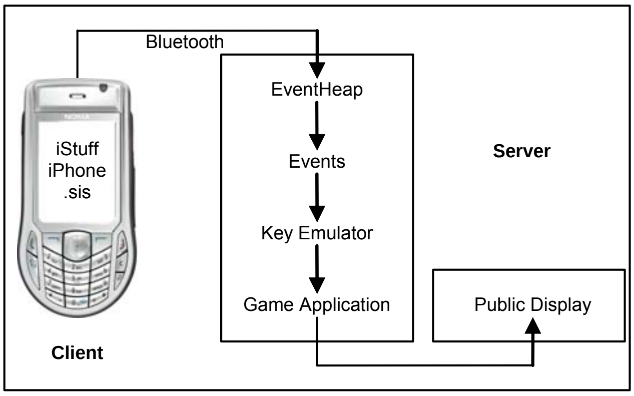


Figure 60: Architecture showing the connection between mobile phone and public display using the iStuff toolkit.

6.2.2.2 User Study

A display - in this case a video projection - was placed in a highly frequented public place at a side wall of a passageway close to the entrance of a main university building. One after the other, two different versions were run: in the first, a laptop was used as an example for an ordinary input device for the game; the second version featured a mobile phone with which people could control game items on the screen (Figure 61).

Figure 61: Impressions from a user study *Mobile Phone Game Control on Public Displays*. One can see how people get curious seeing the testers interact with the mobile phone.

With each version one session was made in which over 76 passing people were observed and videotaped. They were categorized according to the following scheme depicted by Table 21.

curiosity level	ignored	no noticeable interest could be seen at all
	interested (glance)	people saw the setting but decided to proceed
	high interest (watch)	persons who stopped to watch more closely
	try out	those who convinced us to let them take part themselves

Table 21: Curiosity level of observed people.

It was assumed that the gesture input technique would gain more attention, because people are actively and very dynamically playing the game by moving the mobile phone through the air. To get comparable results the same place and time of day for both scenarios was chosen.

6.2.2.3 Results

As can be seen in Figure 62, both scenarios got the attention of people passing by: Altogether, 90 out of 152 people were attracted. However, significantly more people got interested when using a mobile phone than when using a laptop. This effect was not influenced by the application since the public display showed the same game each time. When playing with an ordinary laptop, several people merely glanced at the display and only 3% (2 of 76) showed more interest and stopped to observe the game. Compared to the phone input technique, the number of people who showed higher interest nearly quintupled with 14 % (11 of 76) spending more time to observe the game play.

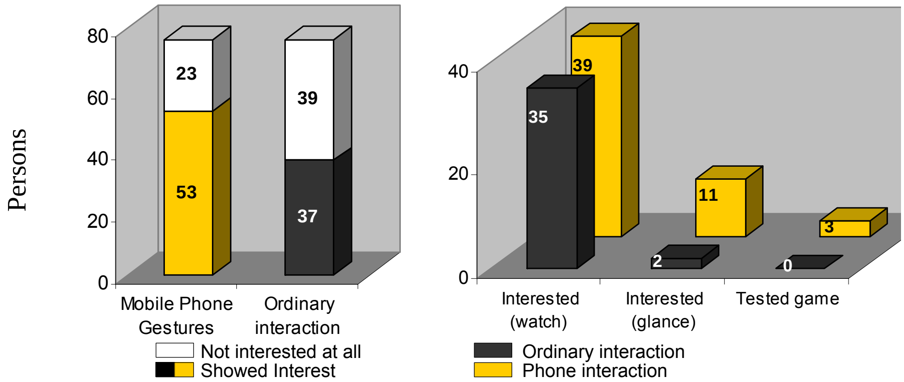


Figure 62: Of the 76 people who passed by during each session of the study, significantly more people showed interest in the public display when using mobile phone interaction.

The difference is even more remarkable as the display content itself was already dynamic, colourful, and quite amusing to watch. In the first scenario, not a single person intended to try the game. This may be because familiar input techniques do hardly arouse curiosity and the laptop setting suggests a more private session. When using the mobile phone gestures, 3 persons were so fascinated, that they actively asked to play themselves. Additionally we could observe that they spent ten minutes on average to observe the game and asked questions about the input technique in general and what could be done with the system. This result shows that with such physical input devices the curiosity level can be considerably increased.

6.2.3 Discussion

The unambiguous result of the user study based on the low-fidelity prototype was that people do not want to show any private data on a publicly visible display. Most test persons were afraid that passers-by could see their personal pictures. But most participants of the test mentioned that they could imagine games based on mobile interactions with public displays and that advertisements were therefore also an interesting application.

In the second user test it was analyzed how curious people really are. Therefore, a prototype was developed in which a laptop was used to control a game which was projected onto a wall. While running this game in a highly frequented public space it was recognized that a lot of passers-by looked at the public display and at the person who plays the games. This supported the argument of the participants of the first test that people are curious and that they would spy onto their private pictures. But this disadvantage for privacy-related applications is an advantage for applications such as advertisements that need the attention of people. Therefore a second version was run in which mobile phone gestures are used to control the game. The result was that more people were interested in the game, that more stopped and there were even some people who played the game. This research shows that there is a high potential for advertisement providers to use a dynamic interaction method like that presented in this paper to raise curiosity and increase visibility.

Furthermore especially the first study confirms the statements described in section 6.1. According to Figure 56, which summarizes the results of this section, it does not make sense to show private information on a public display while everybody can see this information.

After discussing the problems, benefits and challenges in mobile interactions with public displays, the following section presents a new mobile navigation application which shows the advantages of using synchronized public and private displays.

6.3 The Rotating Compass: An Interaction Technique for Mobile Navigation

In current mobile navigation systems users receive the navigational instructions on a visual display and/or by descriptive audio. The mapping between the provided navigation information and the surrounding world has still to be performed by the users. In the rotating compass approach, which aims at public spaces, a public display that shows directions is combined with a synchronized output on a personal device. Within this interaction technique, a public display shows a compass with a rotating needle. When the compass needle points in the desired direction, the mobile device of the user vibrates. This unobtrusive cue allows the user to navigate without listening to or looking at the mobile device. In this section the concept of synchronized information displays for navigation is introduced. A prototype of such a system and a corresponding user study is discussed showing the feasibility of the approach. The research presented in this subsection is mainly based on [Rukzio et al. 2005a].

6.3.1 Synchronized Information Displays

Navigation systems have seen significant advancements in recent years. They are commonly used in planes, cars and trucks. Additionally, a variety of mobile devices for pedestrian navigation, for use in urban areas as well as for hiking, are commercially available. This subsection introduces the concept of synchronized displays for providing navigational information. The basic idea is that displays in the environment and a personal device are used in combination. The output of the mobile device is synchronized with an environmental display in the vicinity of the user to provide personalized information without giving away personal or private data.

The main idea is to enhance the presentations of static directional signs by an animated public display. In the implementation described afterwards, a rotating compass needle is visualized. The direction interesting to an individual user is identified through the vibration alarm of the personal device, which is activated whenever the needle points in the right direction. This allows users to identify the relevant direction without a personalized presentation on the public display. In fact, personalisation is achieved through the combination of the public and the personal device. If the mobile device is carried in the pocket, notifications can be delivered absolutely unnoticed by other parties.

The following example illustrates the concept. A user is carrying a mobile device that can vibrate in a pocket. The user approaches a place where she can turn right, turn left, go straight ahead, or do a U-turn. At such a decision point, a public display (e.g. a projection on the floor) highlights all possible direction for a short amount of time. When all directions have been highlighted clockwise, it starts over again. The user approaches the decision point and the device she carries always vibrates when the direction is highlighted that the user should take. An example showing two people approaching a crossing is illustrated in Figure 63.

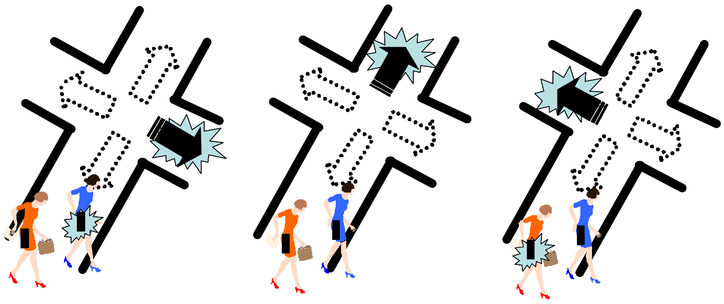


Figure 63: Principle of the rotating compass interaction technique.

When the public display highlights the direction that a person needs to go the personal device of this person will vibrate. The right person in the blue dress needs to go right (first picture within Figure 63); the left person in the red dress needs to go left (last picture). The display highlights the directions independently of the people around (middle picture).

The public display is independent of the users that are around. The display highlights different information, such as directions, over time. Each piece of information is called an option. At one point in time one option is highlighted or displayed. Once all options have been highlighted or displayed, the procedure is repeated. The time needed to show all pieces of information once is called cycle-time. The cycle-time is the upper bound of the waiting time for someone using such a public display.

The public display can be a projection as sketched in Figure 63, where an arrow that changes its direction is projected onto the floor. Each direction is one option. Instead of arrows, adverts and logos could be projected as is already common in some shopping malls. The public display could also be a screen that provides textual information (e.g. *go left*, *go right*, *go straight on*), or a simple spot light that highlights signs that are already used in a certain environment. When designing the public display it is important to make it fit the environment where it is placed in. Criteria for such a public display are similar to those for setting up conventional signs. It should be easy for the user to look at the display in the environment while walking. An important design feature is the distance at which the user can see the entire display and at which the user is able to discriminate all options displayed.

The information shown on the public display is on its own – without a personal device – not useful for navigation. And hence the information displayed does not reveal personal information. To make it usable with a personal mobile device, it is important that the timing of the public display is known. I.e. it must be known when a certain option is highlighted, e.g. when the arrow pointing to the left in Figure 63 is highlighted. This information must be available to the mobile device to allow synchronized notification.

The function of the personal device is to notify the user that the currently displayed option on the public display is targeted to her. To do this, the output of the personal device is synchronized with the public display.

The display on the personal device can have a minimal communication bandwidth to the user. A binary display is in general enough as the function of the personal display is to make the user aware that the currently displayed public information is meant for her. Examples of such displays are a vibration motor (as is often available in a mobile phone), a single LED integrated in a watch or into a pair of glasses, or a sound signal. Such a sound signal could be mixed into the music a user is listening to. In such a scenario a personal stereo worn by the user could be used as an output device (e.g. headphones of a mobile mp3-player).

Personal displays that only communicate one bit can be designed very unobtrusively. The vibrations of a device or the additional sound on the personal stereo are only recognizable by the user and not by others.

In the cases that were investigated, the time constraints for the synchronization are in the order of several hundred milliseconds. This makes it possible to work with clocks on both devices and does not necessarily require a wireless connection for synchronization. It is however necessary that the personal device knows when it approaches a decision point. As the accuracy required is only at which crossing the user currently is, this can be realized by a simple and coarse location system, e.g. based on radio beacons.

A synchronized navigation system consists of a personal device for each user and a public display at each decision point in the navigation space. Additionally, a system component providing location information is required.

To implement the navigation there are two basic options. At each public display the personal device must be able to retrieve the current location or the personal device must tell where it wants to go. In the first approach, the route is held on the personal device and the environment is not informed where the user is heading to. The environment tells the personal device where the user currently is and what options are available. Based on this information and the known target, the option that is right for the user is chosen. In the second approach, the user asks the environment at each decision point where she should go telling the system the final target. The system then informs the mobile device which option is correct. The first approach obviously has the advantage that the user’s privacy is preserved whereas the second one is simpler to implement for the mobile device as no advanced logic is required for this device.

To design a navigation system where people do not have to stop, the following estimates are provided. It is assumed that the walking speed is 1.5m/sec and that the change of direction is directly at the public display. To allow users to retrieve the relevant navigation cue without the need to stop, it is required that cycle-time is less or equal to the distance/1.5.

6.3.2 Prototype of the Navigation System

A prototype of the synchronized navigation system was built to perform user tests. The goal was to explore if such a navigation system can be understood by users, what the user experience is, and what effect the cycle-time has on the user experience. The prototype consists of a public display that is projected onto the floor and a mobile phone used as a personal device.

The projected display shows a circle with a rotating pointer which looks similar to a compass, see the following Figure 64. The public display is implemented as a web page and the graphics are programmed in SVG. The program can be parameterized to change the number of directions available, the time needed to complete one circle, and the layout of the presentation (e.g. colours, additional lines). A ceiling mounted video projector was used to project the display onto the floor.

A Java application on a mobile phone was developed that allows to switch the vibration motor of the phone on and off. The software is based on Java ME (MIDP 2.0 / CLDC 1.1) and runs on a Siemens S65 phone. The application is parameterized with the characteristics of the public display that is used (cycle time, number of options, and option names). The application offers two modes. In the predefined mode a list of options and timings is given to the application and the phone *plays this list* where each option is played twice consecutively. In random mode the phone selects random options, presents them, and waits till the user acknowledges the direction with the keypad.

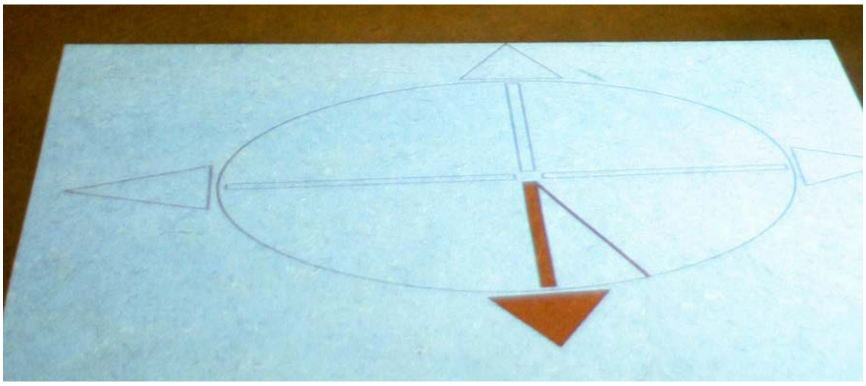


Figure 64: Projected display of the prototype.

For synchronizing the clocks of the phone and the public display, another application on the phone was developed. Before the experiment, the experimenter presses a button when the pointer in the public display is at a certain position. The synchronization has to be performed only once per experiment as the clock drift is minimal.

6.3.3 Study and Results

Using the prototype described in the last subsection a user study was performed. 14 volunteers participated in that study, 6 women and 8 men, aged from 22 to 44 years.

The public display was set up as a projection in a large room. The projected display on the floor was approximately 1.5 meters by 1.3 meters. The number of options was 4 and they were orthogonal. It was in the middle of the room so that people could walk around it. The mobile phone and the public display were synchronized before the experiment.

Participant got the following introduction read to them: *Imagine this installation in a public place in larger size. You have entered your destination in your mobile phone before. Now you come to a point where the system tells you which way to go. Follow in the direction where the arrow is when your phone vibrates.*

The participants were handed the phone and then the following experiments were performed. The order of test 1 and test 2 was alternated between participants.

- Test 1: The user holds the phone in her hand. Each time it vibrates, the user goes to the direction indicated by the public display and acknowledges the step by pressing a button. The same direction is repeated until the user acknowledges. The cycle time in the experiment was 16 seconds, 2 seconds per option and 2 second between options. In total, 10 directions where indicated for each user.
- Test 2: The same as test 1 except cycle-time is 8 seconds, 1 second per option and 1 second between options.

Then users were asked after the tests if they could describe the difference between test 1 and test 2.

- Test 3: Users are instructed to put the phone into a pocket in their garment. Then, whenever the phone vibrates the user has to go in the indicated direction. Each direction is indicated only twice to avoid that the users need to take the phone out of their pockets for confirmation. If the users recognized it the first time they did not move at the second time. In total, 20 direction (each 2 times consecutively) were indicated to each user, half of them with a cycle time of 8 seconds and the other half with 16 seconds.

After the tests the participants were interviewed for about 10-20 minutes. The questionnaire started with specific questions and was leading to an open discussion on the overall concept.

With the simple instructions given, all users understood the basic principle of synchronized navigation and could perform the tests. In the first test (16 seconds cycle time) all users recognized the direction instruction at the first instance. In all 140 cases they went to the right direction. In the second test (8 seconds cycle time); participants went in 137 of 140 cases to the right direction at the first indication and in the other 3 cases at the second. When asked about the difference between the tests, 6 of 14 could not tell the difference. For those who recognized the difference in cycle time all preferred the shorter cycle time as they felt it makes navigation quicker even if they may miss an indication at the first instance.

In test 3, all participants put the phone into their trouser pockets, 12 in a front pocket and 2 in a back pocket. Several women in the study indicated that the usually carry their phone in their handbag, depending on what they wear and that notification by vibration would not work for them in this case. Out of 280 instructions, 276 direction indications were recognized at the first notification and 4 at the second.

When asked if they could imagine to use the system under time pressure 12 answered yes, 1 was not sure, and 1 said no. All stated that the speed to receive the directional cue is critical. Furthermore the participants were asked where they could imagine deploying such navigation systems. The following application areas were stated: airports, railway stations, underground stations, inner cities and tourism, complex buildings (e.g. hospital, museum, and library), shopping malls and trade fairs. In the open interview, participants reported in general that they found the navigation system straightforward and easy to use. Several people indicated that a personal navigation that is blended in the environment is appealing to them and that they did not want to focus on a personal screen while walking. They saw a great advantage in wearing the phone and receiving the direction cues unobtrusively.

The following potential problems were indicated: One user asked how can you discriminate between an incoming call and a navigational cue? In our prototype, we used a distinct vibration pattern for navigational cues, but we did not test calling participants while they performed the experiment. One user did not like the projection on the floor as she said it is not natural to look on the floor while walking, she would have preferred the projection on a wall. Two participants raised concerns if such projections may be distracting and unpleasant in certain environments.

6.3.4 Related Work

There has been a lot of research in the area of pedestrian navigation systems in the last years. In [Kray et al. 2003] a typical outdoor navigation system is presented. An early indoor navigation system is presented in [Want et al. 1992]. In the area of augmented reality there has been research on combined indoor and outdoor navigation, e.g. [Höllerer et al. 1999]. Amongst those it was the REAL system described in [Baus et al. 2002] to be one of the first systems to combine a public and a personal device to provide indoor way instructions. In contrast to the rotating compass, the devices were used sequentially and not in parallel and with a different goal in mind: users were first able to retrieve highly sophisticated 3D-navigation information from a large screen and were then, while walking, able to access sketch-like information on a PDA.

Other navigation systems exclusively rely on public screens, which are either smart doorplates, e.g. [Trumler et al. 2003], or large information screens. In both cases privacy problems may arise, since private information is displayed in a public space. Furthermore, it is difficult to design such systems so that they will work for multiple users.

Other mobile navigation concepts purely rely on tactile feedback to navigate users through spaces. GentleGuide [Bosman et al. 2003] is a concept study that introduces haptic feedback through two vibrating devices that are worn at both wrists to provide indoor navigation. The vibrating devices silently indicate left or right turns to users at specific decision points. In ActiveBelt [Tsukada, Yasumura 2004] the same principle with higher resolution has been implemented. ActiveBelt uses eight vibration devices attached to a waist belt to notify the user about directions to take. Both approaches share with the rotating compass system the advantages of hands-free operation. However, GentleGuide and ActiveBelt require very precise information on the user’s location, which makes their deployment in indoor environments either costly or limited.

In contrast, the rotating compass relies only on coarse information about the proximity of users to the public display. Cell-based localization techniques, e.g. based on Bluetooth, are therefore sufficient for a proper operation. Furthermore, as the rotating compass only needs a one bit personal display, this approach is more flexible with regard to the devices we can use.

6.3.5 Conclusion

The previously discussed study shows that the basic principle of the rotating compass navigation system is easily understandable by users. The laboratory experiments indicate that users easily get the navigational cues on a personal device and can relate them to the information show on a public display. Overall, in more than 97% of the cases, people got the navigational cue at the first indication and in 100% the cases they got it at the second indication.

Furthermore this study confirms the statements described in section 6.1. According to Figure 56, which summarizes the results of this section, it is possible to show personalized information in the public as long as no link to the imitator can be drawn or to show personalized information that can be shown in public.

6.4 Direct Interaction with Dynamic Displays

As already discussed in subsection 2.3.7, there are many examples for indirect interactions with remote displays. But there are just a few examples for direct interaction such as some pointing based approaches or the magic lens based approach for mobile interaction with a map presented in [Schöning et al. 2006]. [Reilly et al. 2005, Reilly et al. 2006] were the first who used the interaction technique touching for complex direct interactions like click-, path-, multi-, lasso- and menu-select.

But so far no research regarding direct touch based mobile interaction with dynamic displays exist. Dynamic displays visualize information that can change over time. A typical implementation of such a display is based on a public screen or a projection. The advantages of this interaction technique are the benefits of using a direct interaction technique and the possibility to use the dynamic display and the mobile phone interface in parallel. This section is based on [Vetter 2006] and presents an application area, an implementation and a compact evaluation for this interaction technique.

A typical application area for direct interaction with a remote display is using the mobile device for interactions with a public map [Reilly et al. 2005, Schöning et al. 2006]. Thereby the remote display shows a map and the user uses her mobile device to select, for instance, a place, a region or a path to get additional information about it. In this case, the mobile device acts as a private display and can be used for storing data like parts of the map or information about points of interest. The main advantages when comparing this interaction technique with a touch screen are that the mobile device can show private information, can be used to store relevant information, can provide additional feedback during the interaction and the user does not have to touch the potentially dirty display with her finger. A further advantage is that through this approach an application is not restricted to the small display of the mobile device because the potentially big remote display can be used. In this case the user interface consists of the mobile device and the dynamic display whereas both can provide different kinds of feedback within the interaction.

6.4.1 Architecture and Prototype

The following Figure 65 shows the architecture of a prototypical implementation for direct interaction with public displays that consists of the dynamic display, a projector, a server and the mobile device. The projector is used to display the interface of an application on a remote surface. The latter is augmented with a mesh of NFC tags representing the touchable pixels (see Figure 66a at page 145). The tags carry information about their position following a 2-dimensional pattern like 0:0, 2:1 or m:n. The parameters m and n define the vertical and horizontal resolution of the touchable pixels of the dynamic display. The server hosts a map application designed for this prototype. The dynamic display consists of the map application that is projected onto the remote surface. The advantage of this approach is that the information shown on the public display can be updated according to the interaction of the user or the purposes of the system. The mobile device is used to touch the NFC tags. The information about the read NFC tags is then transmitted to the map application on the server which can update the dynamic display according to the application logic. The mobile device also provides an interface for direct interactions with the user who can use the mobile device as a remote control to access the map application running on the server.

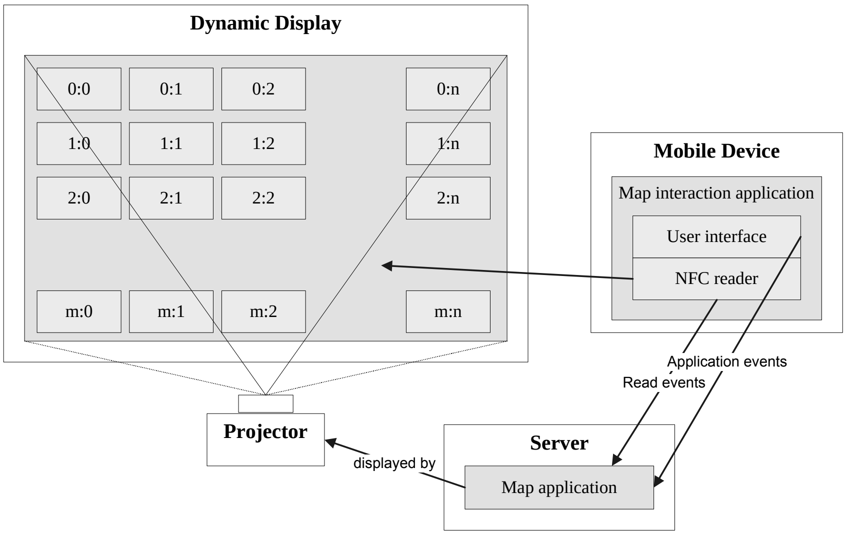


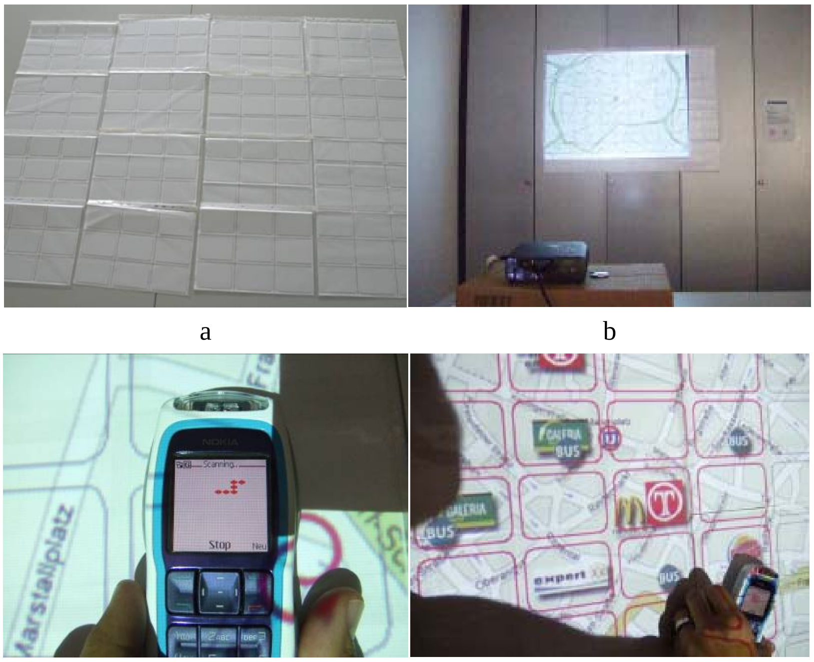
Figure 65: Architecture of the prototype for directly interacting with a large display using a mesh of NFC tags.

Within this interaction technique, the mobile device is used as a pointing device like the stylus when using a PDA or a mouse to interact with a PC. Because of this, the same interaction types like drag and drop, double click or context menus can be supported when using the presented system.

Based on this architecture, a prototype for map based interaction was developed. The following Figure 66 shows the NFC mesh (a), the projection onto a surface augmented with the NFC mesh (b), the mobile device used for the interaction with the active display (c) and the interface of the map application after interacting with it (d).

A Nokia 3220 with an NFC shell CC-229 was used as the mobile device. The mobile application was developed using Java ME (MIDP 2.0 / CLDC 1.1) and the Nokia NFC RFID SDK 1.0 [@NokiaNFCSDK]. The map application running on the server was implemented using Java SE. The matrix of the dynamic display consists of 10x10 NFC Mifare tags. Figure 66d depicts that the map application indicates where the NFC tags are and shows through this the click- or touchable areas. The implementation supports three different selection techniques: bounding box selection, path selection and multiple tag selection. For the first one, the user has to select the top left and bottom right tag. Based on this, the application calculates a corresponding bounding box. When using path selection, the user has to start with an arbitrary tag and can then define a path to another position on the public display. The result is a path of selected NFC tags. When using multiple tag selection, the user can select different tags somewhere on the public display.

One important question regarding this interaction technique is which feedback should be provided by which display. Therefore, three different variations of the prototype were implemented and evaluated. The first and second versions simulated a static map because the map on the public display did not change during the interaction. In the first version the mobile phone presented a visual feedback to the user. In the second version, acoustic and haptic (vibration) feedback informed the user whether a tag was successfully scanned or not. In the third version, the previously described dynamic display was used. The public display shows, as one can see in Figure 66d, through highlighting which tag was touched by the user.



a b c d

Figure 66: Implementation and usage of the prototype.

6.4.2 User Study

A user study was conducted to evaluate the concept of the interaction technique itself and to compare the different feedback options. 8 participants, 3 females and 5 males, aged from 19 to 25 years took part in the user study. The participants were asked to interact with the public display and to select a path from a starting point to a specified destination.

The participants were asked before and after using the prototype whether they saw a specific kind of feedback as very valuable or not. The corresponding results are visualized in the following Table 22. The first column shows that before using the prototype many participants thought that the visual feedback on the mobile device was very valuable. But after using the prototype many of them had a completely different opinion. This is due to the fact that current interactions between a mobile device and a user are mainly based on the visual channel. Therefore most participants thought that this was also true within this new interaction technique and they were surprised that it is not as valuable as they thought in the beginning. This is also true for haptic and acoustic feedback as one can see in the second column of the following table. The results regarding the feedback on the public display are different from the kinds of feedback described before. In this case, the participants thought that the visual feedback on the dynamic display was valuable before using the prototype. After using the prototype even more participants then before mentioned that this kind of feedback was very valuable.

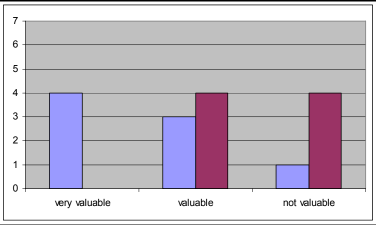
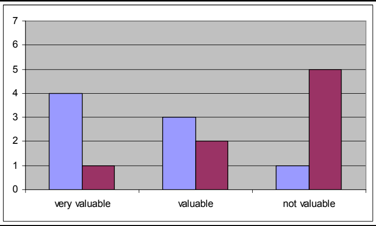
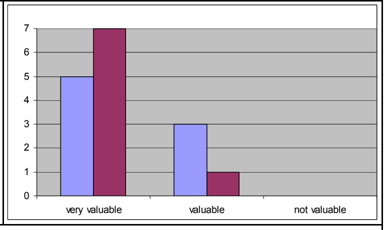
Persons	Visual (mobile device)	Haptic and acoustic (mobile device)	Visual (dynamic display)
			
	before the usage ■ after the usage		

Table 22: Comparison of the different kinds of feedback based on the evaluation of the three variations.

The results of this small user study show that the feedback on the dynamic display is much more important than the visual, haptic or acoustic feedback on the mobile device, which of course renders the implementation of the display service slightly more complex. The participants liked the concept of the interaction technique in general, all of them saw advantages when using the mobile phone for direct interactions with dynamic displays and 7 of 8 participants would use such a service like the one implemented by the prototype.

6.4.3 Conclusion

This section presented a novel interaction technique for direct interaction with dynamic displays. A scenario was described, the implementation of a prototype was discussed and a user study was conducted. The user study shows the advantages of a dynamic display when comparing it with a static display. This can especially be seen on the right diagram of Table 22. It is obvious that the participants preferred the additional feedback and information provided by the dynamic display. The general advantage of this approach is that the mobile device can be used as a first class and direct interaction device for interaction with public displays. Beside the discussed map prototype there are many further application areas like advertisements or meeting scenarios in which this interaction technique can be used. Furthermore there are different advantages when comparing it with the usage of a touch screen like storing the results of the interaction on the mobile device or showing private information on the private display.

The presented work is just a first step into direct interaction with dynamic displays but already shows the potential of this interaction concept. Further work should be invested in reduce the physical constraints like the size of the tags or the time needed for scanning a tag into account. This would allow the development of dynamic displays which provide an NFC mesh with a much higher resolution because of smaller sized tags and a higher interaction speed because the NFC device could read the tags much faster. It might also happen that there will be displays with built-in NFC tags available in the future and that these are used to build such applications. Further work should also focus on guidelines for the design of the dynamic display, the application and the user interface taking the different constraints defined by the used hardware as well as the interaction technique itself into account. Further implementations could also analyze additional interaction techniques like drag and drop, context menus or double clicks when interacting with a dynamic display. The integration of the touch based interaction technique *hovering* [Välkkynen 2006] might also improve the overall interaction technique.

6.5 Summary and Conclusion

The aim of this chapter was to present new findings for mobile interaction with public displays. This research area can be seen as a special case of the physical mobile interaction technique indirect remote controls discussed in subsection 2.3.7. It should be noticed that the prototype discussed in section 6.4 is not an indirect but a direct interaction technique. The big advantage is in general that the remote display can overcome the limited visual output capabilities of mobile devices.

The first section of this chapter discussed privacy and personalization issues that occur when using a remote display. The disadvantage of public displays is its inherent publicity which has to be addressed in the application design. Because of this it was discussed which information can be shown on such a display depending on the number of persons who see the display and the number of persons who interact with the display.

Section 6.2 then analyzed whether it is really a problem to show private information on a public display and whether this would stop people from using such a system. A user study based on a paper prototype clearly showed that people are afraid of others passing by the display and potentially spying on the information displayed. But this curiosity of people can be used when designing applications which profit from this, e.g., advertisements. Therefore, a corresponding prototype implementing a game was developed which showed the potential of such interactions to get the attention of passing people.

Section 6.3 then presented the rotating compass, a novel interaction technique for mobile navigation. The novelty of this approach is the usage of synchronized private and public displays. The latter shows a frequently changing visualization which provides by itself no usable information. Only the combination with a private display which indicates which information visualized by the public display is relevant to the user shows the advantages of this interaction technique. This section discussed an implementation and evaluation of such a system showing the feasibility of the approach and also that users understand and like the interaction technique. This concept of synchronized private and public displays can be used in many different application areas where different kind of information should be shown to different users. A simple example is for instance that the user is informed by a sound while listening to a song from her MP3-player that the display at the airport shows new information regarding her flight.

The last section discussed the first implementation of direct touch-based mobile interaction technique with dynamic displays. The advantage of this approach is that, in contrast to a conventional touch based display, the mobile device can be used to show private information and it can also store the results of this interaction. The implementation and evaluation of this concept illustrated the advantages of this approach, that potential users see the benefits of such a system and which types of feedback are important when developing an application based on this interaction technique.

The research presented in this chapter showed new findings in the area of mobile interaction with dynamic displays. These results can be of use when thinking about the design and development of similar systems. Furthermore, the two new interaction techniques provide a big potential regarding their further development or their usage in future systems and applications.

7 Conclusions

Physical mobile interactions are an emerging research area which can be seen as an intersection of mobile interaction and pervasive computing. In the last few years, many different projects have focused on specific interaction techniques, applications, studies and tools.

But so far there has been no comprehensive overview about this field discussing the different interaction techniques, their characteristics and their implementations. Furthermore, very little research regarding the development process of such applications is reported with the exception of just a few existing tools that only focus on the support of one specific interaction technique. The overall goal of this work was to fill this gap and to develop new physical mobile interaction techniques and applications.

7.1 Summary

After the introduction, a definition of the term physical mobile interaction was given in chapter 2. At this point, the relationship to relevant definitions and research areas was also discussed and a classification and taxonomy of the physical mobile interaction techniques touching, pointing, scanning, user-mediated object selection and indirect remote controls was presented. The chapter was concluded by a discussion of application areas in which such interactions are used.

In chapter 3, the physical mobile interaction framework (PMIF) was presented including a detailed description and discussion of its architecture, implementation and usage. After that, seven different prototypes that were developed using this framework were described. Those that were used in the user studies described in the following chapter 4 are explained in detail.

Chapter 4 then discussed five different user studies which evaluated prototypes of mobile applications based on physical mobile interactions. Their results were discussed in detail and summarized at the end of the chapter. This summary places the results of each interaction technique into one corresponding subsection, giving readers the possibility to quickly browse to findings for the specific technique of interest.

Findings regarding requirements specification and context of use, the development of design solutions and the evaluation of designs were reported in chapter 5. Several case studies, prototypes, architectures and methods that were conducted, developed or used within this thesis were reported and the new results were discussed in detail.

Chapter 6 presented new findings regarding the usage of physical mobile interaction with public displays. The chapter began by discussing the kinds of private, semi-private or public information that can be shown on such displays. Afterwards, two studies were discussed which analyzed the curiosity of people passing such a display and how this can be exploited when developing and designing applications. This chapter was concluded by a discussion of the rotating compass, a novel interaction technique for mobile interaction, and a presentation of a prototype implementation for direct touch-based interaction with dynamic displays.

7.2 Contributions and Results

While the previous section recapitulated the structure and different approaches conducted within the context of this thesis, the main contributions of this work will be concisely summarized here. The overall result is a variety of findings, tools, experiences, best practises, evaluations and techniques which serves as an overview of existing interaction techniques, shows possible applications and application areas and presents guidelines and support for the development of such systems. In addition to that, new interaction techniques and applications were developed which demonstrated the potential of physical mobile interactions and led to original knowledge in that field.

The contributions of this thesis which were discussed in detail in section 1.2 can be summarized as follows.

- The term physical mobile interaction is defined, taking related definitions and research areas into account.
- The first comprehensive analysis and classification of physical mobile interactions as well as application areas in which these techniques are used is provided.
- The physical mobile interaction framework (PMIF) that was designed, developed and used for the implementation of seven prototypes is presented. This framework provides implementations for the interaction techniques touching, pointing, scanning and user-mediated object selection.
- The interaction techniques touching, pointing, scanning and user-mediated object selection are evaluated and compared across five different prototypes. Based on this, advantages and disadvantages of these interaction techniques are described. Context-specific user preferences are presented for the interaction techniques, to help application designers and developers decide which interaction technique(s) should be integrated into their application.
- New experiences and best practices for the development of physical mobile interactions and applications are identified and described. This is based on the following user-centred design process phases:
    - specifying context of use and requirements: field studies, unobtrusive contextual observations, online surveys,
    - producing design solutions: paper and HTML/Flash prototypes, mobile phones as an universal platform, the Physical User Interface Profile (PUIP), integration of context-aware functionalities,
    - evaluating the systems: laboratory or field studies.
- New findings and interaction techniques are listed for the field of mobile interaction with public displays, a specific area of physical mobile interactions. Results are reported which show how the public visibility of displays should be considered when defining corresponding applications.
- The novel interaction technique rotating compass and a first implementation for direct touch-based interaction with dynamic displays are designed, developed and evaluated.

7.3 Open Issues and Future Work

There are a number of open issues and challenges which were identified while conducting the research presented within this thesis and that deserve further investigation.

7.3.1 New Physical Mobile Interactions

Further research should focus on the development of new physical mobile interaction techniques and on new implementations of already existing ones. This process is supported by innovations regarding the usage of novel sensor technologies, the integration of other communication interfaces, the improvement of input and output capabilities of mobile devices and the progress of pervasive systems in general. Research areas in this domain that are of great interest include:

- multi-user, multi-display, multi-device interactions and physical mobile interaction techniques,
- mobile applications for mobile workers and consumers (e.g. field workers, medical staff, and the sports domain) and
- interaction techniques based on novel interfaces such as Head Mounted Displays connected with mobile devices or NFC-based applications.

7.3.2 Mobile Phone Technology in New Housings

Mobile phone technology was designed and is used for user-centred mobile communication. Further research should investigate why and how we should integrate this technology for instance into clothing (e.g. for children, handicapped persons, senior citizens or athletes), novel wearable devices, household appliances, vending machines or goods in transit.

The interesting questions when using mobile phone technology in new housings are how the user interacts with them and how this is used to interact with the environment. Currently the user has to be aware that she uses a mobile device when interacting with smart objects in the environment. An open question is whether wearable devices can be built that accomplish the same tasks without the user's direct awareness of using a mobile computer. This would fulfil the vision of the disappearing computer.

7.3.3 Authoring Tools for Mobile Applications

One of the main reasons for the success of the WWW was that everybody could easily build and deploy corresponding services. This is not true for mobile services. In general, only mobile phone operators and specialized companies provide mobile services. Furthermore we saw in the last years a huge rise in interest in context-aware mobile applications, novel interaction techniques and physical mobile interactions. For these and also for conventional mobile services, authoring tools are needed that allow the easy creation and management of mobile services.

Another open issue is how and where somebody should define the content and interactions of a physical mobile application or context-aware mobile service. Both happen in a real world context and it is problematic to design these things when sitting in an office. It should be investigated which parts of this process can be done in the office and which tasks should be done in the context where the mobile application will be used.

7.3.4 Augmenting the Real World

An important part of physical mobile applications development is the augmentation of objects through which they become smart objects. An important aspect of this augmentation is the visualization of the different possibilities of interacting with it. The user must be able to recognize that a specific object is a smart object, which interaction techniques are supported and what she can do when interacting with the object.

Recent work has begun to explore these questions, but so far they are in a very early stage and are not evaluated through corresponding studies [Arnall 2006, Riekki et al. 2006, Välkkynen et al. 2006]. Furthermore, no guidelines for the user interface presented by the smart object exist. A first step was done with the development of the posters discussed in section 4.5. The results of their evaluation showed that the supported workflow should be somehow visualized by the poster and that some users do not accept having to distinguish between different types of tags like, in this case, action and parameter tags.

7.3.5 Human – Computer vs. Computer – Real World Interaction

A physical mobile interaction consists of the following sub-interactions: human – real world, human – computer and computer – real world interaction. Most interaction techniques focus on a new type of computer – real world interaction. They are mainly used to establish a link between the mobile device and the smart object. After such a link has been set up, the smart augmentation of the object is often no longer needed. The object is then used merely as a reference or for documentation purposes while the user primarily interacts with her mobile device.

When using the cinema advertising poster prototype described in section 4.5, it is for instance possible to define the values for parameters like movie or time slot directly on the mobile phone using a form or by touching or pointing on a corresponding tag on the poster. Further research should analyze how much time each of these sub-interactions needs and how often they are used within a specific interaction technique or application. An open question is the optimal balance between these sub-interactions. It is also of interest under which circumstances it is better that the user primarily interacts only with her mobile device and in which cases it is better when she mainly interacts with the smart object. It is also important to understand how shifts in attention between the smart object and the mobile device influence the usability of an interaction technique or application.

7.3.6 Multi-User und Long-Term Studies

This thesis focused on physical mobile interactions in which not more than one user interacts with a smart object at one time. Further research should analyze what additional considerations exist when many users want to interact simultaneously and how this influences the identified advantages and disadvantages of an interaction technique. In addition to that, long-term user studies should analyze whether users still prefer a specific interaction technique after a long time or if they would switch to another one because of the experiences gathered during previous interactions or because a novelty effect disappears.

Abbreviations

API	Application Programming Interface
CCD	Charge Coupled Device
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
Java ME	Java Micro Edition
JSR	Java Specification Request
GUI	Graphical User Interface
HCI	Human Computer Interaction
NFC	Near Field Communication
OCR	Optical Character Recognition
OWL	Web Ontology Language
MMS	Multimedia Messaging Service
PDA	Personal Digital Assistant
RDF	Resource Description Framework
RF	Radio Frequency
RFID	Radio Frequency Identification
SVG	Scalable Vector Graphics
UPnP	Universal Plug and Play
URL	Uniform Resource Identifier
VRML	Virtual Reality Modelling Language
W3C	World Wide Web Consortium
WSDL	Web Services Description Language
WWW	World Wide Web
X3D	Extensible 3D

References

[@802.11] *IEEE 802.11, The Working Group for Wireless LANs Standards*, http://grouper.ieee.org/groups/802/11/

[@AskOxford] *Oxford Dictionaries*, http://www.askoxford.com

[@BahnHandyTicket] *Handy - Ticket: NEU: Das Handy-Display wird zur Fahrkarte!*, http://www.bahn.de/p/view/planen/reiseplanung/mobileservices/handy_ticket.shtml

[@BarCodeReader] *Capture URLs and Personal Data in an Instant*, NTT DoCoMo, http://www.nttdocomo.co.jp/english/service/function/barcode/index.html

[@Blinkenlights] *Blinkenlights Interactive*, http://www.blinkenlights.de/interactive.en.html

[@Bluetooth] *Bluetooth - The Official Bluetooth Membership Site*, http://www.bluetooth.org

[@BluetoothSpec] *Bluetooth Specification Documents*, https://www.bluetooth.org/spec/

[@BUGAbutler 2005] *Der Einsatz des BUGAbutler auf der Bundesgartenschau 2005 in München.*, http://www.blisinfo.de/download.php?file=/MEDIA/doc/Auswertung_121005.pdf

[@cmode 2004] *Cmode, The unofficial independent imode FAQ*, http://www.eurotechnology.com/imode/faq-cmode.html

[@DIAMD 2005] *Development of Interactive Applications for Mobile Devices, Tutorial at the Mobile HCI 2005*, http://www.medien.ifi.lmu.de/diamd05/

[@Discreet] *Discreet Service Provision in Smart Environments project*, http://www.ist-discreet.org

[@ECMA_NFC 2004] *Near Field Communication White paper (Ecma/TC32-TG19/2004/1)*, http://www.ecma-international.org/activities/Communications/2004tg19-001.pdf

[@eitutorial] *embedded interaction research group: resources / tutorials*, http://www.hcilab.org/resources/tutorials.htm

[@HausDerGegenwart] *Haus der Gegenwart*, http://www.haus-der-gegenwart.de/

[@i-area] *NTT DoCoMo i-area: Location Based Services*, http://www.nttdocomo.co.jp/english/service/imode/site/i_area.html

[@i-modeFelica] *i-mode Felica*, http://www.nttdocomo.co.jp/english/service/imode/make/content/felica/

[@IDBlue] *Cathexis IDBlue (Bluetooth RFID pen)*, http://www.cathexis.com/products/idblue.aspx

[@IDBlueDriver] *IDBlue Java/J2ME driver*, http://auriga.wearlab.de/projects/jidblue/

[@IrDA] *Infrared Data Association*, http://www.irda.org/

[@J-Ware 2006] *Philips demonstrates 'with a swipe' content downloading from a 'smart poster' based on a unique combination of NFC and Java technologies for cellular handsets*, February 14, 2006, http://www.software.nxp.com/about/technologies/j-ware/article-14745.html

[@JSR257] *JSR 257: Contactless Communication API, Final Release*, 17 Oct, 2006, http://jcp.org/en/jsr/detail?id=257

[@KickReal] *Kick Real*, www.kickreal.de

[@Mifare] *MIFARE - contactless Smart Card Ics, Philips Semiconductors*, http://www.semiconductors.philips.com/products/identification/mifare/index.html

[@MobileHCI 2007] *Mobile HCI 2007*, http://www.mobilehci2007.org/

[@Mobipoint] *Deutsche Post - MobilePoint*, http://www.mobilepoint.de/

[@MSNEncarta] *MSN Encarta Dictionary*, http://encarta.msn.com

[@NFCCaen 2005] *City of Caen, France, to demonstrate simplicity of Near Field Communication (NFC) technology*, *News From Philips Semiconductors*, October 18, 2005, http://www.semiconductors.philips.com/news/content/file_1193.html

[@NFCRollout 2006] *First commercial NFC rollout*, http://www.semiconductors.philips.com/news/identification/articles/otm82/firstnfc/

[@NikeID 2005] *Nike iD Billboard Invites Mobile Users*, May 3 2005, http://www.clickz.com/news/article.php/3502186

[@NokiaFieldForce] *Nokia Field Force Solution*, www.nokia.com/fieldforce

[@NokiaNFCSDK] *Nokia NFC RFID SDK 1.0*, http://www.nokia.com/A4136001?newsid=1000788

[@NokiaNFCShell] *Nokia NFC Shell*, http://europe.nokia.com/A4193040

[@NokiaSensor] *Nokia Sensor*, www.nokia.com/sensor

[@Osaifu-Keitai] *Osaifu-Keitai*, http://www.nttdocomo.co.jp/english/service/imode/osaifu/index.html

[@PEMS 2005] *Praktikum Entwicklung Mediensysteme*, http://www.medien.informatik.uni-muenchen.de/lehre/ss2005/pem.html

[@PEMS 2006] *Praktikum Entwicklung Mediensysteme*, http://www-alt.medien.ifi.lmu.de/lehre/ws0506/pem.html

[@Perci] *Perci (PERvasive ServiCe Interaction)*, http://www.hcilab.org/projects/perci/

[@Permid] *Permid workshop series*, http://ubicomp.comp.lancs.ac.uk/workshops/permid2007/

[@Petuelpark] *Petuelpark*, http://www.petuelpark.de/

[@PhilipsNFC] *Near Field Communication*, http://www.semiconductors.philips.com/products/identification/nfc/

[@PME 2004] *Praktikum Programmierung mobiler Endgeräte (Wintersemester 2004/05)*, http://www-alt.medien.ifi.lmu.de/lehre/ws0405/pme.html

[@QR_DoCoMo 2005] *Confirming Food Safety by Mobile Phones: Bar code reading reveals produce history to consumers*, *NTT DoCoMo Report*, May 2005, http://www.nttdocomo.com/files/presscenter/34_No25_Doc.pdf

[@QRCode] *QRCode*, http://www.qrcode.com/

[@QRCode_I-mode 2006] *QR Code in I-Mode*, http://www.nttdocomo.co.jp/english/p_s/i/barcode/

[@Semacode] *Semacode*, http://www.semacode.org/

[@Semapedia] *Semapedia*, http://www.semapedia.org/

[@SiemensNFC] *Siemens / Benq mobile CX70 NFC Prototype*, http://www.benqmobile.com/cds/frontdoor/0,2241,hq_en_0_91523_0,00.html

[@Simplicity] *IST Secure, Internet-able, Mobile Platforms Leading Citizens Towards Simplicity (Simplicity) project (IST-2004-507558)*, http://www.ist-simplicity.org/

[@SMS] *IST Simple Mobile Services (SMS) project (IST-2006-034620)*, http://www.ist-sms.org/

[@SonyFelica] *Sony Global - Felica*, http://www.sony.net/Products/felica/

[@SpotCode] *SpotCode Interfaces*, http://www.cl.cam.ac.uk/Research/SRG/netos/uid/spotcode.html

[@T-ComHouse 2005] *T-Com Haus - Hier kann jeder Innovationen (er)leben*, 01.03.2005, http://www.telekom3.de/dtag/cms/content/dt/de/19364

[@TexasInstruments] *Texas Instruments RFID Solutions*, http://www.ti.com/tiris/default.htm

[@ToruCa] *NTT DoCoMo ToruCa*, http://www.nttdocomo.co.jp/english/service/imode/osaifu/toruca.html

[@TutorialHCILab] *Tutorials: Working with J2ME: GPS via Bluetooth and NMEA parser*, http://www.hcilab.org/resources/tutorials.htm

[@UbiquitousViewer 2005] *Toshiba's New Ubiquitous Viewer Software Gives Anytime Access to PCs from Mobile Phones, Press Release*, 18 January 2005, http://www.toshiba.co.jp/about/press/2005_01/pr1801.htm

[@UCD] *What is User-Centered Design?*, *Usability Professionals' Association : Resources: About Usability*, http://www.usabilityprofessionals.org/usability_resources/about_usability/what_is_ucd.html

[@UML 2006] *Unified Modeling Language (UML), version 2.0*, http://www.omg.org/technology/documents/formal/uml.htm

[@WikipediaTricorder] *Wikipedia: Tricorder*, http://en.wikipedia.org/w/index.php?title=Tricorder&oldid=91273528

[@YahooBillboard 2004] *Interactive Video Game, Yahoo Press Release*, March 22, 2004, http://docs.yahoo.com/docs/pr/release1158.html

[Abowd et al. 1997] Gregory D. Abowd; Christopher G. Atkeson; Jason Hong; Sue Long; Rob Kooper; Mike Pinkerton: *Cyberguide: a mobile context-aware tour guide*. In: Wireless Networks, 3 (5), pages 421-433, ISSN 1022-0038, 1997. http://dx.doi.org/10.1023/A:1019194325861.

[Abramson et al. 2000] David Abramson; Gordon Lowe; Peter Atkinson: *Are you interested in Computers and Electronics?* In Proceedings of the Fourth Australasian Computing Education Conference, Melbourne, Australia 2000. http://doi.acm.org/10.1145/359369.359370

[Ailisto et al. 2003] Heikki Ailisto; Ilkka Korhonen; Johan Plomp; Lauri Pohjanheimo; Esko Strömmer: *Realising Physical Selection for Mobile Devices*. Physical Interaction (PI03) – Workshop on Real World User Interfaces in conjunction with the Fifth International Symposium on Human Computer Interaction with Mobile Devices and Services (Mobile HCI 2003), Udine, Italy, 2003. http://www-alt.medien.ifi.lmu.de/en/events/pi03/papers/ailisto.pdf

[Alzetta 2006] Alexander Alzetta: *Situated Mobile Commerce.* Project thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2006.

[Arnall 2006] Timo Arnall: *A graphic language for touch-based interactions*. Workshop Mobile Interaction with the Real World (MIRW 2006) in conjunction with 8th International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI 2006), Espoo, Finland, 2006. http://www.hcilab.org/events/mirw2006/pdf/mirw2006_arnall.pdf

[Aust 2006] Jessica Aust: *Security and Usability Aspects of NFC based Mobile Interactions.* Project thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2006.

[Azuma et al. 2001] Ronald Azuma; Yohan Baillot; Reinhold Behringer; Steven Feiner; Simon Julier; Blair MacIntyre: *Recent advances in augmented reality*. In: IEEE Computer Graphics and Applications, 21 (6), pages 34-47, 2001. http://dx.doi.org/10.1109/38.963459.

[Ballagas et al. 2003] Rafael Ballagas; Meredith Ringel; Maureen Stone; Jan Borchers: *iStuff: A Physical User Interface Toolkit for Ubiquitous Computing Environments*. ACM CHI 2003 Conference on Human Factors in Computing Systems, Ft. Lauderdale, Florida, USA, 2003. http://doi.acm.org/10.1145/642611.642705

[Ballagas et al. 2004] Rafael Ballagas; Michael Rohs; Jennifer Sheridan; Jan Borchers: *BYOD: Bring Your Own Device*. Workshop on Ubiquitous Display Environments in conjunction with UbiComp 2004, Nottingham, UK, 2004. http://www.vs.inf.ethz.ch/res/papers/rohs-byod-2004.pdf

[Ballagas et al. 2005] Rafael Ballagas; Michael Rohs; Jennifer Sheridan; Jan Borchers: *Sweep and Point & Shoot: Phonecam-Based Interactions for Large Public Displays.* CHI 2005 (extended abstracts), New York, NY, USA, 2005. http://doi.acm.org/10.1145/1056808.1056876

[Ballagas et al. 2006a] Rafael Ballagas; Faraz Memon; Rene Reiners; Jan Borchers: *iStuff Mobile: prototyping interactions for mobile phones in interactive spaces*. Workshop Pervasive Mobile Interaction Devices (PERMID 2006): Mobile Devices as Pervasive User Interfaces and Interaction Devices Permid 2006 in conjunction with 4thrd International Conference on Pervasive Computing (Pervasive 2006), Dublin, Ireland, 2006a. http://www.medien.ifi.lmu.de/permid2006/pdf/Ballagas_Permid2006.pdf

[Ballagas et al. 2006b] Rafael Ballagas; Michael Rohs; Jennifer Sheridan; Jan Borchers: *The Smart Phone: A Ubiquitous Input Device*. In: IEEE Pervasive Computing, 5 (1), pages 70-77, 2006b. http://dx.doi.org/10.1109/MPRV.2006.18.

[Bartlett 2000] Joel F. Bartlett: *Rock 'n' Scroll Is Here to Stay* In: IEEE Computer Graphics and Applications, 20 (3), pages 40-45, 2000. http://doi.ieeecomputersociety.org/10.1109/38.844371.

[Baus et al. 2002] Jörg Baus; Antonio Krüger; Wolfgang Wahlster: *A resource-adaptive mobile navigation system*. Proceedings of the 7th International Conference on Intelligent user interfaces, ACM Press, San Francisco, California, USA, 2002. http://doi.acm.org/10.1145/502716.502723 http://doi.acm.org/10.1145/502716.502723

[Bellifemine et al. 2003] Fabio Bellifemine; Giovanni Caire; Agostino Poggi; Giovanni Rimassa: *JADE - A White Paper*. In: TILAB "EXP in search of innovation", 3 (3), 2003. http://jade.tilab.com/papers/2003/WhitePaperJADEEXP.pdf.

[Bergh, Coninx 2005] Jan Van den Bergh; Karin Coninx: *Towards modeling context-sensitive interactive applications: the context-sensitive user interface profile (CUP)*. Proceedings of the 2005 ACM symposium on Software visualization, ACM Press, St. Louis, Missouri, 2005. http://doi.acm.org/10.1145/1056018.1056030

[Block et al. 2004] Florian Block; Albrecht Schmidt; Nicolas Villar; Hans-Werner Gellersen: *Towards a Playful User Interface for Home Entertainment Systems*. Ambient Intelligence: Second European Symposium (EUSAI 2004), Eindhoven, The Netherlands, 2004. http://www.hcilab.org/documents/Block_TowardsaPlayfulUserInterfaceforHomeof_EUSAI2004.pdf

[Bosman et al. 2003] S. Bosman; B. Groenendaal; J.W. Findlater; T. Visser; M. de Graaf; P. Markopoulos: *GentleGuide: An Exploration of Haptic Output for Indoors Pedestrian Guidance*. 5th International Symposium on Human-Computer Interaction with Mobile Devices and Services (Mobile HCI 2003), ISBN 978-3-540-40821-5, Udine, Italy, 2003. http://www.springerlink.com/content/p82pqm1b50cvy759

[Boyd 2005] John Boyd: *Here Comes The Wallet Phone*. In: IEEE Spektrum, 42 (11), pages 12-13, 2005. http://ieeexplore.ieee.org/iel5/6/32622/01526896.pdf.

[Broll et al. 2006a] Gregor Broll; Sven Siorpaes; Enrico Rukzio; Massimo Paolucci; John Hamard: *A Method for automatic interaction with Web Services through Internet of Things technology*. Patent application, 2006a.

[Broll 2006] Gregor Broll: *Mobile Interaction with Real World Services.* Diploma thesis University of Munich, Department "Institut für Informatik", Media Informatics Group. 2006.

[Broll et al. 2006b] Gregor Broll; Sven Siorpaes; Enrico Rukzio; Massimo Paolucci; John Hamard; Matthias Wagner; Albrecht Schmidt: *Supporting Service Interaction in the Real World*. Workshop Permid 2006 in conjunction with Pervasive 2006, Dublin, Ireland, 2006b. http://www.medien.ifi.lmu.de/permid2006/pdf/Broll_Permid2006.pdf

[Broll et al. 2007] Gregor Broll; Sven Siorpaes; Enrico Rukzio; Massimo Paolucci; John Hamard; Matthias Wagner; Albrecht Schmidt: *Supporting Mobile Service Usage through Physical Mobile Interaction*. Fifth Annual IEEE International Conference on Pervasive Computing and Communication (PerCom 2007), White Plains, NY, USA, 2007.

[Buxton 1995] Bill Buxton: *Integrating the Periphery and Context: A New Taxonomy of Telematics*. Graphics Interface '95, pages 239-246 1995. http://www.billbuxton.com/BG_FG.html

[Buxton 1983] William Buxton: *Lexical and Pragmatic Considerations of Input Structures.* In: Computer Graphics, 17 (1), pages 31-37, 1983. http://www.billbuxton.com/lexical.html.

[Card et al. 1991] Stuart K. Card; Jock D. Mackinlay; George G. Robertson: *A morphological analysis of the design space of input devices*. In: ACM Transactions on Information Systems (TOIS), 9 (2), pages 99-122, ISSN 1046-8188, 1991. http://doi.acm.org/10.1145/123078.128726.

[Chen, Kotz 2000] Guanling Chen; David Kotz: *A Survey of Context-Aware Mobile Computing Research*, Department of Computer Science, Dartmouth College, Technical Report: TR2000-381, 2000 http://elans.cse.msu.edu/ni/restrict/ChenKotz2000.pdf

[Cheverst et al. 2000] Keith Cheverst; Nigel Davies; Keith Mitchell; Adrian Friday; Christos Efstratiou: *Developing a context-aware electronic tourist guide: some issues and experiences*. Proceedings of the SIGCHI conference on Human factors in computing systems, ACM Press, ISBN 1-58113-216-6, The Hague, The Netherlands, 2000. http://doi.acm.org/10.1145/332040.332047

[Cheverst et al. 2005] Keith Cheverst; Alan Dix; Daniel Fitton; Chris Kray; Mark Rouncefield; Corina Sas; George Saslis-Lagoudakis; Jennifer G. Sheridan: *Exploring bluetooth based mobile phone interaction with the hermes photo display*. Proceedings of the 7th International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI '05), ACM Press, pages 47-54, Salzburg, Austria, 2005. http://doi.acm.org/10.1145/1085777.1085786

[Costanza, Leinss 2006] Enrico Costanza; Mirja Leinss: *Telling a Story on a Tag: The Importance of Markers' Visual Design for Real World Applications*. Workshop Mobile Interaction with the Real World (MIRW 2006) in conjunction with 8th International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI 2006), Espoo, Finland, 2006. http://www.hcilab.org/events/mirw2006/pdf/mirw2006_costanza.pdf

[Dahlbäck et al. 1993] Nils Dahlbäck; Arne Jönsson; Lars Ahrenberg: *Wizard of Oz studies: why and how*. 1st international conference on Intelligent user interfaces, ACM Press, pages 193-200, Orlando, Florida, United States, 1993. http://doi.acm.org/10.1145/169891.169968

[David et al. 2005] Scott David; Sharp Richard; Madhavapeddy Anil; Upton Eben: *Using visual tags to bypass Bluetooth device discovery*. In: ACM SIGMOBILE Mobile Computing and Communications Review, 9 (1), pages 41-53, 2005. http://doi.acm.org/10.1145/1055959.1055965.

[De Luca 2006] Alexander De Luca: *Privacy Awareness for Context-Sensitive Mobile Services.* Diploma thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2006.

[Decker et al. 2005] Christian Decker; Albert Krohn; Michael Beigl; Tobias Zimmer: *The Particle Computer System*. 4th International Symposium on Information Processing in Sensor Networks (IPSN), Los Angeles, California, USA, 2005. http://dx.doi.org/10.1109/IPSN.2005.1440969

[Dey, Abowd 2000] Anind K. Dey; Gregory D. Abowd: *Towards a Better Understanding of Context and Context-Awareness*. Workshop on The What, Who, Where, When, and How of Context-Awareness in conjunction with 2000 Conference on Human Factors in Computing Systems (CHI 2000), The Hague, The Netherlands, 2000.

[Dix et al. 2003] Alan Dix; Janet Finlay; Gregory D. Abowd; Russell Beale: *Human Computer Interaction.* 3rd Edition, Prentice Hall, ISBN 0130461091, 2003.

[Dubois et al. 2003] Emmanuel Dubois; Philip Gray; Laurence Nigay: *ASUR++: Supporting the design of mobile mixed systems*. In: Interacting with Computers, 15 (4), pages 497-520, 2003. http://linkinghub.elsevier.com/retrieve/pii/S0953543803000377.

[Dykstra-Erickson et al. 2001] Elizabeth Dykstra-Erickson; Wendy MacKay; Jonathan Arnowitz: *Perspectives: trialogue on design (of)*. In: interactions 8(2), pages 109-117, ISSN 1072-5520, 2001. http://doi.acm.org/10.1145/361897.361933.

[Enns, MacKenzie 1998] Neil R. N. Enns; I. Scott MacKenzie: *Touchpad-based remote control devices*. CHI 98 conference summary on Human factors in computing systems, ACM Press, Los Angeles, California, United States, 1998. http://doi.acm.org/10.1145/286498.286717

[Falke 2005a] Oliver Falke: *Mobile Services for Near Field Communication.* Diploma thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2005a.

[Falke 2005b] Oliver Falke: *Rule-based Adaption of Mobile Services.* Project thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2005b.

[Falke et al. 2006a] Oliver Falke; Enrico Rukzio; Ulrich Dietz: *Mobile Services for Near Field Communication*: http://www-alt.medien.ifi.lmu.de/rukzio/nfc_final.mpg. Video, 2006a

[Falke et al. 2006b] Oliver Falke; Enrico Rukzio; Ulrich Dietz; Paul Holleis; Albrecht Schmidt: *Mobile Services for Near Field Communication*. Under submission, 2006b.

[Ferscha et al. 2002] Alois Ferscha; Gerold Kathan; Simon Vogl: *WebWall - An Architecture for Public Display WWW Services*. Eleventh International World Wide Web Conference, Honolulu, Hawaii, USA, 2002. http://www2002.org/CDROM/alternate/701/

[Finkenzeller 2003] Klaus Finkenzeller: *RFID Handbook : Fundamentals and Applications in Contactless Smart Cards and Identification.* 2nd Edition, John Wiley & Sons, ISBN 0470844027, 2003.

[Fitzmaurice 1993] George W. Fitzmaurice: *Situated information spaces and spatially aware palmtop computers*. In: Communications of the ACM, 36 (7), pages 39-49, ISSN 0001-0782, 1993. http://doi.acm.org/10.1145/159544.159566.

[Föckler et al. 2005] Paul Föckler; Thomas Zeidler; Benjamin Brombach; Erich Bruns; Oliver Bimber: *PhoneGuide: Museum Guidance Supported by On-Device Object Recognition on Mobile Phones*. International Conference on Mobile and Ubiquitous Computing (MUM'05), Christchurch, New Zealand, 2005. http://doi.acm.org/10.1145/1149488.1149490

[Foley et al. 1984] James D. Foley; Victor L. Wallace; Peggy Chan: *The human factors of computer graphics interaction techniques*. In: IEEE Computer Graphics and Applications, 4 (11), pages 13-48, 1984.

[Fowler 2005] Geoffrey A. Fowler: *QR codes: In Japan, Billboards Take Code-Crazy Ads to New Heights.* In: Wall Street Journal, 10.10.2005, 2005. http://www.mindfully.org/Technology/2005/QR-Codes-Japan10oct05.htm.

[Friedman-Hill 2003] Ernest Friedman-Hill: *Jess in Action: Java Rule-based Systems.* Manning Publications, ISBN 1930110898, 2003.

[Fritz et al. 2004] Gerald Fritz; Christin Seifert; Patrick Luley; Lucas Paletta; Alexander Almer: *Mobile Vision for Ambient Learning in Urban Environments*. International Conference on Mobile Learning (MLEARN 2004), Lake Bracciano, Rome, 2004. http://www.joanneum.at/cms_img/img2450.pdf

[Gellersen et al. 2002] Hans W. Gellersen; Albrecht Schmidt; Michael Beigl: *Multi-sensor context-awareness in mobile devices and smart artifacts.* In: Journal Mobile Networks and Applications, 7 (5), pages 341–351, 2002. http://dx.doi.org/10.1023/A:1016587515822.

[Greenberg et al. 1999] Saul Greenberg; Michael Boyle; Jason Laberge: *PDAs and shared public displays: Making personal information public, and public information personal*. In: Personal and Ubiquitous Computing, 3 (1-2), pages 54-64, 1999. http://dx.doi.org/10.1007/BF01305320.

[Hall et al. 2002] Eric S. Hall; David K. Vawdrey; Charles D. Knutson: *RF Rendez-Blue: reducing power and inquiry costs in Bluetooth-enabled mobile systems*. Eleventh International Conference on Computer Communications and Networks, Miami, Florida, USA, 2002. http://dx.doi.org/10.1109/ICCCN.2002.1043140

[Hardy 2006] Walter Hardy: *Journal 6: JavaOne and Trends in the Java Framework*. In: Sun Developer Network - The Learning Curve Journals, 2006. http://developers.sun.com/prodtech/javatools/jscreator/community/2/journals/hardy/journal6.html.

[Henricksen et al. 2002] Karen Henricksen; Jadwiga Indulska; Andry Rakotonirainy: *Modeling Context Information in Pervasive Computing Systems*. First International Conference on Pervasive Computing (Pervasive 2002), Zürich, Switzerland, 2002. http://www.springerlink.com/content/jbxd2fd5ga045p8w

[Hinckley et al. 2000] Ken Hinckley; Jeff Pierce; Mike Sinclair; Eric Horvitz: *Sensing techniques for mobile interaction*. UIST '00: Proceedings of the 13th annual ACM symposium on User interface software and technology, ACM Press, ISBN 1-58113-212-3, pages 91-100 2000. http://doi.acm.org/10.1145/354401.354417

[Holleis et al. 2006] Paul Holleis; Enrico Rukzio; Friederike Otto; Albrecht Schmidt: *Privacy and Curiosity in Mobile Interactions with Public Displays.* under submission. 2006.

[Höllerer et al. 1999] T. Höllerer; S. Feiner; T. Terauchi; G. Rashid; D. Hallaway: *Exploring MARS: Developing Indoor and Outdoor User Interfaces to a Mobile Augmented Reality System*. In: Computers and Graphics, 23 (6), pages 779-785, 1999. http://dx.doi.org/10.1016/S0097-8493(99)00103-X.

[Huang, Mynatt 2003] Elaine M. Huang; Elizabeth D. Mynatt: *Semi-public displays for small, co-located groups*. Proceedings of the SIGCHI conference on Human factors in computing systems, ACM Press, pages 49-56, Ft. Lauderdale, Florida, USA, 2003. http://doi.acm.org/10.1145/642611.642622

[Iftode et al. 2004] Liviu Iftode; Cristian Borcea; Nishkam Ravi; Porlin Kang; Peng Zhou: *Smart Phone: An Embedded System for Universal Interactions*. 10th IEEE International Workshop on Future Trends of Distributed Computing Systems (FTDCS 2004), Suzhou, China, 2004. http://dx.doi.org/10.1109/FTDCS.2004.1316598

[Ishii, Ullmer 1997] Hiroshi Ishii; Brygg Ullmer: *Tangible bits: towards seamless interfaces between people, bits and atoms*. SIGCHI conference on Human factors in computing systems, ACM Press, ISBN 0-89791-802-9, Atlanta, Georgia, United States, 1997. http://doi.acm.org/10.1145/258549.258715

[Jones, Marsden 2006] Matt Jones; Gary Marsden: *Mobile Interaction Design* John Wiley & Sons, ISBN 0470090898, 2006.

[Kindberg et al. 2002] Tim Kindberg; John Barton; Jeff Morgan; Gene Becker; Debbie Caswell; Philippe Debaty; Gita Gopal; Marcos Frid; Venky Krishnan; Howard Morris; John Schettino; Bill Serra; Mirjana Spasojevic: *People, places, things: web presence for the real world*. In: Mobile Networks and Applications, 7 (5), pages 365--376, ISSN 1383-469X, 2002. http://dx.doi.org/10.1023/A:1016591616731.

[Kray et al. 2003] Christian Kray; Christian Elting; Katri Laakso; Volker Coors: *Presenting route instructions on mobile devices*. 8th international conference on Intelligent user interfaces, ACM Press, Miami, Florida, USA, 2003. http://doi.acm.org/10.1145/604045.604066

[Küpper 2005] Axel Küpper: *Location-based Services : Fundamentals and Operation.* John Wiley & Sons Ltd., ISBN 0470092319, 2005.

[LaMarca et al. 2005] Anthony LaMarca; Yatin Chawathe; Sunny Consolvo; Jeffrey Hightower; Ian Smith; James Scott; Timothy Sohn; James Howard; Jeff Hughes; Fred Potter; Jason Tabert; Pauline Powledge; Gaetano Borriello; Bill Schilit: *Place Lab: Device Positioning Using Radio Beacons in the Wild*. 3rd International Conference on Pervasive Computing (Pervasive 2005), Munich, Germany, 2005. http://dx.doi.org/10.1007/11428572_8

[Leichtenstern et al. 2006] Karin Leichtenstern; Enrico Rukzio; Vic Callaghan; Albrecht Schmidt: *Mobile Interaction in Smart Environments*. Late Breaking Result and Poster at 4th International Conference on Pervasive Computing (Pervasive 2006), Dublin, Ireland, 2006. http://www.medien.ifi.lmu.de/fileadmin/mimuc/rukzio/leichtenstern_mobileinteraction.pdf

[Leichtenstern 2006] Karin Leichtenstern: *Mobile Interaction in Smart Environments.* Diploma thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2006.

[Lewis, Rieman 1994] Clayton Lewis; John Rieman: *Task-Centered User Interface Design: A Practical Introduction*. 1994. http://www.hcibib.org/tcuid/

[Likert 1932] Rensis Likert: *A technique for the measurement of attitudes.* Archives of psychology, 1932.

[Lindholm et al. 2003] Christian Lindholm; Turkka Keinonen; Harri Kiljander: *Mobile Usability: How Nokia Changed the Face of the Mobile Phone.* McGraw-Hill Professional, ISBN 0071385142, 2003.

[Linnhoff-Popien 2006] Claudia Linnhoff-Popien: *Verteilte Systeme/Ubiquitous Computing*. (Lecture of the mobile and distributed systems group, Department "Institut für Informatik", University of Munich), 2006. http://www.mobile.ifi.lmu.de/Vorlesungen/ss06/vs/verteilte_systeme.pdf

[Love 2005] Steve Love: *Understanding Mobile Human-Computer Interaction.* Butterworth-Heinemann, ISBN 0750663529, 2005.

[Ma, Paradiso 2002] Hongshen Ma; Joseph A. Paradiso: *The FindIT Flashlight: Responsive Tagging Based on Optically Triggered Microprocessor Wakeup*. 4th international conference on Ubiquitous Computing, Springer-Verlag, pages 160-167, Göteborg, Sweden, 2002. http://www.springerlink.com/content/jx2dl0yk396dphej

[Madhavapeddy et al. 2004] Anil Madhavapeddy; David Scott; Richard Sharp; Eben Upton: *Using Camera-Phones to Enhance Human Computer Interaction*. Sixt International Conference on Ubiquitouse

Computing (Adjunct Proceedings) (Ubicomp 2004), Nottingham, UK, 2004. http://ubicomp.org/ubicomp2004/adjunct/demos/madhavapeddy.pdf

[Martin et al. 2004] David Martin; Mark Burstein; Jerry Hobbs; Ora Lassila; Drew McDermott; Sheila McIlraith; Srini Narayanan; Massimo Paolucc; Bijan Parsia; Terry Payne; Evren Sirin; Naveen Srinivasan; Katia Sycara: *OWL-S: Semantic Markup for Web Services*. 2004. http://www.daml.org/services/owl-s/1.1/overview/

[Miyaoku et al. 2004] Kento Miyaoku; Suguru Higashino; Yoshinobu Tonomura: *C-blink: a hue-difference-based light signal marker for large screen interaction via any mobile terminal*. Proceedings of the 17th annual ACM symposium on User interface software and technology, ACM Press, Santa Fe, NM, USA, 2004. http://doi.acm.org/10.1145/1029632.1029657

[Myers et al. 1998] Brad A. Myers; Herb Stiel; Robert Gargiulo: *Collaboration using multiple PDAs connected to a PC*. Proceedings of the 1998 ACM conference on Computer supported cooperative work, ACM Press, ISBN 1-58113-009-0, Seattle, Washington, United States, 1998. http://doi.acm.org/10.1145/289444.289503

[Myers et al. 2002] Brad A. Myers; Rishi Bhatnagar; Jeffrey Nichols; Choon Hong Peck; Dave Kong; Robert Miller; A. Chris Long: *Interacting at a distance: measuring the performance of laser pointers and other devices*. Proceedings of the SIGCHI conference on Human factors in computing systems: Changing our world, changing ourselves, ACM Press, Minneapolis, Minnesota, USA, 2002. http://doi.acm.org/10.1145/503376.503383

[Myers 2005] Brad A. Myers: *Using Handhelds for Wireless Remote Control of PCs and Appliances*. In: Interacting with Computers, 17 (3), pages 251-264, 2005. http://linkinghub.elsevier.com/retrieve/pii/S0953543804000712.

[NFCSP 2005] *Siemens AG Corporate Technology - Intelligent Autonomous Systems (CT IC 6), BenQ Mobile Phones - Technology and Innovation (MD PBM TI). NFC Service Platform User Guide. Version 1.2.2.*, 06.10.2005,

[Nichols et al. 2002] Jeffrey Nichols; Brad A. Myers; Michael Higgins; Joseph Hughes; Thomas K. Harris; Roni Rosenfeld; Mathilde Pignol: *Generating remote control interfaces for complex appliances*. Proceedings of the 15th annual ACM symposium on User interface software and technology, ACM Press, Paris, France, 2002. http://doi.acm.org/10.1145/571985.572008

[Nielsen 2000] Jakob Nielsen: *Killing time is the killer application*. TheFeature: It's all about the mobile internet, 2000. http://www.thefeature.com/article?articleid=8183

[Nielsen 2003] Jakob Nielsen: *Usability 101: Introduction to Usability*. 2003. http://www.useit.com/alertbox/20030825.html

[Noda et al. 2005] Chie Noda; John Hamard; Enrico Rukzio; Alexander De Luca: *Method and Apparatus for Automatic Form Filling on Mobile Devices*. Patent application, 2005.

[Nunes, Cunha 2000] Nuno Jardim Nunes; Joao Falcao e Cunha: *Towards a UML Profile for Interaction Design: The Wisdom Approach*. UML 2000 - The Unified Modeling Language. Advancing the Standard: Third International Conference, York, UK, 2000. http://www.springerlink.com/content/fca8x1mmwq0em05p

[Otto 2006] Friederike Otto: *Verwendung von mobilen Endgeräten für Interactionen mit öffentlichen Displays.* Project Thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2006.

[Paterno et al. 1997] Fabio Paterno; Cristian Mancini; Silvia Meniconi: *ConcurTaskTrees: A Diagrammatic Notation for Specifying Task Models*. Interantional Conference on Human-Computer Interaction (INTERACT '97), Chapman & Hall Sydney, Australia, 1997.

[Paterno 2004] Fabio Paterno: *Multimodality and Multi-device Interfaces*. W3C Workshop on Multimodal Interaction, Sophia Antipolis, France, 2004. http://www.w3.org/2004/02/mmi-workshop/paterno-cnr.pdf

[Persson, Jung 2005] Per Persson; Younghee Jung: *Nokia sensor: from research to product*. Proceedings of the 2005 conference on Designing for User eXperience AIGA: American Institute of Graphic Arts, pages 53, San Francisco, California, 2005.

[Pleuss 2005] Andreas Pleuss: *MML: A Modeling Language for Interactive Multimedia Applications.* Seventh IEEE International Symposium on Multimedia (ISM 2005), IEEE Society Press, Irvine, California, USA, 2005. http://doi.ieeecomputersociety.org/10.1109/ISM.2005.80

[Rao, Minakakis 2003] Bharat Rao; Louis Minakakis: *Evolution of mobile location-based services*. In: Communications of the ACM, 46 (12), pages 61-65, ISSN 0001-0782, 2003. http://doi.acm.org/10.1145/953460.953490.

[Raskar et al. 2004] Ramesh Raskar; Paul Beardsley; Jeroen van Baar; Yao Wang; Paul Dietz; Johnny Lee; Darren Leigh; Thomas Willwacher: *RFIG lamps: interacting with a self-describing world via photosensing wireless tags and projectors*. In: ACM Transactions on Graphics (TOG), 23 (3), pages 406-415, 2004. http://doi.acm.org/10.1145/1015706.1015738.

[Reilly et al. 2005] Derek Reilly; Michael Welsman-Dinelle; Colin Bate; Kori Inkpen: *Just point and click?: using handhelds to interact with paper maps*. Proceedings of the 7th international conference on Human computer interaction with mobile devices, ACM Press, pages 239-242, Salzburg, Austria, 2005. http://doi.acm.org/10.1145/1085777.1085820

[Reilly et al. 2006] Derek Reilly; Malcolm Rodgers; Ritchie Argue; Mike Nunes; Kori Inkpen: *Marked-up maps: combining paper maps and electronic information resources*. In: Personal Ubiquitous Comput., 10 (4), pages 215-226, ISSN 1617-4909, 2006. http://dx.doi.org/10.1007/s00779-005-0043-6.

[Rekimoto, Nagao 1995] Jun Rekimoto; Katashi Nagao: *The World Through the Computer: Computer Augmented Interaction with Real World Environments*. Proceedings of the 8th ACM Symposium on User Interface Software and Technology (UIST '95), pages 29-36, Pittsburgh, PA, USA, 1995. http://www.csl.sony.co.jp/person/rekimoto/uist95/uist95.html

[Riekki et al. 2006] Jukka Riekki; Timo Salminen; Ismo Alakarppa: *Requesting Pervasive Services by Touching RFID Tags*. In: IEEE Pervasive Computing, 5 (1), pages 40-46, ISSN 1536-1268, 2006. http://dx.doi.org/10.1109/MPRV.2006.34

[Rohs, Gfeller 2004] Michael Rohs; Beat Gfeller: *Using Camera-Equipped Mobile Phones for Interacting with Real-World Objects*. In: Advances in Pervasive Computing, Austrian Computer Society (OCG) pages 265-271, ISSN 3-85403-176-9, 2004. http://www.vs.inf.ethz.ch/publ/papers/rohs-gfeller-visualcodes-2004.pdf.

[Rohs 2005] Michael Rohs: *Linking Physical and Virtual Worlds with Visual Markers and Handheld Devices.* Dissertation, Swiss Federal Institute of Technology. 2005.

[Roth 2005] Jörg Roth: *Mobile Computing. Grundlagen, Technik, Konzepte.* 2nd Edition, Dpunkt Verlag, ISBN 3898643662, 2005.

[Royce 1970] Winston Royce: *Managing the development of large software systems*. In: IEEE WESCON, 26 pages 1-9, 1970.

[Rukzio et al. 2005a] E. Rukzio; A. Schmidt; A. Krüger: *The Rotating Compass: A Novel Interaction Technique for Mobile Navigation*. CHI '05 extended abstracts on Human factors in computing system, ACM Press, ISBN 1-59593-002-7, Portland, Oregon, USA, 2005a. http://doi.acm.org/10.1145/1056808.1057016

[Rukzio et al. 2004a] Enrico Rukzio; Albrecht Schmidt; Heinrich Hussmann: *An Analysis of the Usage of Mobile Phones for Personalized Interactions with Ubiquitous Public Displays.* Workshop Ubiquitous Display Environments in conjunction with UbiComp 2004, Nottingham, UK, 2004a. http://ubicomp.lancs.ac.uk/workshops/ubidisplay04/papers/ubidisplay04-rukzio.pdf

[Rukzio et al. 2004b] Enrico Rukzio; Albrecht Schmidt; Heinrich Hussmann: *Physical Posters as Gateways to Context-aware Services for Mobile Devices.* Sixth IEEE Workshop on Mobile Computing Systems and Applications (WMCSA 2004), English Lake District, UK, 2004b. http://dx.doi.org/10.1109/MCSA.2004.20

[Rukzio et al. 2004c] Enrico Rukzio; Albrecht Schmidt; Heinrich Hussmann: *Privacy-enhanced Intelligent Automatic Form Filling for Context-aware Services on Mobile Devices*. Workshop Artificial Intelligence in Mobile Systems 2004 (AIMS 2004) in conjunction with UbiComp 2004, Nottingham, UK, 2004c. http://w5.cs.uni-sb.de/~baus/aims04/cameraready/P13.pdf

[Rukzio et al. 2005b] Enrico Rukzio; Michael Rohs; Daniel Wagner; John Hamard: *Development of interactive applications for mobile devices*. Proceedings of the 7th international conference on Human computer interaction with mobile devices and services, ACM Press, pages 365-366, Salzburg, Austria, 2005b. http://doi.acm.org/10.1145/1085777.1085870

[Rukzio et al. 2005c] Enrico Rukzio; Sergej Wetzstein; Albrecht Schmidt: *A Framework for Mobile Interactions with the Physical World*. In Proceedings of Wireless Personal Multimedia Communication (WPMC'05) Aalborg, Denmark, 2005c. http://www.medien.informatik.uni-muenchen.de/fileadmin/mimuc/rukzio/rukzio_wpmc2005.pdf

[Rukzio et al. 2005d] Enrico Rukzio; Andreas Pleuss; Lucia Terrenghi: *The Physical User Interface Profile (PUIP): Modelling Mobile Interactions with the Real World*. Proceedings of 4th International Workshop on Task Models and Diagrams for user interface design (Tamodia 2005), ACM Press, Gdansk, Poland 2005d. http://doi.acm.org/10.1145/1122935.1122954

[Rukzio et al. 2005e] Enrico Rukzio; Sven Siorpaes; Oliver Falke; Heinrich Hussmann: *Policy Based Adaptive Services for Mobile Commerce*. 2nd Workshop on Mobile Commerce and Services (WMCS 2005), IEEE, Munich, Germany, 2005e. http://dx.doi.org/10.1109/WMCS.2005.18

[Rukzio et al. 2006a] Enrico Rukzio; Chie Noda; Alexander De Luca; John Hamard; Fatih Coskun: *Automatic Form Filling on Mobile Devices*. under submission, 2006a.

[Rukzio et al. 2006b] Enrico Rukzio; Karin Leichtenstern; Vic Callaghan; Paul Holleis; Albrecht Schmidt; Jeannette Chin: *An Experimental Comparison of Physical Mobile Interaction Techniques: Touching, Pointing and Scanning*. Eighth International Conference on Ubiquitous Computing (Ubicomp 2006), Springer, Orange County, California, California, 2006b. http://www.springerlink.com/content/h6jut558g604x083

[Rukzio et al. 2006c] Enrico Rukzio; Massimo Paolucci; Matthias Wagner; Hendrik H. Berndt; John Hamard; Albrecht Schmidt: *Mobile Service Interaction with the Web of Things*. 13th International Conference on Telecommunications (ICT 2006), Funchal, Madeira island, Portugal, 2006c. http://www.medien.informatik.uni-muenchen.de/fileadmin/mimuc/rukzio/MobileServiceInteractionWithTheWebOfThings_ICT2006.pdf

[Rukzio et al. 2006d] Enrico Rukzio; Philipp Holzer; Michael Weiler; René Klüber; Albrecht Schmidt: *MOPS (Mobile Petuelpark System)*. Video, 2006d. http://www-alt.medien.ifi.lmu.de/rukzio/MoPSDivx.avi

[Rukzio et al. 2006e] Enrico Rukzio; Philipp Holzer; Michael Weiler; René Klüber; Albrecht Schmidt: *MOPS (Mobile Petuelpark System)*: http://www.medien.ifi.lmu.de/rukzio/MoPSDivx.avi, 2006e

[Rukzio et al. 2006f] Enrico Rukzio; John Hamard; Chie Noda; Alexander De Luca: *Visualization or Not of Uncertainty in Context Aware Mobile Applications*. 8th International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI 2006), ACM Press, Espoo, Finland, 2006f. http://doi.acm.org/10.1145/1152215.1152267

[Ruseva 2006] Radostina Ruseva: *Erstellung und Nutzung von Informationen für Orte, Dinge oder Personen in der physikalischen Welt, die mittels mobiler Endgeräte genutzt werden können.* Project thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2006.

[Salsano, Martire 2005] Stefano Salsano; Francesca Martire: *Deliverable 2202: Final system architecture specification, IST-2004-507558 project Simplicity*. 2005. http://server.ist-simplicity.org/download.php?OID=163708&FILENAME=D2202-Final%20system%20architecture%20specification.pdf

[Sarma 2001] Sanjay Sarma: *Towards the 5¢ Tag*. MIT AUTO-ID Lab 2001. http://www.autoidlabs.org/single-view/dir/article/6/197/page.html

[Satoh 2004] Ichiro Satoh: *Linking Physical Worlds to LogicalWorlds with Mobile Agents.* 5th IEEE International Conference on Mobile Data Management (MDM 2004), IEEE Computer Society, ISBN 0-7695-2070-7, Berkeley, CA, USA, 2004. http://research.nii.ac.jp/~ichiro/papers/satoh-mdm2004.pdf

[Satyanarayanan 2001] M. Satyanarayanan: *Pervasive Computing: Vision and Challenges*. In: IEEE Personal Communications, 8 (4), pages 10-17, 2001. http://dx.doi.org/10.1109/98.943998

[Schiller 2003] Jochen Schiller: *Mobile Communications.* 2nd Edition, Addison Wesley, ISBN 0321123816, 2003.

[Schmidt et al. 1999] Albrecht Schmidt; Kofi Asante Aidoo; Antti Takaluomai; Urpo Tuomelai; Kristof Van Laerhoven; Walter Van de Velde: *Advanced Interaction in Context.* 1st international symposium on Handheld and Ubiquitous Computing (HUC '99), Karlsruhe, Germany, 1999. http://www.springerlink.com/content/f0d3d5a3ec9enb1r

[Schmidt et al. 2005a] Albrecht Schmidt; Enrico Rukzio; Eva Vodvarsky; Alexander De Luca: *JaGD - An Photo Oriented Learning and Gaming Platform for Mobile Phones*. Poster at The Seventh International Conference on Ubiquitous Computing (Ubicomp 2005), Tokyo, Japan, 2005a. http://www.hcilab.org/documents/JaGDAnPhotoOrientedLearningAndGamingPlatformForMobileDevices_Ubicomp2005.pdf

[Schmidt et al. 2005b] Albrecht Schmidt; Enrico Rukzio; Dominik Schmidt: *Using Mobile Phones for Domain Specific Information Appliances*. Poster at The Seventh International Conference on Ubiquitous Computing (Ubicomp 2005), Tokyo, Japan, 2005b. http://www.hcilab.org/documents/UsingMobilePhonesForDomainSpecificInformationAppliances_Ubicomp2005.pdf

[Schöning et al. 2006] Johannes Schöning; Antonio Krüger; Hans Jörg Müller: *Interaction of Mobile Camera Devices with physical maps*. Adjunct Proceedings of the 4th International Conference on Pervasive Computing (Pervasive 2006) (Demo), Dublin, Ireland, 2006. http://www.pervasive2006.org/ap/pervasive2006_adjunct_2B.pdf

[Shafer et al. 2001] Steven A. N. Shafer; Barry Brumitt; JJ Cadiz: *Interaction Issues in Context-Aware Intelligent Environments*. In: Human-Computer Interaction, 16 (2, 3 & 4), pages 363-378, 2001.

[Shneiderman, Plaisant 2004] Ben Shneiderman; Catherine Plaisant: *Designing the User Interface: Strategies for Effective Human-Computer Interaction.* 4th Edition, Allyn & Bacon ISBN 0321197860, 2004.

[Silfverberg et al. 2001] Miika Silfverberg; Scott MacKenzie; Tatu Kauppinen: *An Isometric Joystick as a Pointing Device for Handheld Information Terminals*. Graphics Interface, Canadian Information Processing Society, Ottawa, Ontario, Canada, 2001. http://www.yorku.ca/mack/gi01.html

[Silva, Paton 2000] Paulo Pinheiro da Silva; Norman W. Paton: *UMLi: The Unified Modeling Language for Interactive Applications*. UML 2000 - The Unified Modeling Language. Advancing the Standard: Third International Conference, York, UK, 2000. http://www.springerlink.com/content/mlk3pfgake0wu1lc

[Singh et al. 2006] Pushpendra Singh; Hai Nam Ha; Zhiwen Kuang; Patrick Olivier; Christian Kray; Phil Blythe; Phil James: *Immersive video as a rapid prototyping and evaluation tool for mobile and ambient applications*. Proceedings of the 8th conference on Human-computer interaction with mobile devices and services ACM Press, pages 264-264, Helsinki, Finland, 2006. http://doi.acm.org/10.1145/1152215.1152276

[Siorpaes 2004] Sven Siorpaes: *Development of Intelligent Agents based on Jade and Jess.* Project thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2004.

[Siorpaes et al. 2006] Sven Siorpaes; Gregor Broll; Massimo Paolucci; Enrico Rukzio; John Hamard; Matthias Wagner; Albrecht Schmidt.: *Mobile Interaction with the Internet of Things*. Poster at 4th International Conference on Pervasive Computing (Pervasive 2006), Dublin, Ireland, 2006. http://www.medien.informatik.uni-muenchen.de/fileadmin/mimuc/rukzio/Mobile_interaction_with_the_internet_of_things_final.pdf

[Siorpaes 2006] Sven Siorpaes: *A Physical Mobile Interactions Framework based on Semantic Descriptions.* Diploma thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2006.

[Sommerville 2004] Ian Sommerville: *Software Engineering.* 7th Edition, Addison Wesley, ISBN 0321210263, 2004.

[Su et al. 2002] Norman Makoto Su; Yutaka Sakane; Masahiko Tsukamoto; Shojiro Nishio: *Rajicon:: remote PC GUI operations via constricted mobile interfaces*. Proceedings of the 8th annual international conference on Mobile computing and networking, ACM Press, Atlanta, Georgia, USA, 2002. http://doi.acm.org/10.1145/570645.570676

[Tarrini et al. 2002] Luca Tarrini; Rolando Bianchi Bandinelli; Vittorio Miori; Graziano Bertini: *Remote Control of Home Automation Systems with Mobile Devices*. 4th International Symposium on Mobile Human-Computer Interaction (Mobile HCI 2002), Springer, Pisa, Italy, 2002. http://www.springerlink.com/content/w18ukbhj8ujrf12q

[Teuber 2006] Matthias Teuber: *Peer-to-Peer - Interaction of Mobile Devices.* Project thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2006.

[Trætteberg 2002] Hallvard Trætteberg: *Model-based User Interface Design.* Doctoral thesis, Norwegian University of Science and Technology, Information Systems Group, Department of Computer and Information Sciences, Faculty of Information Technology, Mathematics and Electrical Engineering. 2002.

[Trumler et al. 2003] Wolfgang Trumler; Faruk Bagci; Jan Petzold; Theo Ungerer: *Smart doorplate*. In: Personal and Ubiquitous Computing, 7 (3-4), pages 221-226, 2003. http://www.springerlink.com/content/0ejwlj39yqhbpxln.

[Tsukada, Yasumura 2004] Koji Tsukada; Michiaki Yasumura: *ActiveBelt: Belt-Type Wearable Tactile Display for Directional Navigation*. 6th International Conference on Ubiquitous Computing (UbiComp 2004) Nottingham, UK, 2004. http://www.springerlink.com/content/m62n21ptynyre66n

[Tuomisto et al. 2005] Timo Tuomisto; Pasi Välkkynen; Arto Ylisaukko-oja: *RFID Tag Reader System Emulator to Support Touching, Pointing and Scanning*. Adjunct Proceedings of the 3rd International Conference on Pervasive Computing (Pervasive 2005) (Demo), Munich, Germany, 2005. http://www.pervasive.ifi.lmu.de/adjunct-proceedings/demo/p085-088.pdf

[Ullmer, Ishii 1997] Brygg Ullmer; Hiroshi Ishii: *The metaDESK: models and prototypes for tangible user interfaces*. Proceedings of the 10th annual ACM symposium on User interface software and technology, ACM Press, ISBN 0-89791-881-9, Banff, Alberta, Canada, 1997. http://doi.acm.org/10.1145/263407.263551

[Välkkynen et al. 2003] Pasi Välkkynen; Ilkka Korhonen; Johan Plomp; Timo Tuomisto; Luc Cluitmans; Heikki Ailisto; Heikki Seppä: *A user interaction paradigm for physical browsing and near-object control based on tags*. Physical Interaction (PI03) – Workshop on Real World User Interfaces in conjunction with Fifth International Symposium on Human Computer Interaction with Mobile Devices and Services (MobileHCI 2003), Udine, Italy, 2003. http://www-alt.medien.ifi.lmu.de/en/events/pi03/papers/valkkynen.pdf

[Välkkynen, Tuomisto 2005] Pasi Välkkynen; Timo Tuomisto: *Physical Browsing Research*. Workshop Pervasive Mobile Interaction Devices (PERMID 2005): Mobile Devices as Pervasive User Interfaces and Interaction Devices Permid 2005 in conjunction with 3rd International Conference on Pervasive Computing (Pervasive 2005), Munich, Germany, 2005. http://www.medien.ifi.lmu.de/permid2005/pdf/PasiVaelkkynen_Permid2005.pdf

[Välkkynen 2006] Pasi Välkkynen: *Hovering: Visualising RFID Hyperlinks in a Mobile Phone*. Workshop Mobile Interaction with the Real World (MIRW 2006) in conjunction with 8th International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI 2006), Espoo, Finland, 2006. http://www.hcilab.org/events/mirw2006/pdf/mirw2006_vaelkkynen.pdf

[Välkkynen et al. 2006] Pasi Välkkynen; Timo Tuomisto; Ilkka Korhonen: *Suggestions for Visualizing Physical Hyperlinks*. Workshop Pervasive Mobile Interaction Devices (PERMID 2006): Mobile Devices as Pervasive User Interfaces and Interaction Devices in conjunction with 4th International Conference on Pervasive Computing (Pervasive 2006), Dublin, Ireland, 2006. http://www.medien.ifi.lmu.de/permid2006/pdf/Vaelkkynen_Permid2006.pdf

[Vetter 2006] Johannes Vetter: *Near Field Communication based Mobile Interaction Techniques.* Project thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2006.

[Vogl 2002] Simon Vogl: *Coordination of Users and Services via Wall Interfaces.* PhD, Institut für Praktische Informatik, Johannes Kepler Universität Linz. 2002. http://www.soft.uni-linz.ac.at/Research/Publications/_Documents/Vogl-PhD-WallInterfaces.pdf.

[Volkwein 2005] Daniel Volkwein: *The Usage of Mobile Devices for Interactions with the Surrounding Physical World, Persons and Places.* Diploma thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2005.

[Wagner et al. 2005] Daniel Wagner; Thomas Pintaric; Florian Ledermann; Dieter Schmalstieg: *Towards Massively Multi-User Augmented Reality on Handheld Devices*. Third International Conference on Pervasive Computing (Pervasive 2005), Springer, Munich, Germany 2005. http://www.springerlink.com/content/gpnqwqe3v7myg9b7

[Want et al. 1992] Roy Want; Andy Hopper; Veronica Falc; Jonathan Gibbons: *The active badge location system*. In: ACM Transactions on Information Systems (TOIS), 10 (1), pages 91-102, ISSN 1046-8188, 1992. http://doi.acm.org/10.1145/128756.128759.

[Want et al. 1999] Roy Want; Kenneth P. Fishkin; Anuj Gujar; Beverly L. Harrison: *Bridging physical and virtual worlds with electronic tags*. Proceedings of the SIGCHI conference on Human factors in computing systems: the CHI is the limit, ACM Press, ISBN 0-201-48559-1, Pittsburgh, Pennsylvania, United States, 1999. http://doi.acm.org/10.1145/302979.303111

[Weiser 1991] Mark Weiser: *The Computer for the 21st Century*. In: Scientific American, 265 (3), pages 94-104, 1991.

[Weiss 2002] Scott Weiss: *Handheld Usability.* John Wiley & Sons, ISBN 0470844469, 2002.

[Wetzstein 2005] Sergej Wetzstein: *Real World Interaction Platform for Mobile Devices.* Diploma thesis, University of Munich, Department "Institut für Informatik", Media Informatics Group. 2005.

[Wilson, Oliver 2005] Andrew Wilson; Nuria Oliver: *Multimodal Sensing for Explicit and Implicit Interaction*. 11th International Conference on Human-Computer Interaction (HCI International 2005), Las Vegas, Nevada, USA, 2005.

[Woodings et al. 2002] Ryan Woodings; Derek Joos; Trevor Clifton; Charles D. Knutson: *Rapid Heterogeneous Connection Establishment: Accelerating Bluetooth Inquiry Using IrDA* Third Annual IEEE Wireless Communications and Networking Conference (WCNC '02), Orlando, Florida, USA, 2002.

[Wright 2005] Kevin B. Wright: *Researching Internet-Based Populations: Advantages and Disadvantages of Online Survey Research, Online Questionnaire Authoring Software Packages, and Web Survey Services*. In: Journal of Computer-Mediated Communication, 10 (3), 2005. http://jcmc.indiana.edu/vol10/issue3/wright.html.

Curriculum Vitae

Enrico Rukzio was born on February 2, 1977 in Rodewisch, Germany. He attended primary school and high school from 1983 to 1995. From 1995 until 1996 he provided his basic military service in Schneeberg, Germany as a mountain infantryman („Gebirgsjäger“).

He entered the Dresden University of Technology in 1996, studying Computer Science with a minor in business economics. During his studies Enrico worked part-time at T-Systems Multimedia Solutions GmbH Dresden (1998), Sächsische Zeitung online Dresden (1998-1999), Märkische Verlags- und Druckgesellschaft Potsdam (2000) and as a student research assistant at the Heinz-Nixdorf Endowed Chair for Multimedia Technology Dresden (1999 - 2001).

In August 2002 he finished his diploma thesis entitled *Implementation of Interactions and Behaviours in Document- and Component-based 3D Applications* (*Realisierung von Interaktionen und Verhalten in dokumentbestimmten, komponentenbasierten 3D-Applikationen*) and received his diploma. This thesis was supervised by Dr.-Ing. Raimund Dachselt and Prof. Dr.-Ing. Klaus Meißner.

In September 2002, Enrico started to work as a research and teaching assistant at the Heinz-Nixdorf Endowed Chair for Multimedia Technology at the Dresden University of Technology in the group of Prof. Dr.-Ing. Klaus Meißner.

In February 2004, Enrico continued his work as a research and teaching assistant at the Media Informatics Group lead by Prof. Dr. Heinrich Hußmann and the Embedded Interaction Group lead by Prof. Dr. Albrecht Schmidt at the Department „Institut für Informatik“ at the University of Munich.

In October 2006, Enrico started to work as an academic fellow and lecturer at the Computing Department at the Lancaster University (United Kingdom).

His research focuses on the intersection between mobile and pervasive computing, human-computer interaction and software engineering. In the last three years he primarily worked on mobile interactions in which the user interacts with the real world through a mobile device which interacts with smart objects. He calls this specific mobile interaction technique *physical mobile interaction*.