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Jonna Häkkilä

USABILITY WITH CONTEXT-AWARE MOBILE APPLICATIONS

CASE STUDIES AND DESIGN GUIDELINES

FACULTY OF TECHNOLOGY,
DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING,
UNIVERSITY OF OULU

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JONNA HÄKKILÄ

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Case studies and design guidelines

Academic dissertation to be presented, with the assent of the Faculty of Technology of the University of Oulu, for public defence in Auditorium TS101, Linnanmaa, on January 12th, 2007, at 12 noon

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Supervised by
Professor Tapio Seppänen

Reviewed by
Doctor Albrecht Schmidt
Professor Kaisa Väänänen-Vainio-Mattila

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Faculty of Technology, University of Oulu, P.O.Box 4000, FI-90014 University of Oulu, Finland, Department of Electrical and Information Engineering, University of Oulu, P.O.Box 4500, FI-90014 University of Oulu, Finland
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Abstract

Context-awareness, a state where the device is aware of the situation in which it is used, is a technology which has gained an increasing amount of attention in recent years. A context-aware device can infer the use condition, and adapt its behavior according to the circumstances. Mobile handheld devices, which have been highly adopted by large user groups, especially in the form of mobile phones, constitute an interesting platform for context-awareness. They are used in different kinds of situations, where the preferences of users may vary, and where different features are prioritized. While the increasing complexity and growing number of features set challenges to intuitive and easy use of devices, context-awareness may offer solutions to more efficient use of mobile applications and services.

This thesis investigates the interaction issues with context-aware mobile devices. The research has been exploratory including several separate case studies, where interaction and usability matters have been charted. These studies consider topics such as location-awareness, user-defined settings of context-aware applications, and information sharing and privacy. In addition to these case studies, the author has sough to draw a bigger picture on interaction and usability issues with context-aware mobile devices, and incorporated the findings to a more general framework.

Through presenting the case studies it is concluded that context-awareness can improve the usability of mobile devices, but careful design in the application development phase must be emphasized. The usability risks identified through case studies relate to numerous themes, such as diminished user control, increased number of interruptions, information overflow, users' subjective understanding of context attributes and privacy threat. As context-aware technology employs greater risks, e.g. due to the uncertain nature of context recognition, the user-centric design practices and testing in the authentic environment of the context-aware applications should be stressed.

The author proposes design guidelines, which have been developed based on the findings from distinct case studies. The design guidelines aim to offer tangible help to application designers, who may not be acquaint with the special characteristics of context-awareness, and intend to prevent potential usability problems identified through the individual studies. Moreover, an evaluation for the design guidelines and their iteration to the presented form is demonstrated.

Keywords: context-awareness, human computer interaction, mobile computing, usability

To Emmu, Jasky, Hansaplast, and starlit skies

Preface

During the process of getting a PhD degree, I have received support from numerous people, who deserve to be acknowledged here.

While working in Nokia, I have had privilege to work with many talented people, and with several encouraging superiors. I want to thank Mr. Urpo Tuomela, Mrs. Helena Tokkonen, Mr. Jukka Parkkinen, and Mr. Sami Paihonen, in whose inspiring and competent teams I have had a pleasure to work. I especially want to thank Urpo for believing in me by employing me at Nokia Corporation as well and introducing the research field of context-awareness to me, Jukka for going through all the trouble in helping me to attend different research forums, and Sami for trusting in my way of working and granting me the best possible support in it. In addition, I own my deepest gratitude to my colleagues who have been a source of joy, inspiration and support, and who have demonstrated admirable patience – I am sure it has been required from time to time, especially with all kinds of ad-hoc tasks and spontaneous plans I am good in generating. In addition to my colleagues at Nokia, I wish to thank my co-researchers and peers acting in various other institutes, who I have had a pleasure to work with.

I want to thank my co-authors Dr. Jani Mäntyjärvi, Dr. Rene Hexel, prof. Minna Isomursu, Dr. Panu Korpipää, Mr. Ilkka Känsälä, Mr. Sami Ronkainen and Mr. Urpo Tuomela. I own my deepest gratitude to Jani, who has to a great extent acted as my professional idol, and who has been exemplary in encouraging me throughout the whole process. Sami has been my closest colleague and my voice of reason in many professional and research-related activities, and faced the ups and downs of my spirits well. In addition, I want to acknowledge Mr. Kaj Mäkelä, and thank him for his time and collaboration in formulating the design guidelines. I would also like to thank Mr. Panu Kanervo for his professional expertise and flexibility in his help with the final editing of this thesis.

During my studies, I have had the pleasure to work in an international environment on several occasions. I want to thank the faculty and my colleagues at Griffith University, Australia, for their support and company in 2003. Especially I want to acknowledge prof. Liisa von Hellens, Dr. Rene Hexel and Mrs. Jenine Beekhuysen for making my stay so rich and interesting. I want to thank the people at Human Computer Interaction Institute, Carnegie Mellon University, especially Prof. Anind Dey, for making my stay as a visiting

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I thank my supervisor prof. Tapio Seppänen for guiding me through the PhD process and for interesting conversations during our meetings, and my pre-examiners, Dr. Albrecht Schmidt and prof. Kaisa Väänänen-Vainio-Mattila, who gave valuable feedback for improving my thesis. I own my gratitude to Prof. Anind Dey and prof. Kaisa Väänänen-Vainio-Mattila for accepting the invitation to act as my opponents in the public examination. I also want to gratefully acknowledge the University of Oulu, Nokia Foundation, and Finnish Information Processing Association for their financial support.

Finally, I want to thank my family, relatives and friends for their support and love. My parents have always encouraged me in my choices in education and career, although they must have been worried every now and then for the amount or diversity of the activities with which I have been engaged. I thank my sisters Salla and Hanna for being with me all my life, and together with my cousins for their energy and inspiration. I thank Teemu for his positive attitude and patience during the long process of both the PhD and life, and providing important support such as cooking dinners and fixing my car. I also want to thank the friends and loved ones who have stood with me.

'How about the long-term goals?' - 'Well, it is to see a permanent space station in the Moon.'

Abbreviations

CA	context-aware; context-awareness
CSCW	computer supported collaborative work
GL	guideline
GPS	global positioning system
HCI	human-computer interaction
HW	hardware
MMS	multimedia messaging service
PDA	personal digital assistant
RFID	radio frequency identification
SMS	shortmessaging service
SW	software
UCD	user centric design
UI	user interface

List of Original Publications

I Häkkilä J & Mäntyjärvi J (2006) Situated Multimedia for Mobile Communications. In: Ismail Khalil Ibrahim (ed) Handbook of Research on Mobile Multimedia. Idea Group Inc: 326-339.

II Häkkilä J & Hexel R (2003) Interaction in Location-Aware Messaging in a City Environment. Proceedings of Australasian Conference of Computer Human Interaction (OZCHI) 2003: 84-93.

III Häkkilä J & Mäntyjärvi J (2005) Combining Location-Aware Mobile Phone Applications and Multimedia Messaging. Journal of Mobile Multimedia 1(1): 18-32.

IV Häkkilä J & Isomursu M (2005) User Experiences of Location-Aware Mobile Services. Proceedings of the 19th Australasian Conference of Computer Human Interaction (OZCHI) 2005. ACM International Conference Proceeding Series; Vol 122.

V Häkkilä J & Mäntyjärvi J (2005) Collaboration in Context-Aware Mobile Phone Applications. proceedings of 38th Annual Hawaii International Conference on System Sciences (HICSS) 2005. DOI: 10.1109/HICSS.2005.145.

VI Häkkilä J & Känsälä I (2004) Role Based Privacy Applied to Context-Aware Mobile Applications. Proceedings of 2004 IEEE International Conference on Systems, Man and Cybernetics (SMC) 2004. Vol 6: 5467-5472. DOI: 10.1109/ICSMC.2004.140163.

VII Häkkilä J, Korpipää P, Ronkainen S & Tuomela U (2005) Interaction and End-User Programming with a Context Aware Mobile Application. Proceedings of Interact 2005: 927-937.

VIII Häkkilä J & Mäntyjärvi J (2006) Design Guidelines for Context-Aware Mobile Applications. Proceedings of Mobility'06. ACM Press.

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1 Introduction

1.1 Background and Motivation

During the last ten years, mobile handheld devices have become a part of our everyday lives. When development in information and technology enables more complicated functions and services to be integrated, the role of the mobile device as a generic tool in everyday life grows. Mobile phones are no longer used only for voice communication, but they typically employ various kinds of multimedia functionalities from camera to different types of messaging services and information sharing channels from Internet access to the mobile TV.

This development brings possibilities as well as difficulties to the users, as they have to manage a growing number of features and an ever-increasing information push. Mobile handheld devices are used in many situations, which change dynamically and employ different preferred features according to the particular situation at hand. While the input and output functionalities of mobile handhelds are limited by the small size of the device, the efficient input capability and presentation of relevant information are emphasized. Mobility and size requirements set special needs for the user interface design and interaction methods. During recent years, the complexity of mobile terminals has grown rapidly, and they now host a multitude of applications in comparison to earlier models. However, during this time, the input and output capabilities have remained quite much the same, which has lead to elongated navigation paths and key-press sequences. In many cases, this has caused the manual operation of such devices to become slow and cumbersome, creating needs for shortcuts and proactive actions for more fluent interaction. In addition to the technical development within mobile terminals, the infrastructure they use has also evolved rapidly offering possibilities for networked environments, ambient intelligence, and services which utilize mobile terminals. To enhance the use of mobile terminals and support more efficient interaction, context-awareness has been proposed as a potential future trend.

In short, context-awareness aims at using the information of the context of use for adapting the behavior of the device accordingly. It has been proposed as a potential step for future technology development, because it offers possibilities e.g. to smart

environments, adaptive user interfaces, and more flexible use of devices. Taking into account the special characteristics of mobile handheld devices, they form a well-suitable platform for context-aware application development.

Context-awareness itself is a relatively novel field. Although recent research related to context-awareness has given rise to numerous projects and resulted in workshops and conference sessions devoted to the topic, this interest has so far remained strongly among such technical aspects as context recognition, system design and architectural issues. Context-aware mobile handheld devices and applications have previously been investigated very little from a usability point of view. However, when introducing context-aware applications to be used by large audiences, usability is a crucial factor contributing to the product's success. Thus, issues influencing usability and their impact on different aspects of product development need to be charted.

Since context-aware devices have special characteristics in comparison to traditional ones, the means related to the interaction design of conventional mobile applications may not be optimal, resulting in a need for new information to improve the existing design practices. As context-awareness in its different forms seems to be on the rise, and this development paves way to future industrial applications, the research on the subject has motivation also from an industrial point of view.

This thesis looks into the problems related to the human-computer interaction and usability aspects of context-aware mobile applications. The author aims to chart potential usability risks by considering the topic from several viewpoints and approaching the subject with several studies in order to reveal the entirety of the underlying phenomena. The findings are then formulated to design guidelines that help to develop real, functional and usable context-aware applications for mobile handheld devices.

1.2 Focus and Scope of the Thesis

The key term mobile application is here used to denote software applications which run on a mobile device. The physical and logical characteristics of mobile devices are not considered further than to the extent where they directly affect the user interface and usability of mobile applications. In practice, this means characteristics such as the device input methods, screen size, or data connectivity.

The term *mobile devices* is here limited to handheld devices employing data communication channel(s) and applications allowing the use of textual, audible, or pictorial data. This effectively limits the examination to devices featuring properties pertaining to mobile phones and personal digital assistants (PDAs). Traditionally, mobile phones have been viewed as communication devices, which are used for calling and messaging, and PDAs are thought to be easily accessible data storages for personal documents, such as calendar entries or short notes. Of late, however, these two product categories have started to resemble each others to an ever-growing extent, integrating the features conventionally belonging to the other device type, and employing new ones such as Internet browsers or cameras. Due to the convergence of mobile devices, the features traditionally reserved for digital cameras, MP3 players, and handheld game consoles are

often an inseparable part of the device functionality. As a result, the term multimedia terminal is often used when discussing this type of devices.

The thesis also relates to *mobile services*. These are defined as applications, which involve another party in addition to the mobile device. Typically, the user interacts with a mobile service through a mobile device, whereas storing the data or the execution of commands happens, at least partly, outside the physical device.

The concept *context-awareness* relates to a device's ability to be aware of its use situation. Schilit *et al.* (1994) described a context-aware system to *'adapt according to the location of use, the collection of nearby people, hosts, and accessible devices, as well as to changes to such things over time. A system with these capabilities can examine the computing environment and react to changes to the environment.'* The definition for *context* used in the thesis is from Dey and Abowd (2000b). They describe context as

> *'any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.'*

Usability is understood as the characteristics of a device or application, which enable the users to use the device in order to achieve specified goals with effectiveness, efficiency and satisfaction.

The term *usability risk* is used in this thesis to describe a condition, where there is a threat that the intended interaction task cannot be accomplished with the desired level of effectiveness, efficiency, and user satisfaction. In the scope of this thesis, the definition does not involve quantitative measures or probabilities. Although the definition is rather general, it is sufficient for the exploratory and qualitative nature of this thesis, where a quantitatively more precise definition would be hard to ground and evaluate.

This thesis does not describe system architectures or context recognition, which are excluded because of their desired transparency to human computer interaction (HCI) issues which are in the focus of this thesis. However, these issues are inevitably touched upon when relating to the problematics in usability. The research questions of this thesis are introduced in the following section.

1.3 Research Questions

Previous research conducted in the field of context-aware mobile applications does not provide significant amounts of information or experiences on HCI design, but for rather separate or narrowly focused cases. Thus, the author had to start with a number of open questions. The problem is approached by conducting several studies, where different aspects of HCI issues with context-aware mobile applications were charted. This was done to get a larger perspective and fundamental ground knowledge on the issues related to the topic. The findings of individual case studies were then fused to provide a wider and more complete understanding on the topic, and as an outcome of the synthesis, design guidelines were developed.

This thesis aims at contributing to the following research aspects. First, it seeks to chart the problems related to the HCI issues in context-aware mobile applications. Secondly, it proposes guidelines to help the interaction and user interface design of context-aware mobile applications. This twofold contribution is well justified as the existing research has not yet much concentrated on the HCI aspects, even though charting the problems, possibilities and users' expectations forms an essential background for successful application development.

Currently, having a context-aware system integrated on a device is not the default case, but rather devices and applications are implemented without the adaptability to different situations of use. Personalization and configuration is typically done by changing the device settings manually. However, context-awareness may provide a powerful tool to enhance the efficiency and usability of mobile applications. The main research questions of the thesis are:

- *Can context-awareness increase the usability of mobile handheld devices?*
- *What are the potential usability risks of context-aware mobile handheld applications?*
- *What are the design guidelines to facilitate successful interaction design of usable context-aware mobile applications?*

1.4 Research Methods

The research methods employed in each state of this PhD research correspond to the different aspects of this multidimensional project. The scope of this thesis sets up as large framework, as usability is a fairly novel and unexplored field. Therefore the nature of the research is very exploratory and involves much data collecting. Moreover, the key term usability relies heavily on human experience. This involves observing and experimenting with users and relates often to somewhat subjective matters, such as user satisfaction and social acceptability. Due to the heavy involvement of users and their experiences, the qualitative nature of the research is emphasized.

Human computer interaction research methods were used to gather the data in experimental parts considered in *Publications II, III, IV, VI* and *VII*. The research problem of charting interaction and usability issues of context-aware mobile devices was approached by conducting several studies with different kinds of research methodologies, each corresponding to the nature of the study and research questions in focus. Generally, the preliminary studies conducted in the earlier phase of this PhD research are more exploratory and employed suitable user study methods, for instance interviews and wizard-of-Oz testing, whereas later studies were conducted with methods such as paper and handheld prototypes with designed UI and architectural considerations. Along these lines, the research aimed first to chart general trends, then focusing on found hot spots and barriers on the problematics of usable, context-aware UIs. Thus, the research problem was confined more during the process.

By building real, functional prototypes or applications one could arguably achieve more reliable results and experiences of long-term usage than with prototyping and using the wizard-of-Oz technique, the overall process with a longer time span and demand for

resources would not have corresponded well with the scope of this thesis. Selecting one context-aware mobile application to be designed and implemented would have not met with the exploratory objectives of the research. What is more, time and resource restrictions related to this PhD thesis would not have allowed for a fundamental investigation and the building of several large scale context-aware systems. Thus, the aim to explore and study several issues and the entirety related to the multi-dimensional HCI problematic was better achieved by utilizing prototyping and the wizard-of-Oz technique.

In addition of being exploratory, this PhD research is also constructive, as it aims to build on something: develop design guidelines based on the research from several separate studies and phenomena. The constructive research includes both the constructing and testing phases. The testing of the design guidelines was first done with two design assignments for university students, where mobile application design was simulated as presented in *Publication VIII*. After this, expert evaluation was carried out, and the guidelines were then refined according to the gained feedback and study results.

The research presented in this thesis combines different UI design and testing methods. The selection of just one method would have limited the potential information flow, as the approach was different ranging from exploratory studies to verifying and testing ready-made applications. The including of several different methods enabled a richer information gain and was selected to ensure and maximize the validity of the findings. The applied methods are now introduced in more detail in Chapter 1 for the case studies and in 4.3.3.2 for the iteration of design guidelines with expert evaluation.

1.5 About the Research Group

The author has been a part of and influenced by several research communities in the mobile telecommunication industry, research institutes, and academia. The author has produced this thesis mostly during her full-time work within the mobile communication industry, which on the other hand has provided great insights to the field and to the issues of research and development for real-life devices and applications, but has also considerably constrained her ability to devote time to a single, long-lasting research project. As there was no possibility for the author to carry out a solitary long-term research project, the nature of the author's PhD research may seem somewhat fragmented. However, composing this thesis of several separate studies has made it possible to experiment with different ideas and has suited well for the exploratory nature of the research set by the novelty of the field.

The research topic is cross-disciplinary and fuses a number of different kinds of fields. The research combining different types of backgrounds and the researchers specializing to the field could not have been found within the author's local research community. Thus, the author has also relied on the international research communities when conducting her PhD thesis.

In addition to the author's home university, University of Oulu, both the course work and research during post graduate studies have been conducted in a number of other universities. The author has also participated several doctoral consortiums at international conferences, namely at *Pervasive, Ubicomp, User Interface Software and Technology*

(UIST), and *Interact*, which have gradually refined and guided the research. These meetings have offered an international, high-quality advisory and peer forum, and acted as quality management during the PhD research process. Especially they have provided support in issues related to usability and interaction research, and provided guidance and peer community to reflect and refine the author's research within this area. In addition to the mobile phone industry, the author has also worked closely with VTT Electronics in several research activities related to context-aware mobile technologies.

During her post-graduate studies, the author was employed full time at Nokia research and development except for the periods between February and December 2003, and August and November 2006, while she was on study leave and visiting Griffith University, Australia, and at Carnegie-Mellon University, USA, respectively. The positions the author has held in Nokia Technology Platforms and Nokia Multimedia have been in the area of user interfaces (UI) and usability. The industry position has offered insights to the product development processes and practices, and valuable reference on developing consumer products for large user groups. Everyday work tasks have provided a solid background in the knowledge of what are the demands of professional level usability work, the requirements product projects set for research and development activities, and the needs the industry has for improved practices that can help in product development.

1.6 Author's Contribution

The contribution of the author in each of the publication listed above is as follows.

Publication I: Häkkilä developed the presented categorization for contextual information sources for mobile devices. From other parts, Häkkilä and Mäntyjärvi shared the responsibility of writing the paper.

Publication II: Häkkilä designed, executed and analyzed the user tests the paper is about. Dr. Hexel was the supervisor approving the experiment and formulating the paper. Häkkilä was the main responsible of writing the paper.

Publication III: Häkkilä planned and executed the experiment, and analyzed the gathered data. The model presented was developed together by Häkkilä and Mäntyjärvi. Häkkilä and Mäntyjärvi shared the responsibility of writing the paper.

Publication IV: The experiments were done by the researchers and students of the Rotuaari project, headed by Prof. Minna Isomursu, at the University of Oulu. Häkkilä contributed to the content of diary questions when designing the study. Häkkilä was the responsible of analyzing the results of the diary study that acted as the data for the paper and writing the publication. Häkkilä was responsible in writing the publication.

Publication V: Häkkilä was in charge of writing the paper and developing the model presented in it. Mäntyjärvi acted as technical expert and supervised the paper.

Publication VI: Häkkilä designed the user interface and Känsälä implemented the demonstration to a mobile device. Häkkilä and Känsälä shared the responsibility of executing the user tests and writing the paper.

Publication VII: Häkkilä was in charge of designing the user interface and its user testing. Ronkainen contributed in the design phase, Korpipää was in charge of the technical implementation. Häkkilä was the main responsible of writing the paper.

Publication VIII: Häkkilä developed the design guidelines presented in the paper. Häkkilä and Mäntyjärvi carried out the Study I, whereas Häkkilä organized the Study II having Dr. Albrecht Schmidt helping in practical arrangements. Häkkilä was responsible for writing the publication.

1.7 Organization of the Thesis

This thesis is organized as follows. First, a literature review of the research in context-awareness, usability, and mobile human-computer interaction is presented, and their overlapping areas in the current research are introduced. Next, the research methods employed during the PhD research are considered. After this, the author's PhD research is introduced. This section is divided into two main themes, where the first one concerns the developed frameworks and conducted case studies. The second half of the chapter describes the development of design guidelines for context-aware mobile applications. This is followed by Discussion and Conclusions.

2 Literature Review

In essence, this thesis deals with to two key concepts: context-awareness and usability. These two areas of research have so far had fairly little to do with one another, and carrying out a literature study on two such topics inevitably leads to somewhat separate sections where the literature of each is considered. This thesis, however, is about bringing these two topics together. Therefore, this chapter first looks at context-awareness, then usability and mobile HCI, and after this, summarizes the current situation where these themes overlap – and where they do not – in the existing research literature.

2.1 Context-Awareness

2.1.1 Defining Context-Awareness

Context-awareness is a young, expanding and vital field of research, which is here illustrated with a quick glance to the amount of published research. Table 1 presents search results from four popular article databases: ACM Digital Library, Elsevier ScienceDirect, IEEE Xplore, and SpringerLink, and it gives an overview how publication on context-awareness has developed during recent years. The growing amount of research is clearly seen from the query results. The results also indicate, that significant amount of the research on context-awareness does not relate to user interface issues by any means.

Table 1. Full text search results from four publication databases for the term 'Context-awareness' (left column) and Boolean search for 'Context-Awareness' AND 'User interface' (right column, in italic font).

Year	ACM		Elsevier		IEEE		Springer	
2005	143	*64*	25	8	64	*2*	64	*1*
2004	92	*51*	21	*9*	31	*4*	28	*1*
2003	54	*37*	17	*9*	28	*0*	21	*1*
2002	53	*29*	5	*1*	7	*1*	6	*0*
2001	36	*25*	5	*4*	6	*1*	6	*0*
2000	34	*23*	5	*0*	6	*1*	1	*0*

The idea of context-aware computing can be tracked down to the days when Mark Weiser published his paper 'The Computer for the 21st Century' (1991). In addition to drawing the fundamental concepts of ubiquitous computing by 'vanishing computers into the background', Weiser also shapes the concepts of context-aware computing: *'... computers will come invisible to common awareness. People will simply use them unconsciously to accomplish everyday tasks'*. He paints a picture of computers knowing their location, being able to capture information and retrieve context-based information, and offering seamless interaction to support the user's current tasks. Context-aware computing is indeed often related to the research on ubiquitous, pervasive[1], and situated[2] computing (Dourish 2004).

The term context-awareness has commonly been used for two different kinds of application approaches: to capture context so that it can be later used as a cue for information retrieval, or, more commonly, to user context to adapt device behavior to correspond to the manner of its usage (Dourish 2004). In addition to these two cases, i.e. tagging context of later use and automatic execution of actions, context-awareness can be used for providing information presentation to the user (Dey 2001). The term context has resulted numerous definitions, where none, despite of the popularity of the field, has gained a position to be considered as a default one. In the following, some well-known attempts to define context-awareness are presented.

Schilit *et al.* (1994) introduced the term *context-aware computing* which

> *'adapts according to its location of use, the collection of nearby people and objects, as well as changes to those objects over time'.*

In conjunction to this, they proposed three general categories describing context: *user context, physical context*, and *computing context*. Here, the user context describes the situation from the user's viewpoint, including components such as the user's activity and social factors. Physical context includes information of the physical environment, which can be gained e.g. with sensor-based measurements. Computing context includes e.g. the device connectivity and available computing and application recourses. As a complement

[1] The terms ubiquitous computing and pervasive computing are typically used interchangeably (Ark *et al.* 1999, Dourish 2004)

[2] Situated computing refers to computing devices' ability to detect, interpret and respond to the user's local environment (Brodersen and Kristensen, 2004).

to Schilit *et al.* (1994), Chen and Kotz (2000) added the *time* context to be the fourth aspect of context-awareness.

A large context-awareness research project TEA (Technology for Enabling Awareness)[3], finished in September 2000, carried out significant research on the area of context-aware computing. In (Schmidt, 2000), two general categories for structuring the concept of context are proposed: *human factors* and *physical environment*. These have three subcategories each: human factors divides into information on the *user*, *social environment* and *tasks*, and the physical environment distinguishes *location*, *infrastructure*, and *physical conditions*. In addition, orthogonal to these categories, *history* provides the information on the changes of context attributes in time.

Dey and Abowd (2000b) define the context as

> *'any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves'.*

In addition they state that a context-aware application may support three kinds of features: 1) presentation of information and services to a user, 2) automatic execution of a service, and 3) tagging of context to information for later retrieval.

The definition by Dey and Abowd is also the closest one adopted by the author in her research. The emphasis is on the word 'relevant', which thus is the key for usable context-aware application development. Although the definition can be criticized as a too vague one to offer help in real life application design, for the purposes of the thesis, i.e. for exploring the usability issues it suits well, as it is not too restricted but easily allows the examination of the phenomena in larger perspective.

According to the selected definition of context, one needs to find out how to select the relevant factors and ensure that they are taken into account in the application design phase, i.e., consider which context attributes will be relevant in the usage situation and have impact on the device or the user. This includes both the technical solutions and enablers, such as considering the sensing technologies and architectural question, as well as fluent and good usability.

2.1.2 Categorizing Context-Awareness

In addition to the large number of terminological definitions, there exist also a number of proposals for categorization of context-aware applications. Barkhuus and Dey (2003) distinguish three application categories according to their mode of operation: active context-awareness, passive context-awareness, and personalization. Here, active context-awareness automatically adapts the device behaviour whereas in passive context-awareness a detected change of the context is communicated to the users but they are let to decide whether this causes any actions to the device behavior. Chen and Kotz (2000) define active and passive context-awareness almost as above, but discuss on passive

[3] http://www.teco.edu/tea/ , last accessed 03 Dec 2006

context-awareness also in the means of storing the context to be retrieved later by the user.

Counting the personalization aspect as a type of context-awareness as in (Barkhuus and Dey, 2003) has been somewhat uncommon on the field of mobile computing. Especially with mobile phone industry, device or application personalization is commonly considered as a more general user interface issue of customizing according to individual user's preferences. This does not exclude context-awareness, as personalizing certain device settings may be related to the execution of context-aware functions. However, the term personalization with mobile handheld devices is strongly associated to make the device appearance match to your personal style and preferences by selecting e.g. personal ringing tone, operator logo or exchangeable device cover, all of which are done without any connection to the context. Because of these arguments, in the author's research, personalization itself is not considered to be a (sub)category of context-awareness.

Mäntyjärvi *et al.* (2003) propose context-aware applications to be classified according to their automation level into three categories: manual, semi-automated and fully automated. Representing the lowest level in automation hierarchy, the manual category refers to the condition, where the user him/herself manually configurates the device settings to match to a certain usage context, e.g. manually setting the phone ringing tone silent when entering a meeting. In semi-automatic adaptation level, the user can preset the device functionality, which is activated in selected contextual conditions. In the third level of automation hierarchy, i.e. fully automation, the device infers and proceeds actions without requiring user actions.

Context-awareness is often categorized to pull and push, see e.g. (Michahelles & Samulowitz 2002, Cheverst *et al.* 2001), where the first type is initiated by the user and the second is event-triggered and initiated, for instance, when a certain sensor threshold value is achieved. The push and pull categorization is often referred when considering location-aware services, where in a push type service the information is automatically delivered to the device when entering to the certain area, whereas the pull type requires the user to actively inquire for the information. The phenomenon is investigated for instance with a tour guide application in (Cheverst *et al.* 2000). In addition to this, the distinction between push and pull may be used also e.g. with mobile service discovery.

2.1.3 Recognizing Context

As the numerous attempts demonstrate, defining the term context is a challenging task. Despite of the difficulties, definitions are still needed in order to set up a unifying framework and enable common ground for application development that can be commonly utilized and implemented. This has lead to ongoing work of formulating ontologies, which are defined as 'explicit spefication[s] of conceptualization[s][4]'

[4] The term *Conceptualization* is defined as 'an abstract, simplified view of the world that we wish to represent for some purpose' (Gruber, 1993).

(Gruber, 1993), and their use in context-aware application development (Ko *et al.* 2005, Korpipää *et al.* 2004, Korpipää *et al.* 2003b, Truong *et al.* 2005).

Context-awareness can utilize numerous different kinds of information sources. In order to detect selected quantities of the physical environment, sensors are a commonly applied technology. Sensor data can be used to recognize the use situation for instance from illumination, temperature, noise level, and device movements, as described e.g. in (Gellersen *et al.* 2002, Mäntyjärvi & Seppänen 2002, Hinckley *et al.* 2005). A typical setting is to attach a sensor box to a device and execute the data analysis and context-recognition locally in the device.

Several different location detection techniques have been utilized in context-awareness. The global positioning system (GPS) is a commonly used technology when outdoors, utilized e.g. in car navigation systems such as the Hertz Neverlost[5]. The network Cellular ID can be used for location purposes with mobile phones. However, the disadvantages of the systems have prevented their adoption, as GPS and Cellular ID suffer from too low a resolution for many application purposes, and GPS does not have coverage indoors. The majority of the research projects have built their own positioning systems for project purposes. Bluetooth and WLAN hotspots are frequently used techniques for outdoors and indoors (Aalto *et al.* 2004, Burrell & Gay 2002, Persson *et al.* 2003). Other methods used for indoor location detection include ultrasonic or IR-based location detection (Borriello *et al.* 2005, Abowd *et al.* 1997).

The challenge to determine context is not only a matter of capture, but also presents a significant inferring challenge. Determining the context with a sufficient confidence summons advanced techniques, and numerous approaches to analyze the data have been proposed. Flanagan *et al.* (2002) have used self-organizing maps to recognize based on several input data types. Korpipää *et al.* (2003a) apply a Bayesian approach in order to recognize context based on sensor data. In addition, time series segmentation (Himberg *et al.* 2001) and hidden Markov models (Eronen *et al.* 2006) are techniques utilized in context-recognition problems. Although several papers report on relatively good recognition results, the experiments are typically done in very limited environments and with simplified settings, and the identified problem of significant uncertainties in context recognition remains valid.

The behaviour of a context-aware application is often not bound to a static formula of condition-consequence that repeats always the same, but learning techniques can be employed. For example, in comMotion system (Marmasse & Schmandt, 2000) the device observes the user's behaviour and learns to adapt to a manner that is perceived useful at a certain location. Pirttikangas *et al.* (2004) have used routine learning for automated mobile phone ringing tone settings to general and silent mode.

Research on mobile context-awareness has also lead to development of toolkits, several of which are publicly available. Examples of these are the Context Toolkit (Dey *et al.* 2001), Smart-Its (Beigl *et al.* 2003), and Multi-User Publishing Environment MUPE[6].

[5] http://hertzneverlost.com/ , last accessed 03 Dec 2006.

[6] Multi-User Publishing Environment (MUPE); http://www.mupe.net/ . Last accessed 03 Dec 2006

2.1.4 Using Context in Mobile Applications

Employing context-awareness is not limited to mobile devices but it has been proposed or demonstrated in various different kinds of applications, for instance automated video and audio capture in a lecture room (Abowd 1999), house front doors (Kim *et al.* 2004), smart furniture (Tokuda 2004), hospital beds (Bardram 2004), or redirecting personal communication to the simultaneously most appropriate media (Nakanishi *et al.* 2000). In scope of this thesis, however, examination is limited to the mobile context-aware applications, which are looked at more closely in this section.

Location is probably the most commonly used variable in context recognition, and it brings easily identified potential use cases. Location information has been used both as one contextual information source among others, and as the only context attribute, although the commonly agreed current understanding is that one should not limit context to location only (Schmidt *et al.* 1999). However, location-awareness forms a significant area among mobile context-awareness research, and has great potential for future commercial applications (Kaasinen 2003). In addition to the information about the physical location itself, the information in the means of distance and presence may provide useful data for time management and social navigation. Discount offers, information of opening hours, advertisement of forthcoming happenings, lunch menu choices, and service availability status are examples of information that may have potential value when transmitted to people passing by. Navigation aids, location-aware information delivery, and location sensitive memory aids are examples of concepts that take advantage of location-triggered device behavior. Common applications demonstrating location-awareness are tour guides in the city, campus or museum environments (Davies *et al.* 2001, Abowd *et al.* 1997, Raptis 2005), shopping assistants (Bohnenberger *et al.* 2005), messaging systems (Rantanen *et al.* 2004), and location-sensitive reminders (Dey & Abowd 2000a). Active Badge location system (Want *et al.* 1992) and ParcTab in Xerox PARC (Schilit *et al.* 1993) represent early work done on location-awareness. Later, location-awareness has been demonstrated in large project entities containing examples of several types of functionalities, as e.g. in Active Campus (Barkhuus & Dourish 2004) and Rotuaari project (Aalto *et al.* 2004). In addition to academic exercises, also location-aware mobile services that involve collaboration with commercial entities have been set up and trialed, such as Elisa Mobilemall[7] or Rotuaari mobile advertisements (Ojala *et al.* 2003).

Location-aware messaging relates inevitably to mobile communication devices. E-graffiti introduces an on-campus location-aware messaging application where users can create and access location-associated notes, and where the system employs laptop computers and wireless network-based location detection (Burrell & Gay 2002). InfoRadar supports public and group messaging as a PDA application, where the user interface displays location-based messages in a radar-type view showing their orientation and distance from the user (Rantanen *et al.* 2004). Distinguishing between public and

[7] Elisa Mobilemall. Available at: http://elisa.fi/ir/index.cfm?t=5&o=5120.00&did=7153 ; http://www.helsinkivirtualvillage.fi/Resource.phx/verkkolehti/yritykset/kauppakeskusarabia.htx . Last accessed 03 Dec 2006

personal messaging aspects has also been demonstrated in location-aware messaging systems (Burrell & Gay 2002, Persson *et al.* 2003, Rantanen *et al.* 2004).

Recently, multimedia messaging service (MMS) has been applied as an implementing technique for experimentation within the field. MMS has offered a practical tool for this, as there is no need to set up any specific infrastructure and standard mobile phones can be used as platforms. The widespread use of mobile phones also enables extending the experiments to large audiences, as no specific gadgets need to be distributed. These aspects are used in the work of Koch and Sonenberg for developing an MMS-based location-sensitive museum information application utilizing Bluetooth as the sensing technology (Koch & Sonenberg 2004). Multimedia messaging has also been applied in the Rotuaari project carried out in Oulu, Finland, where location-aware information and advertisements were delivered in the city centre area (Ojala *et al.* 2003).

Presence applications utilizing the information about the spatial nearness of an entity are also important function in the field of mobile context-awareness. Presence is sometimes considered as a subcategory of location-awareness, as reminders or notifications related to a spatially fixed entity, such as a shop or a printer, at the close neighborhood of the user are often considered as presence notifications. There exist several mobile applications utilizing presence. For example, BlueReminder is a mobile phone application, where a bluetooth-triggered reminder related to another person goes off when it detects the proximity of the corresponding person's bluetooth phone (Osbakk & Rydgren 2005). Poypurev *et al.* have prototyped a concept for spotting the presence of people that are buying and selling items that are in the interest of the user (Poypurev *et al.* 2005).

The term remote presence is used where a virtual presence of a person is mediated with the technology, and it can be used in social means for sharing or connecting to another person's context. It often has an affective perspective, such as sharing emotions or supporting group cohesion (Counts & Fellheimer 2004, Dey & De Guzman 2006). With context-aware mobile applications, another person's context information can be used for passing the availability status. This is used especially with communication devices where it offers a number of potential use cases, as demonstrated e.g. in Context Phonebook (Schmidt *et al.* 2001). The idea is demonstrated also in a mobile phone application by Bardram and Hansen (2004), who seek to increase social awareness and minimize interruptions by exploiting availability information.

Different sensors and their combinations have been used in a number of projects concerning context-aware mobile devices. Hinckley *et al.* (2005) use touch sensor to detect when the device is held in hand to turn the power on. Schmidt (2000) demonstrates a similar feature, and adapts the UI by increasing text fonts if device is shaking, e.g. while walking. In addition, screen layout orientation, backlight, ringing tone and volume adaptation have been proposed (Gellersen *et al.* 2002, Hinckley *et al.* 2000, Mäntyjärvi *et al.* 2003, Schmidt & Gellersen 2001).

A number of existing studies employ additional web-based services, as e.g. with the CybreMinder application (Dey & Abowd 2000a). The problem with these approaches is that they typically make good use of large screen and desktop-like browser interfaces, and do not fit very well into mobile handheld devices. However, with increasing computing power and higher resolution colour displays, some of these problems are overcome.

2.2 Usability

2.2.1 Building Blocks of Usability

By its nature, usability is an inseparable part of the device and its applications. In the ever-tightening competition in the markets, industrial products aiming to the mass markets have become emphasizing usability as one of the key design factors. Usability reflects the easiness and efficiency of use, and is a significant part of the end user experience and thus also user satisfaction. Literature related to usability is wide and extensive, and considers both theory and practice, as well as general principles and issues valid for specific application areas. In this section, the centric usability concepts are introduced.

The standard ISO 13407 (3.3) on Human-Centred Design Processes for Interactive Systems defines usability to be the

> *'extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use'*.[8]

According to this, context is non-separable part of usability.[9] Thus, an attempt to improve the usability of a system by employing context-awareness is a relevant approach. Fig. 1 presents the usability framework defined in ISO/DIS 9241-11, which describes the relations between the product and usability measures and goals.

[8] It must be noticed that the definition does not refer context in a sense of employing context-awareness.

[9] Context of use is defined in the same standard (3.7) as users, tasks, equipment (hardware, software and materials), and the physical and social environments in which a product is used.

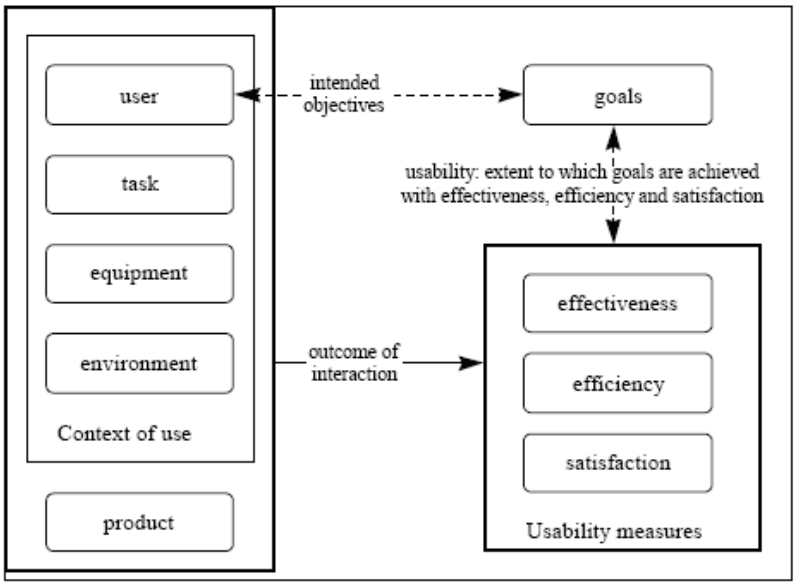

Fig. 1. Usability Framework according to ISO/DIS 9241-11.

Preece *et al.* 2002: 14) lists usability goals, *effectiveness, efficiency, safety, utility, learnability,* and *memorability,* which should guide interaction design process and which determine the overall usability of the design. These concepts are broken down in Table 2.

A commonly used user categorization separates three groups of users: novices, casuals, and experts (Nielsen 1994). Each group brings their own emphasis to the requirements of the device. When novice users are involved, the learnability of the application is emphasized. The consistency of the application functionality in relation to their earlier experiences and available help functions are also important. On the other hand, expert users often value the ability to perform their tasks quickly. They avoid long navigation paths and favor shortcuts (Preece *et al.* 2002: 207). Expert users are also more confident in using different functions and ready to edit application settings to better meet their personal needs.

Table 2. Usability goals (Preece et al. *2002).*

Concept	Explanation
Effectiveness	How good the system is at doing what it is aimed for
Efficiency	How well the system supports the user in carrying out her/his tasks
Safety	About avoiding the risks to lead the user to dangerous situations or conditions, e.g. privacy threads or loss of data
Utility	The extent to which the system allows the user to do what (s)he needs or wants to
Learnability	How easy the system is to learn to use
Memorability	How easily a user can remember how to use the system once it has been learnt

Shneiderman (2000) considers the problem of designing applications for a broad audience of unskilled users in his article about universal usability. Shneiderman lists three challenges for achieving universal usability: technology variety, user diversity, and gaps in user knowledge. Although the article examines the problem from the viewpoint of web-based services, the same issues can be identified with mobile handheld devices. Different kind on hardware and software platforms are used by consumers ranging from children to the elderly, including various user groups who may not have any technical understanding of telecommunication or computing.

In addition to usability issues, the attention has during the last decade expanded to concern the user experience, especially when competing in the end-user markets with commercial products. The term *user experience* is here defined as the overall subjective satisfaction the user has with the application or artefact, including perceptions related to utility, usability, aesthetics and emotional factors. The term user experience is often used to describe how pleasing the system is and what is the user's general feeling about it. Fig. 2 illustrates the user experience and usability goals according to Preece *et al.* (2002: 19).

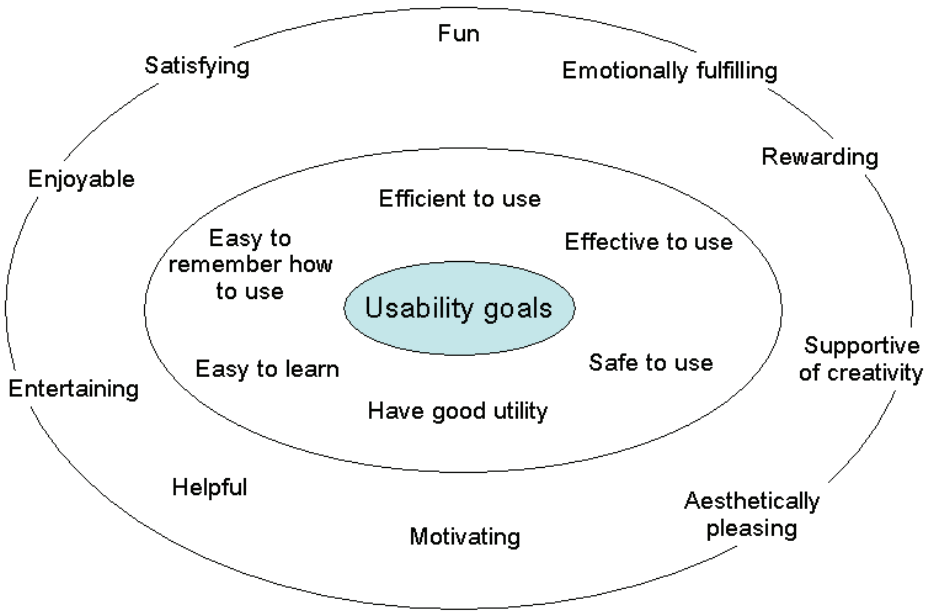

Fig. 2. Usability goals (inner circle) and user experience goal (outer circle) according to Preece *et al.* (2002).

2.2.2 Designing for Usability

In order to ensure and improve usability, several different kinds of methods have been developed. The human-centered design process described in the ISO 13407 standard consists of four different steps in design activities, which are the following:

- Understand and specify the context of use
- Specify the user and organizational requirements
- Produce the design solutions
- Evaluate the design against requirements

There is a variety of methods concerning different types of design activities in all phases of the design process, such as end-user studies in the early design phase and usability inspection methods and usability testing in later phase with the evolved application design (Nielsen 1994). The design methods can be roughly divided into field studies and laboratory studies; or whether or not the method involves users (e.g. when evaluating the user interface with user tests or with experts). Usability research methods employed during the case studies reported in the thesis are introduced in detail in Chapter 1.

An entire discipline, user centric design (UCD), has developed around the key idea that users and their needs should be kept in the central focus during the whole design process (Preece *et al.* 2002). Vredenburg *et al.* (2002) use a definition that UCD considers

> *'the practice of the following principles: the active involvement of user for a clear understanding of user and task requirements, iterative design and evaluation, and a multi-disciplinary approach. UCD methods are modular or identifiable processes involved in UCD practice.'*

The research done among UCD practices shows that in general, the UCD methods are quite widely practiced in industry, but the scale and extensiveness of their use varies broadly. The common industry practices favour the use of informal and less structured methods, such as low-fidelity prototyping, heuristics and informal usability testing, in comparison to more formal methods, such as focus groups and cognitive walkthrough. In a survey conducted among 103 UCD professionals in the industry, the five most commonly used methods were iterative design, usability evaluation, task analysis, informal expert review, and field studies. The study also reports that the cost-factors have a significant effect on the selected methods (Mao 2005).

Design guidelines and design principles - commonly referred to as heuristics (Preece *et al.* 2002: 26) - are a typical tool used for ensuring or improving the usability. The role of design guidelines is to support the designer to achieve the best possible design result in developing the application or device. Design guidelines may provide information on recommended design process, or style restrictions set e.g. by the device manufacturer. Such guidelines, which offer help also in style issues, can be found e.g. for designing UIs for Microsoft Pocket PC[10], Series 60 mobile phones[11], and Palm handhelds[12]. Heuristics

[10] Microsoft Pocket PC User Interface Guidelines.
http://msdn.microsoft.com/library/default.asp?url=/library/en-us/ui_guide_ppc/html/PPCUser_Interface_Guidelines_SKLK.asp (Last accessed 03 Dec 2006)

are a set of rules that are primarily developed for a framework for heuristic evaluation, where a group of specialist evaluates the application against the heuristics (Preece *et al.* 2002: 26). Probably the most famous usability heuristics are developed by Nielsen (1994), presented in Table 3.

Table 3. Nielsen's (revised) usability heuristics (Nielsen 1994).

Heuristics	Comments
Visibility of system status	Keep the user informed of what is going on by giving feedback in reasonable time.
Match between system and the real world	The system should speak the language and in terms familiar to the user.
User control and freedom	Accidentally performed unwanted actions should not lead to going through the whole dialogue again. Support undo, redo, and emergency exits.
Consistency and standards	User should not be left to wonder whether different words or situations mean the same thing.
Error prevention	Preventing problems from occurring is better than providing well-designed error messages.
Recognition rather than recall	Make objects and action visible so that the user should not have to rely on remembering information.
Flexibility and efficiency of use	The system should support both experienced and inexperienced users.
Aesthetic and minimalistic design	Every extra unit of information competes with the relevant ones and diminishes their relative visibility.
Help users to recognize diagnose, and recover from errors	Error messages should indicated the problem and suggest a solution in plain language.
Help and documentation	Provide help and documentation which in easy to search and focuses on the user's task.

2.3 Mobile Human-Computer Interaction

2.3.1 Characteristics of Mobile HCI

The mobile handheld devices considered here are mobile handheld communication and computing devices, above all mobile phones and personal digital assistants (PDAs). These commonly used devices contain numerous, quite complex functionalities and applications. Mobile handheld devices share a lot of features in common, although mobile phones concentrate more on communication applications whereas PDAs deal

[11] Series 60 UI Style Guide. Available at Forum Nokia: http://www.forum.nokia.com/main.html (Last accessed 03 Dec 2006)
[12] Palm OS User Interface Guidelines.
http://www.palmos.com/dev/support/docs/ui/UIGuide_Front.htm (Last accessed 03 Dec 2006
http://www.palmos.com/dev/support/docs/ui/UIGuide_Front.html (Last accessed 03 Dec 2006)

primarily with personal information and documentation management. However, recent development and mobile convergence has lead to devices, which in increasing degree have adopted each other's features, and the traditional categorization is already volatile.

Mobile handheld devices have special characteristics, which affect their usability and which should be taken into account when designing applications for them, as illustrated in Fig. 3. The most obvious difference to personal computers is the size and therefore the limited input and output functionalities – the small display and keypad. Inferior computing power and memory capacity also restrict the use of mobile devices and application concepts developed for them. Moreover, mobility being the key concept, varying usage situations and the user's capability to use the device while on the move or multitasking have been significant topics in the HCI research.

Various interaction techniques have been studied extensively due the restricted input methods available in small mobile devices (MacKenzie & Soukoreff 2002). These include e.g. differently organized alphanumeric keypad layouts or pressing sequences with physical keys (Pavlovych & Stuerzlinger 2003), touchscreen based alphanumeric input (Isokoski & Raisamo 2004), and chord text input techniques (Lyon *et al.* 2004). In addition to text entry, other interaction modalities have also been investigated. Multimodal input systems utilizing e.g. speech and stylus have been examined to offer more natural and efficient interaction mechanism for mobile devices (Hurtig 2006). Gesture input methods employing either sensors (Hinckley *et al.* 2000) or a device-integrated camera (Drab & Artner 2005, Rohs & Zweifel 2005) have also been demonstrated.

Fig. 3. Factors affecting the usability of a mobile phone. Revised and complemented from Ketola and Röykkee (2001).

In addition to input, limited output functionality has also provoked mobile HCI research. Enhancing the ability to present information in additional means to a small screen has been investigated by providing auditory cues with sonifically-enhanced buttons (Brewster 2002) and haptic structured vibrotactile messages, tactons (Brown *et al.* 2006). In addition, adaptive techniques to visualize information on small screens have been proposed, e.g. for browsing Web pages with a mobile phone (Roto *et al.* 2006).

Interacting with the physical world and smart environments with a mobile device has become an intense research area. Typical scenarios include connecting to services or accessing information by touching or pointing artefacts equipped with tags. Radio frequency identifier (RFID) and visual tags are the most common solutions for interacting with physical objects, and semantics of interaction has been investigated e.g. by Rukzio *et al.* (2006).

HCI research on mobile handheld devices has demonstrated a range of different types of concepts, which illustrate the capability and potential of mobile computing platforms. Examples of new concepts that enhance the use of mobile devices to new application areas are mobile music navigation (Warren *et al.* 2005), where the way finding cues are incorporated into dynamically changing music, and collaborative mobile image sharing (Sarvas *et al.* 2004).

In addition, the usage culture with mobile devices, especially mobile communication and information access, has been under active investigation in the HCI research forums. Examples of studies on mobile culture are about understanding of users' access and availability anytime and anywhere (Perry *et al.* 2001), teenagers' text messaging practices (Grinter & Eldridge 2003), and use of multimedia messaging Kurvinen (2003) and camera phones (Kindberg *et al.* 2005).

2.3.2 Usability with Mobile Devices

Ketola & Röykkee (2001) categorize the concept of usability with mobile handsets to consider three aspects: user interface, external interface and service interface. Here, the user interface includes input and output techniques, industrial and mechanical design and software applications. The external interface relates to interface which is not physically part of the device but supports the use of the device: e.g. accessories, PC connectivity and add-on software. The service interface is understood as operator's or service provider's service, which the user can contact through the device user interface.

Different usability issues with mobile handheld devices have been studied not least because of their heavily adopted usage and large platform variety. The small physical size results in usability issues related to input mechanisms, usage ergonomics, and information visualization on the screen. Lots of existing usability literature is related to methods that are used in human-computer interaction research in general, but there exists also usability research which focuses on the special characteristics of the mobile domain. Examples of these are as studies comparing the strengths of laboratory and field tests (Duh *et al.* 2006), usability benchmarking of devices (Martin & Weiss 2006), and examining mobile phone use on the move (Roto *et al.* 2004). The growing use of mobile handheld devices has also incorporated into developing design guidelines for this specific

field. In Table 4, Weiss's design guidelines for handheld devices are shortly summarized (Weiss 2002: 66).

Table 4. Design guidelines for handheld devices according to Weiss (2002).

Guidelines	Comments
Design for Users on the Go	The user must be able to use the device in different contexts, often not fully focusing to its usage.
'Select' vs. 'Type'	Pay attention to which form of input should be selected. Text entry is often hard because of the small keypad.
Be Consistent	For instance, use the same terminology within and between the applications, and borrow from well-designed applications when UI standards or guidelines are not available.
Consistency between Platforms	Retain terminology and UI from desktop and other platforms, if appropriate.
Imply User Control	'No one wants to be controlled by technology.'
Design Stability	The user interface should stay stable even though wireless data connections are prone to failures.
Provide Feedback	Provide information to understand what the application is and what it does.
Forgiveness	UI must offer means to correct the user's possible errors.
Use Metaphors	Use metaphors from the real world.
Clickable Graphics should Look Clickable	Clickable-looking defined borders and/or high contrast to the background.
Use Icons to Clarify Concepts	Design icons as (simple) representations of concepts in order to provide users with additional assistance.

2.4 Bridging the Gap Between Usability and Context-Awareness Research

2.4.1 Usability Perspective in Current Context-Awareness Research

Concerns related to the use of context-aware devices have been pointed out, but so far the discussion has remained mainly on a speculative and conversational level, and not much attention has been devoted to the user interface design and interaction methods for context-aware applications. However, interaction design in a context-aware application becomes critical when developing products to large audiences, as poor design may e.g. bring up annoying or privacy violating issues (Erickson 2002).

When the literature of context-aware mobile applications is examined, one can easily notice that most of the studies merely concentrate on demonstrating the system level design or application concept and lack the design perspective that pays full attention to the usability issues. Mostly the research remains in the 'proof of concept' level. Typically this means that the systems have not necessarily been tried out with users, they have not

been publicly available for use, their functions are based on assumed rather than examined end-user needs, and no detailed attention has been devoted to the interaction flow or user interface design.

When user studies are reported in existing research articles, they have been carried out after implementing the system and concentrate on reporting the experiences gained with using the system - not for instance as a background information providing guidelines to the design leading to a certain interaction solution. Reports on design processes, iterations and usability performance are very rare. Commonly, the stated end-user needs are based on intuition, not on end-user studies, and the data behind the design solutions is not presented. However, some literature reporting usability related issues can be found.

The GUIDE tour guide is one of the rare ones that demonstrate long-term public usage and iterations in interaction design. Cheverst *et al.* (2001) consider the usability aspects when integrating information push feature to the GUIDE system. When introducing automatic information pull, there is a risk of overwriting the content the user was reading. To overcome this, the implementation employed a hold function with a notification when new information arrived, and an update button to display it.

Reported user experiences indicate that too complex user interfaces or including too many steps would decrease the user satisfaction with the device. In (Cheverst *et al.* 2001), increasing complexity in UI and any additional efforts required from the user were expressed as a concern. In the tour guide application, the push type information delivery was perceived as convenient. During user interviews it was also suggested, that in order to prevent errors, the device could prompt the users when they were about to make a navigation error and take the wrong path.

Barkhuus and Dey (2003) present a diary-study examining the level of usefulness and intrusiveness of context-aware mobile services. The study used imaginary context-aware services, which were demonstrated as using mobile phones as the platform. The results report that users were concerned of the lack of control, which - however - was perceived more acceptable if the application was seen useful enough.

Applications that tend to disturb users with unnecessary messages or interrupt their primary tasks do not meet the goals of smart devices, which should offer improved usability and flexibility. Interrubtability is an issue that has been discussed in several studies. A possiblity to block messages from a certain person (Persson *et al.* 2003), and creating user profiles to filter delivered advertisements (Ojala *et al.* 2003) have been demonstrated.

Moreover, users may not tolerate the sharing of their current location or give information about their current activities. For application design, these features may become crucial from the point of user acceptance. Demonstrated location-aware messaging systems typically take into account the role of privacy by distinguishing between personal and public messages. This feature has been used in E-Graffiti, GeoNotes, and InfoRadar systems (Burrell & Gay 2002, Persson *et al.* 2003, Rantanen *et al.* 2004). Potential usability risks have been identified also with diminished user control (Barkhuus & Dey 2003) and incorrectly executed device actions due to erroneous context recognition (Erickson 2002).

2.4.2 Interaction Design for Context

Among interaction design methods, there are practices which have a stronger connection to designing for context. Although their use is not limited to developing context-aware applications, they offer insight that is relevant in such a process.

Contextual design, which can be counted among UCD methods, emphasizes the importance of understanding the users in their natural use of context, and involves activities such as monitoring the users carrying out their tasks in authentic environment (Beyer & Holzblatt 1998). Contextual design is a methodology containing practices which are applied according to certain procedure from the early concepting to the last phases of the product or application design. Although the contextual design methodology was not developed for context-awareness, but user centric application design in general, its practices underlining involvement of the authentic use context may offer valuable information when incorporated in interaction design of context-aware applications.

Emphasizing the influence of use context has also been considered in few recently proposed design methods. Oulasvirta *et al.* (2003) introduce bodystorming sessions, where acting out the use situations in realistic usage environment to enhance the understanding the influence of the usage context. With the bodystorming method, the design team generates and preliminary assesses design ideas while the scenarios are acted out in realistic circumstances. Oulasvirta *et al.* (2003) report that bodystorming is an effective way of getting familiar with unfamiliar activities, and is more memorable and inspiring than conventional brainstorming sessions. Moreover, the design team which participated in the bodystorming sessions was able to more efficiently give immediate feedback for the created ideas. A similar approach has been introduced by Iacucci *et al.* (2000), where roleplaying the use situations has been used as a tool in the application concepting phase and included in a participatory design process. Here, the users and designers together refine design concepts by simulating or acting the usage situations in preferably authentic environment. Truong *et al.* (2004) have presented a survey method, where a cartoon illustrates the use scenarios within ubiquitous computing environment. The method was found as an applicable tool when explaining the possibilities of the technology which the users did not have previous experience, such as automated context-aware audiovideo capture in the home environment.

The aspect that designing for real life settings is different than laboratory environment is explicitly recognized in few context-awareness studies. The fact that the existing practices both in technology and culture affect to the way the applications will be used has been pointed out (Barkhuus & Dourish 2004). In the methodological side, Oulasvirta (2004) proposes a *humanistic research strategy* in order to find meaningful uses for context-aware technology. He is calling for relevance, understanding and user empowerment that the design should have as its goals.

2.4.3 Summarizing the Current Situation

Research on context-awareness has gained an increasing amount of attention during recent years, as can be seen from the numbers of publications, workshops, and dedicated

conference sessions. Despite of this, usability issues has received only little attention so far. Some usability risks related to context-aware mobile applications have been recognized, but not systematically inspected or charted. When the research reports on the studied usability issues, the evaluation typically takes place after the implementation phase, when the use of a ready-made system is assessed. There is evidence that the special features brought by context-awareness should be taken into account in the early phase of application design, but there are no examples of analytical steps carried out in this expedition, nor attempts to define how this could be done.

The design of context-aware mobile applications seems to follow very much the conventional design processes, not taking into account the special characteristics of such a system. As commercial mobile applications utilizing context-awareness are still almost non-existent, the design processes are still undeveloped. This is partly explained with the fact that most of the research is done in academic institutes and for non-profitable purposes. In that environment, it is often not critical to refine the usability issues of the system, and many projects demonstrating concepts may lack the resources to do professional level user interface design.

However, emerging technologies and increased attention towards context-aware technologies indicate that it is highly probable that in some point such features are commercially utilized. Currently, there is very little research published with the design methods for context-aware mobile applications. There exist no common practices that would take into account the special characteristics of context-aware applications, and only few examples that propose practical tools for designers. Therefore, there is a clear need to consider these aspects and to try to develop something that would offer hands-on help the future designers. The research on the UCD practices in industry shows that cost-factors play a significant role in selecting the methods (Mao *et al.* 2005). Thus, in order to have impact on product development, it is important to develop methods, which would be helpful for the designers, but also easy to apply in practice in terms of cost.

3 Research Methods in the Case Studies

This section describes the usability research methods used in the case studies reported in the thesis publications. In the following, user testing and field study methods are not described in general, because of the breadth of those disciplines, but rather the more detailed techniques used in the case studies are introduced.

The selected research methods reflect the nature of the conducted PhD research. The user study methods typically used in early design phases, when background knowledge is sought for application concepting, such as contextual enquiry and cultural probes, were not used as the author's research aimed to contribute to a somewhat later phase in the application design. Instead of charting fundamental end-user needs, the author wanted to have hands-on examples in order to provoke feedback from the users. This was achieved by applying different prototypes and demonstrators. The lack of existing context-aware systems, which could have been used for a long time period in real life settings, prevented the author from carrying out long-term field studies. The choice between methods providing similar type of knowledge of the problem area, e.g. using individual interviews instead of focus groups, was done from practical basis, as they lead to fundamentally similar results. User test sessions or interviews with individual participants were commonly used methods in the research traditions in the author's research community.

The studies employed several usability tests, which incorporated wizard-of-Oz and prototyping methods. The field study in *Publication IV* included the diary study method. In addition, interviews, surveys, the think-aloud protocol and use of scenarios were employed in the studies. Expert evaluation used in iterative development of design guidelines, carried out after *Publication VIII*, is explained in section 4.3.3.2 .

3.1 Use of Scenarios

> *'Scenarios are stories – stories about people and their activities. ...Scenarios highlight goals suggested by the appearance and behavior of the system; what people try to do with the system; what procedures are adopted, not adopted, carried out successfully or erroneously; and what interpretations people make of what happens to them' (Carroll 2000: 46).*

Scenarios are a widely used technique in interaction and usability research, and they are typically combined with some other technique(s), such as prototyping, to assist them. Scenarios can be characterised with a set of elements. A *setting* draws a picture of the environment, for instance a teenager sitting at home in the living room sofa, watching TV, having a mobile phone in his pocket. The scenario includes *agents* or *actors* who typically have *goals* or *objectives*, which are the changes the agent wants to accomplish in the circumstances of the settings. The scenario has a storyline or plot, which contain sequences of *actions* and *events*. Usually they are things the actors do or what happens to them, or changes in the circumstances of the settings. (Carroll 2000: 47)

The use of scenarios in user-centric design is recommended by several sources. Sing *et al.* (2004) propose that scenarios should be used in order to communicate understanding of the technology, its adequacy and appropriateness. Carroll points out that the scenarios make use of the design and enforce viewing it in a broader context, thus offering different insight to the designer. (Carroll 2000: 48).

Often the scenarios are used in studies where an imaginary situation with imaginary technology is considered. Although the method serves well in evoking conversation and new ideas, one can argue that the given scenarios may be unrealistic and easily miss out on things that would rise if the considered situation took place in real life. This is where integrating other techniques can complement the method. In the research carried out by the author, the scenarios were typically used together e.g. with paper prototyping and wizard-of-Oz, as in *Publications II* and *III*. In *Publications III,* the use of scenarios with real demonstrators operated in a field environment resembles the role-playing technique proposed by Iacucci *et al.* (2000). With *Publications VI* and *VII*, too, scenarios were used when users were asked to perform certain tasks with the investigated user interface.

3.2 Interviews and Surveys

Interviews and surveys are also widely used techniques for collecting information in HCI, and their nature may vary depending on the case. Often surveys are less time and money consuming and easier to arrange. However, in this thesis, interviewing was the dominantly used technique of these two. However, some of the studies employed survey-type interviews which were conducted e.g. adjunct to user testing.

Survey-type interviews related to author's research have mostly been carried out as written questionnaires rather than in an oral form. The surveys were used primarily in order to gather additional information in the user test situation to support the test findings. In the thesis, survey techniques have been used in a minor role in order to

collect essential information relating to the topic, such as to chart the subjects' previous experiences with mobile devices or context-awareness. Survey techniques have been used in research to which the author has contributed, but which are not included in the thesis. From the author's point of view, they act merely as supplementary material which exposes selected phenomena related to the mobile communication culture (Häkkilä & Chatfield 2005) and subjective understanding of context-awareness (Hiltunen *et al.* 2005).

In-depth interviews have been defined by Taylor & Bogdan (1998) as

> *'face-to-face encounters between the researcher and the informants directed toward understanding the informants' perspectives on their lives, experiences, or situations as expressed in their own words'.*

The nature of in-depth interviews is much more flexible and dynamic than that of survey-style interviews, and thus they suit well for exploratory charting of user experiences, opinions and attitudes, and the reasoning behind them. In-depth interviews had a significant role in *Publications II* and *III*.

3.3 Think-Aloud Protocol

The think-aloud protocol is a commonly used method in usability testing. Here, the users are asked to verbalize their thoughts while performing the tasks (Nielsen 1994). During this, minimal interaction with the usability test moderator takes place. The user is encouraged to express all kinds of thoughts related to the task, revealing information e.g. on overall understanding and expectations with the application, on performed actions with the user interface, and on its visual appearance. While the method has been criticised for its limitation for detecting the utility value of the system (Norgaard & Hornbak 2006), the method remains a very practical and popular method for recording feedback and assessing the user interface. The method was used in all studies in the thesis including usability testing.

3.4 Wizard-of-Oz

The wizard-of-Oz method is a widely used research technique within the field of human-computer interaction. With this method, the functions and behaviour of the device and its user interface are imitated so that the users believe they are interacting with a real, fully functional application. In reality, the device functions are executed by a test organizer, who, hidden from the user, controls the device behaviour and responds to the user's actions. The usefulness of the method is in that it enables experimenting with a functional device, but without the effort needed for an actual, full-scale implementation. The reactions of users are as they would be when operating a fully operational gadget, and thus give valuable and more reliable information of such aspects, which would be hard or impossible to reach e.g. with paper prototyping.

Wizard-of-Oz testing was found to be a fine method for collecting and testing ideas, as the cost and time efficiency would have been far worse had the experiments been carried out with a real prototype and infrastructure. The wizard-of-Oz method offers an easy way to carry out a relatively large number of experiments and allows for rapid prototyping of different ideas. The wizard-of-Oz method was used in the study described in *Publication III*, where location-aware information delivery to a mobile phone could be easily demonstrated with the multimedia messaging service.

3.5 Low and High Fidelity Prototyping

HCI research typically involves lots of prototyping. The forms of prototypes are diverse, and they vary according to the maturity of the concept or application. High and low fidelity prototypes both have their advantages and disadvantages. Low fidelity prototypes, such as paper prototypes or 'dummy' wax models of physical artefacts are used in the early phase of the design, whereas more advanced prototypes are typically employed in a later stage. Moreover, if user testing is conducted in non-laboratory settings, a quite advanced prototype may be easier to handle. Both approaches were used during the PhD research in order to collect data at different levels of the research problems.

Paper prototyping is a widely used technique in design and testing phases of applications, and it has been reported to be an effective tool in finding usability problems (Virzi *et al.* 1996). It has several features that make it a popular and well suited method. It is cheap and easy to implement, very flexible and easily editable. Minor errors in design can be corrected during the tests, and new ideas or design proposals quickly demonstrated (Rudd *et al.* 1996).

A paper prototype consists of a simplified layout of the device, where the key elements are shown. In practice, this means using pictures or drawings of the device and its user interface. Typically, a rough design of the actual device is used. For instance, with a mobile phone, the prototype typically shows the general shape of the device and approximate locations of input keys and the display. The device display is manually updated by placing a picture of the current screen layout according to the input and output actions. In the test situation, the test participant acts as a user of the device, and a test organizer performs the device reactions with the prototype. The users interact with the paper prototype e.g. by pointing the input elements and explaining what they do, and the monitor manually updates the appropriate screen layout to the prototype. Other present test organizers act as *observers* and take notes and keep record of the test session. The interaction and communication with the test participant is done by the *moderator*. Often two test organizers are present with the user, with one interacting with the user and the other being responsible for the prototype functionality.

The paper prototyping method in the research in this thesis has had a two-fold role. First, *Publication II* included low-fidelity prototyping, where the paper prototype was primarily used to communicate the principles, evoke ideas and arouse conversation on the topic while the test subjects were interviewed. Here, the paper prototype acted heavily as a support for the interviews. Paper prototyping was used for a different reason in

Publication VII, where the method was used in the early phase of application development to chart usability problems and iterate the particular design prior to the software implementation phase. Here, iterative approach employing paper prototyping was a cost-effective and efficient way to improve the design. In contrast to *Publication II*, the paper prototype used here was much more sophisticated, demonstrating the UI logic, graphics and design guidelines for S60 mobile phone applications.

Although low fidelity prototyping is a good method to be used in user interface design, there are also occasions where paper prototypes do not fit. Assessing e.g. the look-and-feel of the product or tactile feedback would require the use of industrial design and realistic mechanical solutions. Tasks that in real world conditions would contain time delays because of wireless data transfer, computer processing time, or ad-hoc service discovery, cannot be fully and genuinely simulated. However, when paper prototyping is used, and its restrictions taken into account, it offers an effective tool for exploratory research such as that introduced in this thesis, as it is an efficient way to experiment with different ideas.

Experimenting with functional devices, which employ the feature under investigation, brings new aspects to prototyping and usability testing. The restrictions set by the selected platform, application implementation and detection technology affect, for instance, the reliability, device response times and UI design of the application. The experiences and feedback received while using a high-fidelity demonstrator give valuable information of an application, which is one step closer to a commercial product. High-fidelity prototypes have proven to be valuable also when communicating the application and UI design principles to programmers and project consumers (Rudd *et al.* 1996).

If the usability research can be carried out outside of the laboratory environment, the better: here high-fidelity prototypes are often more useful. The unexpected occasions of a real-life environment, social issues in public use, and placing and handling the device while multitasking or focusing to something else are examples of situations, which are not producible in pre-set laboratory conditions.

Probably the biggest challenge with experimenting a real demonstrator is the effort needed to implement the demonstrator. It is time-consuming and often requires a long-lasting project involving several people. Due to these practical restrictions, the possibilities to utilize high-fidelity prototyping are often limited. (Rudd *et al.* 1996)

In this thesis, *Publications III*, *VI* and *VII* utilize a mobile phone as the demonstration platform, and thus represent high-fidelity prototyping. In addition to these, *Publication IV* concerns with the use of mobile phones and PDAs, although not in prototyping, but with functioning, real life mobile applications.

3.6 Diary Study Method

The diary study method aims at capturing the user's experiences with the application in real-life settings. In addition to diary studies, other methods that can be used to collect data from field use of applications include observational studies, interviews carried out in the field, automated logging of devices events, the experience sampling method (Convolso & Walker 2003), and quasi-experimentation, where the user's activities are

recorded with attached video cameras (Roto *et al.* 2004). Diary studies are typically used in long-term field studies, where data collection takes place over several days, often weeks. With the method, participants are asked to record activities that relate to the problem space or technology under investigation, while the researchers stay remote from the user and the reported use situations (Carter & Mankoff 2005).

The recordings for the diary are done by the user, and can utilize different technologies. Writing notes, taking photographs of a use situation, or audio recordings are typical inputs in diary entries (Carter & Mankoff 2005). During recent years, mobile technology has provided new tools for diary studies, as mobile phones' communication features ease the researchers' collection of the data (Palen & Salzman 2002). Moreover, a mobile phone integrating a camera can be used for recording different media. Traditionally, written diaries have been used for recording the participants' activities, and they are still a commonly used medium. The diaries can be very structured with specified questions and lists of ready-made options, or unstructured, providing merely spaces for describing the time and form of the activity. In addition to text and checkbox type entries, a diary can include e.g. drawings.

Diary studies can be divided into two main categories when examining the collected data. In elicitation studies, diary entries are used merely as prompts for discussion during the interview followed by the data gathering period, whereas in feedback studies the participants answer to predefined questions when reporting the events and the communication with the researcher is asynchronous (Carter & Mankoff 2005). Often, these methods are combined and the participants are interviewed after collecting the diaries, as this provides the researcher to do additional or more focused questions of the entries.

The diary study method utilizing a written, semi-structured diary was used in thesis *Publication IV.*

4 Contribution of the Thesis

In this chapter, the contributions of each publication are summarized. Publication I concentrates on a general framework, and examines mobile context-awareness from a more general point of view, whereas Publications II-VII deal with specific application areas of mobile context-awareness. Publication VIII considers the development of design guidelines for context-aware mobile devices. In the following, the original features of the publications are introduced, and they are compared to existing research literature. The publications are grouped and considered according to their themes.

This chapter can be divided into two main sections. In the first part, including sections 4.1 and 4.2 , *Publications I-VII* are introduced. They touch upon the general framework and case studies, and function as background studies for developing design guidelines. In the second part, section 4.3 , the design guidelines and their development is described, including *Publication VIII*.

4.1 Framework for Context-Aware Multimedia Applications (Publication I)

Publication I examines the general characteristics of context-awareness which relate to context-aware mobile applications. The authors focus especially on mobile multimedia, as this content is exceedingly relevant in the current and future mobile devices. The publication introduces a general framework, which represents the contextual information sources as they appear from the mobile communication viewpoint separating five different main categories - physical environment, device connectivity, user's actions, preferences, and social context - which emphasize the special characteristics of mobile communication technology.

Why 'yet another framework' for context-awareness? The framework presented in *Publication I* was evolutionally developed during the PhD research of the author. Earlier versions of Figure 2 in *Publication I* have often appeared in the presentations the author has given during the process, and has been frequently updated and modified when the framework has been refined. The figure has functioned as a summary when

communicating what context-awareness with mobile devices is all about, and the framework has developed from the basis of a pragmatic approach to explain and take into account the characteristics of mobile handheld devices. The emphasis is somewhat on mobile telecommunication terminals, since communication characteristics are highlighted, which is justified by the fact that mobile phones are the most widely spread handheld mobile computing devices. They have the potential to utilize context-aware applications that are used by hundreds of millions of people – or even more. The framework was developed because the existing ones were not seen as offering a good enough match to summarize the characteristics of context-awareness in relation to current device development trends. In that sense, the framework provided a quick, practical overview to the different aspects of context-awareness.

The publication also draws together a wider perspective of the field indicating directions where mobile multimedia devices are heading. Since multimedia features are becoming an integrated part of more and more mobile handheld devices, it is relevant to assume that the directions highlighted in the publication present quite general and common development trends. Such topics in rise are e.g. mobile TV[13], mobile communities utilizing mobile multimedia for sharing and collaboration, or using mobile multimedia to record personal history and for expressing personal style or creativity. An increasing number of recent publications in these areas also indicate that these trends are gaining momentum. Mobile TV has already dedicated user groups and service providers in Asia, e.g. in Korea, and the first devices focused to western markets are being introduced.

Similarly, there is only little data on mobile communities utilizing multimedia applications or sharing digital content, e.g. photos, music and video clips, on the move, but application or service concepts are being re-evaluated. Most of the studies with current technology relate to the use of camera phones, which can contain various types of user-created multimedia (Sarvas *et al.* 2004, Davis *et al.* 2005). Especially context-based metadata creation linked to multimedia content as well as metadata based annotation and sharing of digital photos has been examined.

As part of mobile multimedia research, mobile music and practices phenomena within the usage culture, e.g. the rapidly grown population of iPod users, has inspired research (Voida *et al.* 2005). Adding the context dimension to mobile music has been proposed in the Sonic City concept by Gaye *et al.* (2002), where music is dynamically composed from the surroundings of the mobile user.

In addition, other research that combines context-awareness and mobile multimedia has been recently published. In Schmidt *et al.* (2006), animated visualizations of mobile communication patterns are displayed on a mobile phone, thus providing information of user's context history. Another example of recording personal context history is to use mobile multimedia applications for creating a personal digital diary (Hartnell-Young and Vetere, 2005).

Above all, *Publication I* sought to be an overview to context-aware mobile multimedia applications. Taking into account the current research and industrial trends, one can claim the attempt quite successful.

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[13] The term *Mobile TV* is here used in a general sense to refer to a TV application running on a mobile, handheld device, and the distinctions between different underlying technologies are not considered.

4.2 Case Studies

4.2.1 User Experiences with Location-Aware Mobile Applications

Publications II, III and IV examine location-aware functionality of mobile handheld devices from a user-experience perspective. The publications consider separate systems, and different research methodologies were used in order to match the characteristics of each study. The studies examined location-awareness in systems representing a different maturity phase, so that Publication II studied an imaginary system with paper prototypes and in-depth interviews, Publication III applied the wizard-of-Oz technique carried out in a field environment, and Publication IV reported on user-experiences of the long-term usage of real-world location-aware mobile services collected with a diary study.

4.2.1.1 User Expectations with Location-Based Messaging (Publication II)

When doing the research for Publication II, the author could not find published research which concentrated on charting the end-user expectations of location-aware mobile services or on the uncertainties related to location-aware applications. Had end-user studies of the early design phase existed, none had been reported. The motivation of the research in this paper was to find out end user expectations when one did not have to be restricted by a specific implementation. The literature so far had considered specific cases and was rather technology-centered focusing on system architecture or implementation of location sensitive systems. The existing implementations considered a limited area or functionality, such as showing information of sightseeing places of a city center or campus area (Cheverst *et al.* 2000, Abowd *et al.* 1997), and they did not approach the user experience in location-awareness in a more general manner. Most of the research on context-awareness did not report user involvement, and if any user studies were described, they were not conducted in the early design phase, but rather after having a demonstration of a functioning system. The results then described the user experiences in respect to the specific project. The author, however, wanted to find out more general issues and carry out an in-depth interview which would give input on the very early phase of system design. This could be useful e.g. in the service concept design phase. Although Publication II does not seek to offer in-depth information on end-user needs, the results indicate some general trends to which attention should be paid.

The paper examines end-user expectations about what kind of information would be presented in location-aware services. The results point out that applying personalization or offering a possibility to filtering on services and information would be beneficial and desirable from the end-user point of view. The fear of spamming and unnecessary interruptions was evident and expressed very negatively.

The results also indicate that designing ontology which is intuitive and effective will be very demanding, and that categorizing services is a challenging task. The classes suggested were numerous and varied very much between the participants. What is more,

the categories' level of detail was varied. However, the idea of personalization was highly valued, e.g. with selected services or targeted notifications.

The results in *Publication II* also gave indications of end-user expectation and acceptability issues related to privacy and collaboration, which had not been reported before. The results reported findings on topics such as people's reluctance to share their own information depending on their context, and wish to form user-defined contact groups for different information sharing levels. These aspects were later studied in the research the author conducted later, and which are addressed in other of the thesis' publications.

Visualizing user's location in a way that indicated how accurate the information was, i.e. with a circle or probability cloud presented on the map, was perceived understandable and equal to - or better than - a conventional presentation with the 'red dot'. Especially the visualisation stability in relation to the detected location was valued. Studies that considered the understandability and preferences of presenting uncertainties in location detection to the user were not published before, and they still remain rare.

Later on, there has been more research on location-aware mobile services (Aalto *et al.* 2004, Kaasinen 2003). Yet today, there exists very few studies which examine user perceptions of location-sensitive mobile advertisement or notifications (Ojala 2003). This is partly explained by the lack of large-scale public systems that would allow for long-term usage and would employ e.g. commercial advertisements.

4.2.1.2 Categorizing and Modelling Location-Aware Applications (Publication III)

A preliminary version of Publication III was first published in the conference for Mobile and Ubiquitous Multimedia (MUM) 2004, where it was invited to the Journal of Mobile Multimedia. For this the paper was rewritten and complemented in theoretical sections. Thus, there was a remarkable temporal delay between the field study and publication dates, as the study was conducted already in January 2004.

Publication III introduced a categorization of location-aware mobile services, proposed a possible implementation mechanism, and reported on user feedback of location-aware messaging collected in a user study, which was organized in a field environment. The study involved receiving location-sensitive multimedia messages, which were categorized to three classes: notification, reminder and presence.

Summarizing the results related to user experiences highlights the following findings. Concerns for privacy were expressed especially with the presence type of notifications. As in *Publication II*, mobile advertisement received critique as annoying and privacy-threatening feature. The participants appreciated the functions having utility value, such as reminders and collaboration-oriented, personally targeted messages, which were seen as capable of e.g. saving time and helping in scheduling.

Creating personal profile(s) and filtering of incoming messages were seen as useful features. This finding was consistent with *Publication II*. The participants suggested different strategies to cope with different priority messages, such as having a different

notification tone for location-aware messages and messages for personal communication. Especially the ability to block commercial notifications was perceived as important.

Interestingly, the participants typically categorized the incoming messages after the sender, i.e. the user him/herself, friend, or another entity (advertiser or promoter), rather than the message function. Similar kinds of results have been reported by Lederer *et al.* (2003) when examining people's interruptability, where *who* was interrupting was perceived as more important than the cause of interruption.

The user study in *Publication III* was carried out in a controlled environment, which was set up in the field instead of a laboratory. This kind of set-up, which utilized a pre-defined and controlled test environment, but still involved authentic physical locations, operated on an off-the-shelf functional mobile device, and had a compact story line, has been rare in the research literature. Barkhuus & Dey (2003) used a wizard of Oz setting where the participants received context-aware mobile messages, but as the research used the diary study method, the location setting was not controlled as in *Publication III*. Iacucci *et al.* (2000) describe how role-playing has been used in participatory design for mobile context, but the research differs from aurthors' approach as we concentrate on the user experience, not on designing a process or method. Bohnenberger *et al.* (2005) have utilized a method similar to that of the authors: they simulatated location detection with virtual infrared beacons in their study on a location-aware shopping assistant. However, *Publication III* used mobile phone messaging, which is a familiar everyday concept to the users (and the study participants). Using a familiar technology in the study situation makes it easier for the participants to relate to the concept and to give realistic feedback.

When comparing our work to the literature from earlier research that had been carried out, the proposed categorization and the architectural elements for composition of location-aware messages were found novel. Earlier user studies with location-aware messaging had not concentrated on how participants categorized location-aware messages, and how their perceptions fit to the theory proposed by study organizers.

When conducting the research, the authors did not find any literature which was utilizing multimedia messages for location-aware applications. By choosing this communication channel, the authors proposed media available for large user groups owning MMS capable mobile phones. Later, the Rotuaari project also employed MMS messaging in location-sensitive advertising in summer 2004 as reported in *Publication IV*, but at the time the authors' research was conducted, the experiments reported deploying web-based mobile advertisement transmitted via WLAN to a handheld PDA (Ojala *et al.* 2003).

4.2.1.3 A Long Term Field Study of Location-Aware Applications (Publication IV)

Publication IV examined end-user experiences with the use of location-aware mobile applications during a long-term field study. This setting in its extent and public availability was unique in the world, especially as it was arranged in a city business district and had public and commercial entities participating in the form of mobile advertisers.

When reviewing the existing research literature on location-aware applications, one realizes that most of the systems have been developed into a phase where one can have a proof-of-concept which then may have been verified with a small user study. Often the application maturity level has not been sufficient to enable studies of long-term usage, or this has not even been in the focus of the research. Functioning large-scale systems which are open for public use have been exceptional, and realizing them in other than university campus settings has been extremely rare. The GUIDE project in Lancaster has been a positive exception in this field, as the ordinary visitors in the city have been able to get a handheld device running the location-aware tourist guide application (Cheverst *et al.* 2000). Another example of publicly available applications is the location sensitive museum guide, but these operate only in small, confined premises (Raptis *et al.* 2005).

The results reported in the paper show that when considering long-term usage, constrains of everyday life have a strong impact on application usage. Long connection times, slow downloading speed, and other temporal delays, as well as occasional system errors have a negative effect on user experience. This hinders the further use even if the users has had positive attitude towards the application itself. These are issues that are not reported in 'one-time trial' user studies, and where simulated systems or use situation cannot give realistic feedback. Albeit the users have a principle interest to try out new features, reliable and robust system functionality must be attained before users make the effort of using new applications. Seamless and comfortable usage, which fits into patterns of the user's life style, and providing content that matches the user's interests and needs are critical for creating a habit of frequent use.

In addition to the published results, going through the diary material also gave feedback and reported implications which affected the creation of the design guidelines. The material gave important knowledge of the use of location-aware mobile services 'in the settings of normal life'. The study illustrated how important it is to gather data from long term usage in real-life settings when context-sensitive applications or services are trialled. The threshold for using the application and how well it incorporates to the user's everyday activities can only be examined through a lengthy period of usage.

The data for the publication was collected as part of SmartRotuaari project, which was a three-year research project (06/2003-05/2006) in the University of Oulu[14]. An overview to the context-aware mobile services for Oulu city center that were developed during the project can be found in (Aalto *et al.* 2004, Ojala *et al.* 2003).

4.2.2 Context-Awareness for Sharing and Collaboration

Sharing and collaboration are significant themes among the context-awareness research. They relate to topics such as information access, privacy, security and trust, which are common topics in the area. The thesis Publications V and VI relate to these themes.

[14] http://www.rotuaari.net , last accessed 03 December 2006.

4.2.2.1 A Collaboration Framework for Mobile Context-Aware Collaboration (Publication V)

Publication V presents a framework for context-aware mobile collaboration and specifies different collaboration types. To clarify the area for concurrent and future research activities, the authors wanted to formulate an abstract level, consequential overview on how context-awareness could be implemented to collaborative tasks performed with mobile technology. When conducting the literature review, it was concluded that the topic had been only briefly touched in earlier research, and enhancing collaboration with context-awareness very much lacked a theoretical examination.

Publication V is primarily a theoretical overview of incorporating the context perspective to collaboration tasks. It carried on from the research done on mobile phones and computer supported collaborative work (CSCW) by adding context-awareness into the picture. The CSCW with mobile phones is defined to *'include two or more parties, at least one being a mobile terminal user, who interact with each other in order to complete a certain task'*. The forms of collaboration are divided into two main categories: distinguishing between community-mediated and service-mediated collaboration, where the latter can be initiated by request from the user or the service, i.e. the pull or push type, accordingly. The paper presents a framework of collaboration process with distinguished subtasks – initiating collaboration, conducting the collaborative task, and ending the task – and introduces how context-awareness can be employed to different stages of the process.

Collaboration itself has appeared in the field of context-awareness in different forms as part of a context-aware system, concept design or use cases. Using presence or availability information of the user to enhance the collaboration with peers has been studied with context-aware instant messaging in (Hansen & Damm 2002), and for increasing social awareness between hospital clinicians (Bardram & Hansen 2004). Utilizing context-awareness in healthcare has recently gained an increasing amount of attention, and tools that support collaboration among medical staff have been demonstrated, as e.g. patient record system in (Skow & Hoegh 2006). These examples, however, focus on discrete cases, and do not attempt to draw more general framework for mobile context-aware collaboration. Research published almost concurrently to *Publication V* has introduced few studies that consider the collaboration in higher abstraction level. Ferscha *et al.* (2004) propose context-awareness to be utilized in group interaction support in visualisation of location information, forming and managing groups, synchronous and asynchronous communication of groups, availability management, reminders, and recognition and notification of group meetings. Recently, the topic of context-aware collaboration has been approached by W. K. Edwards (2005), who in December 2005 published an article on context-enhanced collaborative applications and Intermezzo infrastructure project to support it.

4.2.2.2 Privacy Issues in Context-Aware Mobile Applications for Sharing (Publication VI)

Publication VI considers the privacy issues and information sharing related to mobile context-aware applications. Privacy issues relating to personal mobile content with off-the-shelf technology have been examined mostly without concerning context-awareness, merely concentrating on mobile communication culture (Häkkilä & Chatfield 2005). Privacy issues have also been touched as a subtopic in mobile context-aware literature, as with mobile messaging systems (Burrell & Gay 2002, Persson *et al.* 2003, Rantanen *et al.* 2004). Ubiquitous computing research, which has many contact points with context-awareness, has produced several studies on privacy (Lederer *et al.* 2003, Yee 2005, Langheinrich 2001).

For the study, the authors designed and implemented a simulation of an application, which runs on Series 60 mobile phones. With the application, the user could define different information items to be shared with people appearing in mobile phone contacts. The sharing could be triggered on and off with user-defined values of context attributes *time* and *location*. The application had a twofold purpose. Firstly, the understandability of user interface and application idea was examined, and secondly, the application functioned as a mediator for questionnaire-based interviews for charting user perceptions on privacy and information sharing. With this approach, the authors intended to get more realistic feedback, as the study participants could play with the application and it was set up to a familiar platform, a standard mobile phone.

The results indicated that the application was perceived as an efficient tool for information sharing, but privacy concerns remained. Interestingly, the privacy concerns mainly considered situations, where the users perceived themselves as the cause of the risk – e.g. by accidentally placing some confidential information under the wrong folder, or forgetting to change the settings. The participants defined several (2-6) groups of people with different privacy profiles, and the vast majority responded that they might define overlapping groups so that one person could belong to more than one privacy profile.

The study also demonstrated that careful UI design is required with context-aware applications. The users' interpretations of context attributes vary easily, and their understanding of constructing context-triggered rules may not be the same. Examples of this are defining exclusive rules and overlapping user groups, and in what way the Boolean logic (OR/AND) is used in rule construction. Results that support these findings can be found in other studies (Mäntyjärvi *et al.* 2003, Hiltunen *et al.* 2005).

Although work on privacy-aware design of smart appliances has been published, (Langheinrich 2001, Lederer *et al.* 2002), the author is not aware of corresponding user study demonstrated in *Publication VI* which presents mobile phone application distinguishing between different information types, groups and context-based sharing. Among context-aware mobile phone applications, utilizing metadata in mobile image sharing has recently gained attention (Davis *et al.* 2005, Sarvas *et al.* 2004, Sorvari *et al.* 2004).

4.2.3 Mobile End-User Programming Tool for Context-Aware Applications (Publication VII)

Publication VII introduces an end-user programming tool for mobile phone, which enables the end-user to configure context-triggered rules. The work relates to the larger research program examining context-aware mobile system related to the developed context framework (Korpipää 2005), where it contributed as providing a mature end-user application utilizing it.

Defining and understanding the current context of use in a manner that is unanimous to all users is hard and brings risks and difficulties for the usage of the context-aware application. Difficulties in designing intuitive and understandable user interface had been previously studied in (Mäntyjärvi *et al.* 2003), which gave strong indication that for intuitive rule construction, only one logical function should be used. These issues were carefully considered when doing the UI design for the application.

With ContextStudio mobile application introduced in *Publication VII*, the aim was to enable user control and to give the user some freedom to define application settings, but still maintain intuitive UI design without too complicated settings structures. The resulting, functioning S60 mobile phone application was unique in the world and, to the author's knowledge, contributed to the field as being the first mobile end-user programming tool for context-aware applications in a commercial mobile phone. The design process emphasized usability issues, and this principle was utilized e.g. with iterative usability testing.

Since, ContextStudio tool has been actively used in several research activities, as it has offered an easily configurable environment for mobile demonstrators. As an example of this, the author has used ContextStudio tool in usability tests held at Nokia, where different input elements were mapped to different output actions of mobile phone simulated with Macromedia Flash. The tool has proven its utility, maturity and efficiency in successful exploitation in practice.

To the author's knowledge, this type of fully mobile application that enables the end-user to configure context-aware trigger-reaction rules still has not been developed anywhere else. Rapid prototyping of context-aware applications has been developed in aCAPpella (Dey *et al.* 2004) and iStuff environments (Ballagas *et al.* 2006), but here the programming is done on a computer, not on the mobile device, and they are targeted to the developers rather than the end-users of context-aware applications.

4.3 Design Guidelines

4.3.1 General Process in Developing Design Guidelines

Because of the novelty of the field of context-awareness altogether, the existing research on the field has a strongly exploratory nature, and often a large number of different ideas are proposed and applied in the studies. The same applies to the research presented in the

thesis. Consisting of distinct studies with varying scope, the obtained material was thus relatively scattered. However, since the material was attained from different approaches or viewpoints, it also provided a broad view of the area and offered a good basis for building the overall picture.

The development of the design guidelines was also influenced by additional material than only the thesis publications. Existing literature, as well as research to which the author contributed, but which were not included in the thesis, offered additional information that helped in identifying central problems and phenomena with context-awareness and use of mobile handheld devices in general. They implicitly contributed as to development of design guidelines as they cumulated the author's knowledge on the topic. The process of developing guidelines can be illustrated with a graph presented in Fig. 4. The author's PhD research refers to thesis P*ublications II-VII*; Study I and II have been reported in *Publication VIII*, where design guidelines were presented for the first time.

The development of design guidelines was an iterative process, which did not end to the *Publication VIII*, as after that expert evaluation was carried out. This further research, however, was unpublished when submitting this PhD thesis, and thus the final version of proposed design guidelines including an iteration after feedback from expert evaluation is presented as a separate section.

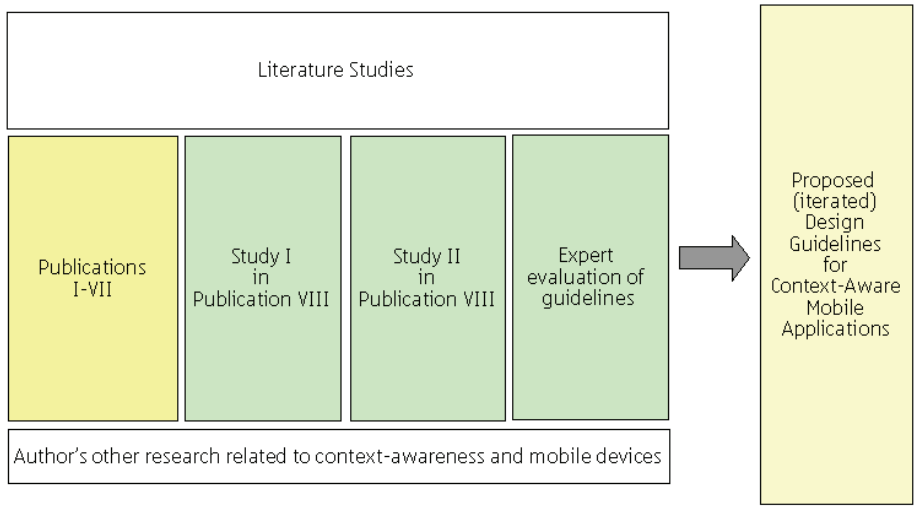

Fig. 4. Illustration of the iterative design guidelines development process.

Formulating design guidelines from distinct studies is an inductive research approach from its nature, and aims on building a theory, contrary to testing one (Strauss & Corbin 1990). Unlike the deductive research methods, which start from the prior hypothesis and move down to data to seek the confirmation for it (Strauss & Corbin 1990), the author started from individual studies, identifying, collecting and comparing the usability issues rising from them. The conducted studies recurrently addressed to certain themes and concepts.

4.3.2 Identifying Usability Risks

When going through several studies that chart user interaction and usability issues of context-aware mobile devices, i.e. the thesis publications and research literature, several themes related to potential usability risks arose. This section examines the means how usable context-aware mobile applications can be pursued by naming potential risk areas.

Table 5. Mobile device-related phenomena that motivate implementation of context-awareness (CA).

Phenomenon	Consequence	Link to CA
Increasing complexity of the devices	Number of applications grows; Device settings get more complex	Need for a quick access to applications and to menu selections; Need to simplify setting structures and automatic configuration of settings
Small device size	Limited input and output functionality	Slow input techniques and long navigation paths require more efficient input methods; Space for information presentation is limited, and the device should be able to decided which information is relevant to present
The same device design is intended for a large number of end-users, although personal needs vary	The device is not optimized for individual user's needs	Need for personal customization of device functionality
Mobile devices are used in various different kinds of situations	Different function priorities in different situations; Restrictions for the use may vary according the situation	Appropriate adaptation for different use situations is needed
Computing and battery capacity are limited	Only a limited number of actions or processes are run simultaneously	Need for optimization – appropriate device resource management according to the use situation
Growing number of mobile services	The possibilities for device usage can be multiplied	How to select the services relevant to the user and use them efficiently
Human behavior includes uncertainties	The device should support the unreliable human memory and dynamically changing intentions of the user	Need for memory aids, reminders and pre-scheduled actions; Need to support flexible management of actions

When starting to identify the usability risks, it is justified to start by considering what the motivations are behind integrating context-awareness into mobile devices. Table 5 draws together phenomena that create needs where context-awareness can assist. By examining the situation, context-awareness can help in overcoming several problematic issues that relate to user interaction with mobile handheld devices. The studies presented earlier in the thesis confirm that there exist numerous use cases where context-aware features can be valued by the users. Particularly this is confirmed with ContextStudio *Publication V*, as the long-term usage of it in the research and development facilities has proven the

application to be a useful tool. Thus, context-awareness can improve the usability of mobile devices, when it is designed in careful manner.

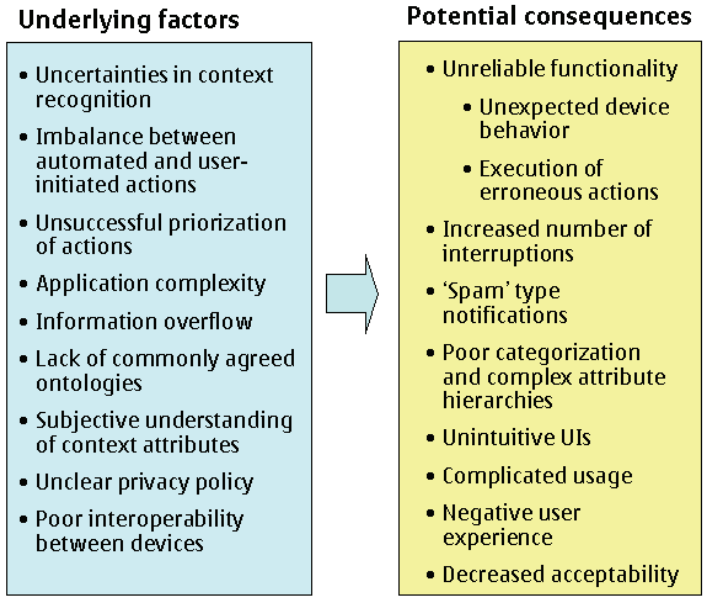

Fig. 5. Underlying factors and their potential consequences related to usability risks with context-aware mobile applications.

Distinct findings of individual studies (derived from the author's research and the literature) can be bound together to form more general outlines, which are introduced in the following and summarized in Fig. 5. A fundamental cause of potential usability risks consists of the uncertainties in context recognition, which can be due to different reasons, such as detection accuracy, information fusion, inferring logic or incompetent system architecture. This is a key question for designing the user interfaces, as it affects the selected features, their functionality and accuracy. In practice, e.g. automation level or variable scale resolutions may be designed differently if the confidence level of context recognition can be estimated correctly. Uncertainties are a part of the nature of context-aware applications. Thus it is important, that the application and UI designers have an understanding of the matter and can take it into account.

Although context-awareness is promoted with concepts such as 'automation of device actions' and 'proactive technology', these features have to be in balance with user control. Lack of user control can happen due to device automation, if context-triggered actions are executed or proactive device behavior is featured. Moreover, incorrect priorization of actions due to poor application or architecture design may lead to inappropriate or unexpected device behavior.

Application complexity has a tendency to grow when functions are added. This forms a potential usability risk in context-aware applications, which often use additional

information sources compared to the current technological solutions. Hiding complex technology but maintaining a sufficient level of transparency so that the user can still make sense of the actions the device is performing is a challenging issue. Subjective understanding of context attributes creates a problem for user interface design, as the measures, such as the light intensity or noise level in everyday life, are not commonly concerned as luxes or decibels. Instead, they are described in relative terms ‘dark’, ‘bright’, ‘silent’ or ‘loud’, which vary between people and situations. This risk is connected to the lack of commonly agreed ontologies, which would guide the development of context-aware applications. The difficulties in categorizing context attributes were evident from all thesis publications, which included dividing attributes into categories or hierarchies.

From the user point of view, the privacy aspect is often central. Lack of proper privacy policies and neglecting the aspect in design phase can lead to privacy violations. These are possible e.g. in presence type applications or if information sharing is involved.

Using contextual information sources can easily lead to information overflow, for instance in the cases of context-sensitive services. One can imagine a potential flow of incoming advertisements when entering a busy shopping street, if every shop was to send one to the device appearing in the radius of a hundred meters. Information overflow can be also employed in the situation, where too much information is tried to show in a small screen typical for a handheld device.

Yet another factor that can affect the usability is the interoperability between different devices and system. Poor interoperability may prevent seamless interaction between a selection of devices and users e.g. by blocking the use of services or preventing information from updating correctly. Poor interoperability often relates to the absence of standardisation and typically limits the application design and number of available services. Interoperability issues have gained increasingly much attention with the current trend of mobile convergence, where different mobile devices resemble more and more each other, and conventional boundaries between e.g. IP and cellular applications become vague.

The consequences resulting from usability risks, if fulfilled, may appear in several forms. The outcome can be an overall negative user experience, and can consist of several factors contributing to unsatisfactory result. It may result from increased number of interruptions, spam, and executing of erroneous or otherwise unintuitive device behavior. Unreliable device functionality and complicated use can lead to decreased acceptability of the context-aware features in general.

The user should be offered the possibility to use context-awareness rather than be forced to use it. This can be done by requesting confirmations before executing the actions, offering shortcuts, and perhaps in some cases by offering a possibility to switch between a context-aware and a non-context-aware application interface. If offered access to the context information, the user could e.g. check the definitions of context-attributes or edit them. Personalization offers a way to refine the application to better correspond to the user’s individual needs. Filtering could be applied to protect the user from spam and also for personalizing e.g. a user-defined selection of context-aware services or social groups. Enabling anonymity for securing user privacy is recommended especially for situations where information sharing is involved.

User-centric design practices offer a way to minimize at least some of the usability risks. Usability testing and user studies performed in authentic environment and iterative design are key elements to find well-performing UI solutions.

When the identified usability risks are compared the ones presented in research literature, one can notice that similar findings have been reported. Barkhuus & Dey (2003) report on users' perceived lack of control with automated context-aware device functions. Erickson (2002) points out socially unacceptable device behavior, such as erroneously automated loud alarms, which can be caused by misinterpretations in context-recognition. In the study on user needs of location-aware mobile services, Kaasinen (2003) reports on the users' criticism of selected design scenarios, e.g. proactive shopping and exhibition guides, which go too far beyond the real needs of people, and users' disapproval of over-controlled environment the context-aware applications may lead.

4.3.3 Guidelines for Usable Context-Aware Mobile Applications

4.3.3.1 Initial Guidelines (Publication VIII)

Publication VIII considers design guidelines, which have been developed by drawing together the knowledge gained in the earlier research. The motivation for developing the design guidelines was to offer tangible, hand-on help to application developers, who design context-aware mobile applications. In addition to proposing design guidelines, the paper presents a validation for them. The validation is based on two separate design exercises and the publication comprehends novelty in its design guideline proposals and their verification.

Assessing the guidelines has a central role in the publication. The validation was arranged in two separate design exercises, which incorporated people with different experience levels in interaction design and context-awareness. To ensure the validity of the results, the design assignment was carried out in two different university environments. The relative large number of the designs that were gained with this method was valuable.

Within the constrains of a PhD, there was no chance to arrange a product level application development or implement the guidelines to a large industrial process, where feedback would have been collected from many professional interaction designers. Although the setting was not an industrial one but rather a design assignment, it also somewhat simulates real-life circumstances, where the people affecting the decisions of application functionality may not necessarily have the expertise in usability or in the specific technology. Similar phenomenon has been discussed in (Kallio & Kekäläinen 2004).

The outcome of the design exercises reported in *Publication VIII* shows that the guidelines were perceived useful and they helped in the phase of developing the design. When pondering between different design solutions, the guidelines were used as a reference and to iterate and refine the design proposals. They were also used as

background literature in the beginning of the design task, and as a checklist in the end phase of the design exercise. Moreover, the guidelines were successfully used by the designers with varying backgrounds. However, the results also show that there were things that could be improved. This matter is treated in the next section.

When examining the literature, the author has not been able to find similar attempts for providing and evaluating design guidelines for context-aware mobile applications. Dey & Mankoff (2005) consider designing for ambiguity with context-aware applications. When unsure of the user's intentions, the application can use mediation techniques to request the user's actual objective. Related to design of context application, Raptis *et al.* (2005) aim to look at design requirements for context-aware applications in the museum domain, but the paper remains on an abstract level and does not offer concrete proposals for UI designers, and thus also lacks an evaluation part. Concentrating on general rather than interaction design, Lei *et al.* (2002) ask for privacy, quality of service, and extensibility when designing context-aware services.

4.3.3.2 Refining the Guidelines

Validation for the design guidelines presented in Publication VIII encouraged iterating the guidelines for a revision. Few of the proposed guidelines in Publication VIII were found to be too wide or overlapping with each other. Moreover, some guidelines were perceived to contradict each other in some situations (e.g. 'Prevention from interruptions' vs. 'Secure user's control'). In addition, examples of good or bad design decisions would have been seen useful. This particular issue was found to be problematic from the author's behalf, as there still exist very few examples of context-aware mobile applications – published research did not offer systematic reports on the matter, and commercial products to be evaluated were not available.

To add to the guideline evaluation presented in *Publication VIII* the viewpoint of professional designers, an additional study was arranged. Four industry professionals that were experts in context-awareness and/or mobile HCI and UI design were asked to assess the guidelines in face-to-face interviews. This expert evaluation was then used as a complementary feedback for the results gained in order to develop the guidelines further. The expert evaluation took place in Tampere, Finland, during one day, and involved four researchers from the Nokia Research Center. Three of the researchers had more than five years research experience in the company, whereas one had four years and additional previous experience in academia. Two of them were specialized on mobile context-awareness, whereas the main expertise of two lay on the field of graphical user interface. When the role of the experts is considered, the former ones can be seen to contribute into the developing and the latter ones exploiting context-awareness for mobile handheld devices.

The expert evaluation loosely followed the expert evaluation used as a usability inspection method, although the item under examination was a set of design guidelines, not a user interface, as typical in an evaluation session. Each researcher was given the set of guidelines, presented in *Publication VIII*, which they were asked to read. After that, the guidelines were discussed with the author, both going them through one by one, and

discussing the set as a whole. Each interview lasted approximately for 20-45 minutes. The interviews were followed by informal group conversation, with two or more of the experts present at a time. In addition, an in-depth telephone conversation over two hours was arranged afterwards with one of the experts, where the expert evaluation comments were reflected and discussed. After the expert evaluation, the author gathered and grouped the feedback on the guidelines around different themes, considering guidelines both individually and as a whole set.

The gained feedback from experts was perceived valuable as it pointed out issues from a different perspective than the design exercises had done. The experts could assess the guidelines from the professional, pragmatic point of view, and emphasize issues based on their personal experience with the topic. Their background with working in industry offered information of what was considered helpful in practice to help designers and application developers.

The central theme emerging from the interviews was that the guidelines pointed to the right direction, but the individual guidelines were somewhat fuzzy and their formulation weak, and the fundamental ideas should be clarified and presented in a more logical order. Cutting the overlaps and addressing one thing at a time were seen to improve the understandability and to make the presentation more solid.

As a result, the presentation order and grouping of the guidelines was refined to better support the reader. The first three guidelines in the refined set deal with the application automation and control. The fundamental underlying decision that the designer has to take, i.e. selecting the automation level for the context-aware application, was presented first. This was followed by guidelines of user control and interruptions, as they link to the same issue. The dealing with uncertainty, appearing as a separate guideline in *Publication VIII*, was removed as a guideline itself and was incorporated to other guidelines, as it was perceived to merge into them in a logical manner. What is more, the *Publication VIII* guideline about accessing the context information was removed as it was found too vague and even confusing, and its themes were included in the refined guidelines considering automation and user control.

The next two guidelines (4 and 5 in the refined set) consider the information presentation: information overflow and visibility of system status. The last group of guidelines (6, 7 and 8 in the refined set) deal with other issues that were perceived especially relevant: personalization, privacy and social context. Whereas personalization and privacy appear as separate guidelines already in *Publication VIII,* the role of social context needed highlighting, as it is emphasized with mobile devices, which are used in different kind of social environments and often in public. Dedicating social context a separate guideline also clarified the privacy guideline, which had included some similar aspects in *Publication VIII*.

The guideline 6 in *Publication VIII* ‘Remember mobility’ was removed as it was perceived somewhat self-evident, and was not seen to offer much extra value in this context. Moreover, the guideline 10 in *Publication VIII* was excluded. It was decided that the issues on overall utility of the context-aware technology and emphasis of user centric design were better handled separately, and they were included as an introductory part of the design guidelines, as presented in Section 4.3.3.3 .

4.3.3.3 Refined Design Guidelines

In this section, the iterated design guidelines are presented, preceded with a short introduction.

When a context-aware application is being developed, one has to carefully concider what is the ultimate value of it – what is gained by implementing context-awareness to the specific application. The utility value, i.e. what is gained by adding context-awareness to the application, is emphasized, as context-awareness typically employs more risks than having a conventional, non-context-aware solution. As context-awareness inevitably employs uncertainties, it is important that there are clear benefits that pursue the use of the application, even if there is a risk it performing not with 100% reliability in some occasions. In addition, one should exploit the approach where the user is offered a possibility rather than forced the use of context-awareness.

The system and its functionality are often described with mental models that people form from the system. The way how the system and its functionality are seen depends on the viewpoints considered – the mental model of the observer. According to Norman (1990), one can distinguish between the designer's model and the user's model. The designer's model infers to the designer's understanding and idea of the artefact to be constructed, whereas the user's model is the user's conceptual model of the same artefact, its features and functionality, which has developed through interaction with the system. In order to respond to the user's needs, efficiently fulfill the user's goals and satisfy the user's expectations, the designer's and user's understanding of the device or application should be consistent with each other, in other words, the user's model and the designer's model should be the same (Norman 1990).

With context-awareness, involvement with users should be strongly emphasized during the design process and a user centric design approach is especially critical. The consistency between the designer's and user's mental models should be checked, as context-aware systems are complex and often incorporate proactive or automated devices actions, which, if poorly designed, may not be intuitive user interfaces. The designs should be tested with users, and involving authentic environment should be preferred to laboratory environments as the context of use is a key part of the system functionality.

Guidelines 1-5 relate to the uncertain nature of the context-awareness. They are connected to the system level decision-making mechanisms, and which should be considered when designing the user interface. Guidelines 6-8 relate to principles other than uncertainty issues that should be considered when designing and implementing the application. Guidelines are referred to with the abbreviation GL.

GL1. Select appropriate level of automation. With the selected level of automation the author refers to automatic, semi-automatic and manual execution of actions (Mäntyjärvi *et al.* 2003). Level of automation must be considered in relation to the overall application design, as it affects the numerous solutions in the user interface design. The more uncertainties are involved in context-recognition, the more important it is not to automate actions. The automation level has also a straight link to user control, and its selection affects heavily the upcoming interruptions.

GL 2. Ensure user's control. The user has to maintain the feeling of control over the device. The ideology on the background is that the user, who originally has full control

over the device, has voluntarily given some of it to the device in order to ease the use of the device, but can also regain this control whenever wished. The willingness to do that can happen due to two basic scenarios – either the device is performing erroneous actions, and the user wants to take a corrective action, or the user just wishes to take full control for personal reasons which do not necessarily have any rational reasons (because that is what we humans do). The user has to have enough knowledge of the context-aware application and the device functionality in order to recognize malfunctioning, at least when errors in context-recognition lead to critical actions. The perception of user control is diminished if the device behaves in any unexpected manner or if the users have a feeling that the device is performing actions without their knowing about it. User control can be implemented e.g. with confirmation dialogues, which however has to be balanced with GL3.

GL3. Avoid unnecessary interruptions. Every time the users are interrupted, they are distracted from the currently active task – something is always paused or at least distracted, which, by default, is a negative occurrence. If the interruption is caused by something that has a high enough priority, allowing the interruption is positive functionality. Examples of these are reminders and the alarm clock. The user's interruptability depends on the context, and the user's threshold for putting up with intrusion may vary accordingly. It should also be remembered that some issues may have a nature that the user may want them to override all other ongoing tasks. This comes down to user control (GL2).

GL4. Avoid information overflow. The throughput of the information channels to the user is limited, and user can fully focus only on one task at time. When several different tasks or events compete on the channel, the priority order needs to be defined. Moreover, the threshold for determining the event's relevancy in the context must be considered in order to avoid unnecessary interruptions (GL3). For example, do not present too much information at once, and implement filtering techniques to avoid spam type messages. In addition, it is important to maintain the understandability of the system, and arrange the information in a meaningful manner.

GL 5. Appropriate visibility level of system status. The visibility level has to be sufficient for the user to be aware of the device actions. The contextual information should be presented in an appropriate level so that the user does not get confused and can still understand what is going on and why the application is acting as it does. If more uncertainty in context-awareness is involved, the visibility of system status should be stronger in order to allow the user to recognize the risk level and possible malfunctions. The visibility level is also related to the priority values, and the user should be informed e.g. of important actions or changes in context. The information of system status can also be applied in persuasive manner, where ambient information presentation in the peripheral is dynamically made more visible if the importance value grows, and may eventually lead to an interruption event to the user if its value high enough.

GL 6. Personalization for individual needs. Context-awareness should cause the device functionality to respond better to the individual user's personal needs. Consider how the user's individual needs or preferences can be taken into account. The preferences may change over the time, and possibility to adjust them can be provided e.g. implicitly with learning techniques or explicitly with user input settings. For instance, an application can implement filtering according to the user's personal preferences.

Personalization may be used also in respect to the subjective understanding of context attributes. Allowing the user to name or change context attributes, such as location names or temperature limits, may contribute to better user satisfaction and ease of use.

GL 7. Secure the user's privacy. Privacy is a central theme with personal devices, especially with communication ones, and affects e.g. on trust, intensity of use, and application acceptability. Special care should be taken with applications employing information sharing. The privacy requirements often vary between who is requesting the information, and different levels of privacy should be supported. If necessary, users should have a possibility to remain anonymous.

GL 8. Take into account the impact of the social context. Consider possible effects of social context in relation to the application. In some social context, certain device or user behavior may be considered awkward or even unacceptable. Social context has also effect on interruptability. For example, a volume alert may be considered as inappropriate device behavior in some social context.

4.4 Summarizing Answers to the Research Questions

In the beginning of this thesis, certain research questions were set to be answered. These questions were

- *Can context-awareness increase the usability of mobile handheld devices?*
- *What are the potential usability risks of context-aware mobile handheld applications?*
- *What are the design guidelines to facilitate successful interaction design of usable context-aware mobile applications?*

This section draws together the answers that can be derived from the thesis research.

First we consider the question if context-awareness can increase the usability of mobile handheld devices. The development trends with mobile devices point to the direction where they are becoming increasingly complex. At the same time, the restrictions set especially by the device size have remained quite much the same. This indicates that designing user interfaces where with good usability becomes more and more challenging, and if no new approaches are introduced beside the conventional solutions, there is a risk that the usability of the devices may decrease drastically. Context-awareness can increase the device usability, i.e. efficiency, effectiveness and subjective user satisfaction, as it can offer solutions to different risk areas which demand improvements, as summarized in Table 5.

The case studies presented in this thesis demonstrate that context-awareness is a potential technique for enhancing interaction, as there was seen value in the presented applications or concepts. Providing a quick access to situationally appropriate device functions, or automatic instead of manual, configuration of settings in *Publication VII* lead to improvements in efficiency and effectiveness in device usage. Enhancing communication between people, providing reminders and memory aids, and offering navigation help (*Publications II, III, IV, VI*) are areas where context-awareness can support users to perform their tasks better or quicker, and thus a context-aware device performs as a more efficient and effective tool for them. The results of the case studies

also indicate that subjective user satisfaction with the applications can be increased if the user can be provided right information in the right place (*Publications II, III, IV*), or ease by providing automated for information sharing *(Publications VI)*. Context-aware personalization according to the user's individual needs was also perceived as a valuable feature, resulting in better satisfaction with the application *(Publications II, III, VI)*. However, evidence of improvements in user satisfaction is hard to provide without studies on using context-aware applications in real-life settings, and this aspect requires further research.

Despite of the positive sides described above, the studies introduced in the thesis also show that in order to gain improved usability through applying context-awareness, careful design is needed. This is evident from the findings of the case studies presented in the thesis, as each of them revealed potential risks with could occur with an ill-designed application. Thus, the answer to the research question whether context-awareness can improve the usability is only conditionally 'yes'.

What comes to charting potential usability risks with context-aware mobile devices, this thesis has exposed several issues that must be considered, illustrated in Fig. 5. The application's failure to perform with satisfactory usability can be caused by several sources that can occur in different level of the system design, as illustrated in Fig. 1 in *Publication VIII*.

Finally, we address the question what are the guidelines to increase the usability of context-aware mobile handheld applications. In this thesis, the author has developed design guidelines for context-aware mobile applications, which have been evaluated in several steps and iterated to a revised form. The revised guidelines, consisting of eight statements, have been described in Section 4.3.3.3 , and summarized again here:

GL1. Select appropriate level of automation
GL 2. Ensure user's control
GL3. Avoid unnecessary interruptions
GL4. Avoid information overflow
GL 5. Appropriate visibility level of system status
GL 6. Personalization for individual's needs
GL 7. Secure the user's privacy
GL 8.Take into account the impact of social context

When designing context-aware applications, the two fundamental issues affecting the usability must be taken into account. Firstly, one has to carefully consider if context-awareness adds value to the application. Because context-awareness inevitably includes dealing with uncertainties that can be traced down to the underlying SW and HW solutions, it also employs risks which threaten the ideal of a 100% correct and reliable device behavior. Therefore, as there are risks, there also has to be benefits to make context awareness feasible. We must bear in mind that it may not suit all application types. Secondly, the user-centric design approach must be emphasized. Involvement of users in different phases of the design process, carrying out usability tests, and testing the application in authentic environment become especially important. For instance, subjective understanding of context that occurs with individual users (Hiltunen *et al.* 2005, Mäntyjärvi *et al.* 2003) is a phenomenon which creates a risk that the designer's and user's mental models of the application do not fully correspond to each other. This

should be studied through user testing. On the other hand, testing the application in authentic environment is important due the fundamental nature of context-awareness. Functionality of context-aware applications cannot be reliably evaluated if it is separated from the context itself. The use context involves variables that alter and may sometimes change in unexpected manner, affecting the behavior of the device. Hence it is important that the testing take place in the kind of environment where the application is intended to be used.

5 Discussion

There are still numerous areas to be charted and areas explored before context-awareness has matured into a field which nurtures solid industrial applications and established practices in design and implementation. The novelty of the field is demonstrated in the existing research and literature, which rarely employs systems that have been built for long-term use or for real-world applications. Most of the context-aware systems or applications referred to in the research literature have their focus on '(just) to get them work', to have a proof of concept, or to demonstrate a functioning architecture or system-level design. Grounding the research to end-user needs is still weak, and the way to produce applications, which have gone through a design cycle typical for industrial quality, is still long.

The author believes that part of the value of this thesis lies in its cross-disciplinary nature, as it cuts across very different aspects of mobile context-awareness and brings together areas that traditionally are rarely combined, partly because research groups typically do not have so multidisciplinary expertise represented. Versatile studies all gathered around mobile context-awareness have provided a good overview to the interaction issues and given background to identifying usability problems that are based on study findings rather than intuition.

The application area demonstrated the most in mobile context-awareness focuses on location sensitive applications, which is somewhat emphasized also in the case studies presented in this thesis. Location-aware applications form an important part of mobile context-awareness, as they employ easily identified use cases and a relatively mature technology, and thus have great potential for new business areas. Location-awareness has also been a pioneer in introducing context-awareness to large user groups, as its technical implementation does not necessarily require much effort and can already be realized e.g. by using cellular ID information and off-the-shelf end-user devices.

Information sharing and collaboration are emerging themes, which have provoked interest in both the commercial and academic communities e.g. with peer-to-peer applications or metadata-related information retrieval and sharing. The end-user programming of context-aware mobile applications is an interesting topic as it offers information for user-configurable application settings, which are likely needed in many applications.

Starting to work on a PhD in an area which was (and still is) as fuzzy and unexplored as interaction and usability within context-awareness, was demanding - there was no clear starting point or hardly anything on which to build. On the other hand, the area was genuinely fascinating, as new and unreported issues were found frequently. In fact, this happened to the extent where one had difficulties in deciding what area to look at next, and the author often felt as if being spoilt with choices. The research field was found so wide and yet undeveloped that many issues remained unexplored and virtually cry for further study.

The research was challenging also from a methodological point of view, as selecting the appropriate research methods for the large number of versatile and somewhat scattered studies was demanding. On the other hand, the use of a variety of different approaches gave valuable insight into the methodological aspects, highlighting e.g. which factors should be emphasized to achieve more reliable study results. The user testing outside of laboratory was found to be valuable, as it clearly inspired the participant to give feedback and also focused attention to practical issues that would have easily been neglected in testing the application in a laboratory, such as the influence of the user's walking speed or the system's temporal latencies. Moreover, the experiences exposed that it is important to conduct long-term user studies, as the features and reliability of context-aware applications cannot be extensively tested in short sessions because of the dynamic nature of the context of use.

A major problem in carrying out exploratory research in such a rapidly developing field is the difficulty to decide 'when is enough': where to stop and wrap up the research, especially when it should contribute to a solid entity such as a PhD thesis. The pace of progress in the field of information and communication technology is so fast that many research results become out-dated in a few years. The temptation to carry on and continue with one more study which would utilize newer technology or use new findings that were just published somewhere is great.

This was found to be especially true when developing the design guidelines, while iteration could have gone on forever; knowledge of the design problematic grows all the time as the field matures and practical experience is gained. However, there is a great need for design guidelines when a technology is still very young, and having something helpful ready as soon as possible is desirable. The author does not claim the proposed design guidelines to be the last and ultimate ones. Rather, they are a first attempt to break down the problem area to some concrete and formulated points, and they seek to offer some practical help when developing mobile context-aware applications. The author's involvement with mobile industry has offered a perspective into practices that relate to designing user interfaces for mobile applications. This has motivated the development of the design guidelines, as in these settings there is often a need for tangible, packaged guidance that can offer background information and advice in a practical form.

The rapid development on the field can already be seen within the time scale of the thesis publications, where the earliest research took place in 2003. Since that, there has been much technical and research progress on both mobile devices and context-awareness. The importance of the themes considered in the thesis is illustrated by the constant flow of new research papers published on these topics.

6 Conclusions

Context-awareness is a potential technology for mobile devices, as it can be seen to respond the challenges set by the current development trends in the area. Context-awareness can facilitate the device use in demanding situations by dynamically adapting the device behaviour by appropriate means which can be due to e.g. more complex devices, versatile use environment, limited size of the devices, and growing number of services.

Context-awareness is a young field, and the research done on the area is still very exploratory or demonstrative in nature. Much of the research concentrates on system-level development or context recognition, and human-computer interaction issues have been investigated only scarcely. Getting acquainted with the research and literature on the field of context-awareness has shown that, to a great extent, the current research lacks the aspects of human-computer interaction and usability. The existing research involving interaction design or user studies has typically concentrated on verifying distinct applications, and the published results in the area are narrowly focused and scattered. There is a need for a systematic approach that charts potential risks related to interaction and usability issues, and formulates the identified themes in a more generic framework.

Designing context-aware applications is challenging. The technology itself is rather complex and involves several underlying layers that contribute to the final outcome, such as sensor technologies, system architecture, and inferring logic design. Context-awareness employs uncertainties that affect the reliability of the application. In addition to technical challenges, there exist also user-related issues, such as subjective understanding the context or comprehension of trigger-action rules, which influence the interaction design. This thesis sought to chart the issues and risks that relate to usability of context-aware mobile devices, and to develop design guidelines that would help in designing usable applications. When applications and devices for large audiences are developed, the interaction and usability issues need to be seriously considered, as they can have critical effect on the product's success in the market.

In this thesis the author has studied the user interaction issues related to context-aware mobile devices by conducting several case studies, which relate to location-awareness, information sharing and collaboration, privacy, and end-user programming with context-aware mobile applications. These studies were used as the basis for developing design

guidelines, which were then evaluated and iterated. The revised guidelines seek to offer some tangible help to designers, who are not necessarily specialized either in context-awareness or interaction design.

The design guidelines include factors related to the uncertain character of context-awareness. An appropriate level of automation for executing actions needs to be selected, and user control secured, so that the user maintains control over the device in any situation. Relating to the uncertainties in context recognition, user control and user's interruptability must be balanced and appropriate visibility to system status provided. As context-awareness may generate or offer access to large amounts of data or services, it is important also to avoid information overflow. Moreover, the application design should respond to the user's needs on personalization and privacy, and to take into account the restrictions of the social context of the use situation.

It is important to consider the utility value the implementation of context-awareness brings to the application. Since applying context-awareness inevitably brings greater risks to the device functionality and reliability, the gained benefits must be high enough to choose the technology over a conventional approach. When designing the applications, user involvement during the design process is important. What is more, testing the design in a field environment, where the device is meant to be used, is essential. A context-aware application cannot be fully evaluated without the use context, as adaptation to the changing context is a fundamental part of their functionality.

Current state of the technology does not yet offer many experiences on context-aware mobile applications in every-day life, as fully functional systems that enable long-term usage with large user groups are still extremely rare. Designing usable context-aware applications will set challenges, but the field also offers much potential for the development of new applications and improved device functionality. The high adaptation rate of mobile devices makes the topic interesting also for larger audiences.

For future work, the proposed design guidelines can be iterated and developed further, and using them in application design would certainly provide valuable insight for their utility. As a step toward this direction, the author is planning to arrange a controlled design exercise to evaluate the refined guidelines presented in this thesis, and to publish the results.

The thesis has also touched upon many subtopics among context-aware mobile applications, which offer interesting future research areas. Privacy-related issues with information sharing e.g. related to the user's own context or user-created content, preferred or sufficient accuracy and scale with location-sensitive mobile applications, and appropriate application automation level are examples of topics, which would benefit from more extensive studies. When the technology matures, running long term usability studies and trying out context-aware applications with large user groups in real-life settings becomes easier, and will inevitably offer new information to the research community. After all, emerging practices with context-aware applications and their utility value for users are issues, which can only be studied reliably with an adequate adoption rate of context-aware devices, applications and services.

When considering future research, one can conclude that with a topic applicable to so many areas among mobile devices and human computer interaction, the research on usability issues with context-aware mobile application has still a lot to explore.

References

Aalto L, Göthlin N, Korhonen J & Ojala T (2004) Bluetooth and WAP Push based location-aware mobile advertising system Proc. Second International Conference on Mobile Systems, Applications and Services, Boston, MA, 49 - 58.

Abowd G (1999) Classroom 2000: An Experiment with the Instrumentation of a Living Educational Environment. IBM Systems Journal, Special issue on Pervasive Computing 38(4): 508-530.

Abowd GD, Atkeson CG, Hong J, Long S, Kooper R & Pinkerton M (1997) Cyberguide: A Mobile Context-Aware Tour Guide. ACM Wireless Networks 3: 421-433.

Ark WS & Selker T (1999) A Look at Human Interacton with Pervasive Computers. IBM Systems Journal38(4): 504-507.

Ballagas R, Memon R, Reiners R & Borchers J (2006) iStuff Mobile: prototyping interactions for mobile phones in interactive spaces. In Proceedings of Pervasive 2006 Workshop on Pervasive Mobile Interaction Devices (PERMID 2006).

Bardram JE (2004) Application of Context-Aware Computing in Hospital Work – Examples and Design Principles. In Proceedings of ACM Symposium on Applied Computing: 1574 – 1579.

Bardram JE & Hansen TR (2004) The AWARE Architecture: Supporting Context-Mediated Social Awareness in Mobile Cooperation. In Proceedings of CSCW'04: 192-201.

Barkhuus L & Dey A (2003) Is Context-Awareness Taking Control Away from the User? Three Levels of Interactivity Examined. In Proceedings of Ubicomp 2003: 159-166.

Barkhuus L & Dourish P (2004) Everyday Encounters with Context-Aware Computing in a Campus Environment. In Proceedings of Ubicomp 2004: 232-249.

Beigl M, Zimmer T, Krohn A, Decker C & Robinson P (2003) Smart-Its – Communication and Sensing Technology for UbiComp Environments. Technical Report 2.

Beyer H & Holtzblatt K (1998) Contextual Desing: Designing customer-centered systems. Morgan Kaufnamm Publisher, San Francisco CA.

Bohnenberger T, Jacobs O & Jameson A (2005) DTP meets user requirements: Enhancements and studies of an intelligent shopping guide. Proceedings of the Third International Conference on Pervasive Computing (PERVASIVE-05). Munich, Germany.

Borriello G, Liu A, Offer T, Palistrant C & Sharp R (2005) WALRUS: Wireless, Acoustic, Location with Room-Level Resolution using Ultrasound. In Proc, of the 3rd International Conference on Mobile systems, application andn services, MobiSys'05.

Brewster SA (2002) Overcoming the Lack of Screen Space on Mobile Computers. Personal and Ubiquitous Computing 6(3):188-205.

Brodersen C & Kristensen JF (2004) Interaction through Negotiation. Proc. NordiCHI'04: 259-268.

Brown LM, Brewster SA & Purchase HC (2006) Multidimensional Tactons for Non-visual Information Presentation in Mobile Devices. In Proceedings of MobileHCI'06: 231-238.

Burrell J & Gay GK (2002) E-graffiti: Evaluating Real-World Use of a Context-Aware System. Interacting with Computers 14: 301-312.

Carroll JM (2000)Making of Use. Scenario-based design of human-computer interactions. (Chapter 8, Chapter 10). The MIT Press.

Carter S & Mankoff J (2005) When Participants Do the Capturing: The Role of Media in Diary Studies. In Proceedings of CHI 2005, ACM Press: 899-908.

Chen G & Kotz D (2000) A Survey of Context-Aware Mobile Computing Research. Dartmouth Computer Science Technical Report TR2000-381.

Cheverst K, Davies N, Mitchell K & Friday A (2000) Experiences of Developing and Deploying a Context-Aware Tourist Guide: The GUIDE Project. In Proceedings of the 6th annual international conference on Mobile computing and networking (MobiCom) 2000: 20-31.

Cheverst K, Mitchell K & Davies N (2001) Investigating Context-Aware Information Push vs. Information Pull to Tourists, In Proc. of MobileHCI'01, 2001.

Convolso S & Walker M (2003) Using the Experience Sampling Method to Evaluate Ubicomp Applications. IEEE Pervasive Computing, April-June 2003, 24-31. IEEE 2003.

Counts S & Fellheimer E (2004) Supporting Social Presence through Lightweight Photo Sharing On and Off the Desktop. CHI Letters 6(1): 599-606.

Davies N, Cheverst K, Mitchell K & Efrat A (2001) Using and Determining Location in a Context-Sensitive Tour Guide. IEEE Computer 34(8): 35-41.

Davis M, Van House N, Towle J, King S, Ahern S, Burgener C, Perkel D, Finn M, Viswanathan V, Rothenberg M (2005) MMM2: Mobile Media Metadata for Media Sharing. CHI'05 Late Breaking Results.

Dey AK (2001) Understanding and Using Context. Personal and Ubiquitous Computing 5: 4-7. Springer-Verlag London Ltd

Dey AK & Abowd GD (2000a) CybreMinder: A Context-Aware System for Supporting Reminders. In Proceedings of Second International Symposium on Handheld and Ubiquitous Computing, HUC 2000: 172-186.

Dey AK & Abowd GD (2000b) Towards a Better Understanding of Context and Context-Awareness, in CHI 2000 Workshop on The What, Who, Where, When, Why and How of Context-Awareness 2000.

Dey AK & De Guzman ES (2006). From Awareness to Connectedness: The Design and Deployment of Presence Displays. In Proceedings of CHI 2006: 899-908.

Dey AK, Hamid R, Beckmann C, Li I & Hsu D (2004) A CAPpella: programming by demonstration of context-aware applications. In Proceedings of CHI 2004: 33-40.

Dey AK & Mankoff J (2005) Designing Mediation for Context-Aware Applications. ACM Transactions on Computer-Human Interaction 12(1): 53-80.

Dey AK, Salber D & Abowd GD (2001) A Conceptual Framework and a Tookit for Supporting the Rapid Prototyping of Context-Aware Applications. Human-Computer Interaction (HCI) Journal 16(2-4): 97-166.

Dourish P (2004) What We Talk When We Talk About Context. Personal and Ubiquitous Computing 8: 19-30.

Drab SA & Artner NM (2005) Motion Detection as Interaction Technique for Games & Applications on Mobile Devices. In Proc. Pervasive Mobile Interaction Devices (PERMID), 2005: 48-51. Available from: http://www.medien.ifi.lmu.de/permid2005/pdf/ Proceedings_Permid2005.pdf .

Duh HB-L, Tan GCB & Chen VH-H (2006) Usability Evaluation for Mobile Device: A Comparison of Laboratory and Field Tests. In Proceedings of MobileHCI 2006: 181-186.

Edwards WK (2005) Putting Computing in Context: An Infrastructure to Support Extensible Context-Enhanced Collaborative Applications. ACM Transaction son Computer-Human Interaction 12(4): 446-474.

Elisa Mobilemall. Available from http://elisa.fi/ir/index.cfm?t=5&o=5120.00&did=7153 ; http://www.helsinkivirtualvillage.fi/Resource.phx/verkkolehti/yritykset/kauppakeskusarabia.htx. Last accessed 03 Dec 2006.

Erickson T (2002) Some Problems with the Notion of Context-Aware Computing. Communications of the ACM 5(2): 102-104.

Eronen AJ, Peltonen VT, Tuomi JT, Klapuri AP, Fagerlund S, Sorsa T, Lorho G, Huopaniemi J (2006) Audio-Based Context Recognition. IEEE Transactions on Audio, Speech, and Language Processing 14(1).

Ferscha Al, Holzmann C & Oppl S (2004) Context Awareness for Group Interaction Support. In Proc. MobiWac'04: 88-97.

Flanagan J, Mäntyjärvi J & Himberg J (2002) Unsupervised Clustering of Symbol Strings and Context Recognition. Proceedings of IEEE International Conference of Data Mining 2002: 171-178.

Gaye L, Holmquist LE, Mazé R (2002) Sonic City: Merging Urban Walkabouts With Electronic Music Making. Demonstration at UIST´02, 2002. Extended abstract available at http://citeseer.ist.psu.edu/gaye02sonic.html , last accessed 11th Aug 2006.

Gellersen HW, Schmidt A & Beigl M (2002) Multi-Sensor Context-Awareness in Mobile Devices and Smart Artefacts. Mobile Networks and Applications 7: 341-351.

Grinter R & Eldridge M (2003) Wan2tlk?: everyday text messaging. In Proceedings of the SIGHCI conference on Human factors in computing systems CHI 2003: 441-448.

Gruber TR (1993) A Translation Approach to Portable Ontology Specifications. Knowledge Acquisition 5(2): 199-220.

Hansen KM & Damm CH (2002) Instant Collaboration. Using Context-Aware Instant Messaging for Session Management in Distributed Collaboration Tools. Proc. NordiCHI 2002: 279-282.

Hartnell-Young E & Vetere F (2005) "Lifeblog: A New Concept in Mobile Learning?" WMTE 2005 - IEEE International Workshop on Wireless and Mobile Technologies in Education: 174-178.

Hiltunen K-M, Häkkilä J & Tuomela U (2005).Subjective Understanding of Context Attributes – A Case Study. In Proceedings of Australasian Conference of Computer Human Interaction (OZCHI) 2005.

Himberg J, Korpiaho K, Mannila H & Tikanmäki J (2001).Time Series Segmentation for Context Recognition in Mobile Devices. In Proceedings of the 2001 IEEE International Conference on Data Mining: 203-210.

Hinckley K, Pierce J, Horvitz E & Sinclair M (2005) Foreground and Background Interaction with Sensor-Enhanced Mobile Devices. ACM Transactions on Computer-Human Interaction 12(1): 31-52.

Hinckley K, Pierce J, Sinclair M & Horvitz E (2000) Sensing Techniques for Mobile Interaction. CHI Letters 2(2): 91-100.

Hurtig T (2006) A Mobile Multimodal Dialogue System for Public Transportation Navigation Evaluated. In Proceedings of MobileHCI'06, ACM Press: 251-254.

Häkkilä J & Chatfield C (2005) 'It's Like if you Opened someone Else's Letter' – User Perceived Privacy and Social Practices with SMS Communication. In Proceedings of MobileHCI 2005: 219-222.

Iacucci G, Kuutti K & Ranta M (2000) On the Move with a Magic Thing: Role Playing in Concept Design of Mobile Services and Devices. In Proceedings of DIS'00: 193-202.

Isokoski P & Raisamo R (2004) Quickwriting as a Multi-Device Text Entry Method. In Proceedings of NordiCHI 2004: 105-108.

Kaasinen E (2003) User Needs for Location-Aware Mobile Services. Personal and Ubiquitous Computing 7: 70-79.

Kallio T & Kekäläinen A (2004) Effectiveness of Mobile Application Design: User-Pairs Testing by Non-professionals. In Proceedings of MobileHCI 2004, Springer Berlin/Heidelberg.

Ketola P & Röykkee M (2001) The Three Facets of Usability in Mobile Handsets. In CHI 2001 Workshop, Mobile Communications: Understanding Users, Adoption & Design. April 1-2, 2001 Seattle, Washington.

Kindberg T, Spasojevic M, Fleck R & Sellen A (2005). The Ubiquitous Camera: An In-Depth Study on Camera Phone Use. Pervasive Computing April-June: 42-50.

Kim SW, Park SH, Lee JB, Jin YK, Park H, Chung A, Choi SE & Choi WS (2004) Sensible appliances: Applying Context-Awareness to Appliance Design. Personal and Ubiquitous Computing 8: 184-191.

Ko E-J, Lee H-J, Lee J-W (2005) An Intelligent Context-Aware Service Engine Based on Ontology. In Proceedings of International Conference on Computational Intelligence for Modelling, Control and Automation, and International Conference on Intelligent Agents, Web Technologies and Internet Commerce 2005 (CIMCA-IAWTIC'05). Vol 1: 485-491.

Koch F & Sonenberg L (2004) Using Multimedia Content in Intelligent Mobile Services. Proceedings of the WebMedia & LA-Web 2004: 41-43.

Korpipää P (2005) Blackboard-based software framework and tool for mobile device context awareness. PhD thesis. VTT Publications 579.

Korpipää P, Häkkilä J, Kela J, Ronkainen S & Känsälä I (2004) Utilizing Context Ontology in Mobile Device Application Personalisation. In Proceedings of MUM 2004.

Korpipää P, Koskinen M, Peltola J, Mäkelä S-M & Seppänen T (2003a) Bayesian Approach to Sensor-Based Context-Awareness. Personal and Ubiquitous Computing 7 (2): 113-124.

Korpipää P, Mäntyjärvi J, Kela J, Keränen H & Malm E-J (2003b). Managing Context Information in Mobile Devices. IEEE Pervasive Computing: 42-51.

Kurvinen E (2003) Only When Miss Universe Snatches Me: Teasing in MMS Messages. In Proceedings of DPPI'03 (June 2003): 98-102.

Langheinrich M (2001) Privacy by Design – Principles of Privacy-aware Ubiquitous Systems. In Proc. Ubicomp 2001: 273-291.

Lederer S, Dey AK & Mankoff J (2002) A Conceptual Model and a Metaphor of Everyday Privacy in Ubiquitous Computing Environments, IRB-TR-02-017, Intel Research, July 2002.

Lederer S, Mankoff J & Dey AK (2003) Who Wants to Know What When? Privacy Preference Determinants in Ubiquitous Computing. In Proceedings of CHI 2003: 724-725.

Lei H, Sow DM, Davis JS, Guruduth B & Ebling MR (2002) The Design and Applications of a Context Service. Mobile Computing and Communication Review 6(4): 45-55.

Lyon K, Starner T, Plainsted D, Fusia J, Lyons A, Drew A & Looney EW (2004) Twiddler Typing: One-Handed Chording Text Entry for Mobile Phones. In Proceedings of CHI 2004, ACM Press, 671-678.

MacKenzie IS, Soukoreff RW (2002) Text Entry for Mobile Computing: Models and Methods, Theory and Practice. Human-Computer Interaction 17: 147-198.

Mankoff J, Dey AK, Hsieh G, Kientz J, Lederer S & Ames M (2003) Heuristic Evaluation of Ambient Displays. CHI Letters 5(1): 169-176.

Mao J-Y, Vredenburg K, Smith P & Carey T (2005) The State of User-Centered Design Practices. Communications of the ACM 48(3): 105-109.

Marmasse N &Schmandt C (2000) Location-Aware Information Delivery with comMotion. In Proceedings of HUC:157-171).

Martin R & Weiss S (2006) Usability Benchmarking Case Study: Media Downloads via Mobile Phones in the US. In Proceedings of MobileHCI 2006: 195-198.

Mäntyjärvi J & Seppänen T (2002) Adapting applications in mobile terminals using fuzzy context information. In Proceedings of Mobile HCI 2002: 95-107.

Mäntyjärvi J, Tuomela U, Känsälä I & Häkkilä J (2003) Context Studio – Tool for Personalizing Context-Aware Application in Mobile Terminals. Proc. OZCHI 2003: 64-73.

Michahelles F & Samulowitz M (2002) Smart CAPs for SmartIts – Context Detection for Mobile Users, Personal and Ubiquitous Computing, 6: 269-275.

Microsoft Pocket PC User Interface Guidelines. Available from: http://msdn.microsoft.com/library/default.asp?url=/library/en-us/ui_guide_ppc/html/PPCUser_Interface_Guidelines_SKLK.asp. Last accessed 03 Dec 2006.

Multi-User Publishing Environment (MUPE). Available from: http://www.mupe.net/ Last accessed 03 Dec 2006.

Nakanishi Y, Tsuji T, Ohyama M & Hakozaki K (2000) Context Aware Messaging Service: A Dynamical Messaging Delivery Using Location Information and Schedule Information. Personal Technologies 4: 221-224.

Nielsen J (1994) Heuristic Evaluation. In: Nielsen J & Mack RL (eds) Usability Inspection Methods, Chapter 2. Canada: John Wiley & Sons Inc.

Norgaard M, Hornbak K (2006) What Do Usability Evaluators Do in Practice? An Exploratory Study of Think-Aloud Testing. In Proceedings of DIS 2006: 209-218.

Norman DA (1990) The Design of Everyday Things. Doubleday, New York, USA.

Ojala T, Korhonen J, Aittola M, Ollila M, Koivumäki T, Tähtinen J & Karjaluoto H (2003) SmartRotuaari – Context Aware Mobile Multimedia Services, In Proceedings of Mobile and Ubiquitous Multimedia (MUM) 2003, 9 - 18.

Osbakk P & Rydgren E (2005) Ubiquitous Computing for the Public. In Proceedings of Pervasive 2005 Workshop on Pervasive Mobile Interaction Devices (PERMID 2005): 56-59.

Oulasvirta A (2004) Finding Meaningful Uses for Context-Aware Technologies: The Humanistic Research Strategy. CHI letters 6(1): 247-254.

Oulasvirta A, Kurvinen E & Kankainen T (2003) Understanding context by being there: case studies in bodystorming. Personal and Ubiquitous Computing 7: 125-134.

Palen L & Salzman M (2002) Voice-Mail Diary Studies for Naturalistic Data Capture under Mobile Conditions. In Proceedings of CSCW'02, ACM Press, 87-95.

Palm OS User Interface Guidelines. http://www.palmos.com/dev/support/docs/ui/UIGuide_Front.html. Last accessed 03 Dec 2006.

Pavlovych A, Stuerzlinger W (2003) Less-Tap: A Fast and Easy-to-learn Text Input Techniques for Phones. In Proceedings of Graphics Interface 2003: 97-104.

Perry M, O'Hara K, Sellen A, Brown B & Harper R (2001). Dealing with Mobility: Understanding Access Anytime, Anywhere. ACM Transactions on Computer-Human Interaction 8(4): 323-347.

Persson P, Espinoza F, Fagerberg P, Sandin A, Cöster R (2003) GeoNotes: A Location-based information System for Public Spaces. In: Höök K, Benyon D & Munro AJ (eds) Designing information spaces: the social navigation approach. Springer-Verlag, London, UK: 151-173.

Pirttikangas S, Riekki J & Röning J (2004) Routine Learning: Analyzing Your Whereabouts. In Proceedings of the International Conference on Information Technology: Coding and Computing (ITCC) 2004. Vol 2: 208-213.

Poupyrev P, Sasao T, Saruwatari S, Moridawa H, Aoyama T, Davis P (2005) Service Discovery in TinyObj: Strategies and Approaches. In Proceedings of Pervasive 2005 Workshop on Pervasive Mobile Interaction Devices (PERMID 2005): 19-22.

Preece J, Rogers Y & Sharp H (2002) Interaction Design. Beyond Human-Computer Interaction. John Wiley & Sons Inc.

Rantanen M, Oulasvirta A, Blom J, Tiitta S & Mäntylä M (2004) InfoRadar: Group and Public Messaging in the Mobile Context. Proceedings of NordiCHI 2004: 131-140.

Raptis D, Tselios N & Avouris N (2005) Context-based Design of Mobile Applications for Museums: A Survey of Existing Practices. In Proc. MobileHCI'05: 153-160.

Rohs M & Zweifel P (2005) A Conceptual Framework for Camera Phone Based Interaction Techniques. In Proc. of Pervasive 2005: 171-189.

Roto V, Oulasvirta A, Haikarainen T, Kuorelahti J, Lehmuskallio H & Nyyssönen T (2004). Examining Mobile Phone User in the Wild with Quasi-Experimentation. HIIT Technical report, 2004-1, August 2004.

Roto V, Popescu A, Koivisto A, Vartiainen E (2006) Minimap – A Web Page Visualization Method for Mobile Phones. In Proceedings of CHI 2006: 35-44

Rudd J, Stern K & Isensee S (1996) Low vs. High-Fidelity Prototyping Debate. Interactions 3(1): 76-85.

Rukzio E, Leichtenstern K, Callaghan V, Holleis P, Schmidt A, Chin J (2006) An Experimental Comparison of Physical Mobile Interaction Techniques: Touching, Pointing and Scanning. In Proc. Ubicomp: 87-104

Sarvas R, Herrarte E, Wilhelm A, Davis M (2004) Metadata Creation System for Mobile Images. Proc. MobiSys'04: 36-48.

Sarvas R, Viikari M, Pesonen J, Nevanlinna H (2004) MobShare: Controlled and Immediate Sharing of Mobile Images. In Proceedings of the 12th annuan ACM international conference on Multimedia 2004: 724-731.

Schilit B, Adams N, Gold R, Tso MM, Want R (1993) The ParcTab Mobile Computing System. In Proceedings of Fourth Workshop on Workstation Operating Systems, Oct 1993: 34-39.

Schilit B, Adams N, Want R (1994) Context-Aware Computing Applications. In Proceedings of IEEE Workshop on Mobile Computing Systems and Applications: 85-90.

Schmidt A (2000) Implicit Human Computer Interaction Through Context. Personal Technologies, 4(2-3): 191-199.

Schmidt A, Beigl M & Gellersen H (1999) There is more context than location, in Computers and Graphics Journal 23(6): 893-902.

Schmidt A & Gellersen H-W (2001) Context-Aware Mobile Telephony. SIGGROUP Bulletin 22(1): 19-21.

Schmidt A, Häkkilä J, Atterer R, Rukzio E & Holleis P (2006). Utilizing Mobile Phones as Ambient Information Displays. Extended abstracts on Human factors in computing systems CHI'06 (Work-in-progress) 2006: 1295-1300.

Schmidt A, Stuhr T & Gellersen H-W (2001) Context-Phonebook – Extending Mobile Phone Applications with Context. Third Mobile HCI Workshop, Lille, Sept. 2001.

Series 60 UI Style Guide. Available from: http://www.forum.nokia.com/main.html. Last accessed 03 Dec 2006.

Shneiderman B (2000) Universal Usability. Communications of the ACM 43(5): 85-91.

Sing S, Bartolo KC, Satchell C (2004) Grounded Theory and User Requirements: A Challenge for Qualitative Research. In Proceedings of QualIT 2004. Nov 2004, Brisbane, Australia.

Skow M & Hoegh R (2006) Supporting information access in a hospital ward by a context-aware mobile electronic patient record. Personal and Ubiquitous Computing (2006) 10: 205-214.

Sorvari A, Jalkanen J, Jokela R, Black A, Koli K, Moberg M & Keinonen T (2004) Usability Issues in Utilizing Context Metadata in Content Management of Mobile Devices. In Proc. NordiCHI'04: 357-363.

Standard: ISO/DIS 9241-11

Standard: ISO 13407 (3.3)

Strauss A & Corbin J (1990). Basics of Qualitative Research: Grounded Theory Procedures and Techniques. SAGE Publications.

Taylor SJ & Bogdan R (1998) Introduction to qualitative research methods: a guidebook and resource. Wiley, New York, 3rd ed.

Tokuda H (2004) Smart Furniture: A Platform for Context-Aware Embedded Ubiquitous Applications. Keynote at EMSOFT'04.

Truong BA, Lee Y-K, Lee S-Y (2005) Modeling and Reasoning about Uncertainty in Context-Aware Systems. IEEE International Conference on e-Business Engineering 2005: 102-109.

Truong KN, Huang EM, Stevens MM, Abowd GD (2004) How Do Users Think about Ubiquitous Computing? In the Extended Abstracts of ACM Conference on Human Factors in Computing Systems: CHI 2004: 1317-1320.

Virzi RA, Sokolov JL & Karis D (1996) Usability Problem Identification Using Both Low- and High-Fidelity Prototypes. In Proceedings of CHI '96: 236-243.

Voida A, Grinter RE, Ducheneaut N, Edwards WK, Newman MW (2005) Listening In: Practices Surrounding iTunes Music Sharing. Proc. of CHI 2005. ACM Press: 191-200

Vredenburg K, Mao J-Y, Smiwth PW & Carey T (2002) A Survey of User-Centered Design Practice. CHI Letter 4(1): 471-478.

Want R, Hopper A, Falcao V & Gibbons J (1992) The Active Badge Location System. ACM Transactions on Information Systems 10(1): 91-102.

Warren N, Jones M, Jones S, Bainbridge D (2005) Navigation via Continuously Adapted Music. CHI 2005 Late Breaking Results: 1849-1852.

Weiser M (1991) The Computer for 21st Century. Scientific American 265(3): 94-104.

Weiss S (2002) Handheld Usability. John Wiley & Sons Ltd, West Sussex, England.

Wirth N (1971) Program Development by Stepwise Refined. Communications of the ACM, 14(4): 221-227.

Yee G (2005) Using Privacy Policies to Protect Privacy in UBICOMP. In Proc. of the 19th International Conference on Advanced Information Networking and Applications (AINA 2005), IEEE Computer Society 2005.

Original Publications

I Häkkilä J & Mäntyjärvi J (2006) Situated Multimedia for Mobile Communications. In: Ismail Khalil Ibrahim (ed) Handbook of Research on Mobile Multimedia. Idea Group Inc: 326-339. Reprinted with permission of IGI.

II Häkkilä J & Hexel R (2003) Interaction in Location-Aware Messaging in a City Environment. Proceedings of Australasian Conference of Computer Human Interaction (OZCHI) 2003: 84-93.

III Häkkilä J & Mäntyjärvi J (2005) Combining Location-Aware Mobile Phone Applications and Multimedia Messaging. Journal of Mobile Multimedia 1(1): 18-32. Reprinted with permission of Rinton Press.

IV Häkkilä J & Isomursu M (2005) User Experiences of Location-Aware Mobile Services. Proceedings of the 19th Australasian Conference of Computer Human Interaction (OZCHI) 2005. ACM International Conference Proceeding Series; Vol 122.

V Häkkilä J & Mäntyjärvi J (2005) Collaboration in Context-Aware Mobile Phone Applications. proceedings of 38th Annual Hawaii International Conference on System Sciences (HICSS) 2005. DOI: 10.1109/HICSS.2005.145. © 2005 IEEE. Reprinted, with permission.

VI Häkkilä J & Känsälä I (2004) Role Based Privacy Applied to Context-Aware Mobile Applications. Proceedings of 2004 IEEE International Conference on Systems, Man and Cybernetics (SMC) 2004. Vol 6: 5467-5472. DOI: 10.1109/ICSMC.2004.140163. © 2004 IEEE. Reprinted, with permission.

VII Häkkilä J, Korpipää P, Ronkainen S & Tuomela U (2005) Interaction and End-User Programming with a Context Aware Mobile Application. Proceedings of Interact 2005: 927-937. Copyright 2005. Reprinted with kind permission of Springer Science and Business Media.

VIII Häkkilä J & Mäntyjärvi J (2006) Design Guidelines for Context-Aware Mobile Applications. Proceedings of Mobility'06. ACM Press. © 2006 ACM Press. Reprinted, with permission.

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