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Interacting with Wearable Computers: Techniques and Their Application in Wayfinding Using Digital Maps

ACADEMIC DISSERTATION

To be presented, with the permission of the Faculty of Information Sciences of
the University of Tampere, for public discussion in
Auditorium B661 (Attila) of the University on September 27th, 2002, at 12 noon.

DEPARTMENT OF COMPUTER AND INFORMATION SCIENCES
UNIVERSITY OF TAMPERE

A-2002-2

TAMPERE 2002

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Electronic dissertation
Acta Electronica Universitatis Tamperensis 207
ISBN 951-44-5460-X
ISSN 1456-954X
http://acta.uta.fi

Department of Computer and Information Sciences
FIN-33014 UNIVERSITY OF TAMPERE
Finland

ISBN 951-44-5316-6
ISSN 1457-2060

Tampereen yliopistopaino Oy
Tampere 2002

Contents

List of publications

This doctoral dissertation comprises of the following publications:

I. Suomela Riku, Lehikoinen Juha. Context Compass. Proceedings of the Fourth International Symposium on Wearable Computers (ISWC) 2000, Atlanta, GA, IEEE Computing Society, pp. 147-154.

II. Lehikoinen Juha, Suomela Riku. Accessing Context in Wearable Computers. Personal and Ubiquitous Computing, vol. 6, no 1, Jan 2002, Springer-Verlag London Ltd, pp. 64-74.

III. Lehikoinen Juha, Röykkee Mika. N-Fingers: A Finger-based Interaction Technique for Wearable Computers. Interacting with Computers, vol. 13, no. 5, May 2001, Elsevier Science, pp. 601-625.

IV. Lehikoinen Juha, Salminen Ilkka. An Empirical and Theoretical Evaluation of BinScroll – A Rapid Selection Technique for Alphanumeric Lists. Personal and Ubiquitous Computing, vol. 6, no. 2, Apr 2002, Springer-Verlag London Ltd, pp. 141-150.

V. Lehikoinen Juha. Virtual Pockets. Proceedings of the 5th World Multiconference on Systemics, Cybernetics and Informatics (SCI) 2001, vol. IV, Orlando, FL, IIIS, pp. 479-484.

VI. Lehikoinen Juha. An Evaluation of Augmented Reality Navigational Maps in Head-Worn Displays. Proceedings of the Eighth IFIP TC.13 Conference on Human-Computer Interaction INTERACT ’01, Amsterdam IOS Press, pp. 224-231.

VII. Lehikoinen Juha, Suomela Riku. WalkMap: Developing an Augmented Reality Map Application for Wearable Computers. Virtual Reality, vol. 6, no. 1, 2002, Springer-Verlag London Ltd, pp. 33-44.

VIII. Lehikoinen Juha, Suomela Riku. Perspective Map. To appear in the Sixth International Symposium on Wearable Computers (ISWC) 2002, Seattle, WA, IEEE Computing Society.

Acknowledgements

Creating a doctoral dissertation is a job with many faces. Sometimes it becomes really tedious, while sometimes it is extremely rewarding and enjoyable. Nevertheless, it is always challenging. In responding to this challenge, I have many people to be thankful to. First and foremost, I would like to thank my supervisors, Prof. Kari-Jouko Räihä, University of Tampere, and Dr. Hannu Nieminen, Nokia Research Center. Their acuity and insight have firmly guided me through the creation process. I also wish to thank Hannu, as a representative of Nokia Research Center, for providing fine circumstances to concentrate on this work.

Thanks are due to the reviewers: prof. Petri Pulli, prof. Tapio Takala, and prof. Jukka Vanhala. I thank Tapio and Jukka for their thorough reviews with constructive and relevant comments and suggestions.

While preparing this dissertation, I have had the privilege to work with an extraordinary research team in Nokia Research Center, Tampere, Finland. Never before have I seen such enthusiasm and commitment as in this team during the years we have shared. I wish to thank the whole team: Riku Suomela, Mika Röykkee, Ilkka Salminen, Tero Hakala, Marja Salmimaa, and Titta Lähteenmäki. Special thanks are due to Riku Suomela and Mika Röykkee, who have greatly assisted me in developing the software and user interface prototypes, as well as in arranging the usability studies. Further, I would like to thank my superior Juha Kaario, and all the others not mentioned here. You know who you are.

I wish to thank Antti Aaltonen for lending me his Depeche Mode CD collection while finishing this dissertation. Better music for Ph.D. writing is hard to find! Further, I thank Antti for reading and commenting this text in many phases during the writing process, never short of a sense of humor.

I wish to express my appreciation to my parents and brothers. They never ceased to have faith in me, always continuing to encourage me and being proud of my achievements.

I thank my family for loving me and always being there. My wife, Tiina, has kept me connected to the real world during the hectic moments of writing, tranquilly and lovingly. My daughter, Anniina, always shines a great joy of life and expresses unselfish love, providing light even in the most depressing moments. Together Tiina and Anniina have provided me with love and confidence that has kept me going.

Above all, I thank my Heavenly Father for providing me with abilities required in this – and any other – work, and bringing the confidence and peace of mind that will always remain in me.

Ylöjärvi, September 2002
Juha Lehikoinen

Abstract

Wearable computers are a special case of mobile computers. They are either embedded in clothing, or they may even be the clothing. They are very personal in nature, being always with the user, always on and always ready. The aim in developing wearable computers is to provide the user with instant and easy-to-use access to digital information sources anytime, anywhere.

Wearable computers are a potential platform for several location-aware software applications. One such application is a personal navigation assistant that is aware of the user's current geographical location, and has access to a database that contains maps of the current surroundings. Equipped this way, the assistant can provide the user with easy to understand and real-time instructions on how to reach a specific destination, and assist in exploring the environment without getting lost.

This dissertation addresses the issues that arise when personal navigation assistants for wearable computers are developed. The research comprises eight studies in the areas of human-map interaction, wearable computing, and human-computer interaction. Two research methods have been applied: in the constructive research part, a navigation application, including several interaction techniques suitable for wearable use, has been developed. In the empirical research part, the methods and techniques developed have been evaluated to assess their usability. As a result – in addition to the navigation application itself – a set of user interaction techniques and interface components that support the various tasks needed in wayfinding has been proposed. These include a finger-based interaction technique, an efficient list searching technique, and a novel pocket-based user interface metaphor. The results also include guidelines for designing the map behavior while navigating.

1. Introduction

Computing is on the threshold of a new era. While a few years ago nearly all computers remained firmly inside offices and homes, the small, portable computing devices that are available today allow computing out-of-the-office. They are taking computing into the streets, making it more and more part of one’s life. These computers are referred to as mobile computers.

There are two aspects that entitle a computer the attribute ‘mobile’. First, the computer has to be small enough so that it can be taken along and carried relatively conveniently; and second, the computer has to be usable while standing or walking (Rosenberg, 1998, p. 16-17). Further, mobile computers are usually expected to offer a communications channel by the means of wireless networking. It should be noted that computers installed into vehicles are not called mobile: even though they are in motion when the vehicle moves, they cannot be taken along when leaving the vehicle.

There are various ways of categorizing mobility. One may categorize the mobility of the computer itself, the user, or the task that the computer is used for. One such classification has been suggested by Kristoffersen and Ljungberg (1999a), concerning the mobility of the *user*. These categories are as follows:

- wandering (the user wanders around with no specific destination),
- traveling (the user spends some time in a vehicle in order to get to the destination), and
- visiting (where the user may spend some time in different locations).

Further, they classify *technology* into mobile, portable, and desktop categories. Another classification has been presented by Pascoe *et al.* (2000), where the classes are static usage and mobile usage. This classification concerns the mobility of the *activity*, not the user or the device that is used.

Today, there are various kinds of mobile computers, or mobile terminals available. Rosenberg (1998, p. 50) classifies them as follows: portable computers (laptops and other miniaturized computers), handheld computers (including Personal Digital Assistants – PDAs, and equivalent devices), and wearable computers. In addition, mobile phones are providing increasingly many features and can be considered yet another class of mobile terminals.

Probably the least known of the aforementioned devices is a wearable computer. A wearable computer is embedded into clothing, or it may even *be* the clothing. It is distinguished from all the other mobile computers by one remarkable feature that could be called seamless accessibility. In other words, while you use a handheld computer by taking it out when needed and putting it back when not in use, the wearable computer remains accessible all the time. The user does not have to suspend his or her current task in order to use the computer. In an ideal case, a wearable computer can be used with the same ease you use the zipper in your jacket: it is a part of your clothing, and it can be operated very effortlessly.

Three dominant aspects characterize wearable computers: they are always on and always ready, they are totally controlled by the user, and they are considered both by the user and by the others around to belong to the user’s personal space (Mann, 1997).

A wearable computer should be usable while in motion and with one or both hands free. Further, it should remain usable in different environments. The point is that a wearable computer should be usable where it is actually worn, regardless of the conditions of the environment. These requirements set great challenges to the user interaction design.

When it comes to the form factor of wearable computers, there are two different approaches: these could be referred to as American and European styles. In America, a wearable computer is usually understood as a portable computer that is worn on a belt; it has all the functionality a regular portable computer can offer in a somewhat inconvenient form. In Europe and Japan, by contrast, the approach is often to enhance an already mobile device – such as a mobile phone – with features that provide more functionality without losing mobility. For instance, the Nokia Communicator is a mobile phone equipped with many features found on handheld computers. A Communicator equipped with a headset can be used for making phone calls without taking the device out of the pocket, making it in one respect wearable.

A wearable computer is a potential platform for many different applications that require privacy, mobility, and continuous access to information. One such application is navigation. A personal navigation assistant provides the user with a representation of the current environment, as well as instructions on how to reach a certain destination.

Navigation is the process of finding one's way from the point of origin to the destination. Usually, this process can be understood as a series of actions that are to be carried out at specific locations; these action-location combinations can be referred to as wayfinding decisions. Once all the wayfinding decisions have been successfully performed, the destination has been reached.

Traditionally, navigation has been carried out with a map and a compass. Using a map is not a trivial task, requiring cognitive processes such as relating the scaled two-dimensional map to the three-dimensional real world, and finding the correct orientation. By applying the newest technology, the process of navigation can be greatly facilitated.

This doctoral dissertation combines three distinct research areas: navigation, wearable computing, and human-computer interaction (HCI). The research focuses on a wayfinding guide for a walking user in an urban environment. The guide should provide the user with information on the surrounding area, to assist in finding a route to a specified destination, and to prevent the user from getting lost. The user is expected to have a wearable computer equipped with a see-through head-worn display, and an input device for both discrete input (buttons) as well as continuous input. The intention is to utilize as simple and intuitive input devices and techniques as possible – techniques that one might be able to use even while walking down the street. The intention is to to study a view that is familiar to the user (such as a 2D map), uses screen estate moderately (leaving most of the screen to the see-through view), and can be produced from existing geographical information system (GIS) databases without much extra effort.

The research problems studied in this work are user interface and human-map interaction issues of such a guide, addressing the questions *how should the user control the functionality offered by the software, how should the map behave and respond to the user's actions* and *how can the specific nature of the mobile using environment be supported on the user interface level?* The quality of the user's experience with the navigation system is determined in great deal by these issues.

On a higher level of abstraction, I will study the interface and interaction design principles for wearable computers. The map and the navigation task provide a concrete context for developing the techniques and principles.

There are two starting points for this study. The first is traditional navigation with a hard-copy paper map: the specific requirements for a wearable navigation system are considered against the prior knowledge gained in this area. The second deals with wearable computing, concentrating on the challenges that it poses to navigation system development in general, and particularly to user interaction. In this respect, the focus is on minimal interaction that seamlessly fits within wearable computing paradigm.

The work done within this dissertation is based on iterative design. The system, along with its user interface, is developed, evaluated and revised on a continuous basis. Consequently, both constructive research methods (in system development) and empirical research methods (in usability studies) have been applied.

To achieve the aim described above, I have developed and evaluated several new interaction techniques that take into account the specific nature of wearable computing (for the sake of clarity, throughout the text these papers are referred to using their shorter ‘nicknames’ rather than complete paper titles). One of these techniques is *Context Compass* – a technique that allows selecting a location-based object on a head-worn display. The object is selected by just turning one’s head towards its real world location, allowing hands-free interaction. Context Compass is more than just an interaction technique, however. It is a complete subsystem that supports downloading, filtering and accessing location-dependent content.

Another technique, called *N-Fingers*, deals with issuing direct commands to the computer. N-Fingers is based on the fingers: a command is issued by touching the thumb with another finger. N-Fingers can be used along with Context Compass to access the virtual objects. Another technique that benefits of N-Fingers is *BinScroll*. BinScroll is a selection technique that allows the selection of any item on an alphanumeric list rapidly with only four buttons. It is best suited for lists consisting of thousands of items, such as street name lists.

I have also developed a new metaphor for wearable computer user interfaces. This *Virtual Pockets* metaphor is based on regular pockets, allowing the user to define virtual pockets anywhere in the clothing. Once defined, the pockets can be used to store virtual objects, such as documents or applications. The objects can be taken out of the pocket, used, and then put back into the pocket.

Virtual Pockets is an example of a general user interface approach which can be applied in the navigation task, but which has not yet been integrated in the prototype. In contrast, some of the papers focus on this specific task. In particular, I wanted to find out whether a map shown on a head-worn display should be rotated automatically when the user turns. This issue, which had not been studied earlier, was addressed in *Map Evaluation*.

The research work culminated in *WalkMap*, a navigation application for wearable computers. This application was developed by combining the results achieved in other studies, leading to a personal wayfinding assistant that also provides access to the digital content available in the environment.

The last paper, *Perspective Map*, provides some future directions for WalkMap visualizations. It presents a map view that is based on perspective distortion. Again, the developed concept was implemented and evaluated; the results showed that while an egocentric display may facilitate some navigational tasks, it is not feasible for others.

In contrast to many existing studies dealing with head-worn displays and augmented reality, this work takes a 'lo-fi' approach[1]. In other words, I do not consider sophisticated three-dimensional immersive environments, but concentrate on more familiar two-dimensional (or even one-dimensional) representations and interactions. This is a deliberate choice: the research problems related to immersive environments and 'hi-fi' augmented reality address different problems and should therefore be studied on their own.

This dissertation is composed of the research papers published on the topics discussed above, and an introduction to and literature survey of the research area. The text is organized as follows. First, navigation in general is discussed, including issues in human-map interfaces, problems in map using, and characteristics specific to digital maps. The navigation theme concludes with remarks on personal navigation in wearable computers.

Next, wearable computing is discussed in detail, addressing issues such as the development of clothing functionality, the history of wearable computing, the key terms, enabling technologies, and current application areas. This chapter is concluded by introducing numerous wearable computing research projects that concentrate on personal, context-aware navigation, and discussing future trends in wearable computing.

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[1] With 'lo-fi' augmented reality I am referring to systems that add digital content to real world objects but do not necessarily present the content on its accurate real world location.

An introduction to interaction with wearable computers, the third part of the triangle in this research, follows. I begin by taking a look at the “traditional” HCI research, and then discuss some deviations that the out-of-the-office paradigm is bound to cause. I also present an alternative approach to human-computer interaction.

Then, to bring the whole research together, I present the target platform for the research, followed by brief descriptions of the papers themselves.

2. The task: Navigation

The first leg of the tripod is personal navigation, or wayfinding. In this dissertation, the focus is on a walking user in an urban environment; therefore, I am not discussing vehicle navigation – which is a widely studied area in itself – unless the discussion can be generalized to wayfinding by foot as well. Hence the term personal navigation.

The English word *navigation* is adopted either from the French word *navigation,* or directly from Latin *navigationem*. It means “to sail or steer a ship”, or “the action or practice of passing on water in ships” (Barnhart, 1988, p. 696; Simpson and Weiner, 1989, p. 259). Over time, the term has gained a more widespread meaning. Today it can be defined as follows (Sinclair, 1993, p. 958):

> *If you navigate, you work out which direction to go while you are travelling by using maps and a compass or the sun and stars.*

There are numerous ways to navigate, or to find one’s way from the point of origin to the destination. Using the sun and stars is, or at least has been, definitely one of them; the position of setting and rising stars on the horizon is the key element (Passini, 1984, p. 42). In addition, the environmental cues, such as the prevailing winds, are also generally used.

An integral part of modern navigation is the map. The term *map* can be defined as follows (Sinclair, 1993, p. 886):

> *A drawing of a particular area, for example a continent, a country, or a city, as it would appear to you if you saw it from above. A map shows the main features of the area and the way they relate to each other.*

There are three notions that draw our attention: *a drawing*; *from above*; *the main features and the way they relate.* Indeed, a map is usually understood as a drawing. There is much more to a map than a drawing, however. Let us examine some additional points of view to the map.

A map can be seen as *integrated spatio-symbolic media* (Barkowsky and Freksa, 1997). In effect, a map can be defined as

> *a geometric projection in which the projected entities are replaced by symbozlic interpretations of these entities.*

Ideally, the transformed entities should keep the precise position, size, and shape of the original projections. Since this is not possible in reality, a map is always a compromise of what is presented and how.

A map is a *model of a part of the environment*. In effect, the map user has to create two mental models when navigating: a terrain model and a map model (Crampton, 1988). In the map model, the map-maker (the cartographer) has tried to analyze the environment and to describe the results of the analysis to the map-reader. Hence, a map can be seen as a one-way *means of communication* (Ottosson, 1986; MacEachren, 1995, pp. 4-5). Thus, a map is also a *mediator* of the relationship between the environment and the map reader (Warren *et al.*, 1992).

A special kind of map is a “You-are-here” map (YAH map). Conventional YAH maps are fixed to a certain location in the environment (in a shopping mall, for instance), and the reader’s position is marked on the map to facilitate navigation.

In addition to navigation, maps can also be used for other tasks, such as *measurement* (to compare the features on a map), and *visualization* (Board, 1978). In this text, however, only navigational maps are discussed.

2.1 Human-map interaction

There are no explicit definitions for the term *human-map interaction*. Rather, there can be several alternative views to the interaction, based on different approaches to maps. As stated by MacEachren (1995, p. 12),

> *There is no* single *correct scientific, or nonscientific, approach to how maps work.*

Consequently, in this dissertation no single definition for human-map interaction has been adopted. However, the emphasis is on the cognitive processes that using maps requires, as suggested by MacEachren (1995, p. 12).

Using a map is a complex task. Map use can be defined as “the ability to relate a two-dimensional map to the three-dimensional world” (Blades and Spencer, 1987a), that is, an ability to match the terrain and map models in one’s mind. This requires that several cognitive and spatial processes are mastered. To understand a map, one has to be able to understand the spatial relationships between real-world features. The greatest problems in map understanding seem to relate to this issue (Ottosson, 1988). After the map is understood, it can be used.

The skills required for a successful navigation (Board, 1978) can be stated as

- ☐ to locate oneself on a map,
- ☐ to recognize the destination, and
- ☐ to plan and execute the route to the destination.

To locate oneself on a map, the person must be able to perform the conversion of the 3D environment to the scaled 2D map, to match the objects in the environment with the symbols on a map, and to find the correct orientation. Only after that can the route planning and execution begin.

There are numerous terms and notions related to human-map interaction. I will next briefly present some of the most relevant concepts.

Wayfinding styles

There are two basic wayfinding styles (Passini, 1984, p. 76). The first relies on linearly organized information, while the second relies on spatially organized information. In *linear wayfinding*, a map acts as a means to find a way to a destination. The decision plan links the origin to the destination. The user has to memorize the decisions, their order, and where they are to be executed. In *spatial wayfinding*, on the contrary, the map is seen as a whole, and the origin and destination are searched for on the map at the same time. A linear map is called a route map while a spatial map can be referred to as a survey map.

Wayfinding knowledge

People have various types of knowledge concerning maps and navigation. This knowledge can be divided into two categories: *survey knowledge* and *procedural knowledge* (Thorndyke and Hayes-Roth, 1982). Survey knowledge is acquired from different sources, including maps and verbal descriptions. It includes knowledge about objects, their positions, and distances. The procedural knowledge, on the contrary, is acquired from navigation. It is usually based on direct navigation experience, and encodes a sequential record of the space between starting points, subsequent landmarks along the route, and destinations. This, in effect, makes procedural knowledge part of the linear wayfinding style.

The procedural knowledge must identify at least the locations (landmarks) at which an action has to be taken (such as "At the church, turn left"). These parts of procedural knowledge are called wayfinding decisions.

Wayfinding decisions

A *wayfinding decision* describes what should be done and where in order to reach the destination. It consists of an action part and an image part (for instance, “turn left” and ”at the church”). Information relevant to a decision should be accessible at the point where the decision has to be made.

Basic building blocks

The image part of a wayfinding decision is most often a landmark. *Landmarks* are distinctive environmental features used as reference points. In addition to the general landmarks, people can and will pick up small details and use these as their own landmarks.

Landmarks play an important role in forming a cognitive representation of a city. In addition to landmarks, there are several other building blocks that can be used when processing the image of a city (Lynch, 1960, p. 46-48). These building blocks can be identified as follows:

- paths (parts of the circulation system, such as corridors, elevators, promenades, and roads),
- landmarks (point-references),
- nodes (places that can be traveled to and from),
- edges (linear elements that are not paths, such as boundaries, barriers), and
- districts (homogenous areas with some common character).

In effect, the building blocks are the key elements that people look for when navigating in complex urban environments.

The building blocks described above were first identified in western culture. Later, it has been found that they can be generalized to other cultures as well; the importance of each element may vary from culture to culture, however. (Passini, 1984, p. 111)

There are two basic strategies when navigating in a man-made environment. Either the actions and number of related objects are counted (such as “second right, then third left”), or the street names are looked for (Blades and Spencer, 1987b). Landmarks can facilitate both navigation strategies.

Alignment

An important aspect concerning maps and navigation is *alignment*. Basically, this term defines how the user holds the map, that is, it specifies how the map is oriented with respect to the user and the environment.

A map may be *reader aligned*, in which case the orientation of the map remains constant with regard to the reader’s body. A typical example of this is a reader holding the map with the print upright. In these cases, the map is usually, although not necessarily, misaligned with respect to the environment.

An *environment aligned* map, on the contrary, is oriented consistently with regard to the environment; in other words, north on the map always corresponds to north in the environment. This implies that in order to keep the map aligned, the reader is required to turn the map in relation to himself or herself when turning in the environment.

A map is said to be *contraligned* when it is misaligned by 180°, *i.e.*, either the user is holding the map "upside down", or north on the map is actually south in the environment.

Discrimination

The ability of vision to recognize a difference is called *discrimination* (MacEachren, 1995, pp. 107-108; 124-134). One problem in seeing what is depicted in a map is to distinguish between the figure and the ground, or the significant and insignificant elements. Figures are defined by their contour or the boundary between object and nonobject. The figure-ground problem is one form of discrimination problem, called detection. Additional discrimination problems can be identified as well, such as point feature discrimination (how to differentiate different symbols from each other), pattern discrimination, and color discrimination.

When navigation fails

It can be seen that using a map consists of several parts requiring cognitive processes. Thus, it is no surprise that it has been found that even adult map users often use maps inefficiently, and they do not feel confident with navigational maps (Blades and Spencer, 1987b). Failure in navigation results in getting lost.

Being lost effectively means that the user’s map model and terrain model for some reason become disconnected. Crampton (1988) has suggested four degrees of lostness: *unknown lost, known lost, corridor found,* and *functionally found.* Of these, unknown lost is the most severe: it means believing that one’s position is known, when it actually is not. Once the error has been found, the user is known lost (he or she knows that the current location is incorrect). Corridor found means that the user knows his or her position to some extent, and functionally found means that the position is known exactly.

A common error in navigation is a *parallel error*. Parallel error has to do with the unknown lost situation. It means that there are two or more similar features (both visually and by location), and the user fails to discriminate correctly between them. A parallel error is hard to remedy, since the users are prone to make the terrain fit their expectations and thus cannot start to solve the problem (Crampton, 1988).

Key results

There have been an extensive number of empirical studies on human-map interaction. Since the field is rather complex, involving several disciplines, the research methods are also extremely varied. The empirical studies range from field studies to tightly controlled laboratory experiments. Next, I will introduce some key results obtained in a few relevant studies.

Alignment is clearly the single most significant factor concerning spatial knowledge and hence map understanding. The fundamental research to point out this issue was conducted by Levine *et al.* (1982). They conclude that a map is easiest to use when it is aligned with the terrain. Similar results have been subsequently obtained by several researchers, among them Warren *et al.* (1990).

Warren and Scott (1993) studied alignment effects in a variety of experiments. These experiments contain both interesting methods and results; therefore, I will explain them briefly.

Three experiments were conducted – two in a restricted man-made area, and one in a larger, wooded environment. There were 24 users in the experiments, 12 male and 12 female. The tasks in the first two tests included

- ☐ Find-your-location task, in which the user was taken into a place inside the experiment area, was given a misaligned map, and asked to indicate his or her location on the map. This task was repeated.
- ☐ Path task, in which two locations were marked on a map by a circle and a square. A route connecting these points was shown by a solid line. The user was taken to the start point (circle), and was told to follow the path to find the square. At each turn, he or she was supposed to stop right after the turn, and show the map to the experimenter.

- ❑ Start-goal task, in which the map contained the circle and the square, but no route was indicated. There were always at least two alternative routes from start to goal.
- ❑ Segment task, which was similar to the path task, except that the user received a new map after each segment of the route.

The only difference between the first two tests was that in the first test the map contained no text, whereas the map used in the second test had labels on it. In the first test the map was given to the users misaligned to the environment; in the second, it was aligned neither to the environment nor to the subject.

The results showed that when the map was aligned with the environment, the performance was excellent; when the map was misaligned, the performance was poor. The subjects also preferred aligning the map when given a choice. This was the case in all tasks. Even in experiment two – where one might think that since labels are easier to read when the map is aligned to the observer, the user would have been eager to align the map to himself or herself – the map was aligned to the environment in 93% of the cases.

The third experiment tested the generality of the first two experiments. Six start-goal combinations were used. The user was taken to the start point and instructed to find his or her way to the goal. The path the users chose was recorded, likewise every change made to the map orientation.

The results showed that most of the total route distance was traversed with the map aligned to the environment. Also, it was clear that when the user actively turned the map, the predominant choice was to turn it so that it was aligned to the environment. The map was not consulted at every turn, but when it was, it was aligned to the environment in 67% of cases.

Similar results also hold for YAH maps (Levine, 1982). Furthermore, Roskos-Ewoldsen *et al.* (1998) have found that the ease with which people can navigate through the environment depends on whether the map is aligned with the environment. They also found that this does not depend on the scale of the map.

Misaligned maps have also been studied (Rossano and Warren, 1989). It was found that two types of errors could be predicted beforehand when misaligned maps are used. An *alignment error* means that the user was not able to perform the mental rotation at all to align the map. A *mirror-image error*, on the contrary, refers to incorrectly performed mental rotation: instead of rotating the map mentally in two dimensions to align it correctly, the map was rotated over the third dimension (flipped) causing the resulting image to be a mirror image of the original image.

One problem is to understand what is actually shown on the map, that is, distinguishing between image and ground, and recognizing and identifying map symbols. In an experiment where the users planned routes to drive to a destination (Streeter and Vitello, 1986), some drivers even chose rivers as a part of their route. It was also concluded that about 64% of the general public have difficulties in reading a map.

Streeter *et al.* (1985) compared maps to auditory guidance while driving a car. They found that the subjects who listened to the instructions performed clearly better in each measured area – distance driven, time used, and errors made. The users also preferred the voice instructions. The instructions were very brief, including only the left and right turns, the distance after which the turn is to occur, and the road into which to turn.

There are some issues worth noting in the experiments above. First, spoken (taped) instructions in a way simulated an experienced navigator sitting next to the driver. Second, even though no overall plan of where to go was available with the spoken instructions, the performance was superior; and finally, a map which is not overlaid on the real world view is particularly inconvenient in a driving situation, where the attention requirement is high and relies mostly on the visual sense.

In essence, the results discussed in this section are general and can therefore be applied to any form of navigation. However, when a paper map and a traditional compass are substituted with a digital map shown on a computer screen and an electronic compass, some additional issues arise. I will next provide an overview of the research issues specific to these new generation maps. It should be noted that the navigation research concerning digital maps mostly focuses on vehicle navigation. Therefore, even though my focus is on personal navigation, I will discuss mostly vehicle navigation in the next section.

2.2 Digital maps

Nowadays, more and more maps appear in electronic form. Most of the research on digital maps has been carried out in the context of aviation and route guidance. The cognitive processes required from pilots while flying an aircraft have been studied especially widely. However, in many respects these studies have achieved results that can be applied to pedestrian users as well. Further, digital maps for personal usage have also started to emerge, in the form of tourist guides running on small hand-held computers, for instance.

A digital map usually consists of an electronic representation of the environment (the data), and a software component to interpret and display that information (the map application). The flexible nature of the information behind the visualization allows several varying views over the same area.

Digital maps can be divided into two categories: there are digital maps of the real world, and digital maps of virtual environments. It has been shown that many issues concerning navigation in the real world can also be transferred into virtual environment maps. For instance, Vinson (1999) has generated design guidelines for landmarks in virtual environments. He based the guidelines on existing research on navigation in the real world. Another study reported that virtual environments can be used to train real world route knowledge (Witmer *et al.*, 1996).

In the context of this dissertation, the focus is on real world maps and real-world navigation. Therefore, from now on – unless otherwise stated – the term “digital map” refers to a digital map of the real world.

Digital maps are able to free the user from some of the cognitive processes involved in navigation. They also provide the user with features that are not possible with paper maps, such as reacting to changes in the environment, or marking the positions of other map users.

There are two basic ways to bring maps into electronic form. Either the conventional paper maps are scanned into digital form and represented as raster bitmaps on the screen, or the information is represented in vector form. The raster maps look exactly like their paper counterparts, whereas the vector maps can be more varied in form, allowing certain information to be left out dynamically, depending on issues such as the assumed use of the map. The vector data is often obtained from a geographic information service (GIS) database.

Positioning is closely related to digital maps. A positioning service provides the map user with information on the current location. The most common positioning service is the satellite-based Global Positioning System, or GPS. The position can be acquired with a GPS receiver. The accuracy of a GPS service is usually around 7 meters, but with differential correction it can be brought down to a few dozen centimeters. An extensive explanation on GPS has been provided by Getting (1993).

In addition to GPS, there are also other positioning services available. As an example, the current cellular network is capable of determining the location of a connected mobile phone. There are various techniques to obtain the location coordinates; however, regardless of the technique used, the positioning accuracy is clearly lower than with GPS. The accuracy depends on the technique used, as well as on the cell size, and is typically hundreds of meters.

Interacting with digital maps

Since digital maps are usually shown on displays, they are very flexible when it comes to issues concerning human-map interaction. For example, it is the map software (or user interface) designer's responsibility to decide which alignment modes to implement, and how they are used.

Navigational tasks with digital maps can be defined as searching tasks (naïve search and primed search), and exploration tasks (Darken and Sibert, 1996). A fourth task can be defined as targeted search (Darken and Cevik, 1999). In targeted search, the target is shown on the map; in primed search, the target is known, but does not appear on the map; in naïve search, there is no a prior knowledge of the position of the target, and the target is not shown on the map. In exploration, no specific target has been set[2].

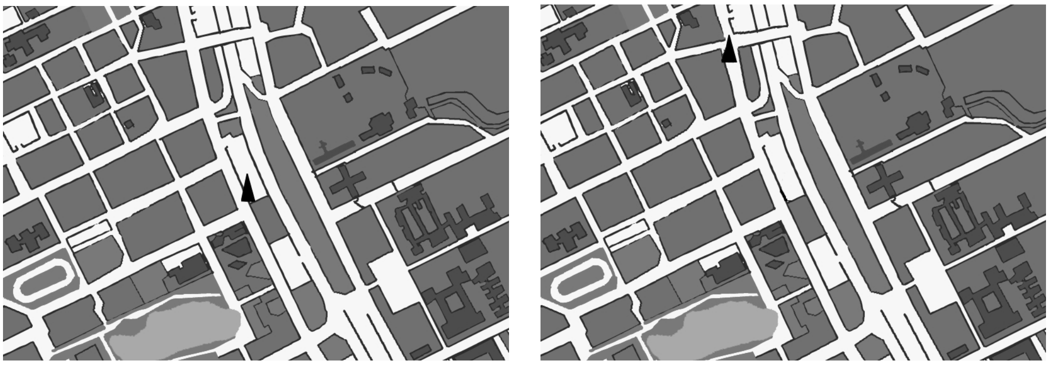

Figure 1. *The behavior of the YAH symbol in two cases when the user moves. In the lefthand picture, the YAH remains in the middle of the screen and the map moves, whereas in the righthand picture the map remains static and the YAH symbol moves.*

There are two basic ways to visualize dynamic positioning information on a digital map. Either

- the YAH symbol is drawn in a static position in the middle of the screen and the map moves as the user moves, or
- the YAH symbol moves on the screen and the map image remains static (see Figure 1).

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[2] Even though these definitions have been originally applied to virtual environment maps, in my opinion they can also be used in the context of real world maps.

In the latter case, when the user is about to move out of the displayed area, a new image has to be created and the whole display has to be changed at once.

The same choices hold for rotation. Either the YAH symbol rotates and the map does not (the map is aligned *north-up* – up on the map corresponds to north in the environment), or the map rotates and the YAH symbol remains static (the map is aligned *forward-up* – up on the map is forward in the environment).[3] The most important advantage of a forward-up map is that using it requires no mental rotation. These alternatives are shown in Figure 2.

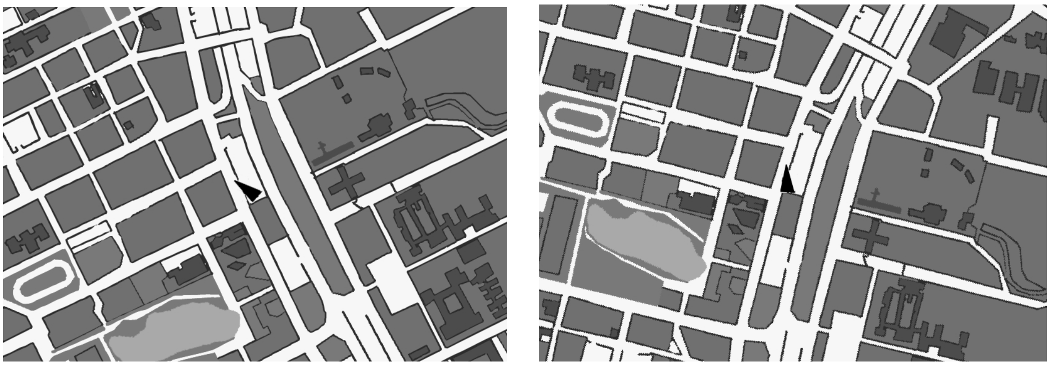

Figure 2. *Alignment variations. In the lefthand picture, the map is aligned north-up (the YAH symbol rotates), whereas in the righthand picture the map is aligned forward-up (the map rotates).*

Two reference frames (RFs) can be defined with respect to the orientation and alignment: an egocentered reference frame (ERF) is established by a navigator's forward view, and directly corresponds to this perspective. The ERF is always aligned forward-up. The world-centered reference frame (WRF), on the contrary, is established by a visually presented two-dimensional map in which the traditional canonical alignment is north-up. To navigate, one must be able to associate the current view of the world to its location in the map. Usually, the WRF is aligned north-up. However, it can also be aligned forward-up.

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[3] It is fairly easy to become confused with the different alignment terms. A north-up aligned map is usually the same as reader-aligned, and a forward-up aligned map is aligned to the environment. North-up and forward-up are terms used with digital maps.

Kim *et al.* (1997) examined the effects of rotation and movement of the map in an automobile. They had a simulated driving environment to measure the arrival time, navigation efficiency, and map reading time. Among other things they found that the arrival time is shorter if the car is not moving on the map but the map moves and the car is fixed to the middle of the screen. This was due to the fact that the changes in a display were constant and smooth. With a moving car, when the car reaches the edge of the screen, the whole display should be changed at once.

Aretz (1991) studied the design of electronic displays. He performed a cognitive analysis on pilots’ navigation task in an aircraft in a simulated environment on a workstation. In the simulation, the aircraft remained in the middle of the screen while the map moved. He compared the forward-up and north-up approaches. The results showed that the alignment should depend on the task: tasks that primarily use the ERF should use forward-up alignment (such as localization), whereas tasks that need WRF should have north-up aligned maps (such as reconnaissance). He also found that the inconsistency of the rotating map display hinders the development of a cognitive map.

Spoerri (1993) examined whether a computer-based route guidance system should use a traditional 2D map display, or an ERF based driver-centered perspective display. He hypothesized that a perspective display would perform better: it simulates what the driver sees through the windscreen, and thus the view is easily integrated with the real-world view. His experiments showed that the perspective display did indeed perform better.

Darken (1999) found that for ERF tasks, such as a targeted search, a forward-up map is preferable to a north-up map, whereas a WRF map would perform better with primed or naïve search tasks.

The wayfinding design should take into account the user group (who the instructions are intended for). Different user groups may require different instructions. The same applies to the wayfinding task (is the user just exploring the environment, searching for a specific destination, is there an emergency and so forth). The key destinations should also be identified (the districts from which and into which a lot of traffic moves), and the routes chosen to them (the width of the circulation system and the directness of access may define the preferred routes).

2.3 Summary and discussion

In this chapter, I have presented some of the most important research issues concerning human-map interaction. I have identified the key components of wayfinding, stressing the fact that wayfinding is a demanding cognitive task. Further, I have described some relevant studies that have addressed these components.

In addition to regular paper maps, I have also presented digital maps. I have pointed out that they provide the user with help in navigation and significantly lighten the cognitive load. I have also brought up some key research issues, such as alignment and the behavior of the YAH symbol.

Human-map interaction as such is a well established area, with its roots in many disciplines. When considering the development of navigation assistants in new platforms, one should definitely refer to existing research on the topic. I think that in order to construct applications and services that are supposed to assist users in wayfinding, one first has to understand what navigation is in general, what problems there are, and how they can be addressed. This approach has been used when digital maps have been studied; likewise, the knowledge obtained in previous cartographic and map research, on both paper and digital maps, provides the essential building blocks for developing a mobile, personal wayfinding assistant.

When it comes to technology, wearable computing allows several interesting approaches regarding navigation. One possibility is to choose audio as the primary – or even the only – interaction channel. This would effectively mimic a human experienced navigator sitting inside the wearable computer, guiding the user when required. As described earlier, the results obtained by Streeter *et al.* (1985) clearly support this approach. Another possibility is to take a more traditional vision-based approach, and present the user a map on a display. The advantage is that the map is a familiar form of representing geographical information. This is the approach taken in the constructive part of this dissertation, particularly in the WalkMap application (Lehikoinen and Suomela, 2002a).

In WalkMap, the linear wayfinding style is adopted. This approach allows experimenting with various strategies, such as displaying waypoints on Context Compass at locations where the wayfinding decisions are to be made. Among other things this approach makes it possible to move over from traditional two-dimensional route maps towards more task-oriented solutions.

An interesting issue in WalkMap deals with alignment. Since the primary task in WalkMap is a targeted search, based on the results presented above it is quite obvious to prefer the forward-up alignment mode. However, a wearable computer equipped with a reasonable efficient central processing unit and a capable display – in contrast to lower-end handheld computers – would make it possible to keep the map aligned forward-up at all times. In other words, whenever the user turns, the map is rotated on the screen in such a way that up on the map again corresponds to forward in the environment. Since no study has addressed this issue, we arranged a field experiment. The results showed that even though such an automatic alignment can be used, it is in no way superior nor preferred to the manual alignment mode. Consequently, WalkMap has both manual and automatic alignment modes available.

Research on personal navigation using digital maps on wearable computers is quite rare, and many of the issues discussed in this chapter have not so far been considered at all. Some research has been done, however. Before getting deeper into existing personal navigation research, let us first discuss wearable computers in general.

3. The platform: Wearable computing

There are various reasons for wearing clothes. Some clothes are designed purely with functionality in mind: the clothes provide protection, durability or comfort. Some clothes are used to express personality or to communicate a message. And, of course, in many cases the clothes are used just to cover our naked bodies without any underlying meaning (other than conforming to the norms of our society).

Innovations in clothing are surprisingly rare. Probably the most important occurrence (at least as far as this study is concerned) was the invention of pockets; one day somebody noticed that you are actually able to embed carrying bags into the clothing. Certainly pockets cannot hold as much as large bags; however, they free the user from carrying something external which probably occupies the hands, and from having to remember to take the extra baggage along. The pockets remain with the user implicitly as long as the clothes stay on.

The latest significant improvement in clothing is probably the zipper, invented and patented by Judson in the late 19th century. The zipper was originally meant to replace shoelaces. It got its current form in 1913, when Judson's design was reformed by Sundbach. During the 1930's, the zipper finally became a commercial success. (Friedel (1994) provides more information on the invention and development of the zipper). Since Judson's times, only the materials and styles have changed; the functionality has remained more or less the same – until now, when smart clothing has started to emerge.

Smart clothing is a relatively novel research area. It combines several disciplines, such as textile engineering, psychology, software engineering, and human factors. It targets at enhancing clothes so that they are capable of assisting the wearer in managing his or her daily tasks, or performing some tasks automatically. Usually, the "smartness" is achieved by embedding some computational power into the clothing. Smart clothing creates new functionality for clothes, adding to the list of reasons for wearing them.

Smart clothing and *wearable computing* are two terms that are often used synonymously. There are some implicit semantic differences in the approaches, however. When talking about smart clothing, the origin of the research is often in clothing, and the goal is to add functionality (or “smartness”) to the clothing. Smart clothing research concentrates on issues such as conductive fibers, physiological factors, or even fashion. Wearable computing research, on the contrary, starts from the computer and computing technology as the origin and aims at embedding the technology into clothing, possibly by miniaturizing the hardware components, optimizing the wireless networks, developing distributed software, and minimizing power consumption. Even though the approaches differ, the ultimate goal is the same – offering ease of use and unobtrusive access to the computing resources in a form that can be worn. Therefore, in this dissertation these two concepts are not divided off, and the term wearable computing is used[4].

So far, no generally accepted definitions for wearable computers exist. However, widely accepted characteristics of a wearable computer can be stated as follows (Mann, 1997):

- a wearable computer belongs to the personal space of the user,
- it is always active when worn, and
- it is totally under the user’s control.

The first bullet implies that both the wearable computer user and the other people regard the wearable computer as part of the user's personal space.

Since a wearable computer is worn as clothing, or better still, it *is* the clothing, it goes wherever the user goes: it is mobile (as noted earlier, in order to

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[4] There are also different ways to describe how these two terms relate. For instance, Mann (1996) characterizes smart clothing as “the combination of mobile multimedia, wireless communication, and wearable computing”.

be mobile a computer has to be small enough so that it can be taken along and carried relatively conveniently, and it has to be usable while standing or walking).

What, then, distinguishes a wearable computer from any other mobile computer? One might justifiably argue that any mobile computer fulfills Mann's aforementioned criteria. Indeed, discussion on this issue in the research community is lively. Some researchers claim that a mobile phone that is kept in a pocket is wearable; others say that you do not *wear* a device, you *carry* it. In the latter case, only computers seamlessly merged into the clothing can be considered wearable, making real wearable computers extremely rare. The third approach is to develop totally new form factors that are not traditional clothes, but can be worn as clothes or accessories, and also provide computational capabilities.

I argue that in addition to the physical form factor, one has to consider the whole design when judging whether a system is wearable or not. In other words, even if the device itself were not actually wearable, the system as a whole can be considered wearable if the aforementioned criteria are met in most parts of the system. As an example, one might construct a wayfinding application that runs on a hand-held computer screen. Were the actions needed to operate the application easy enough to complete with a wearable input device, and the output understandable on a wearable display, and so forth, the system can be considered wearable since it would be straightforward to convert the computer itself into a wearable one in the near future.

One may wonder whether the integration of wearable computers could be taken even further by implanting them under the skin. This way, with computers as fixed implants, one really would always have the computer along. Without considering all the social, ethical, or medical aspects of implanted computers, I confine myself to raising one concern: with implants, the user would not be in control – he or she would not be able to take the computer off any time. Therefore, at the very least, this option does not fulfill the requirements for wearable computers, and consequently it cannot be classified as wearable.

Historical account and current trends

As in many other research areas, within wearable computing there is most probably an everlasting discussion on “who was the first”. The answer depends on the speaker, and how he or she defines wearable computing.

One potential candidate for the first wearable computer was that used to predict roulette, designed in 1955 and developed in 1961 (Thorp, 1998). The idea was to measure the position and velocity of the roulette ball and rotor in order to predict their future paths, and where the ball is likely to stop. The computer was then hidden in the clothing, so that it could not be noticed while gambling. The implementation was based on an analog computer that had twelve transistors, and was the size of a cigarette pack. For input, there were microswitches in the shoes that were operated with the big toes; the output was based on musical tones, with skin-colored wires running from the computer to the earphones. In spite of some hardware problems, the computer actually worked, with a gain of as much as 44% compared to betting without assistance.

It is broadly agreed that the hatchery of wearable computing is the Media Lab at Massachusetts Institute of Technology, or MIT. For more information on MIT wearable computing research and a fine collection of links to even more online information on wearable computing, see (MIT, 2001).

A lot of the pioneering work in wearable computing relates to one individual, Prof. Steve Mann (2001a). He began his work on wearable computers in the 1970’s, and transferred to MIT at the beginning of the 1990’s (Figure 3). Currently Mann works for the University of Toronto, Canada.

Figure 3. *The evolution of Steve Mann's wearable computer. Photo by courtesy of Steve Mann.*

In addition to MIT, Carnegie Mellon University, or CMU (2001) has been involved in wearable computing research since the beginning of the 1990's. CMU has concentrated especially on interdisciplinary research and design methods: see *e.g.* (Smailagic and Siewiorek, 1999).

For years, the wearable computer was understood as a miniaturized PC carried in the clothing. Several research projects emerged, targeting various aspects of wearable computing, such as hardware (Smailagic and Siewiorek, 1993), software architecture (Fickas *et al.*, 1997), and applications (Bass *et al.*, 1997). It became a norm that a wearable computer is a bulky device that is either worn on the belt or carried as a backpack, operated on a miniature keyboard or a trackball, and viewed through a head-worn display. During the first years, no particular attention was paid to resembling garments, not to mention the effects of prolonged usage or social acceptability.

When it comes to research, it is worth noting that publications on wearable computing were rather rare until 1997, when the first International Symposium on Wearable Computing (ISWC) was arranged. Since then, the area has grown rapidly, and also become more and more widely known.

The first commercial wearable products began to emerge at the beginning of the 1990's. One of the first was the Xybernaut (2001), closely following the mainstream in the product design. Xybernaut's research on wearable computers began in 1990. Their current wearable computer, Mobile Assistant V, the successor of their best-known product Mobile Assistant IV, still follows the 'traditional' wearable computer form factor – the mobile assistant is equipped with a central processing unit, a head-worn or a hand-held display, and a miniature keyboard, which can be substituted with a wrist-worn keyboard. A belt is provided as an option for carrying the CPU. The Mobile Assistant is equipped with a standard Intel Pentium processor, making it compatible with many current operating systems and external devices.

Xybernaut is targeted at vertical industry markets. Today, Xybernaut is in use in many application areas, including manufacturing, maintenance, and mobile geocomputing to name but a few.

As the research progressed, it was gradually understood that in order to be wearable, other aspects should be taken into consideration as well. New products and research projects started to emerge. Of commercial products, an example is Smart Shout by the Finnish clothing company Reima-Tutta (Mikkonen *et al.*, 2001). Smart Shout consists of a regular jacket, and a bodybelt that can be attached or detached easily. The wearable computer central processing unit, coupled to a mobile phone, is embedded into the belt. Smart Shout is designed for easy and fast group communications using the existing wireless GSM network. The idea is to allow the members of a previously formed group to send voice messages to the other members of the group with ease.

Products like Smart Shout are small steps towards more and more wearable computers; they provide the user with enhanced functionality in addition to acting as regular clothing. The origin of the research has been the garment itself, and the environment of use. Only after that has it been enhanced to support activities commonly found in the primary using environment.

In my opinion, the motivation for developing wearable computing systems is not only to make the computer, or any other device for that matter, disappear into the clothing. I think that the objective is also to make access to ever-increasing digital information more and more easy, efficient, and also personalized.

With this point of view in mind, let us start discussing some key concepts closely related to wearable computing, explore some of the enabling technologies that in part make the existence of wearable computers possible, and take a look at the various application areas in which wearables are currently used.

3.1 Key concepts

Wearable computing is a very interdisciplinary research area, involving disciplines such as computer science, electrical and mechanical engineering, psychology, and sociology. Since the roots of wearable computing lie in mobile computing, computer science has naturally been in the key role. Within computer science, there are several additional research areas, which in one way or another deal with wearable computing. In this section, I will present some of the most relevant key concepts in these areas.

Wearability

Wearable computers are intended to be worn. Once real wearable computers are developed, this becomes trivial – the jacket or the tie *is* the computer. However, to reach this goal one has to know how the various components of a wearable computer can be embedded into the clothing, and what the most convenient locations for them are. This issue is called wearability.

Wearability was first addressed by Gemperle *et al.* (1998). They define wearability as *the interaction between the human body and the wearable object*. It considers the design issues involved in developing objects that are intended to be worn. The approach includes studying the human body, wearable objects, and individual experiences. They define several guidelines that illustrate the steps needed to take into consideration when designing wearable objects. The guidelines cover the following issues:

- placement (where on the body the wearable object should go),
- form language (defining the shape),
- human movement,
- proxemics (human perception of space),
- sizing,
- attachment (fixing forms to the body),
- containment (considering what is inside the form),
- weight,
- accessibility,
- sensory interaction,
- thermal (issues of heat next to the body),
- aesthetics, and
- long-term use (effects on the body and mind).

When these issues are considered, it is possible to create wearable objects that enhance people, and also feel good.

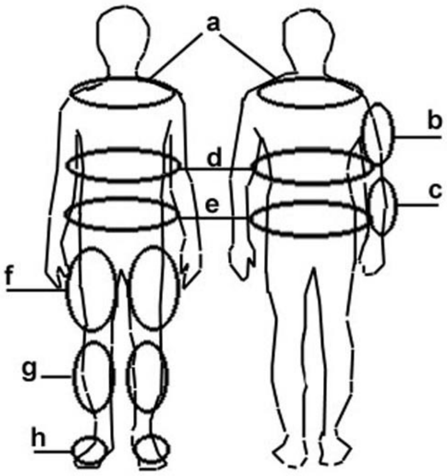

Figure 4. *The areas found most unobtrusive by Gemperle et al. (1998) in front (left side) and rear (right side). a) collar area, b) rear of the upper arm, c) forearm, d) rear, side, and front ribcage, e) waist and hips, f) thigh, g) shin, h) top of the foot. Image by courtesy of Francine Gemperle, retouched by Tero Hakala.*

In addition to the aforementioned guidelines, Gemperle *et al.* also developed a set of forms conforming to the guidelines. They created 2D drawings, 3D foam models, and arranged two user studies in order to evaluate the wearability of the forms. As an example, they found that the areas shown in Figure 4 are the most unobtrusive for placement.

In my opinion, this is one of the most significant studies made in the field of wearable computing. The importance of wearability cannot be overestimated. Even if a device provided significant processing power or some advanced functionality, it would not be used if it were cumbersome, too heavy, or simply uncomfortable. When designing wearable products, knowledge from the textile industry, physiology, and biomechanics should definitely be taken into consideration.

Augmented reality: enhancing senses

Man has always wanted to enhance the natural physical and psychical abilities. One form of enhancement has been, and still is, tweaking senses. For centuries, the hard of hearing have been assisted by hearing aids; likewise, those with poor sight have worn spectacles. Technology has provided users with abilities that had otherwise been beyond their reach.

The advent of wearable computing allows even greater opportunities for sense enhancement. It is not only a question of overcoming some deficiencies, but also allowing sensing entities that do not exist in the real world at all. One technique that allows such enhancement is augmented reality.

Augmented reality enhances the user's senses by overlaying a perceptible virtual layer on the physical world (Azuma, 1995). The virtual layer may be visual or audible. When combined with a head-worn display often used with wearable computers, visually augmented reality can offer the user plenty of additional information on the surroundings in graphical form. For instance, while watching a famous landmark, a tourist in an unfamiliar city may get additional information on the landmark displayed on the head-worn display.

Augmented reality has been regularly applied in wearable computing research. As an example, the real world has been augmented with multimedia presentations by Höllerer and Pavlik (1999). They use two computers, one equipped with a tracked head-worn display and one with a hand-held display. The augmented reality multimedia documents are displayed in their actual real-world locations on the head-worn display, while some additional information is displayed on the hand-held display. The content consists of stories and events that took place on their university campus.

Augmented reality is closely related to outdoor usage. Hence, it is no surprise that some fine examples in applying augmented reality can be found in personal navigation research (Thomas *et al.*, 1998a; Feiner *et al.*, 1997). These cases are further discussed in Section 3.4.

Augmentable reality

Augmented reality could be compared to read-only access rights in computer science; the user is granted access to some previously stored information but is not allowed to make any modifications. When adding and changing the content is allowed – when the user has read-write access to the content – we are referring to *augmentable* reality.

The term augmentable reality was introduced by Rekimoto *et al.* (1998). Their system allows the users to attach digital content, such as photographs or audio notes, to the physical environment. The approach can be thought of as a virtual counterpart of the famous adhesive yellow Post-It office notes. A virtual object is stored in a network database; it is identified by contextual information stored together with the created object. The contextual information is an identification code, such as an ID from an infrared beacon or a visual tag. Geographical coordinates such as those provided by the GPS can also be utilized. The various sensors attached to the wearable computer provide this information. Later, when the user approaches such content, the sensors notify of its existence.

Context-awareness

A concept often referred to in wearable computing research is *context-awareness*. In essence, it is a question of

- knowing where the user is, what he or she is currently doing or about to do, what the state of the user and the environment is, and what the relationships are between them; and
- applying the obtained knowledge to assist the user in performing his or her tasks more efficiently and reaching his or her goals.

Mobility is an essential characteristic of wearable computing; context-awareness is there to take mobility into account and to process the obtained information for the user's benefit. Location information is indeed often the primary attribute in determining the context. However, the other aspects of context should be taken into consideration whenever possible. As an example, in the above definition the user's state does not include only his or her mental and physical state, including emotions, but also the social state.

Several studies address context-aware computing, concerning issues such as wearable computing and smart environments. In this dissertation, I will restrict myself to presenting some studies related to research on context-awareness that also address wearable computing.

Abowd *et al.* (1998) have defined the general mechanism for context-aware computing as follows:

1. Collect information on the user's physical, informational, social or emotional sense.
2. Analyze the information, either by treating it as an independent variable or by combining it with other information collected in the past or present.
3. Perform some action based on the analysis.
4. Repeat from Step 1, with some adaptation based on previous iterations.

An interesting point is the consideration of information collected in the past – the historical context – related to geographical context. It may consist of the user's previous experiences in the same place, or even add the experiences of some other users.

Pascoe (1998) defined the core capabilities of context awareness in wearable computers. These capabilities – independent of application, function, or interface – are as follows:

- ❑ *Contextual sensing*. The environmental states are detected and presented to the user in understandable terms (sensing the environment).
- ❑ *Contextual adaptation*. The computer, the software, and the user interface sense the context and react accordingly (reacting to the changes in the environment).
- ❑ *Contextual resource discovery*. The system makes use of the contexts of other entities by discovering other resources in the current context (interacting with the environment).
- ❑ *Contextual augmentation*. The environment is augmented with additional digital information (compare to augmentable reality).

In practice, context-awareness can be seen partly as a filter to reduce the amount and diversity of information that is offered to the user at any time. This filter can then be altered dynamically, either manually by the user or automatically by defining triggers that activate a specific set of filters. These filter sets, in turn, allow building user profiles that define higher-level contexts (such as “when the user is outside the office on a weekday at noon, he or she is most probably going to lunch”).

As in augmented reality research, so research on context-awareness is in many cases related to location-awareness and personal navigation. Therefore, context-awareness is considered further when discussing personal navigation.

Ubiquitous computing

The term ubiquitous computing means literally ‘computers everywhere’. This is a term originally proposed by the late Mark Weiser (1991). In short, the idea is to fill the environment with computers and hide them in a way that makes using them transparent. This would enable the people to concentrate on the task, not the tool, when interacting with the environment. This phenomenon has also been referred to as invisible computing.

There is a lively discussion going on in the research community concerning the differences between ubiquitous and wearable computing: see *e.g.* (Rhodes *et al.*, 1999). Some claim that they are fundamentally different and should be studied separately; others think that in spite of the differences, there are some commonalities as well – 'computers everywhere' could also include those that are inside clothing. Indeed, in principle ubiquitous computing is very far from wearable computing. It favors public computers instead of intimate personal computers; furthermore, in a ubiquitous computing environment the user is not in control with regard to the computer. Still, ubiquitous computing relates to wearable computing in one important area – environment interfacing. Even though the invisible computers in the environment are not used as we use our personal computers today, they could be operated via wearable computers to gain more functionality or power. In other words, the wearable computer user could use his or her computer to access the ubiquitous services that are available in the environment. Ubiquitous services could be thought of as a part of the location-based context-awareness information.

Another term related to ubiquitous computing is *pervasive computing*. Some researchers consider the two terms synonymous, while others take the view that pervasive computing is the combination of wearable computing and ubiquitous computing. Once again, there is no consensus of opinion on the exact semantics involved in these terms.

3.2 Enabling technologies

A wearable computing system consists of numerous components. There is the computer itself, hidden inside the clothing. Since the design is most probably distributed, some sort of buses and small-area networks are needed to transfer information between various parts. A wireless communication channel is needed, as well as new input devices. Likewise, an output device is required.

Many of the issues listed above are applicable not only to wearable computers, but also to mobile computers in general. In this section, I review some of the issues that mostly concern wearables. Instead of describing each technology in detail, I only present the main problems and research issues in each case.

Smart textiles

An essential aspect of clothing is the clothing material, that is, the material of which the garment is made. This is equally important to wearable computing, since an ideal wearable computer is totally embedded into the clothing. There are two aspects that have to be considered: the devices have to be minimized, and the garment should provide at least some basic functionality in itself. Currently, this functionality is most often just acting as a bus, offering a path for the electricity to travel.

The simplest way to implement smart textiles is to augment a regular garment with miniaturized sensors and other electronics. Even if today this is in many cases the only viable solution, it makes using such clothes difficult – for example, the cloth cannot be washed in an ordinary washing machine without first removing the electronics. Additional problems are caused by the power requirements: even if many sensors run on minimal energy, they still need some power in order to function. Either they have to contain the power source in themselves (or to harvest the power from the environment), or they have to be wired to the main battery.

Conductive textile fibers have been studied by Post and Orth (1997). They use textile-based electronic circuits to distribute data and power, and to provide touch sensing for input. They use passive components that are sewn into the clothing, using materials such as silk thread wrapped in copper foil. Additional electronic components can be soldered onto the metallic wire. These components can be connected to the garment in various ways (with snap fasteners, for example), so that they are easy to remove for washing.

More advanced textiles have also been designed, such as the technology designed and manufactured by ElectroTextiles (2001). Their conductive fiber technology, ElekTex, adds positioning sensing to the clothing. In effect, a piece of textile made of ElekTex is capable of sensing where it has been pressed (X-Y location) as well as the pressure. ElekTex is totally woven into the cloth, making it actually a durable, wearable, and even washable material. One potential application area for ElekTex is in user interaction (Figure 5). It can also act as a sensor to provide information for context-awareness.

Figure 5. *A folding soft keyboard for Palm Pilot hand-held computer by ElectroTextiles. Photo by courtesy of Electrotextiles Company Ltd.*

Displays

Vision is a very efficient sense when it comes to receiving information. Therefore, it is natural to use a display as an output device in computing systems. Indoors this is straightforward: a desktop monitor can be used. In outdoor usage many problems are encountered, however. In this section, I will take a look at display devices suitable for wearable computing usage. Again, I do not intend to delve deep into the technology, but consider the available technologies in general, and their appropriateness to the task at hand.

In principle, the display devices that can be used with wearable computers can be divided into two main categories: hand-held (or wrist-worn) displays, and head-worn displays[5]. Both of these categories have their strengths and weaknesses, some of which are common and result mostly from outdoor usage, while the others depend on the display technology itself. For a very thorough on-line comparison chart on existing head-worn displays, refer to (Bungert, 2001).

Hand-held displays as such cannot be considered wearable. However, when such a flat display is installed into the sleeve, for example, it becomes more or less wearable – that is, part of the clothing. A display used as a wristwatch is an example (Narayanaswami and Raghunath, 2000). These displays have to be small in size in order to be unobtrusive, which also restricts the resolution, and therefore both readability and the amount of information that can be shown on the screen at once.

Figure 6. *A monocular opaque head-worn display. Photo by Tapani Levola.*

When head-worn displays are considered, there are several subcategories. First, the display may be monocular (for one eye only), or

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[5] The term “head-mounted display” (HMD) is often used instead of “head-worn display”. However, I prefer the term head-worn display; this emphasizes the fact that in the context of wearable computing, the display should be worn as well. In my opinion, the term “mounted” does not reflect this aspect. See (Feiner, 1999). Head-worn displays have been traditionally used within virtual reality applications. However, in this text I consider only wearable computing usage.

binocular (covering both eyes). Binocular displays can further be divided into monoscopic and stereoscopic displays, depending on whether both display elements show the same picture or not. Both monocular and binocular displays may be opaque or see-through. Most monocular displays are opaque. A monocular opaque display is shown in Figure 6, and a binocular see-through model in Figure 7.

Should an opaque binocular display be used, there has to be a way to display the real world as well. This is often done with a video camera installed into the display frame. Then, the user sees an image that is composed of the real time real world video feed, with the computer image overlaid on it. In the case of see-through displays, the user is able to see the computer-generated image “floating” in the air in front of the real world view seen through the display optics.

Figure 7. *A binocular see-through head-worn display. Photo by Tero Hakala.*

Head-worn displays allow much greater resolution and display area compared to hand-held displays; in this respect, they allow using the same applications that are used with desktop computers. However, they cause other problems, related to issues such as safety and prolonged usage. While a user is moving outdoors, in the traffic, any image overlaid on top of the real world view can severely impair concentration and observation. Further, the display should be extremely light in order to be worn for hours and hours continuously. Also, it is not known whether using a head-worn display would affect the vision or cause other harmful effects in long-term use. Therefore, a lot of further research is required.

Other devices and sensors

There are a number of additional peripherals that could or should be used in a wearable computing system. For instance, to achieve comprehensive knowledge of the state of the user and the environment – in other words, to implement context-awareness – several sensors should be attached to the computer. These sensors include biological sensors, such as heart rate monitors or respiration rate measuring sensors; environmental sensors such as temperature, lighting, and humidity sensors; and optical and acoustic sensors.

When it comes to personal navigation, there are two peripherals worth noticing. The first, a GPS receiver, is used to obtain the user's (or, to be exact, the receiver's) geographic location, and the other, a digital compass, provides the user's orientation. The compass may be head-worn or body-worn, depending on which orientation is desired.

In addition to the compass and GPS, other techniques to provide location information have also been studied. These techniques often combine a device with an advanced software algorithm to provide the information. Location determination can be based on image matching (Aoki *et al.*, 1999), where previously visited places can later be recognized by the means of a cap-mounted camera and a dynamic image comparison algorithm. This technique can be used both indoors and outdoors. In general, indoor navigation requires different techniques, such as the smart tags introduced by Want and Hopper (1992).

The technologies discussed in this section represent some of the key building blocks required for a wearable computer. However, rarely is the computer itself the ultimate goal; rather, it is most certainly designed for some purpose. I will next consider some potential applications for wearable computers.

3.3 Applications

There are different reasons for developing applications on the wearable computing platform. A much desired feature is the option to work hands-free, which is required in fieldwork related activities. Another aspect is the privacy offered by a head-worn display, allowing tasks such as reading confidential material while sitting on a bus. Further, applications that require or rely on augmented reality, such as sophisticated virtual conferencing, may not even consider any other mobile computer platform due to display capabilities. Some of these characteristics and examples of the respective application areas are shown in Table 1.

Feature	Application
Wearability	Fieldwork, such as inspection
Hands-free operation	Fieldwork, such as maintenance
Head-worn display	Any requiring privacy, such as e-mail reading
Always on	Environment monitors, agents, assistants
Always ready	Any requiring frequent use, such as tour guiding
See-through display	Any requiring augmented reality, such as conferencing

Table 1. *Key features of wearable computers, and some relevant application examples that benefit from these features.*

In this chapter, I provide some examples of the applications developed for wearable computers. The applications presented here form a cross-section on what has been done. More application examples can be found in (Starner, 2001).

Combining virtual spaces and wearable computing has been studied by Billinghurst *et al.* (1998a). They apply traditional virtual reality techniques to present information on the head-worn display in an augmented reality setting. There are three ways to present the information:

- *head-stabilized*: the view is fixed to the user's viewpoint. Changes in orientation or position do not change the view – the view is always in front of the eyes, like a sticker fixed on the eyeglasses,
- *body-stabilized*: the view is fixed to the user's body. Changes in orientation change the view, but changes in position do not – the view could be behind the user, and
- *world-stabilized*: the view is fixed to the real world location, and changes in both orientation and position change the view – the view could be fixed to a certain real-world wall.

A head-stabilized view and a body-stabilized view are shown in Figure 8.

Usability studies showed that one degree of freedom body-stabilized views outperformed traditional head-stabilized displays.

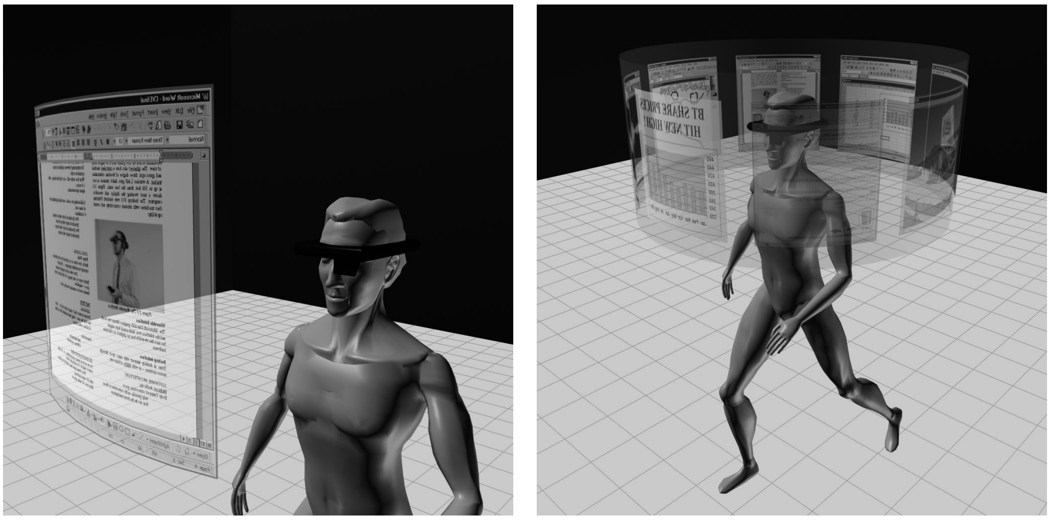


Figure 8. *A head-stabilized (left) and body-stabilized (right) view. Images by courtesy of Mark Billinghurst.*

One potential application area for wearable computers is collaboration, including virtual conferencing. Billinghurst *et al.* (1998b) have developed a wearable communication space that offers the users both visual and audio cues to enhance communication between two groups. In developing the communication space they have exploited the body-stabilized display described above. In the communication space, the user is able to see avatars (or agents) that represent the other participants in the conference; likewise, the participants can be located anywhere on the one degree of freedom conferencing space, making it possible to use spatial audio cues to indicate each user's relational location.

One form of collaboration is remote sensing, sometimes referred to as telepresence. It allows other group members to see and hear what one member, remote from the others, sees and hears. Remote sensing is achieved by means of wireless transmission of video and audio signals as recorded by the user. Again, remote sensing is a potential application area that could benefit from wearable computers. A typical example is a field engineer who is constantly connected to an expert that is located at the office (Bauer *et al.*, 1998). The expert is able to see what the engineer sees, and can efficiently assist in tasks such as repairing a complex machine.

Maintenance is an example of in-the-field activity that benefits from wearable computing. Bass *et al.* (1997) have developed VuMan, a series of wearable computing systems for aircraft maintenance personnel. When designing VuMan 3, the whole system was based on a circular concept; both the visible user interface and the input device reflect the computer's circular design. Definitely consistency in design is one issue to consider when developing a wearable system.

In addition to design issues, VuMan is also an example of a wearable system targeted at a vertical user group. The system has been designed together with the end-users – aircraft maintenance personnel in this case. The system found its final form after going through several iterations.

A very natural role for wearable computers is acting as a personal intelligent assistant. A computer may act as an augmented memory, like the remembrance agent by Rhodes (1997). The remembrance agent is a continuously running context-aware software component that observes the environment and displays notices that may be relevant in the current situation.

The notices are text-only one-line summaries of notes, e-mail, or any other information that the agent considers of potential importance. As an example, when meeting a person in a conference, the wearer may type that person’s name. The computer then notifies the wearer whether that person has been met before, and displays any other stored information.

The remembrance agent is also proactive – it automatically observes various sensors and displays notices without specific requests. As an example, when meeting a person in a conference, the computer might try to identify the person by applying techniques such as face recognition, and display the name if a match is found.

One sort of assistant is the one targeted at museum visitors (Schiele *et al.*, 2001). The wearable computer is first trained to act as a museum guide; later, the computer can be used to present multimedia information on the objects it recognizes. This way, the user can show interest towards an object, and get additional information from the wearable guide. The wearable guide has multiple application areas in addition to guidance, including education, recollection of past events, and augmented perception.

Wearable computers, residing close to our bodies, are very intimate in nature. This feature raises some application areas, including medicine. A fine example of a wearable computing platform aimed at medical usage is the Wearable Motherboard, or GTWM (Georgia Tech Wearable Motherboard) (Gopalsamy *et al.*, 1999). GTWM can be understood as an intelligent garment into which various sensors can be attached – sensors like monitoring the wearer’s vital signs. The obtained information can then be utilized in healthcare. The garment itself is built into a T-shirt, consisting of several layers of different materials that can conduct electricity or dissipate static, for instance.

Reaching the general public is a challenge for any novel technology area. An example of an application targeted at horizontal markets is the shopping jacket (Randell and Muller, 2000). The shopping jacket is designed to assist the user in day-to-day activities by advising him or her of interesting shops, or guiding the user around in a shopping mall. The shopping jacket relies on two positioning techniques, ‘pingers’ and GPS. The pinger is a short-range radio frequency transmitter, installed in the environment, which provides the IP address associated with a location or an object. The pinger signals the presence of a particular shop and indicates its type and website. The GPS receiver is used in larger-scale positioning to reduce the amount of information required for the pinger.

In a way, the shopping jacket can be considered as one form of personal navigation: it provides the user with information on where he or she could go next. Personal navigation is discussed further in the following section.

3.4 Personal navigation

A wearable computer is a potential platform for digital maps. Attaching a GPS receiver to the computer is straightforward; after that, only a map is needed. The map may be a simple raster image stored locally, or it may be a full GIS database on a remote server. In either case, the user's current position can then easily be superimposed on the displayed image.

A map in its traditional sense is not necessarily needed to provide personal navigation. Eventually, the aim is to assist the user to find his or her way to a certain destination in case of a targeted search task, or to prevent the user from getting lost in an exploring task. For instance, an arrow pointing to the destination, showing where the next wayfinding decision is to be made and what it is, may be more than sufficient in many cases. Consequently, not all research concerning personal navigation has to deal with maps as such. In general, the navigation applications can be roughly divided into three categories: wayfinding, tour guiding, and exploring.

In most of the research, context-awareness plays an important role. It not only supports navigation by providing location information, but also broadens the concept of navigation to areas such as navigating to stores that are known to be of interest to the user.

One of the first wearable computers capable of navigation assistance is the Navigator (Smailagic and Siewiorek, 1994). In Navigator, the location is determined by a differential GPS receiver. A map, displayed on a head-worn display, is obtained from a locally stored database. The user is also able to choose a destination; the path from the current location to the destination is then added to the displayed map. The research focus was on technology, both hardware and software.

Another early navigation assistant is Metronaut (Smailagic and Martin, 1997). Metronaut provides visitors to a university campus with guidance instructions. The location is determined with barcodes: the computer is equipped with a barcode reader, and barcode labels installed at the information signs around the campus contain the relevant location information.

One example of a mobile personal guide is the Cyberguide by Abowd *et al.* (1997). Cyberguide is a handheld, mobile, context-aware tour guide. More precisely, it is a family of tour guide prototypes. It is aware of the user’s current position, and can assist the user in several ways. For the assistance, Cyberguide consists of various guides, all having different roles. These roles are cartographer, librarian, navigator, and messenger. The cartographer has knowledge of the physical surroundings as well as the locations of the points of interest. The librarian has information on the sights the tourist is able to see. The navigator knows where the user is currently, and the messenger works as a communications assistant.

The first Cyberguide prototype was designed for indoor use. The user is shown a map of the building he or she is currently in: the map could be panned and zoomed. The YAH symbol is shown on the map as well. If so desired, the map can be scrolled automatically as the user moves to keep the YAH symbol on the visible area. This version uses infrared tags for positioning. Later, a GPS-based outdoor version was developed (Figure 9).

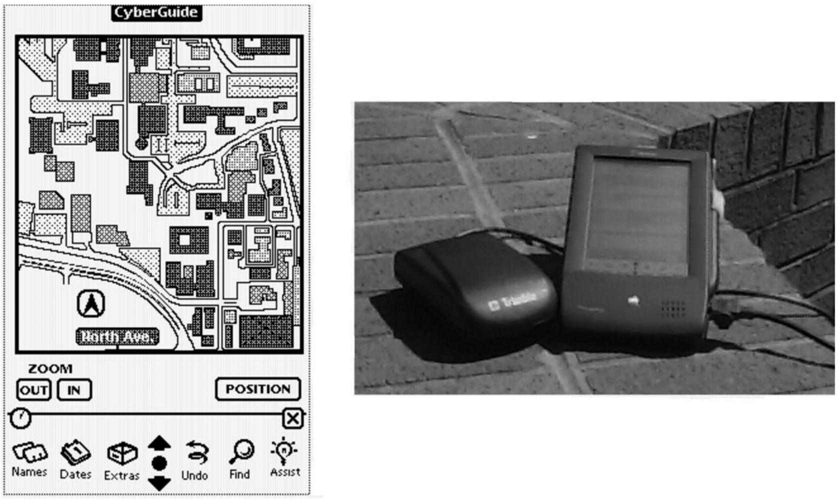
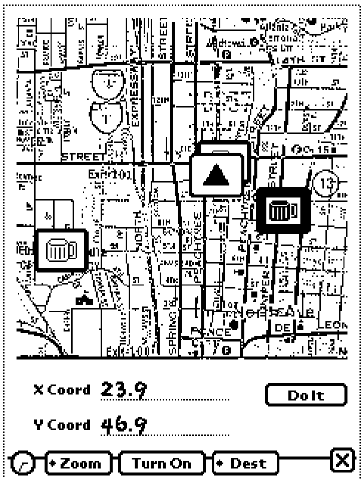


Figure 9. *The outdoor version of Cyberguide. A screenshot of the PDA is shown on the left, and the equipment on the right. Photo by courtesy of Gregory Abowd.*

CybARguide is another prototype in the Cyberguide family (Figure 10). It was designed to assist a tourist in finding restaurants in a city. The tourist can indicate a desired destination; the system then automatically chooses a map with the greatest detail that contains both the user and the destination. The user can also add interesting destinations to the database. Previously visited destinations can be shown on the map as well.


X Coord 23.9

Y Coord 46.9

Figure 10. *A screenshot of CybARguide. The triangle in the middle denotes the YAH symbol. Image by courtesy of Gregory Abowd.*

According to the strict characterization, Cyberguide is not actually wearable. It is not embedded into clothing, but is implemented on a hand-held device. Again, the fine line identified earlier between wearable computers and mobile computers in general is easy to cross: if the Cyberguide was implemented on a different hardware platform, it would become wearable, since in the design the various aspects of wearability are fulfilled.

Another tourist guide is Smart Sight (Yang *et al.*, 1999). Smart Sight assists the tourist especially in foreign countries by providing speech and image recognition, and natural language processing capabilities. Furthermore, it provides navigation assistance. The prototype setup has two computers, one in the backpack to take care of the processor intensive tasks, and another on the waistbelt. As the processing power increases, the system can be run with just one computer. The research focus is on system architecture and setup.

Touring Machine (Feiner *et al.*, 1997) relies on wearable computing and augmented reality techniques to present additional information on the surroundings on a head-worn display. The ultimate goal is to support users in their everyday interactions with the world. The research focus has been on developing the user interface software for such a system. Touring Machine especially supports the exploration task.

Touring Machine consists of a wearable computer on a backpack equipped with a head-worn display, and an additional handheld computer with a touch sensitive display. The 2D handheld display is used to display hypertext documents, whereas the augmented reality 3D space is seen on the head-worn display.

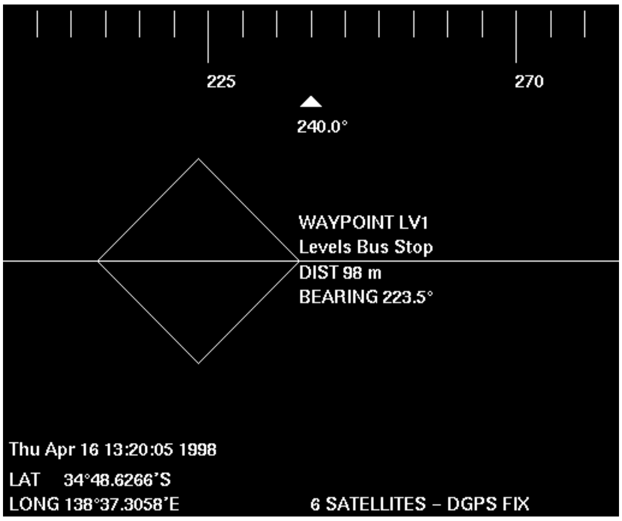
In the Touring Machine prototype, the augmentation has been applied to buildings in the form of overlaid textual labels (see Figure 11). The labels increase in brightness as they get closer to the display center. The label that is closest to the center is highlighted; if it remains in this state for more than a second, it is considered to be selected. Consequently, a menu for the selected object is displayed. Once the user turns his or her head away from the building for more than a second, the building is deselected.

Figure 11. *An image of Touring Machine as seen through the head-worn display. Notice the augmented labels overlaid on real world objects. Photo by courtesy of Steven Feiner.*

GUIDE (Cheverst *et al.*, 2000) is yet another tour guide. GUIDE is targeted at tourists, providing the user with navigational and context-aware information. Furthermore, it supports guided tours around the city. Again, GUIDE runs on a hand-held PDA using a modified web browser to access the contextual information.

As noted earlier in this section, navigation does not have to rely on maps. An alternative navigation guide, based on haptic output, has been constructed by Ertan *et al.* (1998). The system is targeted at users with impaired vision to assist them in navigating in unfamiliar environments. The idea is to provide the user with navigational guidance by delivering haptic signals into the user's back by an array of 4x4 vibrating micromotors. There are five instructions: the four cardinal directions, and a stop signal. The direction is indicated by turning on and off the respective rows or columns of motors. For instance, the right signal is indicated by pulsing the first column of motors three times, the second column three times, the third column three times, and finally the fourth column three times. The stop signal is indicated with a circular pattern.

"Map-in-the-hat" addresses terrestrial navigation issues by incorporating augmented reality (Thomas *et al.*, 1998a). Map-in-the-hat provides navigation assistance by means of a GPS and compass attached to the wearable computer. The route from origin to destination is traversed via several waypoints. Hence, Map-in-the-hat supports the linear wayfinding style.



WAYPOINT LV1
Levels Bus Stop
DIST 98 m
BEARING 223.5°

Thu Apr 16 13:20:05 1998
LAT 34°48.6266'S
LONG 138°37.3058'E
6 SATELLITES – DGPS FIX

Figure 12. *A screenshot of Map-in-the-hat. Image by courtesy of Wayne Piekarski.*

In Map-in-the-hat, a linear compass is visualized on the head-worn display, showing the current direction (Figure 12). In addition, a diamond-shaped polygon is drawn on the screen, representing the next waypoint. The diamond shape is positioned relative to the compass on the screen. The idea is to make reaching the waypoint as easy as possible; the user should only keep the diamond aligned to the center of the display. Should it slide to the left or right, the user just rotates his or her head to the left or right, respectively, until the diamond is aligned again.

Name	Display type	Target area
Navigator	Head-worn	Navigation
Metronaut	Hand-held	Navigation
Cyberguide	Hand-held	Tour guide
CybARguide	Hand-held	Tourist guide
Smart Sight	Hand-held	Navigation
Touring Machine	Head-worn	Exploration
GUIDE	Hand-held	Tourist guide
Ertan *et al.*, haptic system	Tactile output	Navigation
Map-in-the-hat	Head-worn	Wayfinding

Table 2. *A summary of the applications presented in this section.*

To summarize, the applications presented in this section are shown in Table 2. It can be seen that three of them are equipped with a head-worn display, whereas five make use of hand-held displays. Only one is specifically aiming at wayfinding.

The research projects described in this section form a cross-section of what has been achieved in wearable computing research concerning personal navigation. As can be seen, most of the research is in its infancy, evidenced by approaches such as technology feasibility considerations and performing experiments in combining various techniques. In many cases, the applications themselves are used only as demonstrators of what can be done with a specific technology rather than as important tools in their own right. However, I believe that personal navigation is an important application area as such, and particularly appropriate for wearable computers.

3.5 Summary and discussion

In this chapter, I have provided an overview of wearable computing research. My primary message has been that the area is continuously developing; the researchers are focused on issues such as potential application areas, hardware, and context-awareness. Further, I have stressed the interdisciplinary nature of the field. A fine example of this characteristic is the call for participation of the most important wearable computing conference, The International Symposium on Wearable Computing (ISWC) that lists possible submission categories such as software architectures and social acceptance.

The current development predicts some likely future trends. The focus that has been on the hardware and applications in the early years is likely to spread to concern more and more user interface research, textile integration, and using various accessories, such as jewellery. The interdisciplinary nature of the area is likely to increase; once wearable products are slowly but steadily becoming available to more and more people, methods and theories in areas such as psychology and sociology will certainly be needed. At the same time hardware miniaturization will advance and the power requirements of the various devices will continuously decrease.

When considering personal navigation applications, human-map interfaces have usually not been addressed at all. The goal has been in applying and combining new technologies in new ways. In the early stages of research, this can be understood. However, as the topic becomes increasingly mature, the fundamental human factors should be thoroughly considered as well.

It seems that most personal navigation applications have evolved, in one way or another, in the form of a guide. The fundamental difference between a guide and a navigation assistant is the generality – a guide is restricted to a certain area, be it a university campus or a city, whereas a navigation assistant is targeted at any area. The goal in both approaches is the same, only the scopes differ.

Compared to the research projects discussed above, WalkMap has a different approach. Even though the target application area is wayfinding, the origin of the research is in traditional wayfinding and navigation research. Further, in WalkMap the user interface, or the way to access the functionality and context-aware services, has been the key design driver.

When it comes to the target application area, Map-in-the-hat is probably the closest equivalent to WalkMap. It is based on wayfinding decisions at certain waypoints – a feature that can be achieved in WalkMap either by using Context Compass to display the waypoints as virtual objects, or to display the objects on the map once they are approached. Besides wayfinding support, the generic nature of Context Compass enables simultaneous access to other contextual information with the same technique.

In my opinion, context-awareness will play an increasingly important role in the near future. The number of personal mobile computers, including smart mobile phones, is continuously increasing, making location-dependent information more and more attractive, and consequently opening up huge potential in location-aware research – and commerce.

4. Controlling it all: User interface

As has been discussed in the previous chapters, wearable computers are a potential platform for personal navigation applications. They provide the computing power and output capabilities necessary to fully exploit digital maps and navigation aids. Further, it has been seen that the human-map interface is an essential element when designing navigation applications and should not be omitted from the context of any research concerning personal navigation.

One essential research area remains to be covered. While we now have a basic understanding on how humans use maps and how these aspects should be taken into consideration, we still have to find out how the user should operate the *navigation application,* in other words how he or she should control the software that provides the navigation aids. We already know how that software should present the information to the user and how it should behave when it comes to providing assistance.

In this chapter, I will provide a closer look at the area of human-computer interaction (HCI). I focus on the most important characteristics of the field that are relevant to this study, present an overview of the past and present research as well as speculate on trends likely to emerge in the future. I will also present an alternative perspective on human-computer interaction. This leads us then into the research done in the field of HCI concerning wearable computing (or, wearable computing research that addresses HCI).

There are numerous definitions for HCI. The most simple include definitions such as ‘the study of people, computer technology and the way these influence each other’ (Dix *et al.* 1998, p. XV). A broader view has been presented by the Human Computer Interaction Working Group of the ACM Workshop on Strategic Directions in Computing Research, coined by several esteemed authors in the field, including Hollan, Myers, Olsen, and Shneiderman (Myers *et al.*, 1996). They define HCI as follows:

> *HCI is the study of how people design, implement, and use interactive computer systems, and how computers affect individuals, organizations, and society.*

As can be seen from the definition above, HCI is an interdisciplinary field, involving areas such as computer science, psychology, ergonomics and human factors, and sociology.

As the term implies, there are three parts involved in HCI: the human (the user), the computer, and the interaction between the two. The interaction can be further divided into two categories: input (the user's actions), and output (the computers responses and feedback). Both input and output can make use of different media, or modalities, such as vision, speech, and sense of touch. When many simultaneous input modalities are combined, the term multi-modal interaction can be used (Dix *et al.* 1998, p. 154).

The interaction can be seen as a dialog between the computer and the human (Dix *et al.* 1998, p. 115). There are several interface styles that define how the dialog is managed, such as command-line interfaces, form-filling interfaces, and natural language interfaces. A dominating desktop user interface today is a graphical user interface, or GUI. As the term suggests, GUIs are heavily dependent on the visual sense. This aspect regards both the input and output channels.

In this text, I will consider two relevant areas of HCI. First, I will present the current mainstream approach with desktop computers and GUIs, called WIMP (windows, icons, menu, pointing device). This is followed by discussion on how mobile HCI differs from the WIMP paradigm, and the alternative approaches for mobile usage, referred to as post-WIMP or non-WIMP paradigms.

4.1 WIMP and beyond

An essential aspect in HCI is the use of metaphors. In HCI, just as in general usage, metaphors are used to help in understanding new concepts by means of familiar terms and their relations. However, in HCI the use of the term ‘metaphor’ has been extended quite far from the original meaning, making some researchers suggest that instead of metaphors we should be talking about logical analogies (Hamilton, 2000). Essentially, logical analogies are more explicit. However, for the sake of uniformity the term metaphor is used in this text.

The most widely used user interface metaphor in graphical user interfaces today is the *desktop* metaphor, realized in common operating systems such as Microsoft Windows and Apple OS. Choosing a desktop as a user interface metaphor reflects the fact that the computer is mainly used in an office environment; in other words, the metaphor relies on the using environment and its common equipment and concepts, such as a folder or a trash bin (Perkins *et al.*, 1997). The WIMP paradigm is an embodiment of the desktop user interface metaphor.

An integral part of WIMP is direct manipulation (Shneiderman, 1982). The fundamental point in direct manipulation interfaces is to represent any interface objects visually, and to provide the user with means to manipulate the objects themselves instead of manipulating them indirectly. The ‘I’ (icons) and ‘P’ (pointing device) in the WIMP abbreviation emphasize this functionality.

The WIMP paradigm relies heavily on visual sense, several input devices, and large graphical displays. As can immediately be seen, it is not an ideal paradigm for wearable computers. It usually requires high attention, accuracy in interaction, and relies heavily on the sense of sight. It requires a table-top or some other static flat surface in order to be easily operated. Further, the pointing devices are either difficult or impossible to use while standing or walking.

The WIMP paradigm has remained with us for more than two decades. However, more and more criticism of this “age-old” paradigm has started to emerge. In these new user interfaces the interaction is not based on the windows or icons, but on techniques such as speech recognition and gestures. To a great extent this development has been due to the progress of mobile computing. Where a desktop cannot be used, a desktop metaphor should not be applied, either.

Van Dam (1997) has introduced the term “post-WIMP user interfaces”. By post-WIMP he means interfaces that contain at least one interaction technique that is not dependent on classic two-dimensional graphical user interface elements, such as menus or icons.

In my opinion, post-WIMP is a step in the right direction. However, as far as wearable computers are considered, I would prefer to talk about non-WIMP user interfaces (Green and Jacob, 1991; Jacob *et al.*, 1999), *i.e.*, interfaces that do not contain any element from the WIMP paradigm (except the menu, when understood as a general list-based structure). Abandoning WIMP is not an end in itself; rather the reason for abandoning is simply that WIMP does not provide the means that support the elements inherent in mobile usage, such as using while walking.

Some research concerning potential interaction paradigms for post-WIMP user interfaces has been done. I will next present some promising alternatives to these solutions, focusing on the approaches that are relevant to mobile computing – post-WIMP approaches that are not applicable to mobile use are beyond the scope of this text.

More than ever there is a need to stress the blurred difference between wearable and mobile computers; therefore, in this section these two are generally taken to be equal.

MOTILE is a mobile alternative to the WIMP paradigm, designed for fieldworkers (Kristoffersen and Ljungberg, 1999b). It offers an interaction technique and a system for operating mobile computers. On the interaction side, it rests on minimal visual attention, structured, tactile input, and extensive use of the audio feedback. The user input is based on using only four buttons for discrete input. The idea is to offer the user a selection of virtual keyboards, with one keyboard for each task (such as text input, controlling the cursor, or selecting hyperlinks). The user switches between keyboards (and tasks) by pressing certain regions on a touch screen. By pressing the North region, the user can switch between keyboards; East and West are used to select the next higher or lower half of the keyboard, respectively, and South executes the current command (*e.g.*, activates the hyperlink).

One paradigm proposed for mobile user interfaces is called minimal attention user interfaces, or MAUIs (Pascoe *et al.*, 2000). The authors classify fieldwork as static usage (using a portable computer as a desktop computer) and mobile usage (using a portable computer while in motion). They concentrate on the latter category, and offer fieldworkers an alternative interface paradigm.

The purpose of MAUI is to decrease the amount of attention required by the user interface, although not necessarily the number of interactions. The paradigm was designed for fieldworkers observing giraffe behavior. Four characteristics were identified for such users: dynamic user configuration, limited attention capacity, high-speed interaction, and context dependency. MAUI tries to address these issues.

Unlike many other data collection systems, the MAUI concept rests on the model of fieldwork activity, not on the model of the data. This approach also makes it possible to generalize the model to other user groups requiring fieldwork data collection. The purpose is to provide the fieldworker with a user interface that supports use in various dynamic environments. This is believed to be achieved by means of eyes-free interaction, one-handed controls, and layered sequential screens that allow easy navigation through the user interface.

MAUI is closely related to context-awareness. In effect, some of the benefits within MAUI are gained through observing the environment and automating the data collection process where possible. For instance, since location is one of the parameters to be recorded, each piece of data can be automatically stored along with the respective location information obtained by means of a locator device, such as a GPS receiver.

The alternatives to WIMP presented above, even though they differ in many areas from WIMP, still retain the conservative HCI model. I will next present an alternative model to HCI.

4.2 Humanistic intelligence

In ‘traditional’ HCI research, as described above, the human and computer are treated as separate entities that communicate with each other via certain channels for input and output. The user goes to the computer (or takes the computer out of the pocket), performs the required tasks, and leaves the computer (or puts it back to the pocket). However, as we have seen in the preceding chapters, this is not a salient feature of a wearable computer, which is expected always to be on and always ready. As a result, a new approach, called humanistic intelligence, has been proposed by Mann (2001b).

Humanistic intelligence (HI) discards the dualistic nature of HCI. Instead, in HI the user is part of the feedback loop of a computational process. The computer uses the human mind and body as one of its peripherals, just as the human uses the computer as a peripheral. In other words, the computer can be thought of as the second brain, and its peripherals as additional senses. In essence, the idea is not to simulate human intelligence, but to assist it. (Mann, 2001b) A wearable computer is an ideal embodiment of HI.

HI is one of the few user interface theories that have been devised with exclusive reference to wearable computing usage.

An embodiment of HI has three operational modes: constancy, augmentation, and mediation. These modes will be discussed next.

Constancy

An embodiment of HI is *operationally constant*. This means that it is never shut down, thus fulfilling the general requirement for a wearable computer to be always active. Furthermore, it is also *interactionally constant*, which means that its inputs and outputs are always active. Again, this fulfills the wearable computer requirement of being always ready.

Augmentation

One cannot assume that using the computer is the primary task with regard to wearable computers. On the contrary, the user is often performing other tasks, such as navigating in the environment, while using the computer. The second operational mode of HI, *augmentation*, supports this notion. Augmentation is required to assist the senses in performing the primary task, without causing distraction. This implies that the computer is aware of the context. When compared to one of Pascoe's context awareness capabilities, contextual augmentation (page 36), HI augmentation can be seen to represent the reverse side of the coin. While the contextual augmentation concerns augmentation in the environment (the source of the augmented information), HI augmentation concerns augmentation of the senses (receiving both the augmented information and real information).

Mediation

A good embodiment of HI can encapsulate the user, unlike traditional computers. This encapsulation may occur on many levels. As with augmentation, a spatiotemporal awareness in the computer sensors is assumed.

There are two aspects to encapsulation, solitude and privacy. The former allows the computer to act as an information filter, acting on the incoming information, while the latter lets us block the information leaving the personal encapsulated space. It can be thought of as 'virtual clothes'; while clothes are used to protect and preserve our intimacy, the mediation aspect of HI protects the intimate information that would be otherwise accessible to others. Again, there can be various levels of privacy, such as one for family members and another for the general public.

The mediation mode relates closely to ubiquitous computing discussed in the previous chapter. A user entering a smart space equipped with environmental computers is able to 'draw a curtain' over his or her information space. Hence, in addition to the interaction device to access the services offered by ubiquitous computing, a wearable computer can also simultaneously act as a privacy safeguard.

Humanistic intelligence is an “ultimate” theory, creating a seamless stream of information between the wearer and the computer. As such, it will not become reality for a while. Nevertheless, wearable computers existing today also have to be operated in one way or another. The current solutions for human-wearable computer interaction are discussed in the next section.

4.3 Interacting with wearable computers

There has been some research on user interfaces for wearable computers. Much of this research has concentrated on either input devices or interaction techniques. Other components of the user interface, such as metaphors, have not been widely addressed. In this section, I will present some promising results in the area. It should be noted that as wearable computing research itself is a rather new area, so is user interaction research for wearables as well. Therefore, most of the research relies on traditional HCI research concepts, assumptions, and methods, even though in many cases this is not an optimal approach.

Mobile computer users can be divided into two categories: *nomadic* users take their computers from place to place, but do not operate the computer while moving, whereas *continuous* users operate their computers also while moving (Rosenberg, 1998, p. 17). Often, computing is not the primary task for continuous users.

There are some commonly agreed requirements for wearable user interfaces. First, the user should be able to operate the computer while standing or walking – this implies that the interface should be developed for continuous users (when, obviously, nomadic users can operate it as well). Second, the computer should be accessible with at least one, preferably both hands free. And third, the user interface should take into account the current using environment and adapt to it, at least by choosing the appropriate input and output modalities.

One important issue to consider is the metaphor. For desktop computing, the choice was straightforward. However, for wearable computing the typical using environment may change at any time. Hence, the desktop metaphor cannot be considered an adequate user interface metaphor for wearable computers, or even mobile computers in general.

Audio

One of the most promising user interaction techniques for wearable computers is based on pure audio, or with audio as the primary interaction channel. There are numerous advantages, such as discrete and private output (via headphones), and no need for an energy-hungry display. Further, an audio user interface allows using the computer totally hands-free. Not surprisingly audio has been addressed in numerous studies, for both input and output channels.

A well-known concept is the Wearable Audio Computer (WAC) introduced by Roy *et al.* (1997). The idea is to use wearable auditory displays that enhance the environment by providing timely information and a sense of peripheral awareness. Speech recognition can also be utilized. A WAC can be used as a platform for developing audio based wearable computing applications; one such application is Nomadic Radio (Sawhney and Schmandt, 1998; Sawhney and Schmandt, 2000).

Nomadic Radio is a distributed wearable computing system for asynchronous audio communications. It offers hands-and-eyes-free user interaction for wearable computer users by applying various auditory techniques such as spatial audio, auditory cues, and speech recognition. The goal is to provide the user with notification, passive awareness, and user interface navigation and control. As the name suggests, Nomadic Radio makes use of a radio metaphor to present audio sources.

Instead of stereo headphones that would block the outdoor soundfield more or less completely, Nomadic Radio uses directional speakers on the user’s shoulders. This approach allows using spatial audio without interfering with the real world soundscape. The spatial audio, in turn, is used to position the audio messages around the user according to the time of arrival: they form a round clock dial around the user.

With audio as a primary interface, input is often an issue. Speech recognition does not work reliably in a noisy environment, or it may not be used at all due to the intimate nature of the application area. A good candidate for input is manual interaction. Quite a lot of work on mobile computing and finger input has been done. I will next present some of the most relevant studies in this area.

Finger-based interaction

There are both advantages and disadvantages in using fingers in interaction. On the one hand, fingers are very flexible and accurate, and can perform a great number of different tasks. On the other hand, using the fingers usually means that at least one hand is tied and cannot be used to accomplish the primary task. This is an undesirable feature, particularly in a wearable input technique.

Usually, interaction is divided into two basic categories: discrete input (such as pressing a button or typing a character), and continuous input (such as operating a mouse). With regard to non-WIMP user interfaces, an alternative categorization can also be applied. There are techniques that rely on finger tapping (such as in typing or pressing a button), and techniques that make use of interpreting gestures made with the fingers. The gestures may be single movements, or more complex series of movements.

FingeRing is a wearable device for discrete input, based on tapping (Fukumoto and Tonomura, 1997). A ring shaped sensor is attached to each finger. The sensors measure finger acceleration, making it possible to determine whether the finger has been tapped on any solid surface. The design allows both issuing commands as well as typing using chords (that is, to press several keys simultaneously to type a single character). To further facilitate wearability, the commands can be forwarded wirelessly to the CPU, using the human body as part of the electric circuit.

UbiButton is another tapping-based interaction technique (Fukumoto and Tonomura, 1999). UbiButton relies on the same technique as FingeRing – tapping fingers onto a solid surface. A wrist-mounted device determines the number and rhythm of the strokes and translates the resulting code into a single command. This way UbiButton can be used to control a simple user interface by giving commands reminiscent of Morse code. UbiButton was designed as a part of a complete user interface for controlling a mobile phone.

The Finger-Joint Gesture Wearable Keypad, or FJG, is another finger-based tapping technique (Goldstein and Chincholle, 1999). It is based on a glove-like design and targeted at mobile phones. In FJG, the thumb is used as an operator to click buttons located in the finger joints. The buttons are laid out as a regular twelve-key mobile phone keypad; in addition, buttons such as YES, NO, and CLEAR are located at the fingernails. The FJG stresses distributed design – the physical interaction device, in this case the keypad, is not required to be fixed to the terminal itself.

Attaching sensors to the fingers is not always desirable. In essence, it could make it more difficult or even impossible to perform some daily tasks with extra hardware on fingers. An alternative solution for achieving finger-based input is the WristCam (Vardy *et al.*, 1999), based on gestures. In WristCam, a camera is installed in the underside of the forearm, pointing towards the hand and fingers. By viewing the fingers, the finger movement information can be obtained. These movements, in turn, are translated into predefined gestures that are formed on seven base symbols; whenever a finger moves from a rest position to one of the gesture positions and back, a gesture is made. Only the first three fingers are used. WristCam allows a totally hands-free interaction (in the sense that no input device has to be carried), while providing the versatility of finger input. The greatest problems relate to technical issues, including the quite high performance requirements for the computer in order to be able to translate the gestures in real-time. Further, dynamic lighting conditions require intelligent, adaptive algorithms in order to achieve reliable gesture recognition in different environmental conditions.

An interesting approach is the Gesture Pendant (Starner *et al.*, 2000). This is a wearable interaction device designed for controlling home automation systems. The user wears a pendant that is equipped with a miniature camera, surrounded by infrared LEDs. Further, the camera has an IR pass filter installed. The LEDs illuminate the area in front of the pendant with infrared light. Whenever hand movements are performed in that area, the camera captures the movements and passes the images to the wearable computers. The images are then analyzed and the gestures recognized.

The approach used in the Gesture Pendant has many advantages. First, it allows controlling the home even in the dark thanks to the use of infrared wavelength. Second, it can also be operated by those suffering from impaired vision, motor skills, or mobility. The Gesture Pendant is also truly wearable in nature.

A common problem in most gesture-based approaches is that the fingers have to be in the right position in front of the camera in order for the recognition to work properly. This may cause inconvenience and sometimes even inability to operate the computer at all.

A unique design is Yo-Yo user interface, targeted at smart clothing users in arctic environments (Rantanen *et al.*, 2000). Yo-Yo consists of a small hand-held device that is equipped with a display (Figure 13). This unit is connected to the computer, and operated by moving the hand back and forth while holding the unit in the hand. This yo-yo movement is measured by the computer and converted to one-dimensional input, making it possible to browse menu structures up and down. A menu item can be selected by squeezing the unit. The menu is displayed on the unit itself.

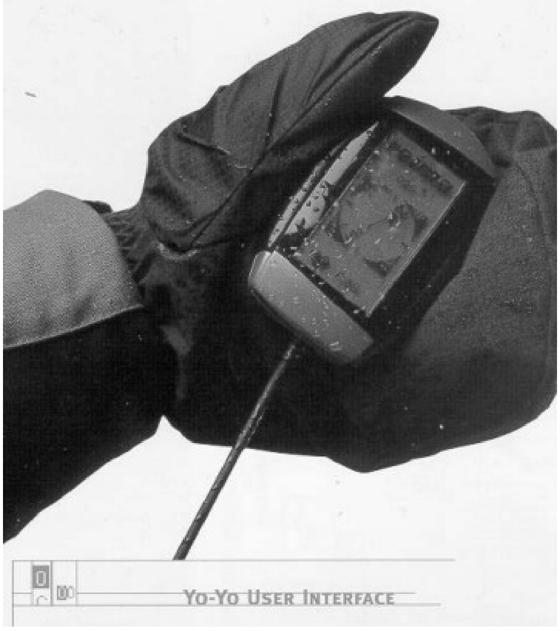


Figure 13. *Yo-Yo user interface. Photo by courtesy of Jaana Rantanen.*

Yo-Yo is an example of a wearable user interface that has taken the environment of use into consideration. Since the system is meant to be used by warmly dressed snowmobile riders in arctic environments, there is a need to wear thick gloves at all times. Yo-Yo allows operating the user interface without taking the gloves off.

Text entry

One of the most difficult interaction tasks for mobile computers is entering text. A regular QWERTY keyboard can obviously not be used (Figure 14). Even miniaturized versions of this familiar desktop keyboard are not truly mobile, since they require either a static supporting surface, or using two hands (one hand is needed to support the keyboard, while the other one can be used for typing).

Figure 14. *A full-sized QWERTY keyboard is hard to wear.*

There are a few alternative text input methods available that are meant for mobile users. These can be categorized as follows:

- modified keyboards,
- hand-writing recognition, and
- speech recognition.

In this section, I will focus on various forms of keyboards intended for mobile use. Generally, the keyboards can be used only by nomadic users, not continuous users.

The modified keyboards can be divided into three categories: Physically modified QWERTY keyboards, virtual (or soft) keyboards, and chording keyboards. Physically modified QWERTY keyboards are usually miniaturized keyboards that have been designed for a specific purpose, such as the keyboards that are attached to the forearm (see *e.g.* (Xybernaut, 2001)). Alternatively, they may be folded. A folded keyboard can be kept in a pocket when not in use, and opened when needed. Both of these types usually contain all the alphabetic characters.

A special case is the soft folded keyboard for the Palm Pilot by Electrotextiles (2001) (see Figure 5 in Chapter 3). This keyboard can be folded around the PDA and used as a protective case when not in use. When needed, it is easy to roll it open and start typing. This kind of a textile-based keyboard is a step towards wearable keyboards.

Virtual keyboards, in turn, are implemented in software, and displayed on the computer screen. They can be laid out as a regular QWERTY keyboard, or according to some other criteria. They are either pen-operated (in the case of a touch-sensitive display), or selection-based (*i.e.*, the user is required to point at the desired character in order to type it). The selection can be performed with a variety of techniques, including traditional cursor keys, or with a more up-to-date technique such as gaze tracking.

The chording keypads include only a few keys; a character can be typed by pressing a combination of one or more keys simultaneously (hence the term ‘chording’). Chording keypads can be made relatively small, making them more suitable for mobile usage. They can also be operated by one hand without a solid surface. Many finger tapping based devices, such as FingeRing (Fukumoto and Tonomura, 1997) described above, can also be used to input chords.

The Chording Glove is a text input device that has the keys of a chord keyboard mounted onto the fingers of a glove (Rosenberg, 1998). The result is a wearable text input device that can be used while standing or sitting; further, the results of a user evaluation revealed that there are no significant performance differences between these two use scenarios. The Chording Glove has a lot in common with the FJG described earlier.

Twiddler (Handykey, 2001) is a commercially manufactured chording keypad (Figure 15). Twiddler is in use in many wearable research prototypes.

Figure 15. *Twiddler, a chording keypad by Handykey (2001).*

Thomas *et al.* (1998b) have evaluated text input mechanisms for wearable computers. They concentrated on three forms of keyboards: forearm-mounted keyboards, virtual keyboards, and chordic keypads. There were twelve subjects in the evaluation. Each subject performed six one-hour test sessions within a three-week period. The results showed that the forearm-mounted device was both the most efficient and best liked, even though the users learned to use each input device rapidly.

4.4 Summary and discussion

In this chapter, I discussed the interaction between humans and computers. I reviewed the traditional HCI research, including WIMP interfaces, how they relate to wearable computers, and how to overcome the problems and limitations implied by WIMP in mobile use, resulting in post-WIMP and non-WIMP paradigms. I also presented an alternative approach to HCI, called humanistic intelligence. Finally, I discussed some issues specific to human-wearable computer interaction, and presented research accomplished in that area.

When considering human-wearable computer interaction, one cannot overestimate the importance of solutions targeted at continuous users. As computers become more and more intimate and closer to our bodies, so the issues that complicate the usage “anytime, anywhere” become more and more annoying. In my opinion, the solutions that do not provide operation “anytime, anywhere” are only an intermediate phase on the way towards truly wearable user interfaces. Consequently, even though humanistic intelligence as such may seem overly biased towards the seamless connection between the user and the computer, I believe that its main message still holds – making the *interaction* as seamless as possible.

As there are differences between wearable computer definitions, there are likewise differences between HCI research directions concerning wearables in issues such as what makes an interface wearable. As stated above, I claim that a user interface can be considered wearable once it fulfills this one simple requirement: it can be operated by a continuous user. Therefore, the measure is not absolute, but depends on the user: for some users, it is possible to use a trackball while walking, while the others have to stop in order to operate such a device.

A definite problem in wearable computing user interaction research is evaluation. In many cases, the experiments required to assess the usability of an interface have to be conducted outdoors, in real using environments. As a result, in many cases the traditional HCI evaluation methods cannot be applied as such. One of the most important steps towards wearable user interfaces is to develop new evaluation methods for wearable user interfaces.

It can be argued that user interaction research on wearable computing is in many respects still in its infancy. The problems encountered when taking the computing out of the office are not easy to overcome; traffic, weather conditions, primary tasks, social acceptability and so forth are issues that greatly influence wearable computing user interfaces. Consequently, a lot of research remains to be done before wearable computers can be operated with ease, while continuing primary tasks.

Much of the constructive part of this dissertation deals with interaction – that is, how to provide wearable computer users with more natural interaction techniques for wayfinding. The goal is to tackle at least some of the challenges mentioned above, and to gain general knowledge of wearable computer user interface issues. The research papers dealing with these issues are introduced in the next chapter.

5. A wearable navigation assistant

A substantial part of this dissertation is contained within the eight research papers. In this chapter, I will briefly introduce each paper, presenting its relevance to the whole study. I will also present the hardware and software platform that was used in the studies.

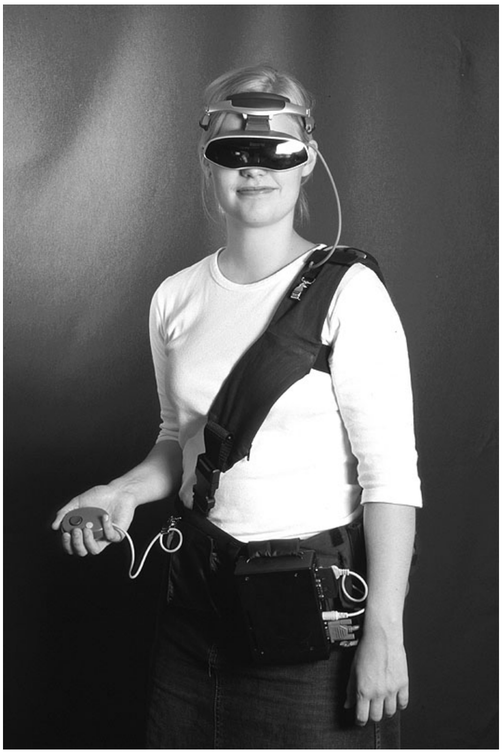


Figure 16. *The wearable computer prototype used in this study. Photo by Tero Hakala.*

In order to study a computing system, one has to have a platform for writing the applications and developing user interfaces. As far as this dissertation is concerned, I have used the wearable computing platform we developed in the 'NetWalk' project in Nokia Research Center (Figure 16)[6]. The platform consists of three primary parts: the computer itself (which contains standard off-the-shelf components), a 'carrying case', and software architecture for the applications.

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[6] As can be seen in the picture, the computer is equipped with a head-worn display. Consequently, most of the solutions in the research papers rely on a head-worn display, although it is not indispensable in every case.

The design of the carrying case is based on a belt with a shoulder strap; the computer is located in the front, whereas the display control unit and the GPS receiver are in the belt case at the back. The GPS antenna is in the shoulder strap. The compass, which is not visible in the photograph, is in the display frame. The belt approach allowed a fairly easy-to-wear solution, where most of the wiring and hardware has been hidden. Further, it was made as adjustable as possible to allow people of various sizes to wear it. It was designed and developed by our project team.

We have developed a dedicated software architecture for wearable computers, called MessageExchanger, or MEX (Lehikoinen *et al.*, 1999). MEX is a low footprint architecture and message delivery system that allows communication between applications (or services) within one computer as well as wirelessly between computers.

The primary application developed in NetWalk is WalkMap, a navigation assistant that displays information on the surrounding area, including contextual information, and provides wayfinding assistance. In one way or another, the objective of the other research papers is to enhance the functionality or usability of WalkMap.

Three of the papers – *N-Fingers*, *BinScroll*, and *Virtual Pockets* – focus on human-wearable computer interaction, concentrating on various tasks required in personal navigation applications, or in wearable applications in general. *Context Compass* and *Accessing Context in Wearable Computers* focus on presenting and accessing the current context, with emphasis on interaction with wearable computers. The *Map Evaluation* paper discusses human-map interaction issues concerning maps shown on head-worn displays, and the *WalkMap* paper introduces the complete wearable system and navigation assistant – the hardware, the software, and the user interface. *Perspective Map* proposes a potential future map visualization technique for WalkMap. These papers are presented next, along with short notes on the roles of the authors in papers with multiple authors. I mostly describe only the contributions of the second author, in which case the rest of the work is attributed to the first author.

5.1 Context Compass

Context Compass is a system for retrieving and filtering contextual data, an information visualization technique for presenting the context to the user, and an interaction technique for accessing the objects that belong to the context (Suomela and Lehikoinen, 2000). This paper introduces the different parts of the Context Compass system as a whole.

Whenever any information is presented on a head-worn display, some compromises have to be made. Either the amount of information is reduced so that most of the view area is dedicated to the real world view, or the amount of real world view is reduced so that more information can be presented. Context Compass belongs to the former category.

Context Compass relies on the traditional compass metaphor. The difference is that the compass is not absolute, pointing to the North Pole, but relative, pointing to the direction in which the user is looking.

Figure 17. *The Context Compass is displayed at the top of the screen. This is a synthesized image as it would appear through the head-worn display.*

The context is visualized on the screen in a linear compass drawn at the top of the screen (Figure 17). The object that is straight in front of the user is in the middle of the compass; it is highlighted so that it can be activated with a press of a button. The objects to the left or to the right of the user are drawn in their relative positions on the linear compass area on the left or on the right, respectively. Once the user turns his or her head, the objects on the screen move accordingly. This implies that an object can be accessed by looking at it.

Context Compass is an essential component of WalkMap. It provides access to contextual information without restricting the type of information in any way. The objects may be virtual only, or they may represent an existing real world object. They may even be navigation aids left by some other user attached to a certain geographical location. Further, Context Compass uses a digital compass as a sensor, allowing it to be used simultaneously as a traditional compass. To facilitate this functionality, the compass bearing points are displayed on the screen below the linear compass.

Context Compass is Riku Suomela’s original idea. I was responsible for most of the user interface development. The section dealing with design was authored by both of us.

5.2 Accessing Context in Wearable Computers

This paper focuses on user interaction issues with Context Compass (Lehikoinen and Suomela, 2002b). First, two tasks concerning context access are identified. Either the user is looking for a known real world object, or exploring the context by looking around. The aim is to find out whether Context Compass is usable for both tasks. We also wanted to develop an evaluation method for a system such as Context Compass; therefore, the usability study was considered a pilot study that addressed both the evaluation method and Context Compass. The results showed that Context Compass is very easy to learn; it also seems to be more suitable for accessing known real-world objects.

In this paper, Riku Suomela’s role was to assist in research on previous work and in the development of the usability evaluation method.

5.3 N-Fingers

Once the context has been retrieved and displayed, there has to be a way to manipulate the objects that belong to the context. One proposal for this task is N-Fingers (Lehikoinen and Röykkee, 2001). The aim was to develop a wearable interaction technique that would allow discrete commands to be given rapidly and easily, without suspending the current primary task.

As the name suggests, N-Fingers is a finger-based interaction technique. The buttons located in the finger joints are operated by the thumb (Figure 18). There are four buttons in each hand, allowing a maximum of eight discrete commands when both hands are used. The finger tips are deliberately left uncovered, making it easier to perform other tasks, such as drinking coffee or using a zipper.

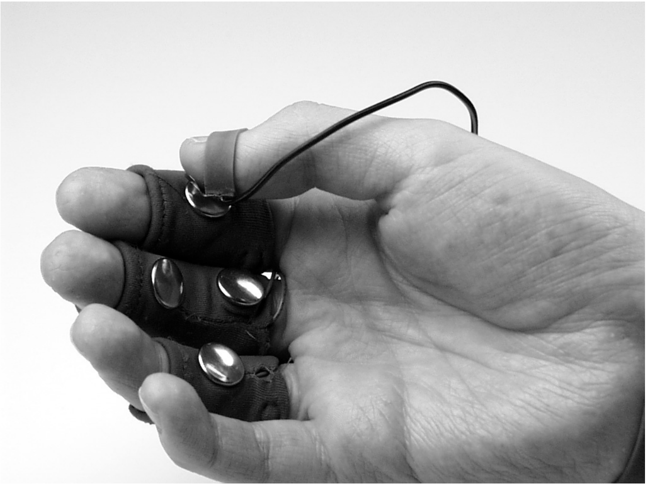


Figure 18. *N-Fingers in use.*

There are two primary ways to use N-Fingers. Either the buttons can be operated as arrow keys on a regular keyboard, supporting indirect commands, such as activating functions by browsing the menus, or the commands can be directly attached to the buttons. Such an approach was applied to Context Compass: once an object has been activated, the actions that can be performed with that object are displayed on the hand icon at the bottom right corner (see Figure 17). Clicking the appropriate buttons causes the action to take place immediately.

Extensive user evaluations revealed that N-Fingers is as efficient as the regular cursor keys in a keyboard for cursor controlling tasks. According to the evaluations, it was also easy to learn and fun to use.

N-Fingers is a wearable solution for discrete input. It is always ready, and it can be used unnoticeably. The drawback is that it requires using at least one hand, restricting the usage to some extent.

Mika Röykkee’s role included assisting in the method development for the usability studies, and arranging the studies. He also analyzed the results concerning errors.

5.4 BinScroll

Many tasks require searching for information in huge data sets. Such data sets may include phone books, multimedia databases, or street name lists. Bin Scroll was developed to allow such tasks while walking (Lehikoinen and Salminen, 2002).

BinScroll relies on the well-known binary search algorithm; any list consisting of sorted items can be quickly searched through by comparing the target item to the middlemost item in the list. Based on the comparison, only the upper or lower half of the list is retained, depending on whether the target item was smaller or greater than the middlemost item. Then, the same procedure is applied to the remaining half of the list.

In BinScroll, the difference from the algorithm is that it is the user’s task to decide which half of the list is retained. Therefore, once the user is about to make a search, BinScroll displays a three-item list on the screen; this list contains the first, the middlemost, and the last item of the whole list. The user then indicates which half of the list is to be retained by clicking either the “up” or “down” button. The same procedure is repeated, until the correct item becomes the middlemost item, in which case the search was successful, or all three items become the same, in which case the item was not in the original list.

The basic version of BinScroll requires only four buttons; the up and down buttons, a button for making the selection, and a button for canceling the search. BinScroll can be enhanced by adding two more buttons: one button for marking a letter correct (*i.e.*, only the items that have a common prefix are retained), and one button for undoing the latest choice.

BinScroll is ideal for wearable usage. In navigation, it can be used to search through street name lists, or points of interest. It can be used with a minimum of four buttons – this is where N-Fingers come into play. Further, user evaluations revealed that BinScroll is comparable, or even superior, to other existing list searching techniques dealing with very large data sets.

Ilkka Salminen contributed the theoretical evaluation of BinScroll.

5.5 Virtual Pockets

As discussed in the previous chapter, metaphor is one of the cornerstones of a today’s user interface. The metaphor should support the using environment. Therefore, the current desktop metaphor is a natural choice for computers that are used in the office environment. It relies on the concepts and equipment that are commonly found in offices, such as the desktop itself, a folder, and a trash bin. However, it is not appropriate for wearable computer use.

Virtual Pockets is a user interface metaphor for wearable computers (Lehikoinen, 2001a). It is based on arbitrary locations on clothing that can be defined to form a virtual pocket. A virtual pocket may reside on top of a real pocket, or it may be located elsewhere.

Virtual Pockets emulates the usage of regular pockets. An object can be put into the pocket, kept there, taken out when needed, and put back after use. Likewise, a virtual object, such as a map contained in a virtual pocket can be taken out of the virtual pocket (activated), used, and put back after use (closed). To support this functionality, ‘Virtual Pockets’ defines four actions that can be performed on a pocket: preview, cancel, activate, and close.

A pocket is previewed by lightly touching its location on the clothing. Consequently, a preview of the contents is displayed on the head-worn display. If the contents were not what was expected, the hand is taken off. This cancels the preview. However, if the contents were correct, the pocket is pressed slightly more, causing the contents to open on the screen. The contents can then be manipulated and operated as usual. Once the same pocket is touched again, the object is closed (*i.e.*, it is put back in the pocket).

Developing a common metaphor is an important step towards user interfaces that truly take the environment of use into consideration. Therefore, Virtual Pockets can be used in not only personal navigation applications, but in other wearable applications and systems as well.

5.6 Map Evaluation

As pointed out in Chapter 3, human-map interaction is not widely taken into consideration when mobile navigation applications are developed. This papers presents a study that takes a step in that direction (Lehikoinen, 2001b).

The aim of the study was to find out whether a map shown on a head-worn display should be aligned forward-up automatically (that is, the map rotates as the user turns), or whether the alignment should be user-initiated (the YAH symbol rotates and the map remains static until the user explicitly issues a command to align the map forward-up).

We arranged an outdoor empirical evaluation to find the answer. The experiment was divided into two sections: manual alignment and automatic alignment. Each user performed both tasks in varying order. Both sections had ten virtual targets. The user was shown one target at a time on the map on a head-worn display; he or she was then expected to walk to the target and say once it was found. Then, the next target was shown.

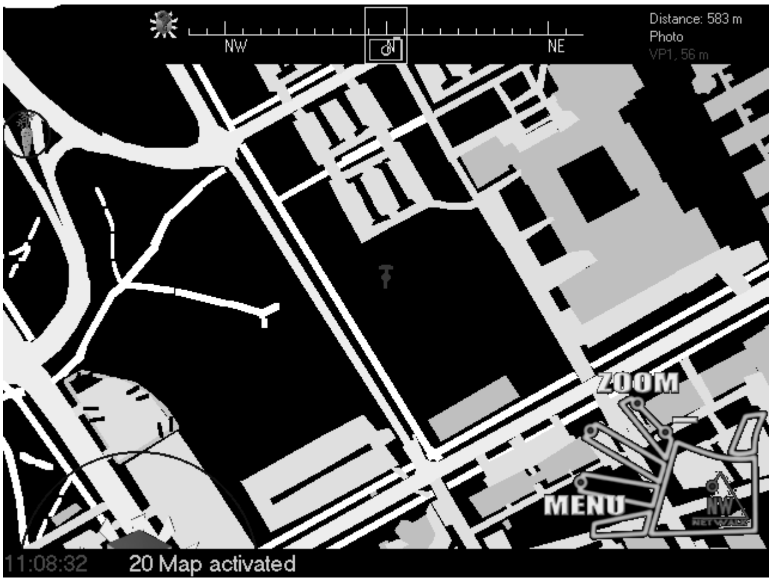
The results indicated that neither method can be preferred. There were no statistically significant differences between the methods in performance or accuracy. Likewise, the subjective comments were distributed roughly equally as well. It was found, however, that the users who performed the automatic section first used the manual alignment function much more frequently than the other users. This may indicate that over time, the automatic orientation may turn out to be better.

To my knowledge, this was the first human-map interaction study arranged for navigation applications in wearable computers. In this study, methods were borrowed from cartography and applied to wearable computing research.

5.7 WalkMap

There was a common target for all the research described earlier – to develop a personal navigation assistant. The effort culminated in WalkMap, a navigation application developed using not only the techniques described above, but many others as well (Lehikoinen and Suomela, 2002a). The application as a whole, along with the iterative development process, is described in this paper.

WalkMap has several visualization modes. These modes can be switched easily to choose a mode that best fits the task at hand. The modes that are best for wayfinding are Context Compass (only the Context Compass is displayed, leaving most of the screen see-through) and Map, which adds either a vector graphics map or a raster image map to the Context Compass display (Figure 19). Even though the map is displayed full-screen, it should be noted that the real-world can still be seen through the map.



Distance: 583 m
Photo
VP1, 56 m

11:08:32 20 Map activated

Figure 19. *The WalkMap map mode. The black parts are fully see-through. The YAH symbol is in the middle.*

In addition to WalkMap visualization modes, the paper describes human-map interaction and the way this knowledge was incorporated into WalkMap, according to both existing research and our own studies. It also introduces the wearable system itself, including our software architecture, MEX (Lehikoinen *et al.*, 1999). Further, the hardware setup is described, followed by a summary of the user interface. The paper also discusses our usability evaluation technique for outdoor experiments (Suomela *et al.,* 2001). Finally, WalkMap is compared to other existing mobile navigation applications.

This paper describes the complete WalkMap system based on previous published work as well as additional research. It was written in close co-operation between me and Riku Suomela, and contains contributions from both authors equally.

5.8 Perspective Map

In addition to traditional two-dimensional map views, view distortion techniques may also be applied. Probably the most common distortion technique is perspective distortion. In *Perspective Map*, we aimed to study whether such a map view would provide some additional value for the user (Lehikoinen and Suomela, 2002c). This study can be understood as a potential future visualization method for WalkMap.

The idea is to set the viewpoint above and behind the user in order to provide a broader view to the map. The information close to the user is displayed in more detail, whereas the objects further away are shown with decreasing amount of detail. This view is always aligned forward up; consequently, the user always sees only a small portion of the area that is behind him or her,while the area in front can be seen further away.

The results of our usability study were two-fold. While some users regarded the perspective view as natural and easy to understand, the others thought that a familiar two-dimensional presentation would be more efficient. The users thought that a perspective map could be useful for exploration tasks but not for targeted search tasks. It is also essential to carefully choose the correct values for the viewpoint location and orientation.

Like the WalkMap paper, this paper was also written in close co-operation between me and Riku Suomela, and it contains contributions from both authors.

5.9 Summary and discussion

In this chapter, I have briefly introduced the research papers that form the constructive part of this dissertation. In addition, I have presented the wearable computing platform that was developed primarily for these studies.

Together, all these papers form a major part of WalkMap. Context Compass is one of the primary context and navigation presentation models in WalkMap. N-Fingers, in turn, is used among other things to control Context Compass, which makes it an integral interaction technique in WalkMap. Since sometimes there might arise a need to manipulate large amounts of information while on the move, BinScroll is offered as choice; again, it can be controlled with N-Fingers.

Virtual Pockets makes a difference. It is a more generic system and not a part of WalkMap. However, it describes a metaphor that can be utilized when wearable applications such as WalkMap are stored and accessed on a wearable computing system. The Map Evaluation paper, in turn, describes different potential yet economical ways of presenting the augmented reality environment to the user. Finally, the Perspective Map paper provides some potential additions to the WalkMap visualization models.

The papers described in this chapter form a basis for developing a wearable navigation assistant. They focus on some of the most important issues in human-map interaction and human-computer interaction. However, in order to take the functionality even further, many issues remain to be studied. These include additional factors concerning especially human-map interaction, such as discrimination.

There are numerous practical concerns that need to be addressed in future work. One of these is the positioning technique. Even though GPS is a fine system as such, it does not work reliably in areas with high buildings, for example. Even worse, it does not work indoors at all. As a result, future locationing will most probably rely on multiple mutually supportive techniques in determining the location.

6. Summary and discussion

In this dissertation I have presented a survey of the literature on three research areas: human-map interaction, wearable computing, and human-computer interaction. I have pointed out the key issues in each area that are relevant to this study, describing how these issues have been addressed. Further, I have briefly described the constructive and empirical research I have carried out in the area of personal navigation in wearable computing.

Mobile computing as a research area is on the threshold of a completely new era – rapid commercialization. In the very near future the number of mobile computers equipped with a wireless network connection and positioning capability will most probably see a rapid increase – just as occurred with mobile phones a few years earlier. This implies new challenges for the research community: user interfaces and services must be easy enough for any user to operate.

One important aspect of the aforementioned rapid growth is identifying a *killer application*, that is, a reason why one just cannot live without a mobile computer. In my opinion, such an application has not yet emerged (or at least we are not aware of it). There are some potential candidates, including personal navigation as described in this study; location aware Internet browsing; entertainment, such as augmented reality games; and so forth. Or perhaps the killer application will be a bolt out of the blue, similar to the Short Message Service (SMS) in GSM phones. Nevertheless, in one way or another, the killer application has to offer something that is not available now. I claim that most probably this will have to do with location- or context-awareness, a feature that is implicitly present in each mobile computer.

What, then, will be the future of wearable computing among other mobile computers? Surely the vertical user groups will continue to use wearable computers as they are doing now; probably even more groups will benefit from wearables. The future of a layman's wearable computer is less secure. There are some practical problems that have to be addressed before a layman’s wearable computer will become reality. For example, if a computer is embedded into clothing, does this imply that each and every piece of clothing will have its own computer? Or does one have to detach and attach the computer each time clothing is changed? Or is the computer in the belt, or perhaps inside some jewellery? In that case, does one always have to wear the same belt? These fundamental questions, among others, will require proper attention when a layman’s wearable computer is developed.

The research that constitutes this work – by developing new, easy to use interaction techniques – is a step towards a layman’s wearable computer. It is also a prediction of a potential killer application for such computers.

The research questions addressed in this study were *how should the user control the functionality offered by the software, how should the map behave and respond to the user’s actions* and *how can the specific nature of mobile using environment be supported on the user interface level?* The studies conducted give potential, verified answers to these questions: the user interface research – Context Compass, N-Fingers, and BinScroll – are all related to the first question, while the Map Evaluation and Perspective Map addresses the second question. The third question, in turn, is addressed both explicitly and implicitly in each and every study on many levels – system requirements definition, design, and implementation.

Obviously, the results presented in this work do not exhaustively answer these research questions but present some trends and guidelines. Human-map interaction, for example, is a well understood area, yet “human-electronic map” interaction is all too often omitted in the contexts of both cartographic and mobile computing studies. Likewise, it would be imperative to conduct ethnographic studies within mobile computer users for prolonged periods of time in order to identify usage patterns and understand the regularities of real-world usage.

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