Wear, Point, and Tilt

DESIGNING SUPPORT FOR MOBILE SERVICE AND MAINTENANCE IN INDUSTRIAL SETTINGS

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Through theoretical influences, particularly drawing on the phenomenological notion of embodiment, and through the findings of an ethnographic study of the work practice of service technicians at two industrial assembly manufacturing units, we present the philosophy behind and practice in designing a mobile support system for real-life application. In this particular setting, we have come to question both the usefulness of the currently available and applied styles of interaction, and the role such a system should play in the everyday activities of service and maintenance. In this paper, we introduce the findings of the field study and explain how these findings have been interpreted to constitute design incentives. We especially focus on three aspects of the design of the prototype system: the functionality it encompasses; the interaction style with which the user performs input to the device; and the mobile prototype's graphical user interface

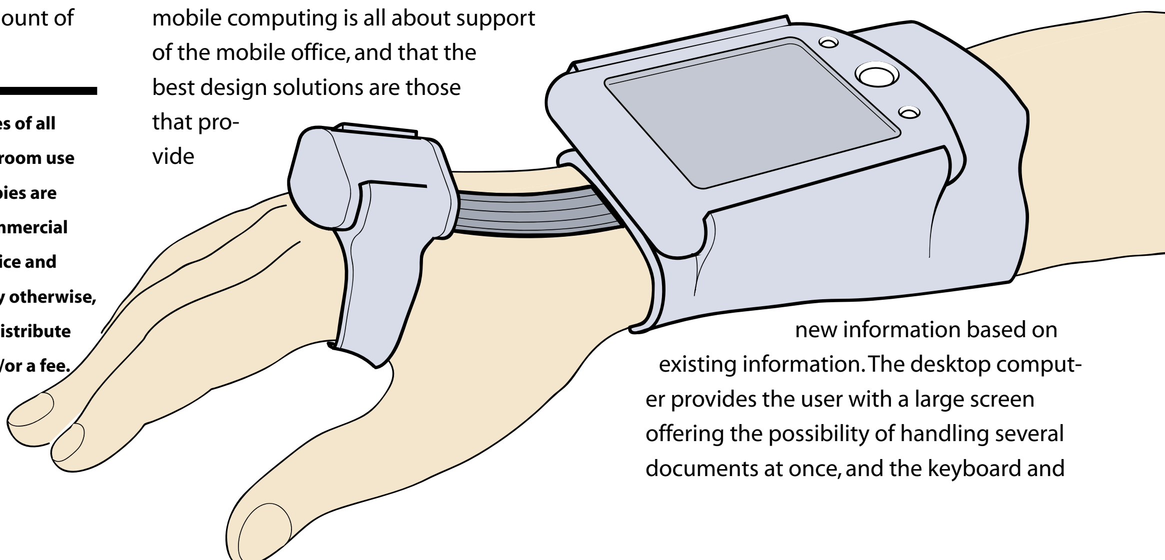
Keywords: Mobile Computing, Design, Embodiment, Interaction, Pointing, Tilt

Introduction

Mobile information technology is emerging as an influential computing paradigm. Palmtop computers, cellular phones, and other mobile devices are gaining ground as an alternative mode of computing far from the physical confinement brought about by the desktop computer. These new devices are indended to better support the growing category of white-collar workers whose style of work has changed from being stationary to demanding a considerable amount of mobility; people that must travel, need to visit colleagues and distant sites, or just need to wander around locally in their workplace to interact with others. The role the mobile devices designed to support this work force play is often that of a desktop computer substitution. Devices like the numerous brands of Personal Digital Assistants (PDAs) seem to a large extent to be designed according to ideals founded within the world of desktop computing. When using them, it seems mobile computing is all about support of the mobile office, and that the best design solutions are those that provide as much functionality as possible from the desktop computer in as small form factor as possible.

While these mobile devices' computational power increases dramatically for every new version being manufactured, concerns have remained for quite some time regarding Human-Computer Interaction issues. In the current literature on interaction with mobile computers, two primary causes have been suggested as the two main barriers which confine usability. First, there are no adequate methods available for text input, and second, the output is limited because of the devices' small screens [3, 4, 12].

It should be considered that these two problems can be regarded as highly dependant on what the mobile devices are primarily designed to accomplish. In order for a mobile device, such as a PDA, to provide the mobile office, users need to be able to manage and process a lot of information, possibly also many different pieces of information at the same time. To produce new information, users need also to be able to input large bodies of text. Somewhat simplified, office work could be seen as the creation of new information based on existing information. The desktop computer provides the user with a large screen offering the possibility of handling several documents at once, and the keyboard and



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mouse used for input are designed to be effective, efficient and ergonomic tools aiding the input to the system, i.e. to manage and create information. This should be compared to a PDA, such as the Compaq iPaq running Windows PocketPC operating system. In terms of interaction, it offers its user a small pressure sensitive screen, but it does not have a physical keyboard; in its place is a pen to handle all input. The "stylus" pen is typically used to operate a virtual keyboard, which tends to occupy a substantial amount of the already undersized screen, hiding even more of the information of which the user wants to take part. Stylus input of characters is also a tedious matter, and is often not suitable for large bodies of text.

> *"Stylus-based input of text is also a tedious matter, and is often not suitable for large bodies of text"*

From this, it seems that small form factors are in fact counterproductive to the tasks that mobile devices are developed to support. In our view, this constitutes a paradox of contemporary designs in mobile computing. While small form factors are necessary to provide mobility and ubiquity, large form factors are in fact needed to support the activities proposed by the mobile office metaphor.

Paper Overview

In this paper, we will address several of these issues by means of a project in which mobile information technology is applied in a different environment and to a different work force. These users—service and maintenance personnel at industrial manufacturing units—bring about a whole set of issues that question the role of mobile information technology as sketched out in the introduction. Rather than providing the mobile office, we seek to use mobile information and communication technology to provide support for the specific needs of their work practice in their specific organizations.

As will follow, we believe that our work has three main contributions to the design of mobile information technology, that should go beyond this particular prototype design and implementation. First, we question the role of the mobile computer as a device designed to provide the mobile office, by applying it in a specific context and demonstrating that the change of context brings about a different set of issues. Second, the difference between the white-collar world and the world of industrial service work is also one of physical activity. We here question the currently implemented styles of interaction with mobile technology, and consider them inappropriate for use in this setting. Third, altering the way the user interacts with the mobile computer, and the rethinking of its key functionality—and as such completely changing its role and its purpose in user activities—led us to reconsider and redesign the graphical user interface.

The paper now proceeds with an introduction to the two ethnographical studies that have been conducted, and we will then present these studies' findings and some possible design incentives. After that, we will present, exemplify and discuss our prototype design. The paper then ends with a conclusive section.

Empirical Backdrop

We argue that the design of current mobile devices to a large extent is founded on what we might address as a *desktop computer paradigm*. For us to be able to design for a very different category of users, with needs that do not correspond to those of the mobile office, we need to learn more of these future users; if and how they differ from white-collar workers. We want to be at least partially capable of answering questions like: What is it like to be a service technician? What role could a future mobile support system play in their everyday work? What kind of functionality would be suitable to implement in this setting? With what do the service technicians currently experience problems and issues of concern? Hence, to be able to find potential use of mobile computers in this setting, we need to consider more than just technology alone. We need also try to understand the target users in terms of their work practice—their thoughts and actions in a social and organizational setting, i.e. how people actually go about their everyday work, solve problems, and keep the organization operative. Consequently, to learn more about service technicians and their work, we conducted an exploratory ethnographic study at two industrial manufacturing units during 2001; *Volvo Trucks* in Umeå and *Volvo Cars* in Gothenburg, both of which are large Swedish vehicle manufacturing companies.

An important goal of the study was to observe and interpret what was actually happening and how work was carried out in practice, in which we were influenced by previous ethnographic efforts within HCI that rely on ethnomethodological analysis [1]. To do this, we followed closely and took detailed notes of everything that single service technicians did during entire shifts. In this, we relied by necessity to a large extent on our own interpretations of what was going on, but we also constantly asked contextual questions and chatted with the service technician, to find out what their interpretations were of what was happening. In the following analysis, we do not to a large extent rely on formally set up interviews with service technicians and their managers. It is our conviction that such interviews tend to be most useful for finding out how things should be, e.g. how specific work procedures should be carried out by-the-book, which may actually be the way a service technician thinks they are carried out—rather than how things actually, and sometimes more or less unconsciously, are completed—i.e. the work practices that make an organization work, e.g. what a service technician really does to solve a specific problem. The primary goals of the study were to find out what service technicians did; whom they talked to during their shifts; what some of their problems were and so on. In short, to form an understanding of the work practice of the service technicians, and see if this could be supported by mobile information technology without turning it into specific work procedures.

To contextualize this effort, there is a considerable history of use of ethnography and ethnographically influenced methods of inquiry in HCI and design research, as it provides a means of studying activities in their own contexts to inform design of information technology as well as to gain understanding of its use. Significant examples of ethnography in HCI include work by Suchman [14], Heath & Luff [5] and Hughes *et al* [6]. Suchman studied the troubles involved in using a photocopier, and showed that the complexity and context dependency of even seemingly simple tasks extend well beyond the point of decomposition and specification. Heath & Luff's study of the London Underground line control room is an example of where ethnography has been able to inform design of new information technology, which is also true for the studies conducted by Hughes *et al* on air traffic controllers. In addition, these authors note that ethnography is useful in uncovering crucial aspects of work which may remain hidden from psychological task-based approaches as well as from formal organizational divisions of labor.

Findings which Influenced Design

The service technicians already use a number of different mobile information technology devices. Apart from various physical tools, such as hammers, screwdrivers, and so on, there are also primarily two instances of mobile information technology in daily use. First, the service technicians use short-wave radios, which are always on and employed to send out emergency requests or general information which everyone should receive. Second, the service technicians are also equipped with cordless digital telephones (DECT) used for person-to-person communication, either between service technicians and managers or planning personnel, or between different service technicians. The short-wave radio and the DECT phone are the mobile communication and information devices in use today, at both the two sites.

A basic delineation between different types of service technicians is that between those that deal solely with mechanical repairs and maintenance, those that have the training to also handle electrical maintenance, and those that also deal with electronics. Surprisingly, we found that service technicians do not generally repair components that break down on-site. Especially so for electrical and electronic problems, erroneous components are rather sent away for repair. With the design of a mobile support system in mind, this would suggest that a system which provides mobile access to manuals and extensive help on specific repair work issues would be little needed. Instead, it would make more sense to equip the service technicians with help on how to remove, install and replace components. Moreover, it was found that the newly employed sometimes had difficulty with the procedures suggested for the many different kinds of installations, which too might be a possible design incentive pointing in the same direction.

> *“The service technicians already use a number of different mobile information technology devices”*

Also, rather than extensive use of manuals, the service technicians tended to rely on two strategies for solving the problem of not knowing how to handle a component or for troubleshooting. In short, the first strategy involved the use of graphical blueprints rather than manuals. Second, and the more common strategy, was to use the DECT phone to immediately place a call to the manufacturer of the specific component, instead of even trying to find the right piece of information in the extensive manuals. Of course, when speaking to a real person, the service technicians also had access to a certain kind of knowledge not available by browsing manuals, such as the possibility of direct interaction with an expert; knowledge of common problems; the possibility of being redirected, etc. Hence, two possible design incentives emerge; one would be to equip the service technicians with digital access to blueprints rather than written manuals, and the second to provide quick and effortless access to manufacturers of components.

In conjunction with the replacing rather than the repairing of components, it seemed one of the major issues all service technicians shared was the finding of spare parts. When something broke down in the industrial assembly line, a service technician was contacted—either informally by local production cell operators or more formally by the service technicians' manager over the short-wave radio—and usually headed to see what was that cause. Usually, this resulted in the service technician either being able to quickly solve the problem at the site or find out that a defective component needed to be replaced. If the component in fact needed to be replaced, there was generally no computer system available at either of the two sites studied that would allow a service technician to check whether or not there were such spare parts in stock. At this stage, the service technician could do one of two things. First, she could head back to the office room to use a desktop computer based system to find out whether or not such a spare part was available or if it would need to be ordered (which was the common approach). Second, the service technician could call or head towards the stockroom to find out for herself (an endeavor carried out on some occasions, but less frequently). A design incentive here, as we interpret it, is to allow the service technicians quick and effortless access to what is kept in the organization's spare part stock, so that for every component there is a direct link to the number of such components available, and that there is a possibility of quickly placing an order of such components if they happen to be missing. The fact that the service technicians would know if there were any spare parts available would also give them the opportunity to choose whether or not they should try to repair on-site, or if they should immediately replace the malfunctioning device with an existing spare part, and trouble-shoot the malfunctioning component off-line.

Additionally, when a service technician stood in front of a malfunctioning component, at least one thing seemed missing. While being difficult to perceive merely though observation, several service technicians commented on numerous occasions that they in a particular situation would largely benefit from some sort of history of each component. We interpreted this as a call for access to a list of every maintenance and service event for each component. If, for instance, a specific part of a component (such as a rubber bearing) had needed to be replaced numerous times the same week, it seemed likely that the error was not so much a problem to be found in the bearing itself, but rather that the cause was to be found somewhere else. Hence, the whole component could be replaced, and not just the specific part that failed. If the problem persisted, it seemed likely that the cause of the break down of a specific component was the result of a malfunctioning or bad tuning of another component along the production line. To assist these kinds of considerations, the service technicians expressed a need to access a history function for each component, which would make every replacement, maintenance or repair activity on the specific component explicit. Obviously, if such a history list could be accessible in front of the component rather than in the office, this would also enhance the service technicians' working situation in that it would reduce the running back and forth between the production line and the office. Providing an on-site history function for each component and each cell thus becomes another important design incentive.

> *“To quickly find a telephone number it was not unusual that the nearest manager was asked to look it up.”*

Related to the need for a history function was the perceived need for some sort of notice board, possibly not useful for each component, but rather for each assembly cell. Notice boards would allow service technicians to cooperate in an uncomplicated and direct fashion. Sometimes glitches and malfunctioning within a specific assembly cell were not obvious or directly solvable phenomena. Although each service technician usually had an opinion or an idea about what was really the cause of the problem, often there was just not enough time to look more closely into the matter and hence those ideas were often lost, or at least not communicated with other service technicians. Similarly, at times one service technician would have done something to a component—e.g. an undocumented, temporary solution just before leaving for the day—which often remained unknown to the other service technicians. On some occasions, a substantial amount of time was spent not on correcting a malfunction but on figuring out how another service technician had implemented a temporary solution.

At Volvo Cars in Gothenburg, there were in fact ordinary notebooks scattered throughout the factory to allow service technicians to express similar things. But after reviewing them, we found that they remained largely unused. This could be because they were not physically located close to the assembly cell, as they were placed in a quite strange, quasi-office environment placed in the outskirts of the production line. Here, a design incentive would be to let the assembly cells themselves embody these notebooks, i.e. to move them closer to what they describe. Also, by making them virtual, the service technicians would only need one device to access all these notebooks, and hence the effort needed to take part in the discussion or note one's activities would be smaller.

Quite surprisingly, one of the largest problems within the service work as a whole was as simple as lack of knowledge about where other people were physically located, and what their telephone numbers were. The service technicians at Volvo Cars in Gothenburg gazed in awe at their managers who benefited from the use of PalmPilot PDAs. If the service technicians needed to quickly find a telephone number of another service technician or of a manufacturer of a specific component, it was not unusual that the nearest manager was asked to look it up. The need for a similar service available to the service technicians as well seemed obvious, while the current work-practice—that of bothering managers—scarcely seems productive. A design incentive here would be to equip the service technicians with a list of useful telephone numbers which could benefit from partitioning, such as separating between which service technicians are currently working, i.e. which are currently active in some sense, and which are not available. Further partitioning could be based on e.g. managers, foremen, planning personnel and manufacturers of components.

The findings reported on in this section represent only a small part of the study as a whole, but are the most distinctive ones in terms of constituting design incentives. One of the most important parts of doing an observational study is not only to find design incentives and problems in the current work practice, but it is also to get to know the intended users, the context of work and the environment in which the work is being carried out. This contextual, but largely implicit, knowledge also influences design, and is as such as necessary as the findings that have been presented which deal with specific issues.

Prototype Design

On the findings of the empirical work, we have designed and implemented a prototype system for mobile support of service and maintenance work in industrial assembly settings. The design work has been conducted mainly at the Interaction Design Lab (IDL) at Umeå University Institute of Design, but in close collaboration between IDL and Umeå Center for Interaction Technology (UCIT), the department of Informatics and the department of Applied Physics and Electronics, both at Umeå University. The project is funded by the industrial company ABB.

From the list of collaborators, it should be clear that this design project has been intrinsically multidisciplinary, and transcended the traditional discipline borders within design, technology and scientific research. As an overall goal, we wanted to design and implement a working prototype that challenged the interaction and interface paradigms in current mobile technology. Also, we wanted the functionality of the prototype to reflect actual and empirically

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observed needs of a specific work group, that of the service technicians in industrial assembly settings. The following sections deals with the project's design phase. As such, it is a description of how we have moved from our initial understanding of what it is like to be a service technician to design of a mobile computer support system. It is important to recognize that many of the ideas which we present here have gone through numerous design iterations, caused by e.g. design flaws, early user feedback, technological compromises, and did certainly not appear in this rather complete state at once. For reasons of space, we have chosen not to go through all design iterations extensively, but rather present the final design iteration in some detail.

Initially, we will present our design vision that has developed during the project, to serve as a tool for the reader to understand the basic notion about the prototype being developed. We will then on a more detailed level present the design of the prototype itself, in three separate sections. First, we will briefly present the technology used to produce the prototype. Second, *Interaction Design* shows how we have altered the ways in which the user controls and interacts with the system, mainly in terms of two novel input methods. Third, *Graphical User Interface Design* encapsulates and exemplifies both the underlying ideas behind the interface design, as well as some pixel-level design choices of the mobile device's graphical user interface. Finally, *Systems Design* deals with how we have designed the functionality the system embodies, founded in the findings of the ethnographic study.

Design Vision

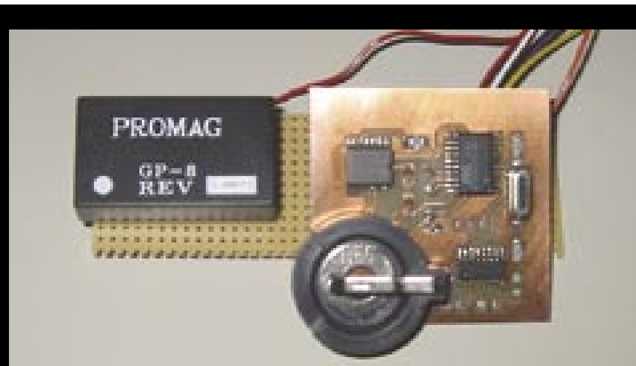
The project's design vision, i.e. our conceptualization of the prototype being developed, can be described as: *a PDA-based, arm-worn, gesture-driven, perceptually seductive and contextually aware embodied system supporting a particular set of useful and interconnected activities for service and maintenance work in industrial assembly settings.*

In short, our vision has been that of a mobile computer system which is attached to the user's arm, and with which she should be allowed to interact in a direct sense with objects in the physical environment, by pointing directly at them in the physical world. This view of pointing in the physical world should be seen in comparison to how pointing normally proceeds in interaction with computers, where the user controls a virtual pointer which is used to select virtual objects. Instead, we allow users to point directly at physical objects using their own hands to initiate interaction. Furthermore, an important design goal of the project has been to try to pursue the phenomenological notion of embodiment as introduced by Merleau-Ponty [10], and as interpreted by Dourish [1], Ihde [7], and Fallman [2].

Implementation Technology

Briefly, in terms of technology the prototype system that has been developed is based on a customized Compaq iPaq™ H3660 with the Microsoft Pocket PC 2002 operating system. The iPaq is considered a PDA-level computer, and has a 206 MHz Intel Strong ARM 32-bit Processor, a color reflective TFT liquid crystal display, 64 MB memory, a RS232 serial communication port, and a lithium polymer rechargeable battery. To produce the software used for developing the prototype, we have used Microsoft Embedded Visual Tools C++ 3, and to allow us to have complete control over the interface, we used a free game developer's software development kit entitled GapiTools (*www.gapitools.com*). The prototype is further equipped with a Radio Frequency Identification Tag (RFID) reader and a 2G accelerometer sensor, which are put together in a physical glove like configuration typically worn on a right handed user's left arm. The RFID tag reader allows the user to interact with the environment by literally pointing at objects in the physical world, as opposed to pointing to virtual versions of them on a computer screen, as it is mounted on her glove and when activated reads the component's RFID tag; a cheap tag that has been previously attached. The device then communicates the identification number received from the RFID tag to a server though a wireless LAN connection, which in turn sends back information about the particular component at which the user is pointing. To cater for sensing tilting of the device, the glove also embodies a custom made tilt sensor device consisting of small, inexpensive standard electronic components. An AVR 2313 microcontroller is connected to a 2G accelerometer with PWM output (ADXL202). The microcontroller samples the tilt sensor's signal transmits it to the computer device through standard RS232 serial communication. Please see *Figure 1* for a picture of the custom made hardware.

Figure 1. The custom made hardware required for the prototype implementation. The RFID tag reader to the left, and the tilt sensor to the right, including battery holder and microprocessor



Interaction Design

An important HCI and design research goal of the project was to make a contribution to issues regarding interaction and interface in mobile computing. The idea was that these results would stand on their own feet, i.e. they should be applicable and valid beyond the immediate implementation in a specific setting, but we obviously build our notion of what is a feasible interaction style on the work practice of the service technicians. We wanted to challenge common styles of interaction with mobile computers; most prominently the stylus pen based method of input. From the empirical findings, we understand that two handed input, which is the common form of interaction with palmtop computers, would not be suitable in the context of service technicians. Two handed input would require its user's complete attention, both in terms of physical attention (where both hands are confined), as well as cognitive attention (reading the screen, pointing and clicking on interface widgets, etc.) Hence, we wanted to explore if there are other means of interaction that would free up at least one hand as much as possible, making the service technician able to use it for manipulation of objects in the physical world, outside the realm of the mobile computer. This would obviously also bring the act of using a mobile device in this setting closer to the activity it is intended to support, i.e. maintenance of physical objects. We have capitalized on three design ideas to explore and support these perceived needs. First, we chose to implement the mobile computer as an arm-worn device, as opposed to handheld which is the common operating mode of a PDA device. To some extent, this makes it possible for us to draw on work conducted in the field of wearable computing. Typically, a wearable computer system is a worn personal computer equipped with input and output devices designed to be available and usable while its user is moving around in the physical world [9]. It is possible to characterize wearable computing as having a set of qualities not generally accumulated by other technology. These qualities include improving and facilitating user activities independent of time, location and user motion; being integrated with the user, in clothes, attached to the body or through implants; allowing for unobtrusive interaction, e.g. through hands-free use or sensors to reduce the need for user input; and augmenting the user's perception of the physical world [2].

By moving the device from the user's hand to her arm, we are able to make use of the device less conscious, where the distinction between using and not using becomes blurred, and the working hypothesis is that this will contribute to an embodiment relation to this particular technology, which increasingly becomes a natural part of service work, and to some extent an extension of the service technician.

Second, the notion of embodiment is further drawn on in our design through interaction by pointing. Instead of providing the service technician with two parallel worlds, a physical world of components and production and a virtual world of information, we have actively sought to connect these two through the notion of interaction by pointing. When the service technician is in front of a physical device, such as a dilapidated component, she interacts with it not by navigating to the component in a virtual sense (such as selecting it from a list on the computer screen), but rather, she points in the direction of the component, and the prototype system is immediately able find information about the specific component and presents its available functionality through the graphical user interface.

Third, a growing body of research suggests that the physical configurations of mobile devices should be determinant of their operation [3,4,8,12]. This is also in line with a broader trend in HCI which seeks to go beyond dependency on shallow metaphors for interaction towards the phenomenological

> *“From the empirical findings, we understand that two handed input would not be suitable”*

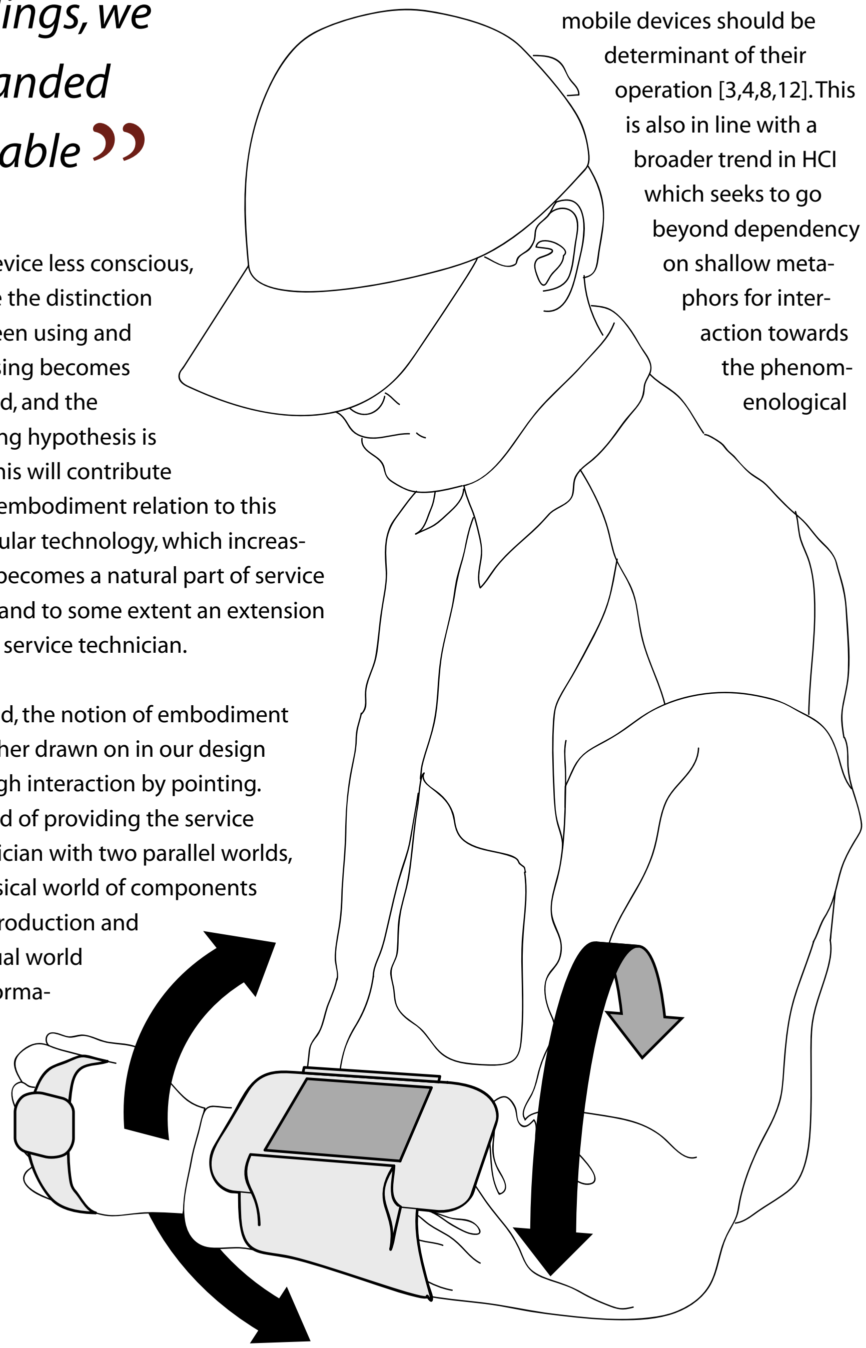


Figure 2. *The ABB Mobile Service Technician. This sketch presents an outline of the arm-worn device, typically worn on the left arm by right handed users, and its one hand operation*

notion of embodiment, where meaning is created through direct and engaged interaction with artifacts within the physical world [1]. This advance is also evident and explored in detail by the growing interest in tangible aspects of virtual phenomena, a field of research often entitled tangible computing [8]. Within such work, tilt has been suggested as an input method to ease interaction with palmtops, where the devices are understood as embodying their interfaces [3,4]. Tilting the device itself is here the means of interaction, which has largely concerned scrolling and pointing on a graphical user interface or for menu selection [3,4,12].

In this project, we explore the use of tilt as an input method to allow both one handed input to the system, as well as contributing to the design vision of embodiment. Our contribution in this area is to found embodiment not only in terms of the specific input method of tilting, but also in terms of the feedback given to the user through the screen output. To do so, we chose the force of gravity to be the common denominator between the human user and the computer system, a form of shared understanding which we believe to be substantially deeper than a metaphor, as it is omnipresent in human sense making of the world. The idea is that human beings instinctively know and hence can anticipate how two objects with mass will behave. If we can provide the user the experience of having an interface with weight, i.e. an interface that behaves in accordance to its configuration the physical world, we believe this experience affords a basic understanding of the device's mode of interaction and explains its behavior.

Hence, to the user it seems as if the graphical user interface answers to changes in the physical world; that the interface "slides" down if the device is tilted. Hence, the interface slides in the direction the device is tilted, thus in the opposite direction in which scrolling by tilt is typically implemented.

We believe these three interaction efforts add to the level of embodiment as experienced by the service technician. The fact that the prototype is arm-based moves the entire act of computing closer to the human user, to help reducing the level of attention and conscious effort needed for operation. The interaction by pointing initiative bridges the gap between the objects in the physical world of service and maintenance work and the mobile support system, by connecting the physical world with the virtual world in a straightforward, obvious and what we believe for service work to be positive manner. Using tilt as an interaction style provides both the possibility of handling many interaction activities with one hand, and it adds to the embodiment of the computer system by giving the user the experience of having an interface with weight, that responds to changes in the physical world. In the next section, we will look more closely at the actual interface controlled by the tilt style of interaction, and how interaction and interface are brought together.

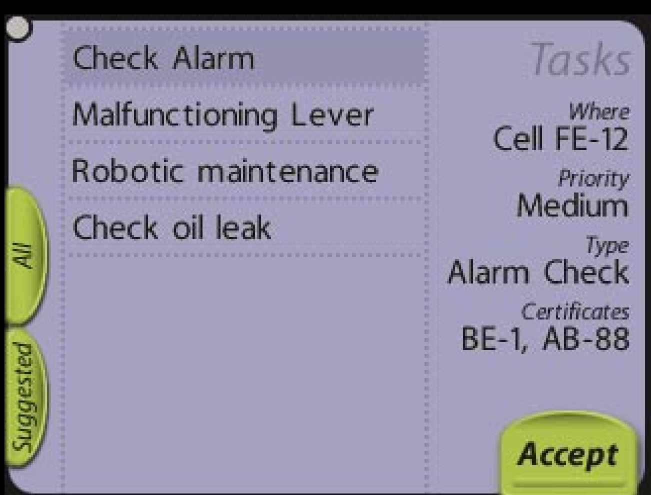
Graphical User Interface Design
It is our view that the design choice of tilt as a means of input should indisputably have an effect on the design of the actual user interface. We believe the graphical user interface should be designed in a way that answers to some hypothetical benefits of the new interaction paradigm rather than to force tilt to operate on a traditional WIMP style interface originally designed for a 2D

Graphical User Interface Screenshots

Pixel-level Design Examples from the Prototype Implementation

This first screenshot shows the always accessible list of contacts. The user switches between the different categories by pressing the tabs to the left. All interface objects that require selection—contact names, tabs, and the *Call* button in this example—are selected by finger-tapping the screen.

For this to be usable, all clickable objects need to be of a certain size, with a certain distance to the next clickable object. Experiments with our prototype suggest that the smallest usable finger tapping area is about .3 square inches.



The second screenshot shows the list of tasks suggested to a service techncians based on physical location. Throughout the implementation, activity related buttons are right-aligned along the bottom of the screen, while any available categories have left-aligned, verical tabs. Lists and other information of primary interest appear in the middle of the screen, while subsidiary information is given to the right. Our main aims with this design is to provide a simple, clear, and consistent GUI.

input device, such as a mouse. Our assumption was that this would do justice neither to traditional GUIs nor to tilt as an interaction style.

The basic setup of the interface provides the user with a number of screens (320x240 pixels) aligned next to each other; each offer conceptually related functionality. The number of screens is dynamically determined by the user's context within the factory. Navigating the interface is a matter of horizontal scrolling through a flat surface which is substantially larger than the available screen, and made possible by the tilt interaction device. A model of gravity is implemented in the software controlling the user experience of the graphical user interface scrolling. The software model used contains a possibility of altering the perceived friction of a surface on which the interface can be thought to be placed, in order to control acceleration and sensitivity, which we believe adds to the embodied user experience of having an interface with weight, and controlling it by changing the device's physical position.

If a service technician has not recently pointed at a specific component in the assembly line, the context unaware functionality is available, as introduced earlier. The user may switch between a list of people, and a list of proposed tasks. When a component is selected within the factory, by pointing at it, the previously presented context aware functionality is added to the graphical user interface and allows the user direct access to relevant information and functionality.

Preliminary user studies, in which 6 subjects have been exposed to the prototype in various stages of completion, have suggested that the proposed *"interface with weight"* style of interaction is useful for navigating through the prototype system's different screens. The style of interaction has also been rated highly on a subjective scale of acceptance and appeal. However, some in-house testing suggests that while this style of interaction can be useful for navigating through different screens, it is much less useful for also controlling traditional interface widgets on these screens. Our hypothesis is that this is because the embodiment relation that is established between the user and the system for navigation is broken when interface widgets instead become the focus of attention, and operating these widgets by tilt seems not to result in the same level of embodied activity.

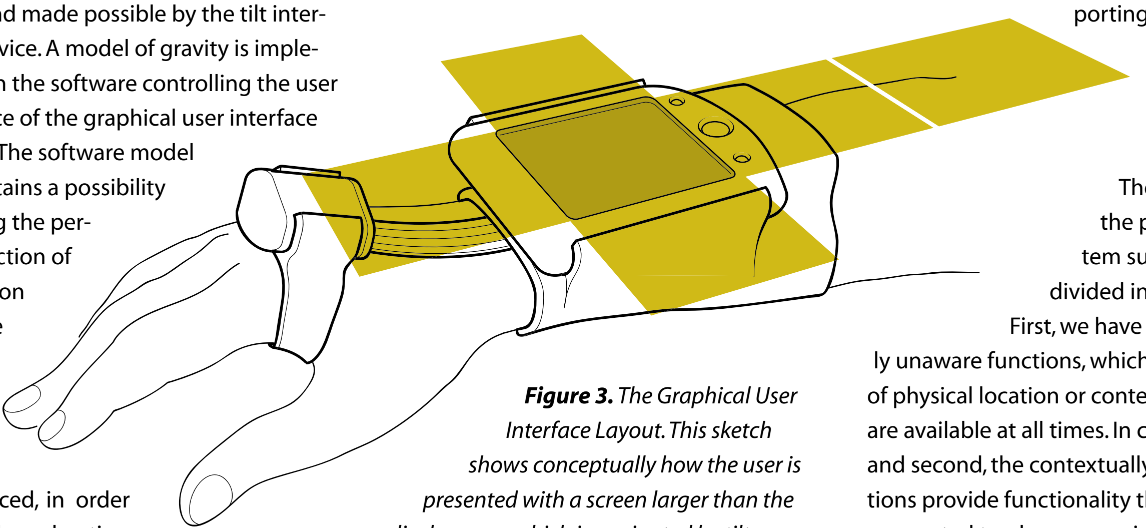


Figure 3. *The Graphical User Interface Layout. This sketch shows conceptually how the user is presented with a screen larger than the display area, which is navigated by tilt*

Systems Design

Rather than implementing a prototype system that captures all the functionalities a service technician may ever need (following in the spirit of a desktop computer) we have instead chosen to pursue a view of what functions to offer which is more in line with Norman's [12] notion of *Information Appliances*. Norman sees the information appliance as the vehicle for moving away from the intrusive, imperious and intrinsically complex desktop computer, toward a more humane, unobtrusive and invisible model of computer use. The term appliance is normally used to name devices designed to perform specific functions and which do so efficiently and with little conscious effort from the user [11]. Information appliances are also defined as being designed to support specific activities, but specialize in information [11]. Mohageg & Wagner broaden the definition to include artifacts dedicated to a small group of related tasks, which most often come as small, easy to use and low cost consumer devices. Examples of information appliances are: calculators, fax machines, telephones, electric musical instruments and digital cameras [11]. The main characteristic of an appliance, as well as of an information appliance, is its simplicity to learn and use, and an element of elegance that comes from the simplicity of its limited purpose and scope. Information appliances also benefit from the specialization of function that allows customization in terms of operation, look, shape and feel. The qualities of the information appliance have been expanded upon to pursue our vision of the prototype supporting a particular set of useful and interconnected activities.

The functionality the prototype system supports can be divided into two groups. First, we have the contextually unaware functions, which are not aware of physical location or context, and as such are available at all times. In comparison, and second, the contextually aware functions provide functionality that is directly connected to phenomena in the physical world, with which the user interacts by pointing at them.

Contextually Unaware Functions

One of the initial design ideas for the prototype system was to combine the use of the DECT phone with the short-wave radio, which is frequently used for such things as emergency calls. The reason, of course, for not having emergency calls being made on the telephone is that it is not possible to call all available service personnel at the same time, and that it should be important to differentiate between a normal telephone call and an emergency call (of which the latter should have the highest of priorities). But by combining the telephone and the short-wave radio with the mobile device, we may solve all these issues, and also add useful functionality and interconnections between them. For instance, as one of two ever-present functions, the mobile device presents a list of people. This list is partitioned into a sub-list of active service technicians, a list of managers, a list of external contacts, etc. This list is simple to obtain and interact with. As the telephone and the mobile device are the same device, it becomes very easy to first find a contact in the list, and then quickly—without having to dial any numbers—just select that person in the list, after which the system automatically places the call. The telephone's microphone and speaker are placed on the wrist side of the arm wearing the mobile device, making the transition from placing a call to speaking quite simple. In addition, by combining the functions of the short-wave radio (by substitution) with that of the mobile device we are not only able to reach out to all service technicians at once, several benefits emerge. First, the prototype communicates the emergency call to the user in more than one modality. While the traditional short-wave radio is audio only, the mobile device can communicate the emergency call though three different modalities; sound, vision and force feedback. For instance, a buzzer attached to the device that gives tactile feedback may prove to be very useful for this purpose, and that it used carefully will become a secure and reliable way of communicating emergency calls (rather than the sometimes hazardous act of short-wave radio messaging).

Apart from combining a short-wave radio with a telephone and a list of people, including the possibility of placing an emergency call to all users of mobile devices, the basic set of functions provided by the tool also includes a list of tasks, which is the second main and ever-present function regardless of context. However, as the overall system will know by the use of the last scanned RFID tag that certain service technicians are at certain places in the factory at a given time, it is possible to design a system that keeps this list of tasks updated dynamically. Hence, if a service technician is occupied with a task that is more complicated than was first imagined, it should be possible for a centralized system, computer based or human based, to dynamically reassign tasks from one person's list to that of others and vice versa. This way, the scanning of RFID tags also provides at least a clue to where the technicians are in time and space, and allow redistribution of tasks accordingly.

Contextually Aware Functions

When a service technician moves around in the physical space and scans a specific component's RFID tag, some functionality that is connected with that component becomes available. The basic set of component-related functions consists of a history function, a notebook function, component information, and component context information.

The history function allows the service technicians access to all previous maintenance and service that has been carried out on a particular component (including that of previous components, if often replaced). An incentive to this function comes directly from the field study, where several service technicians suggested that it would be good to know how many times a particular component has been subject to repair or been replaced entirely. Here, these activities are presented in a list, where it is also possible to see who has carried out a particular activity, and be able to place a call directly to discuss e.g. what was done. The history list also provides a knowledge base for the service technician in order to find out why a certain component is always malfunctioning or needs to be replaced every now and then. According to the service technicians that were studied during the case study, it is often the case that it is not the component itself that is bad, but rather something else in the production line which has influence on the particular component. A history of maintenance and service activities for every component gives the service technicians fast access to this kind of knowledge, which we believe to be an important part of service work which the system will support and ease. Hence, the history function is a list of all service and maintenance activities carried out on a specific component, interconnected with the contact list.

Every assembly cell (which consists of several components) also has its own virtual notice boards, where service technicians can leave small voice notes, e.g. to explain what has been done, and to give their view of what may cause problems. This feature is also a finding of the case study, especially at Volvo in Gothenburg, where such notice boards (or actually physical folders) existed for every cell, though seldom used. The idea here is that the effort needed to listen to and record small voice notes on the virtual notice board connected with each assembly cell is small compared to the current situation, where the service technician actually needs to sit down, find the right folder and write down the message.

Naturally, the actual component itself also has a function and carries information. First of all, the device would recognize exactly which component it is in terms of model, manufacturer and its placement in the factory. The status of the component, e.g. whether it is running or not, is also made visible. Based on a generalization of how long different components should last until they need to be replaced, and maybe also based on the history list (i.e. how often it is replaced in practice), an assessment of the component's estimated "burn time" is presented, i.e. how long it is until it needs to be replaced. Another important finding of the case study, as noted, was the fact that service technicians rarely use component manuals. Instead, if there is any doubt about how to operate, repair or replace a specific component, service technicians prefer to call the manufacturer and ask, instead of looking for answers in manuals or other forms of documentation. Hence, our prototype does not include support for viewing documentation, partly because of technical constraints but most importantly because the work practice of the service technicians studied does not promote extensive use of manuals. Instead, they tend to call the manufacturer, and the design consequentially capitalizes on this finding and allows the service technicians to easily connect a specific component in the assembly line with the component manufacturer's phone number.

> *“Every assembly cell has its own virtual notice board”*

The last of the common contextually aware functions is that of component context information. In a manufacturing factory, a number of components—some large, like robots and pneumatic lifts, and some small, like levers and fans—make up an assembly cell. When a service technician points at an object in the factory, she might want to get an overview of what components comprise the assembly cell as a whole. The component context information function allows the user access to such a list of components, as well as indications of which assembly cells precede and succeed the current cell. To summarize, the functions provided form support of a small set of closely related activities, with a strong focus on supporting work practice, i.e. our interpretation of how work is actually carried out by the service technicians established through the field study. From a hardware system's perspective, we also made the design choice of incorporating functionality from different existing devices into the same form factor to benefit from simple but useful integration of services, such as the directness of pointing at a component in the physical world and immediately being able to place a call to the manufacturer of the component.

Conclusions

This paper has presented the design of a prototype for support of service and maintenance work within an assembly manufacturing setting carried out by a highly multidisciplinary design team. Design incentives have come from theory as well as from an ethnographic study conducted at two manufacturing sites. Theory has provided the concept of embodiment as found in phenomenological literature, and which has been applied in fields such as tangible computing and social computing. This project is an effort to bring ideas of embodiment to play in the context of mobile computing.

The ethnographic field study has contributed to an understanding of what kind of functionality service technicians crave, which is different from the presuppositions of what kind of role a computer system should play which normally guides design. The field study also opened our eyes to new ways thinking in designing mobile interaction and interfaces for mobile computing.

Particularly, we have presented and exemplified our iterative design efforts in terms of systems design of functionality; design of interaction styles and methods; and the graphical user interface design. First, the functionality can be characterized as a small set of closely related functionality, divided in practice into two groups: the contextually unaware functions, which are not aware of physical context and available at all times; and the contextually aware functions that provide functionality directly connected to phenomena in the physical world. Second, the prototype presented three styles of interaction not generally found in mobile interaction: the system itself is embodied in a literal sense on the user, as it is arm worn as opposed to handheld; it allows the user to interact with the physical environment by pointing; and it allows one handed navigation of a surface substantially larger than the screen by tilting the device itself. Third, we introduce a graphical user interface that substantially differs both in layout and operation from traditional WIMP style interfaces, designed especially to be useful for the tilt style of navigation.

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