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Mediated Reality Through Glasses or Binoculars? Exploring Use Models of Wearable Computing in the Context of Aircraft Maintenance

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Aircraft maintenance is often considered a typical application for specialized wearable computer systems, designed and used for a specific purpose only. From the findings of an interpretive case study conducted at Scandinavian Airlines Systems, the largest commercial airline in Scandinavia, there is evidence to question the potential usefulness of such a system.

Instead, in this article, aircraft maintenance is used to explore the potentialities of different use models of wearable computing (i.e., the way the system is designed, used, and understood, and which should also make sense in other environments). The use models are (a) a vertical model addressed by a binoculars-analogy, where the system is designed and used for a specific purpose; and (b) a horizontal model, approached by perceiving wearable computers as eyeglasses, where the system is used throughout the day for a number of activities. Problems with both models suggest an alternative use model, which is presented as the embodied use model, drawing on the notion of embodiment introduced by Ihde (1990).

1. INTRODUCTION

The first "wearable computers", developed by Ed Thorp and Claude Shannon in 1961 (Thorp, 1966), were shoe-based devices with push buttons used to assist the wearers in playing roulette. What is noticeable is that their design had a specific purpose (i.e., to support playing against the croupier), and it was the product of a careful assessment of the application context (i.e., the casino). More recent research into the field of wearable computing tends not to take the same approach. Although some studies have considered notions of use, including the target users' tasks and contexts, the majority of efforts still seem to be driven primarily by advances in technology. To some extent, this does not come as a surprise given that the early adopters of wearable computers were visual artists, computer sci-

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entists, and physicists in academic laboratories, or engineers from the industrial or the military sector.

It seems fair to say that most research into wearable computing may still be categorized both quite easily and quite narrowly. Many research papers published in the field concern issues of technology exclusively, such as the design of hardware systems or components (Bass et al., 1997), fundamental software issues (Fickas, Kortuem, & Segall, 1997), context awareness (Abowd, Dey, Brotherton, & Orr, 1999; Kortuem, Segall, & Bauer, 1998; Pascoe, 1998) and interaction devices (Matias, 1996; Spitzer, Rensing, McClelland, & Aquilino, 1997; Thomas, Tyerman, & Grimmer, 1997). A few authors concentrate on "human factors," which is usually limited to issues such as the ergonomics of the physical shape of the wearable computer system (Gemperle, Kasabach, Stivoric, Bauer, & Martin, 1998). There is a category of research that focuses on industrial applications of wearable technology, primarily in settings such as within the military (Thompson, Najjar, & Ockerman, 1997), medicine (Bruegge & Bennington, 1996; Horvitz & Shwe, 1995; Pentland, Petrazzuoli, Gerega, & Starner, 1997), maintenance and manufacturing (Baudhuin, 1996; Daude, 1997; Siegel & Bauer, 1997; Thompson, Ockerman, Najjar, & Rogers, 1997). Other authors focus on everyday use of wearable computers and what influence this might have on the future of everyday life (Mann, 1997a, 1997b; Rhodes, 1997). What is true for the majority of efforts within the research field so far is that the motivation seems to be a particular piece of technology, which has often been developed before, and not for, a specific activity or use context.

In this light, this article is quite unusual in that it endeavors to establish an understanding of a particular work practice, that of flight technicians within a commercial airline, and with this knowledge in mind to explore conceptually distinct use models of wearable computing. This approach is arguably closer to that of Thorp and Shannon (Thorp, 1966) than to most other efforts in wearable computing research today.

There are several reasons why aircraft maintenance was chosen as the context in which to discuss the perceived use models. First, there has already been related research conducted by other authors (Baudhuin, 1996; Ockerman & Pritchett, 1998; Siegel & Bauer, 1997; Siewiorek et al., 1998) and some companies, such as Boeing and McDonnell Douglas, already use wearable computers for manufacturing purposes. Second, it is an enticing work environment, where there seem to exist real problems and needs—in terms of information load, time criticality, and a requirement for mobility and hands-free use—for which wearable computing seems to have the potential to provide an answer. Third, due to these needs, aircraft maintenance is often considered a typical example of vertical wearable computer application at its best. That is because the wearable computer in this case consists of one tightly focused application, such as a particular aircraft manual or a specific checklist to which the technician has instant access by hands-free operation.

The main purpose of this article is to discuss different use models for mediated reality through wearable computer systems. The notion of wearable computing is introduced further in section 2.1., while the concept of different "use models" is explained in section 2.2. To focus the argumentation, use models are discussed in the particular setting of aircraft maintenance. This environment has been approached through an interpretive case study. Section 3 introduces the objectives of the interpretive case study, and its findings are presented in section 4. Section 5 explores how existing use models apply in this setting, while section 6 is used to outline an alternative to these models. To conclude the article, section 7 summarizes the findings.

2. WEARABLE COMPUTING AND DIFFERENT USE MODELS

2.1. What is Wearable Computing?

Rahlff, Rolfsen, & Herstad (1999) describe a wearable computer system as "A never-sleeping ever-present net-connected electronic butler that unobtrusively supports you in what you do wherever you may choose to do it" (p. 219). However, given the wearable computers built and used today, we may employ another definition: "A bulky, obtrusive and prone-to-fail low capacity rebuilt laptop worn as a gigantic backpack with an extraordinarily bad display." 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. They should be designed to provide their users with information and ways of communication in different modalities while at the same time striving not to overburden the user's hands or attention. This is often achieved by adding sensors, such as global positioning system devices and biometry sensors, to the system to reduce the need for user input. A class of wearable computers uses the concept of mediated reality (Mann, 1994), where an image of the physical world is captured by a digital camera, transformed as needed, and then presented to the user in real time, while other systems (e.g., Feiner, MacIntyre, Hollerer, & Webster, 1997; Hollerer, Feiner, & Pavlik, 1999) rely on the concept of augmented reality, where an image or sound is juxtaposed on the real world and the user perceives both simultaneously.

Many different authors have expanded or restricted this broad conception to include or exclude many other characteristics at various levels of abstraction. Attributes of what is, and what is not, wearable computing will not be defined in detail here, so as not to restrict overly the scope of this article, which is to discuss different types of use. Rather, it seems fair to characterize wearable computers as having a set of qualities not generally accumulated by other technology. These qualities include (a) improving and facilitating user activities independent of time, location, and user motion; (b) being integrated with the user (in clothes, attached to the body, or through implants); (d) allowing for unobtrusive interaction (e.g., through hands-free use or sensors to reduce the need for user input); and (d) augmenting the user's perception of the physical world.

2.2. Use Models

Instead of rigorous and exclusive definitions, it may be more worthwhile to investigate what consequences different views of what wearable computing is might have on the activities for which they become used. The hypothesis is that this would also elucidate how they are designed, and explain the way they are understood by users, developers, and researchers, and why they are used in a particular way by the target users. This is what is addressed by the term "use model" throughout this article—it captures both how the technology is designed to support user activities, as well as how the users make sense of the technology which is presented to them.

What follows is an introduction to the two perhaps most distinctive use models, which are approached by two analogies—binoculars and eyeglasses.

Mediated reality through binoculars. In the binoculars use model, use of a wearable computer to mediate reality resembles the use of a tool in the physical world. It would typically contain one software application used for a specific job and it would be removed when the job is finished. In a sense, wearable computers that rely on this use model become information appliances, tools useful and designed for a dedicated purpose (Norman, 1998).

To capture the nature of this use model, the analogy with a pair of binoculars is used. People use binoculars to enhance their own vision, more specifically to be able to zoom in on details in the distance. Binoculars are not generally used for activities that are not in any way connected to this main purpose. Hence, a pair of binoculars works well as an example of an appliance, an artifact designed and used for one purpose only. Current research into the use of wearable computers for aircraft maintenance tends to rely on this model of use (e.g., Ockerman & Pritchett,1998; Siegel & Bauer, 1997). Here, the user is provided with relevant information or a detailed set of instructions to accomplish a specific and pre-defined task. Issues related to the specific task supported (such as communication abilities and other sources of information), as well as related services (such as spare part ordering), are not included in these wearable computer systems.

The potential benefits of this use model are that designers would be able to concentrate on supporting a particular activity, which may reduce development time and cost for products that serve a specific purpose. In addition, the computer hardware used, the physical shape and placement on the body as well as the interaction devices of the wearable computer could be chosen with the specific task and setting in mind. Other benefits may include user familiarity with the use of applications perceived as tools, derived from the desktop metaphor in most graphical user interfaces of today's personal computers. Designers would also be able to provide custom interfaces exclusively for the specific task at hand.

Mediated reality through glasses. Wearable computers may also be used to mediate reality in another fashion, quite unlike how specialized tools such as binoculars are used and understood. Some users of wearable computers tend to use their systems in ways that bear a certain resemblance to how they use clothing. Here, this use model is addressed by another analogy, namely that of eyeglasses. Not only is the use of glasses in obvious and clear opposition to that of binoculars, but this analogy also more sufficiently describes how reality is mediated through such a system.

Wearable computers that are used and understood as glasses have certain characteristics not generally found in those that conform to the binoculars analogy. They are more personal in that they are often highly customized for and by their user, and hence are not generally used by anyone else. This of course contrasts sharply with the wearable computers used as binoculars, which are appliances with few customizable parts and often accessible by different users. In principle, wearable computers used as glasses are always on, and worn throughout the day. They are not removed when a specific task is finished, simply because they are not generally designed to fulfill only a single task. Rather, these wearable computers are employed for many different activities, just like a desktop computer. To allow these many activities to be carried out, the wearable computers need to be designed as general-purpose computers, with interaction devices that allow input and output that makes sense for more than one task in one setting. Because of this, the design may be more complex and time consuming, while the result is more flexible in that it more easily adapts to new tasks and changes in the environment than would a wearable computer designed to be used as binoculars.

Hence, the basic difference between a wearable computer used as binoculars and glasses is that the latter is a general-purpose computer while the first is an information appliance. If one needs to carry out two tasks, one develops two separate wearable computers based on the binoculars analogy, each specialized for one of the tasks; however, one develops two software systems for use on the same wearable computer if one relies on the glasses analogy.

3. HOW TO UNDERSTAND AIRCRAFT MAINTENANCE

3.1. The Point of Being Interpretive

The research efforts on wearable technology for use in maintenance or repair work mentioned earlier do not generally focus extensively on the user. In fact, sometimes users are not even mentioned, which should come as a surprise since the user is seen an important actor in closely related fields of research and design approaches, for instance User-Centered Design within Human–Computer Interaction (HCI), Computer Supported Co- operative Work (CSCW), and Rapid Application Development (RAD) and Participatory Design within information systems development.

To be able to discuss potential use of wearable computers in the setting of aircraft maintenance, we need to consider more than technology alone. We should also try to understand the target users in terms of their work practice—their thoughts and actions in a social and organizational setting—which will influence their acceptance or rejection of new technology. An understanding of the work practice of several flight technicians has been achieved through an interpretive case study conducted over a period of 7 months during 1999 (Fallman & Holmstrom, 1999). The case study covers work practice of flight technicians within Scandinavian Airlines System (SAS) at three different airports: Alvik Airport and Arlanda International Airport in Sweden, as well as Gardermoen International Airport, in Norway.

The interpretive case study focuses predominantly on human interpretation and meaning. It assumes that our knowledge of reality is gained through social constructions—including language, consciousness, shared meanings, tools, and other artifacts—and aims at understanding phenomena through the meanings that people assign to them (Klein & Myers, 1999). Questions about the relative merits of the interpretive empirical school versus positivistic approaches (e.g., Orlikowski & Baroudi, 1991), and the possibilities of a combination of the two (e.g., Gable, 1994; Lee, 1991), have been a matter of controversy. Nonetheless, as Walsham (1995b) notices, interpretive research has emerged in recent years as an important and accepted strand in information technology related research. Klein & Myers (1999) provide a useful set of principles for the conduct and evaluation of interpretive field research. In this work, which involves critical investigation of the historical background of the research setting, the principle of contextualization was found especially useful for understanding how the current situation had emerged. It also provided suggestions for expected difficulties that may arise from the transformation of work practice that occurs with the introduction of new information technology.

The interpretive case study has its philosophical foundation in the ethnographic research tradition in anthropology (Walsham, 1995a). There is a considerable history of use of ethnography within HCI, since it provides a means of studying activities in their own contexts to inform the design of information technology as well as to gain an understanding of its use. Significant examples of ethnography in HCI include Suchman (1987), Heath and Luff (1992), and Hughes, Randall, and Shapiro (1992). 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 and 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 that may remain hidden from psychological task-based approaches, as well as from formal organizational divisions of labor.

3.2. Case Study Design

During our interpretive case study, we made frequent visits to the test sites over an extended period of time. We drew on three sources of empirical data (Fallman & Holmstrom, 1999) suggested by Yin (1989). First, to grasp the work practice, the complexity of the setting, and the current role of IT support used, participant observations were carried out at all three sites. Second, interviews were conducted with both flight technicians and managers at different levels in the organization. Third, to allow for an understanding of the hierarchy within the organization, and the numerous regulations and work routines prescribed "by-the-book" that each flight technician has to understand, a substantial amount of SAS in-house documentation was reviewed. The triangular form the data sources yield gives a better chance of perceiving the actual work practice of the flight technicians than would a single source. For instance, the observations allow recognition of whether or not work is carried out in the way SAS prescribes in the documentation and if work corresponds to the way flight technicians themselves describe it during interviews. The in-house documentation allows for an understanding of some parts of the work practice and the setting (e.g., the complex pattern of regulations as well as the hierarchy within the maintenance organization, which is obvious from neither the interviews nor the observations). Finally, the interviews allow for detailed explanations of the work routines and opinions about the work being carried out from the perspective of each individual flight technician, a perspective missing both in the formal documentation and the observations where the focus is more on activities than on individuals.

4. UNDERSTANDING THE WORK PRACTICE OF FLIGHT TECHNICIANS

Even if we restrict ourselves to SAS Technical Division where the maintenance takes place, there are over 3,500 flight technicians employed. Obviously, it is not possible to study every possible routine in every possible location, but in order to learn something about the work practice in an organization the size of SAS, it seems indispensable to conduct the study at different sites. It is important to understand variations between flight technicians, as well as differences in their working environments, to be able to break down the stereotypic concept of the advantages of vertical applications of a wearable computer system for aircraft maintenance. Studying multiple sites allowed us to perceive both similarities and differences between work in various locations, and because of this, it seems likely that the results, if generalized,[1] could be applied to sites other than those studied.

4.1. Work at the Regional Airport

During an initial phase of the study we tried to understand the work practice of a group of flight technicians at Alvik Airport (a regional airport in northern Sweden), in terms of what kind of work is carried out, how the different sets of manuals available are used, how they document their work, and to what extent technology is involved in the work practice. Iteratively, through inquiry and observation, we moved from an understanding at a general level to a more detailed knowledge of aircraft maintenance.

Throughout the study, the observed flight technicians were carrying out their normal work activities. Notes were taken and the studied technicians were questioned extensively about the activities in which they were involved. In addition, when working on a task, each technician we observed was asked to "think aloud" (i.e., to explicitly state each of the actions that he carried out). This allowed for a de-

[1]Yin (1989) argues four ways to generalize findings of interpretive case studies. These include development of concepts, generation of theory, drawing of specific implications, and contribution of rich insight. Additional examples are provided by Walsham (1995a) and Klein and Myers (1999).

tailed understanding of the kind of work that took place, where the problem areas usually occurred, and the technicians' different strategies for solving them. We found this strategy especially helpful in aiding us to grasp the use of different software systems that constitute important tools for flight technicians in order for them to carry out their work. At the same time, we found that poor design, diversity among the applications, and their lack of mobility seem to hinder the activities that most flight technicians regard as their work practice.

At Alvik Airport, the eight flight technicians take turns and work unaccompanied for 12-hour shifts. Every flight technician that goes on a shift must be able to handle all work in connection with the host of aircraft from different manufacturers that are bound for the airport that day, as well as administrative efforts. The most common task carried out during the day is that of receiving aircraft, checking them, and declaring them airworthy or not. Craft are declared airworthy after a check, carried out with the help of a formal checklist, made by the flight technician. It includes checking of engines, wings, and undercarriage. During the winter, anti-icing of the craft is a time consuming, tedious, but crucial additional effort prior to every take-off. If glitches of any kind are detected during the check, the technician has to decide whether instant repair work is required or if the particular malfunction may just be noted and seen to later. For their help, extensive trouble- shooting guides have been compiled and may be used to assist if the cause of the malfunction is not apparent. The price tag of canceling a flight due to technical problems is prohibitive and, not surprisingly, the technicians express the view that they should avoid this at all times. When the technician repairs the craft, routines for each action are carefully stated in the flight technician's manual.

In addition to the activities that are in direct connection with the handling of craft, the technicians are also responsible for taking care of administrative work and for handling incoming information such as changes to the manuals and the work routines.

4.2. Work at Two Major Airports

At both Arlanda and Gardermoen the state of affairs appeared to be different in many ways from that of the regional airport. Arlanda is the key international airport of Sweden, while Gardermoen is its Norwegian counterpart, and it is here that the more advanced maintenance activities are carried out. Since there are a surprising number of many different types of craft visiting these airports, it is not possible for a single technician to hold all necessary maintenance certificates. Hence, unlike most regional airports, the many hundreds of technicians at Arlanda and Gardermoen work in teams composed according to the current activity. Work is conceptually divided between the docking bays and the hangars. The activities that take place by the docking bays resemble in many ways the work being done at the regional airport.

At Gardermoen, we focused extensively on work in the hangar setting, which is also divided into subgroups, one that does checks and repair work on the craft, called Traffic Related Maintenance (TRM), and one called Heavy Maintenance

(HM), where the components of the craft are dealt with individually. Much of the work in HM revolves around preplanned activities. This includes mainly the extensive checks of all craft at regular intervals, where the individual craft is entirely taken apart and inspected for errors and where it is not uncommon to discover more than 2,000 inaccuracies, each of which needs to be explicitly documented and handled separately by a certified technician. This list is then added to an equally large compulsory record of maintenance. These checks usually take about 3 weeks to complete, during which many hundred technicians work on a particular set of components from the aircraft. All errors, checks, and tests are carefully documented. Each separate task—consisting of what is to be done, what kind of certificate is needed to do the work, and which parts of the documentation need to be considered—is written down on a special job card which, with the help of senior technicians, is handed out to an appropriate technician to execute.

Work in TRM is structured in a similar way and the work routines are almost equivalent. However, here the flight technicians (in a hangar setting) do not work on single components, but rather on particular parts of the craft as a whole. Besides working in the hangar, if problems occur with craft by the docking bays or on the runway, staff from TRM use van-sized cars in order to get the craft airworthy on location.

4.3. Current Use of IT Support

Besides frequent use of communication technologies (such as VHF radio and cellular telephones), the flight technicians at all three sites make use of a host of different computer applications to carry out their work, which are almost exclusively run on desktop computers. The pool of applications used, which is not homogeneous throughout the organization, may be divided into three categories: First, there are a number of different software systems to handle manuals, job cards, trouble shooting, and checklists. Second, there is a specific software system to handle the ordering of spare parts. Third, each flight technician also uses a mix of standard desktop applications, such as time scheduling applications, e-mail clients, and web browsers.

The first and second category of software systems, which seem conceptually connected, are not integrated and not even based on the same platform, which makes the use of them difficult. One flight technician, when asked directly, stated that these are problematic to use since they do not provide good and usable interfaces and are tricky to learn. The actual documentation of the different aircraft comes in at least three media: (a) in folders, which are becoming obsolete and may no longer be used for reference; (b) on microfilm, which also is on the verge of extinction; and (c) on servers or CD-ROMs (stored digitally), though the latter seems to currently gain dominance.

However, the digital documentation used by SAS does have its weaknesses as well. There are primarily two different applications that are used to view the documentation of the aircraft being maintained in Gardermoen. The first software system for reviewing documentation and manuals is based on scanned pictures of the pages in the folder-based manuals. These pages are, therefore, stored as pictures, which makes searches by contents impossible. The only way to find information, except for browsing, is through a poorly designed indexing function, which makes this solution difficult and obtrusive to use. This software system also seemed to cause quite some frustration during the observation study when a flight technician needed information quickly. Presumably, this was because the software tends to respond quite slowly, even when run off a local CD-ROM, and because of the reduced searching abilities. The second software system is not exclusively based on pictures as a data format for storage, but instead uses a mix of pictures, text, and links that resembles a hypertext based system. It has searching functions and seemed to cause much less frustration than the picture-based system.

The cars used by TRM for maintenance are equipped with a VHF radio (to communicate with each other, the aircraft crew, and the flight control tower), as well as a laptop computer, a printer, and different sets of CD-ROMs with aircraft documentation. These laptops are not connected to the same network as other computers in use which to some extent limits their usage, but the technicians interviewed look at the cars as something that improves their working conditions. They used to be forced to first go from the hangar to the faulty aircraft on the runway, find out what was wrong with it, return to the hangar, find the right information for the perceived task using a software manual system on a desktop computer, print out the relevant pages and then go back out on the runway. By the use of these cars, a technician can bring all the information needed out to craft on the runway or to the docking bays, and print the right pages from the manual while the problem is close at hand.

Depending on the size of the currently held aircraft, or the number of craft that are currently stationed in the hangar, work does not take place in exactly the same location from one day to another. This would make the use of stationary desktop computers quite inconvenient, because it would be difficult to find a location where they would be both nearby and not in the way. To solve this situation, TRM uses "computer tables." These consist of a desktop computer with keyboard and mouse, a printer to print job cards and Telex-messages, and a telephone. The tables are equipped with wheels that allow them to be mobile in the sense that they do not have to have a fixed position within the hangar. To allow the computer tables to be hooked on to the network, there are certain spots—which resembles floor drains—within the hangar that provide a fiber optical connection to the network.

4.4. Mobility in Progress

Especially in the case of TRM, there is a clear tendency towards mobility in the use of computer equipment, which is not a surprise considering the inherently mobile nature of the work practice in this setting. The cars that are used to go to the runway and to the docking bays, as well as the computer tables on wheels are evidence of this, which to some extent justifies further inquiry into potential wearable computer applications within TRM. The physically stationary work of HM does not seem to provide the same encouragement. What should be noticed is the fact that in the case of the computer table, mobility is limited by the need for a network connection, while in the case of the cars, mobility is not restrained, but at the price of having no connection to the network.

A wireless network would solve this problem to some extent, allowing the computer tables to be placed anywhere within the hangar, and the cars could be online anywhere on the runway or by the docking bays. However, there are several problems involved in having a radio-based wireless LAN in this environment. Not only are there questions that concern the possibility of interference with aircraft instruments, but also the hangar itself is not ideal for radio transmissions, with a huge amount of metallic equipment and surfaces. For instance, there may be a severe amount of echo from these surfaces that could cause the actual bandwidth to drop dramatically. These limitations and considerations would, of course, also apply to any wearable computer system, and stands as an example of things that need to be taken into consideration before such a system is developed. It is believed that the interpretive case study allowed us to recognize this class of considerations, as well as to provide insight about the work practice. Furthermore, we found the interviews to be an excellent method of acquiring knowledge about previous ideas and projects involving IT support tools—both successes and failures. Most projects are, of course, documented, but we believe the interviews (with both those who used the tools, and sometimes also with those who developed them) allowed us to perceive why a particular IT tool had succeeded or failed; information that is rarely found in formal documentation.

5. EXPLORING USE MODELS IN THE AIRCRAFT MAINTENANCE SETTING

From what we have come to realize about aircraft maintenance, it seems appropriate to question a stereotypical view of a flight technician as someone who would largely benefit from a binoculars-like wearable computer that is designed to fulfill a specific purpose. The question, of course, is what that purpose would be. From the gained awareness of actual work practice within a commercial airline, we know that they do not only carry out actual maintenance work on aircraft. In fact, the time used for documentation of maintenance activities, which includes the handling of job cards, the ordering of spare parts, and the reporting of inaccuracies, is considered wasted or unproductive by neither the flight technicians themselves nor the organization, but is on the contrary seen as important in the long term. For instance, it allows a documented maintenance history of every individual craft to be made, which may be reviewed when technicians search for the cause of recurring malfunctions. This work would perhaps also benefit from a wearable computer system. However, one might argue that documentation work such as reporting job cards does not require the hands-free use that maintenance work does, and accordingly we are better off using wearable technology for the latter.

Subsequently, we have to decide on an appropriate use model for our purposes quite early in the design of a wearable computer system. On the one hand, we may choose to design a binoculars-like maintenance system in which, for instance, the manual of a specific aircraft is accessible. On the other hand, we could choose to pursue the glasses use model and provide the technician with a diverse set of functionality and features.

5.1. Exploring the Binoculars Use Model

If we choose the binoculars-like maintenance system it would, of course, increase an already existing issue, that of the separation of conceptually related software systems. For instance, it would probably be even harder to associate information in the job-card system with the correct sections in the aircraft manual. In addition, since the handling of the job cards still has to be carried out, this solution would require the use of a stationary computer. It would seem a paradox that the mobility afforded by the wearable computer would be of little value, since the flight technicians would still have to be near a stationary computer to confirm their activities.

We could also design a binoculars-like wearable computer that works as a tool for different trouble-shooting guides. However, once the cause of a trouble is made visible, the technicians would not benefit further from such a system. Of course, each technician could bring a number of wearable computers to the location, one for the trouble-shooting guides, another for manuals, a further one for job card documentation, one for descriptions of work routines, and so on. This is sometimes seen as a viable way to go, which is especially true for tools in the physical world. For instance, the screwdriver and the hammer (not unusual within aircraft maintenance) are tools that probably would benefit little from blending. However, these tools roam in the physical world only and they have, unlike computers, no virtual dimension. In fact, for tools such as hammers and screwdrivers, their physical shape is what is important, while computers rely largely on their intangible character.

Thus, the value of combining a hammer and a screwdriver would probably be limited, while the blending of two information appliances, such as a trouble-shooting guide and a manual, might yield synergistic effects that are difficult to assess. It should be noted, however, that once we begin to include different software systems into the wearable computer we would quite rapidly be moving away from some of the benefits of the binoculars use model (e.g., development time, custom interfaces, and dedicated interaction devices) that we initially might have considered to be important and so caused us to choose this particular use model.

5.2. Exploring the Glasses Use Model

A wearable computer aircraft maintenance system built on the premises suggested by the glasses use model would incorporate every possible software system and communication tool needed by aircraft maintenance personnel. It would be designed to be a personal companion to each single flight technician, used throughout the day and customized to suit each individual's preferences. It would not just incorporate the manuals, trouble-shooting guides, job card system, and the descriptions of the work routines, it would perhaps also benefit from different proactive features, such as automatic time-scheduling, job card management, and keeping track of co-workers.

Obviously, this use model makes it possible to combine many conceptually related tools used for aircraft maintenance. It would allow these aircraft maintenance systems to be accessed and used by technicians who are truly mobile, and it would in addition permit the software systems within the wearable computer to communicate with each other without the need for the flight technician as an intermediary actor. The main drawback of the glasses use model in this specific context is that aircraft maintenance is based on a large number of different activities that are supported by a large number of software support systems. Combining these in a wearable computer would be demanding, and there would probably be a number of obstacles. Clearly, such a system would be time consuming to develop. It would also be more complex and demanding in terms of hardware, and hence more costly than a binoculars-like wearable computer. There will also be difficulties involved in the design of interaction strategies to suit all kinds of communication that are needed between the system and the user for such a broad range of activities. It is also noticeable that the glasses-like wearable computers rely more heavily on an ever-present network connection than do the binoculars.

The glasses use model draws on the analogy that the users would be wearing them in a way similar to how they wear glasses (i.e., they are tools used for the purpose of enhancing vision, but unlike most ordinary tools they are not taken off). Rather, they tend to become quite close to the user, and even likely to become one with the user in some ways. Glasses however, have an extremely straightforward interface and the functionality provided is obvious to the user. When designing wearable computers that rely on this use model, it will be an immense challenge to retain this property of the analogy's source. How do we allow straightforward, usable, and clear interaction between the user and the wearable computer system? It is especially necessary to consider this in the aircraft maintenance setting, as well as in many other use cases, where the target users are not doctoral students in computer science. Several of the technicians interviewed in this study stated quite explicitly that they are not content with the software systems used today.

5.3. Is the Middle Way a Feasible Solution?

The question is, then, how we should go about designing wearable computers for aircraft maintenance—as well as for other use contexts—that make use of synergy effects produced by interconnection of conceptually related software systems, at the same time as the high level of usability expected of binoculars- like wearable computers is retained?

Of course, the two use models explored do not mutually exclude each other. It may be possible to design wearable computers that may be seen as both glasses and binoculars. For instance, a middle-way system might include a few of the software systems needed for an activity, such as both the trouble-shooting guide and the manual. This would make the design less complex (e.g., in terms of interface customization for a specific purpose), and allow the choice of interaction style to be based on a smaller set of activities. Obviously, questions will be raised about which software systems to include and which not to include, and the answer might not be easy to produce—or will at least require extensive field-testing and evaluation.

However, a middle-way wearable computer may also turn out to be a tool that is not particularly good at anything. It might also be difficult for users to benefit from this middle-way compromise since they could have problems conceptualizing it, because it is neither a tool used for a clear purpose (such as a pair of binoculars), nor a tool used to enhance activities on a higher level of abstraction (such as a pair of glasses).

Instead of trying to discover the most appropriate position on the scale between the use models of glasses and binoculars, which might not even exist, it is of more value to look ahead and try to develop new use models which lie beyond the scope of the existing, in order to not get caught by their relative strengths and weaknesses.

6. BEYOND GLASSES AND BINOCULARS

6.1 The Embodied Use Model

The alternative use model to be outlined in this section draws on the phenomenological foundation of how to conceptualize and account for human use of technology provided by Ihde (1990). Phenomenology assumes there exists a correlation between what can be experienced in the world and how it is experienced by the user, a correspondence between what can be seen, heard, felt, tasted, or smelled, and what is actually so (Rathswohl, 1991). Ihde's work is based on the philosophy of technology developed by Heidegger (1962, 1977), for whom technology is a set of conditions, or a framework, within which human activity takes place. For Heidegger, tools are very different from other objects in our environment; they are objects whose functions are defined by their context, design, and human use. Tools, consequently, belong to an environment in which they are being purposively put to use by humans. Ihde extends the idea by implying that technology mediates human—world relations. For instance, what is perceived through glasses is different from what is perceived by the naked eye, which is to say that use of technology alters the correlation between the world and how it is experienced.

Glasses are an example of what Ihde calls the embodiment relation, which is the most basic relation between humans, technology, and the world. In such, the world is directly experienced by humans through technology. The tool persists between the user and the world, but is not the primary focus of the user's attention, and is to some extent an extension of the user. The tool becomes gradually transparent and will eventually require very little particular attention.

Nevertheless, when the bodily capacities are extended using technology, the technology also transforms them. An experience through technology amplifies certain desired aspects while suppressing others. Because of this, technology can be said to magnify the non-neutrality of our own senses, because the design and the use of the technology will decide what is amplified and what is suppressed—and what then is perceived is not the actual state of the world. However, the human sensory systems are not neutral themselves, since they—much like technology—

focus on certain aspects of the environment while other cues are filtered out. To some extent, wearable computers could be used as extensions to human sensory systems, helping us find and filter sensory input that might be too complex or insignificant for the human sensory system alone to recognize. It would also be much easier to decide what should be emphasized, since what is amplified in this sensory system is a part of the technology, while human sensory systems are much more difficult to reprogram. Drawing on Ihde's framework, this is termed the embodied use model, and hence the wearable computers that put this model to use are referred to as embodied systems (Fallman, 1999).

6.2. Perceptual Stimuli Rather Than Cognitive Information

Ihde's (1990) ideas are also useful for forming an understanding of why the glasses use model discussed earlier might be difficult to realize. A glasses-like wearable computer is intended to persist in between the user and the environment, but its level of transparency is actually extremely low. What is intended to be a transparent technology that allows the user to directly perceive and play an active role in the physical world as well as the virtual might, in fact, become the only world the users experience. The glasses-like wearable computer might become so complex to use that the user, in order to understand the tool, forgets what is taking place in the physical world it is intended to support. A probable cause is the fact that existing software systems, as well as those delineated earlier in this article, all rely on cognitive stimuli as the means of interacting between the wearable computer, the user, and the world. The embodied use model is not achieved until the user is focused on the tasks being carried out and the features provided by the embodied system are put to use in a natural and non-obtrusive manner, transparent to the user. When the users make proficient use of features of the wearable computer without consciously considering the fact that they are actually using technology to do so, and when its functionality blends with that of the users, we have a truly embodied use model.

Paradoxically, the extensive amount of cognitive stimuli that would be needed to achieve this would probably in itself constitute the substantive obstacle to embodiment. Consequently, one way to de-emphasize the cognitive overload within the embodied use model could be to allow interaction in a way similar to how the users interact with the real world. If the wearable computer system could mimic the way the real world communicates with us, through perceptual stimuli instead of cognitive information, the chances of embodiment seem better. Advances in fields such as mediated and augmented reality show that some interesting progress in this direction is taking place already. For instance, Hollerer, Feiner, & Pavlik (1999) and Feiner et al. (1997) demonstrate wearable computers that guide their users by the use of virtual objects imposed on the real world. Of course, another way of achieving this goal would have been to describe the way to the users by the use of language. However, spoken language requires cognitive efforts by the user to interpret and act accordingly, and it would be preferable to communicate instead at the sensorimotor level that requires little cognitive interpretation. In Rasmussen's (1986) terms, these efforts would direct the user towards skill-based behavior, as opposed to the current interfaces that require knowledge-based behavior, which in turn restrict them from being active in the physical world.

Ihde (1990) also proposes the hermeneutic relation as a second type of human—technology dependence. Here, the user is not able to perceive the world directly, and the technology serves as the only representation through which the user may experience the world. Thus, the experience is indirect in that the user's primary focus is on the tool and not the world itself. Consequently, representations of the state of the tool are perceived, and not directly of the state of the world. The hermeneutic relation is common in everyday life, with many examples such as petrol gauges, digital thermometers on heating systems, electronic parking space indicators in cities, and so on. People in many different areas have to depend upon displays to perceive the state of the world. Ihde points out that the enigma of the hermeneutic relation lies in the correlation between the technology and the referent. The user usually has no means of knowing whether the tool displays the true state of the world or not. The user has to believe the world as provided by the tool, and act accordingly.

It seems reasonable to suggest that a wearable computer based on the embodied use model weakens Ihde's (1990) distinction between embodiment and the hermeneutic relation to technology. A well-developed embodied wearable computer could turn the hermeneutic instruments that require cognitive interpretation into improvements of perception, which appear embodied to the user, as some examples of Virtual Reality (VR) have been trying to achieve. If so, parts of the users' perception of the world would be the outcome of complex processing done by the wearable computer, now acting as the technological intermediary that Ihde's notion of embodiment suggests. In the context, this would seem feasible since a cognitive interpretation of the processing carried out by the technological "in-between" would not be required from the user. In this sense, it may become difficult to identify whether the wearable computer relies on an embodied or a hermeneutic relation between the user and the technology. Or rather, what used to be the hermeneutic relation is now difficult to separate from the embodied. This is a potential useful way to go in order to design complex wearable computers that offer substantial functionality, while at the same time remaining useful and usable as their users carry out activities in the real world.

Up to now, humans perceive the world and translate parts of it into representations that can be manipulated by computers. Wearable computers based on the embodied use model will allow the opposite, where computer devices perceive parts of the world that we do not fully understand, or are unable to comprehend, and provide us with a comprehensible representation. The perceptions of our sensory systems might tend to blend with sensory information provided by computers. If done unobtrusively, we might tend to forget that part of what we perceive is provided by computers, and the ambitions of invisibility in truly embodied systems will have been fulfilled. Such a relation between humans and technology is not met by Ihde's (1990) framework, and is unique in the sense that the digital world merges with the physical world.

7. CONCLUSIONS

This article is based on an interpretive case study, which investigated the work practice of flight technicians in Scandinavian Airlines System, Scandinavia's largest commercial airline. Through an analysis of three sources of data—participant observation, interviews, and document review—numerous reasons were found to question the static and stereotypic view often found in relation to discussions about IT support for aircraft maintenance. With the gained understanding of the flight technicians' work practice, different use models of wearable computer systems have been discussed in this particular use context. A pair of binoculars has been used as an analogy of such vertical systems where the wearable computer is designed, understood, and used as a tool serving a specific purpose. The problems perceived in this use model were the mutual dependencies and conceptual relations between different software systems used for aircraft maintenance, which seemed in risk of further separation. It was also noticed that the mobility in the real world conveyed by the use of wearable computers would be seriously restrained if many elements of the work still had to be carried out in front of a desktop computer.

The second use model explored was approached by an analogy to a pair of glasses. Here, flight technicians were assumed to make use of multi-purpose wearable computers, customized to each individual and containing all software systems needed for aircraft maintenance. This use model makes it possible to combine many conceptually related software systems and allow them to be truly mobile. In addition, it would also permit them to communicate with each other without the need of the flight technician as an intermediary actor. However, such wearable computer systems would be time consuming and demanding to design. Glasses-like wearable computers would also be highly complex and demanding in terms of hardware, and it will also be difficult to design interaction to suit all the kinds of communication that are needed between the system and the user for such a broad range of activities. The cognitive interpretation needed by the users to make sense of both the virtual world (provided by the wearable computers) and the physical world they roam in, was identified as a possible obstacle.

To extend the notion of the glasses use model, an alternative use model for wearable computing based on the notion of embodiment given by Ihde (1990) was presented. It was noticed that glasses-like wearable computers are intended to persist in between the user and the environment, but the level of transparency is low due to the high level of cognitive interpretation needed from the user. Such interpretation hinders the users from perceiving the real world, since their attention is mostly directed towards the tool itself. The embodied use model suggests moving away from communication of only cognitive stimuli between the user and the system. Similar to the way the physical environment communicates with the user, the wearable computer could communicate at least some of its functionality through a stimulation of our perception and sensory systems. Interesting movements in this direction have been made lately within the field of augmented reality, and the conclusion is that the less cognitive interpretation that needs to be carried out, the more transparent the wearable computers become to the users. This allows the user to focus on the physical world while at the same time putting the virtual world to use, which indeed is the reason for the use of wearable computers in the first place.

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