"Making Place" to Make IT Work: Empirical Explorations of HCI for Mobile CSCW

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ABSTRACT
This paper addresses issues of user interface design, relating to ease of use, of handheld CSCW. In particular, we are concerned with the requirements that arise from situations in which a traditionally designed mobile computer with a small keyboard and screen, may not be easily used. This applies to many mobile use contexts, such as inspection work and engineering in the field. By examining two such settings, we assert that what is usually pointed to as severe shortcomings of mobile computing today, for example: *awkward keyboard, small display and unreliable networks*, are really implications from a conceptual HCI design that emphasise *unstructured, unlimited input; a rich, continuous visual feedback channel* and *marginal use of sound*. We introduce MOTILE, a small prototype that demonstrates some alternative ideas about HCI for mobile devices. We suggest that identifying complementing user interface paradigms for handheld CSCW may enhance our understanding not only of mobile computing or handheld CSCW, but the CSCW field as a whole.

KEYWORDS: Handheld CSCW, user interface design, direct manipulation, video, audio, tactile input

INTRODUCTION
Much research departs from an assertion that the main problems of mobile computers are that they have small keyboards, a low-resolution, limited-size screen and unreliable networks [1]. This paper offers an alternative, empirically-informed interpretation of the practical problems of using mobile computers. The problems that we document give rise to *matter-of-fact*, additional work of users to align the mobile computers with the work situation at hand. We call these extraneous activities "making place" for mobile applications, adapting the situation to the affordances of the technology to fit the use context.

"Mobile CSCW," i.e., when people use mobile computers in collaboration, represents new challenges to the field. To provide users with effective mobile CSCW, it is important to understand the context and practical achievements of mobile computing in real work situations. This need, very much recognised in the CSCW literature, has to some extent been neglected in mobile CSCW (see, [2] for an exception).

In this paper, we report on studies of mobile work in two settings: *telecommunication service engineers* and *maritime consulting staff*. The context in which these people use computers is very different from the office, with which most CSCW research has been concerned so far. Four important features of the work contexts studied are:

- Tasks external to operating the mobile computer are the most important, as opposed to tasks taking place "in the computer" (e.g., a spreadsheet for an office worker).
- Users' hands are often used to manipulate physical objects, as opposed to users in the traditional office setting, whose hands are safely and ergonomically placed on the keyboard.
- Users may be involved in tasks ("outside the computer") that demand a high level of visual attention (to avoid danger as well as monitor progress), as opposed to the traditional office setting where a large degree of visual attention is usually directed at the computer.
- Users may be highly mobile *during* the task, as opposed to in the office, where *doing* and *typing* are often separated.

The results of our empirical research suggests that the current direct manipulation interaction style adopted in most mobile devices may be unsuitable for the mobile work contexts investigated (with the main features as listed above). In particular, the high degree of visual attention that direct manipulation demands seem highly questionable. The main implication of the two studies is the need for new, complementing user interface paradigms for mobile CSCW. The empirical results serve as the foundations of MOTILE, which is a technique and a system to enable easy access and use of mobile computers in work contexts like the two studied.

The rest of the paper is structured as follows: First, we review Mobile CSCW; second, we report the empirical results; third, we discuss the implications the results may have for design; fourth, we describe our design suggestion called "MOTILE;" fifth, we discuss and conclude the paper.

MOBILE CSCW

In this section, we explore current research and technologies of mobile CSCW.

Related work

Few CSCW projects have so far investigated the mobile work context for the purpose of design. Luff and Heath [2] represent one exception. In their paper, they revisited three empirical studies with a focus on "mobility in collaboration." Their concerns, however, were placed chiefly within the larger, social context of work, whilst this paper seeks to draw a specific set of design principles from the "practices of interaction." Another related investigation is reported by Bellotti and Bly [3], whose study of co-operation between two remote companies involved mobility. Again, we feel that the studies presented in this paper come closer to eliciting specific design recommendations. The study by Whittaker et al. [4] of "informal communication" did also involve mobile work, as did Kristoffersen and Rodden's [5] study of the use of distributed video co-operation in a bank, and the study of mobile IT support personnel conducted by Kristoffersen and Ljungberg [6]. These papers emphasised *sessions* rather than *interaction techniques* in CSCW, however. Neither of these studies were concerned with the kind of work context explored in this paper. Furthermore, again with the exception of Luff and Heath [2] neither of them studied the use of *mobile* computers.

Research in the field of mobile computing does not primarily focus on the *use* of mobile computers, but have a far more technical focus. Most projects seek to resolve or improve *limitations* of mobile computers on a computational level, e.g., quality of service, consistency, and transparency. This paper presents a complementing, *application-oriented* perspective.

Mobile computing research often departs from a set of assertions about the limitations of mobile technologies, such as [1]:

- Handheld computers are resource-poor relative to their desktop counterparts.
- Mobility is potentially hazardous, inasmuch as the terminals themselves may be stolen, broken or broken into much easier that stationary equipment.
- Wireless networks are highly variable in performance and reliability.
- Batteries and battery research have not made the same strides as computing power needs, thus, there is usually definite limitations on power supplies for mobile computing.

This paper, on the other hand, maintains that these are largely *implications* from a conceptual HCI design that emphasise *unstructured, unlimited input; a rich, continuous visual feedback channel* and *marginal use of sound.* We introduce MOTILE, a small prototype that demonstrates some alternative ideas about HCI for mobile devices. We suggest that identifying complementing user interface paradigms for handheld CSCW may enhance our understanding not only of mobile computing or handheld CSCW, but the CSCW field as a whole.

Mobile computers

Mobile computers (or PDAs) such as the *Palm Pilot* and the *Psion* have mainly been used for time management, contact lists, and notes. So far, they have largely been used in a fashion disconnected from the network, hence the CSCW support has been, for the most part, asynchronous.

Some mobile computers are equipped with a keyboard (e.g., Ericsson MC 16), while others are pen based (e.g., Palm Pilot), and yet another category relies on both pen and keyboard (e.g., Psion 5 series). There are three dominating operating systems for mobile computers: *Palm OS, EPOC,* and *Windows CE.* Palm Pilot computers run on the Palm OS, while Psion computers, and new mobile phones and hybrids (e.g., Ericsson R380) use EPOC. Palm top computers like the Cassiopeia (Casio) and the Ericsson's MC 16 run on Windows CE.

All three dominating operating systems rely to a considerable extent on the "direct manipulation" interaction style. Direct manipulation is the dominating interaction style for desktop computing. It offers a visual representation of applications and data. The user operates by performing actions like *pointing, selecting,* and *dragging* visual objects on the screen. The results of operations *have to be* immediately visible. Operating systems that rely on direct manipulation are most often based on the "desktop," with files, folders, etc. They are sometimes described as "WIMP systems," since the basic components are windows, icons, menus and point device [7].[1]

Mobile interfaces

Direct manipulation demands a high visual attention from the user. Consider, for instance, the following quote from Shneiderman [8, p. 187]:

"My favourite example of using direct manipulation is driving an automobile. The scene is directly visible through the front window, and performance of actions such as breaking or steering has become common knowledge in our culture. To turn left, the driver simply rotates the steering wheel to the left. The response is immediate and the scene changes, providing feedback to refine the turn."

[1] The Palm Pilot is "less WIMP based" than Psion and Windows CE based palm computers.

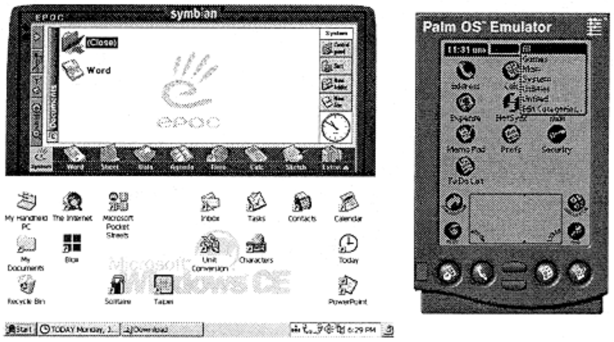

Figure 1: The Psion, the Windows CE palm computer, and the Palm Pilot.

The OAI (object action interface) model of direct manipulation also puts an emphasis on the use of video and the visual attention of the user [8]. It highlights that objects to operate are represented visually on a screen, that the user needs to localise them to perform operations, which in turn produce immediate feedback on the screen [8, p. 205]. Note that both user input and output relies much on video. To *input* the user needs to: first, find the right visual object on the screen, second, perform the operations (clicking, dragging, etc.), and third, receive feedback ("perceiving the system state", see [9], which normally only is visible while the action takes place, e.g., during the drag-and-drop operation when the user moves a file, thus even more visual demanding). These actions all rely much on video, thus they require a high level of visual attention on the users' behalf.

The three dominating operating systems comply with the principles of direct manipulation as described in the OAI model [8, p. 205]. They offer:

- "Continuous representation of the objects and actions of interest with meaningful visual metaphors."
- "Physical actions or presses of labelled buttons, instead of complex syntax."
- "Rapid incremental reversible operations whose effect on the object of interest is visible immediately."

Let us now report the results of the empirical work.

EMPIRICAL RESEARCH

The two empirical studies we report in this paper explore, first, mobile service engineers at Telenor IT Service and Installation AS in Norway, and second, maritime consulting staff at DNV in Norway. Before reporting the results, we describe the two research contexts as well as how the studies were conducted and analysed.

The Telenor study

The research project studied mobile service engineers at Telenor IT Service and Installation AS in Oslo, Norway. The staff was primarily engaged with installation and maintenance of telecommunication equipment in the field. They often work on an individual basis and little interaction with the home base unit. They may receive work orders on the Ericsson MC-12 mobile computer, with which they were equipped in a recent project called DART. The DART project aimed to replace paper-based work orders with mobile computing, but also to provide the mobile staff with access to centralised information. The people studied had been using the MC-12 for four months or more. MC-12 is a mobile computer running on the Windows CE operating system. It has a keyboard and pen, and a touch sensitive screen. A central organisational unit called "the Service Centre" has the responsibility for entering commission in a work order database. To access work orders, and other information, the service staff used MC-12s connected to mobile phones.

We used ethnographic techniques for data collection, i.e., participant observation [10] and qualitative interviewing [11]. Nine engineers participated in the study, which was done for the purpose of design. Conducting ethnography for the purpose of design has become common in CSCW. The approach has, of course, both pros and cons, which have been discussed by, among others, Hughes *et al.* [12]. The field data was analysed using grounded theory, which contributed to a systematic data collection approach.

The DNV study

DNV (Norwegian Veritas) is one of the world's leading maritime classification societies, with maritime services including the authorised survey, classification and certification of ships and offshore units. The objective of DNV is to safeguard life, property and environment. They provides three types of services:

- *Classification*, which is to develop and maintain rules and standards for safe ships, offshore drilling and production units. DNV also verifies compliance with these rules during design, construction and operation.
- *Certification.* DNV is accredited to certify companies with respect to different standards, for example ISO 9000. The main difference from classification is that the certification is grounded in standards developed by organisations outside DNV, typically government agencies.
- *Advisory services.* DNV gives advisory services regarding technical solutions, training and safety, environment and quality management. It is within this section that we have started doing exploratory design for mobile computing.

DNV guidelines, products and services are offered to customers by geographical divisions. The consultants meet customers regularly at their sites, sometimes quite far away from the Home Base Unit (HBU). Mobile work is simply necessary for a global company whose business is mainly location-dependent. After all, ships and oilrigs cannot be inspected "long distance."

Typically, the work of DNV surveyors comprise:

- *Preparing for inspection,* using a classification registry to compile checklists and rule-sets that pertain to the vessel in question.
- *Co-ordinating and performing tests.* The surveyors direct and monitor tests as well as conducting inspections themselves according to the checklists.
- *Entering observations* and compiling reports to the owners as well as DNV centrally and other surveyors.

Consider the following example of what DNV surveyors call a "Steel safari": When inspecting a ships hull or internal tanks, surveyors may use a raft and gradually fill the tank with water. This way they can look for damages and corrosion to the steel plates all the way up, even in a very big tank. They carry checklists, technical drawings, and, obviously, an electric torch. In this use situation, a PDA, which requires putting the device on a flat surface, using the hands for input and relying on good light, even a high-contrast small screen to see what is types, is simply unusable. The user has to "make place" by interrupting the work and finding a suitable environment.

The research approach for the DNV project was almost identical to the one described above, i.e., a small set of brief ethnographic studies combined with interviews and a grounded analysis of the fieldwork data.

The overall problem

Before reporting the studies, we will elaborate and analyse the problem investigated in this paper, as exemplified by the "steel safari."

Direct manipulation demands a high level of visual attention. This imposes requirements on the conditions under which mobile computing can be used effectively. These requirements are not always practical, or even possible in the mobile use context. For example, the high level of visual attention that most mobile computing devices demand may be unsuitable for someone driving in big city during rush hours.

To cope with this the mobile personnel that we studied try to recreate the required conditions. For example, the driver in the example above may stop the car to give the mobile device the level of visual attention required to be operated successfully. Thus, the user recreates the situation that the mobile device requires, in order to be able to operate it successfully.

Our claim is that users should not normally have to be engaged in this kind of activities. They should not have to "make place" for the device in the mobile situation, but just use it instantly in the situation at hand: it should just "take place."

FIELDWORK IN TELECOMMUNICATION

In this section we describe four problems documented in the study at Telenor. The study explored the use of mobile computers among service engineers.

Two hands for input

One problem arises when mobile applications require the use of both hands. For example, in order to perform certain operations on work orders, the service personnel had to press difficult keyboard combinations that required both hands. This created few problems in some situations, e.g., when the mobile computer could be placed on a flat surface in front of the user. However, in many situations this was not possible. For example, when the service engineer has climbed up a post, a very common situation for the service staff, they could only bring the computer in a deep pocket, attached to the belt or in a rucksack. In many such situations, "up the post", the computer was simply unreachable. Moreover, because they have to use one hand just to hang on, they only have one hand left to hold the computer, thus having no possibility to use the keyboard. To handle the problem, users either interrupted the task to perform the operations on the computer in a place where both hands could be used, for later to resume the task. They would, for instance, climb down the post, perform the operation, and climb up again. Alternatively, they could before climbing up transfer the information they think they will need from the computer to a document, which they believe is more easy to overlook. Then they bring the document with them when climbing up the post.

Figure 2: A service engineer at a post.

Similar problems arise frequently as the workers often have the hands occupied with tools and materials. They sometimes need to use one hand just to keep the balance, and certainly to do manual work "outside" the mobile computer. Because visual attention is important for both input and output, the workers needed to "make place" for easy visual access to the screen in order to benefit from the computer (at all). The engineers would often have to hold the computer in one hand in front of themselves, just to see the screen clearly. However, by doing so, they to a large extent disqualify input operations. It is almost impossible to input data with the same hand that holds it. Alternatively, users would try to find a flat surface for the computer in front of them, thus being able to view the screen, and managing to type with only one hand. This may be difficult, however, as there are few flat screens at the top of posts, in passages, and other places where the service staff work.

No place to put the device

One problem occurs when the engineers want easy access to particular information while doing a job, but cannot find any place for the mobile computer. For example, while doing a job the workers usually wanted easy access to the work order. Therefore, they performed the operations required to bring the order to the screen. The problems arose when they could not place the mobile computer in a place that made the screen easily available while doing the job. The job often takes place in environments where it is not easy to find such a place. Furthermore, the workers may move during the job, thus the place needs to be easy to view from all positions involved in the job. To find such a position for the mobile device is not always easy. To solve this the engineers may, again, *look up and transfer* information to a suitable medium before starting the job. However, if there is much information on the order, e.g., many details, this can be difficult. The result is often that that the engineers have to interrupt the task, get the mobile device and check the information before resuming.

Too much visual attention required

A serious problem arose when people needed to use the mobile computer while involved in tasks that required *high level of visual attention.* For example, the engineers often needed to find the addresses of clients while driving to the site. Previously, when the work orders were paper based the engineers often put the order next to the steering wheel to find the address (which even may have been highlighted with a pen). Now, when the paper document has been replaced by a mobile computer, the task to find the address has become much more difficult. The screen is much smaller than the A4 paper document, the task to find the address may require scrolling, and so on, as a result of the direct manipulation paradigm. Because the task of driving demands a so high level of visual attention, the users often find it very difficult to perform even very simple operations, such as finding the address on a work order. This is not to say that artefacts cannot be given visual attention, which apparently was possible previously when paper documents were used. It is the very high level of attention that the mobile computer demands that is the problem. To cope with this, the engineers sometimes look up the address and write it down on a post it note before starting to drive, look up the address at a traffic light, and so on.

FIELDWORK IN MARITIME CONSULTING

The following fieldwork excerpts show that the findings from the study described above may indeed be sufficiently general to offer design guidelines for mobile CSCW. The physical environment in which work takes place puts severe constraints on which applications of today's mobile computing platforms may be used. There seems to be potential relief in two directions: First, by changing the use situation. This entails suggesting new types of applications that do not have to used instantaneously, in order words "taking place", but instead allows the user to "make place" for collaborative mobile computing without seriously disrupting the flow of work. Second, by designing human-computer interface systems that complements the Direct Manipulation paradigm in such a fashion that applications may be used instantaneously in a heterogeneous use context.

As the excerpts below clearly demonstrate, there is little room for direct manipulation based user interface devices in the mobile work setting of DNV surveyors. The place of work, such as factory shop floors, inside pneumatic compressor tanks or within a ship's hull, in itself often prohibits the use of computer displays, especially small, low-resolution screen associated with mobile computers.

Moreover, the work often entails focussing over prolonged periods on physical installations or taking security precautions which require observation and precaution. In the mobile work of DNV surveyors, a directed (and sometimes hasty) call, eventually together with knocking on helmets or tugging uniforms is frequently used to get attention or relay instruction about what to do next.

In the study of mobile surveyors we also found several instances of situation in which the potential for mobile computing today is limited due to the prevalent reliance of keyboards and pen input. Frequently the surveyors have no hands free, or only one hand free. Their work often entails climbing high ladders and crawling in confined spaces—in addition, there is usually no place to put a handheld computer. The following section presents these concerns in more details.

Two hands for input

The surveyors carry out most of their work, depending only on their subject expertise, in factories, workshops, on oil-rigs or ships, which may even be in passage. Today, paper documentation, for instance of a ship's classification lifecycle and certificates, is carried in an A4 binder. Since much of the work means inspecting awkward places, however, a small notebook and pencil is usually put in a pocket. The following figure (3) shows a DNV surveyor (PH) ready to inspect an electric installation onboard an oil super tanker.

Consider the work taking place.

PH climbs the ladder to a tower on the electric installation. He climbs one ladder, managing pretty well with only one hand to hold on, but decides to leave the A4 binder before continuing to climb the next two ladders.

PH is happy with what he finds on the top of the tower. He descends, and finds a cable to a heater, for which the protective cap is worn. He records an entry in the small notebook, whilst kicking hard into several cables' protective caps just to see if they are sufficiently solid.

This excerpt shows that any mobile computing support for this type of work, which requires the use of both hands, will require that the user "make place" for using the equipment. For instance, and similar to using the manual notebook, by making an entry in a computerised notebook after the fact, when it can safely be operated.

Figure 3: A DNV surveyor, traditionally equipped

The following expert and picture shows that even in situations where a mobile device may be safely and comfortable operated, for instance when the user is lying on the "floor", surveyors may still have to use one hand for another purpose, for instance holding an electric torch or pushing buttons on the devices that they are actually testing.

PH climbs into the cable-exit room. He inspects each exit point and looks for sharp edges which may harm the cable caps, if the insulation tapes has been damaged during the cable installation (the cables are heavy and stiff and laying them may in itself damage the fabric). He also looks for AC cables crossing DC cables—they have to be lead in separate covers to avoid danger.

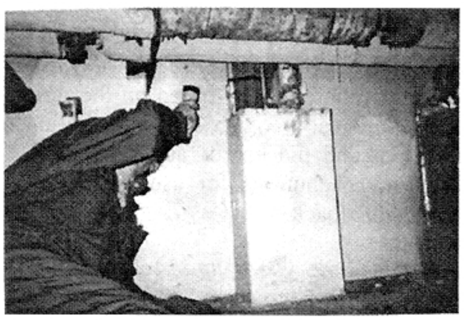

Figure 4: One hand needed to use a torch

For one room, which is on the technical drawing for the installation, PH can find no entry. The cables go through, somehow, and they have to be inspected all the way. PH climbs a ladder, into a man-hole on the wall, and finds the room. There was nothing wrong with the insulation, but the cables lay on to a metal edge. This has to be resolved.

As figure 4 shows, PH is here in a situation where a handheld computer could have been put on the floor of the room in which he is, inspecting the cables, but he still needs one hand free to hold the electric torch, without which he can see nothing to report.

No place to put the device

In another, related situation from a different part of the field studies, a DNV surveyor is working with an engineer, an inventor of oil filters and the manager of an aluminium mill, to test a new oil filter installed in a pneumatic oil tank.

As the figure below clearly shows, mobile work in such conditions is wet and greasy; there are no surfaces without pipes, valves, water and, in this instance, people on them.

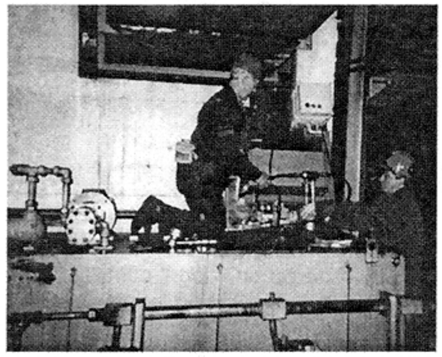

Figure 5: No place to put a computer

This means that current mobile computing equipment is likely to fail, because the traditional keyboard and screen design entails that effective use depends on a flat and stable surface on top of which to place the machine.

Too much visual attention required

On the factory shop floor, such as the aluminium mill, there is not much light, and the little there is must be precisely directed to the places where it is needed, much in the way as driving a car in the dark requires the inside lights to be turned off. The picture below shows the aluminium bars, each weighing around 8 tons, waiting to be collected. The machine in the background puts the bars on the rolling mill.

In such an environment, it is not easy to use a small, low-resolution screen. Moreover, and perhaps more importantly, these workplaces are of a character that requires extreme caution and a keen eye on the environment. From the pneumatic oil tank in which the oil filter was installed to be tested, to the return path of the "shoe" carrying very heavy aluminium bars, the distance was a mere 10 20 inches. Every 40 seconds, thus, the engineer and surveyor had to straighten and step back to avoid being hit by the show returning to collect another aluminium bar. Thus, any user interface system requirement undivided and continuous visual attention to the screen during operation, is likely to be either hazardous or useless in these particular mobile settings.

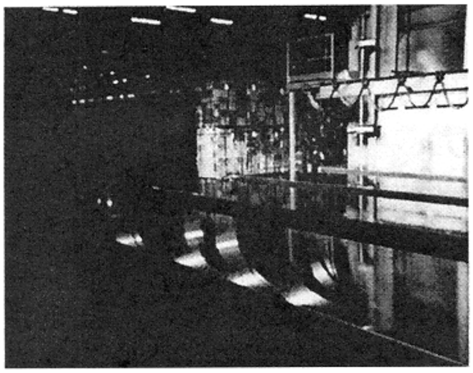

Figure 6: The shop floor of an aluminium mill

IMPLICATIONS FOR DESIGN

The mobile environment is often heterogeneous [13], and mobile users often face several different kinds of use situations, sometimes even within the same session. For example, a commuter may have to stand up the first part of the ride to town, and sit down the last. While sitting down in front of a table, the keyboard based Windows CE palm top may be very suitable. While standing up, however, it may be very difficult to use. The diversity of the mobile use context seems to call for a set of interaction styles among which the mobile user can choose from in the particular situation at hand [13].

This implies that mobile applications and interfaces need to be designed with a particular kind of mobile use context in mind. The use contexts which we have explored, and for which we now derive design implications, may be characterised as follows:

- Tasks other than operating the mobile computer may be the most important, as opposed to tasks taking place "in the computer."
- Users' hands may be occupied, as opposed to users in the traditional office setting.
- Users may be involved in tasks ("outside the computer") that demand a high level of visual attention, as opposed to the traditional office setting where a degree of visual attention can be directed to the computer.
- Users may be highly mobile whilst performing the task, as opposed to sitting at their desks.

When designing interaction styles for mobile computers to be used in this kind of environments, there seems to be at least three issues to consider. These are [9], first, simple "execution of action" that does not demand a high degree of visual attention, second, "perceiving the systems state" should demand no or little visual attention, and third, rich audio feedback. Let us consider these three issues in some more detail [9].

First, "executing actions" should not demand a high degree of visual attention. In that sense the MC-12 computer used by the engineers was unsuitable. One reason may be that most people type on mobile computers with one finger on each hand, which is very difficult without looking at the keyboard. Another reason is that localising the visual objects on the screen is very demanding visually. This calls for input methods that do not demand much video. Such methods seem likely to be very simple and structured.

Second, "perceiving the systems state" should demand no or little visual attention. One important reason is the practical problem of finding a place for the mobile computer that makes the screen easily available for the user. This calls for feedback and output methods that demand little or no video. Such methods may rely on audio, which is the third implication.

Third, in most mobile situations we studied users could have relied on audio feedback. Even in extreme environments this would be possible, because an "ear-plug" may be used underneath the protective cap. Such situations were quite common for the surveyors at DNV.

These implications served as the foundation for the design of the MOTILE interaction style method described next.

MOTILE

MOTILE is a technique (interaction style) and a system for operating mobile computers. It is based on the three implications discussed above: no or little visual attention, structured, tactile input and the use of audio feedback. MOTILE relies on only 4 buttons for user input, and "hands free" audio for feedback.

The technique comprises *binary look-up in sets of virtual keyboards*, currently with keyboards for: text input, moving the cursor, reading text and selecting links from web-pages, as well as reading and sending email. The user "encodes" input by selecting and pressing *regions* on a touch screen. *North* switches between keyboards, *East* and *West* selects the next higher or lower half of the keyboard, respectively, and *South* executes the command (e.g., types a character or takes the user to the selected web-page).

MOTILE informs the user about options and execution via a voice synthesiser. The visual channel that dominates the direct manipulation paradigm is replaced with a less obtrusive audio feedback conduit.

MOTILE relies on "semantic call-back," which entails using the system as a control panel, or ultra-thin client which sends encoded instructions to dedicated servers, *rather than performing any actions locally*. Figure 8 shows an overview of the architecture.

MOTILE consists of an ultra-thin client running on the palmtop terminal. The client communicates "orientation"

(N, W, S, E) using a Lucent wireless LAN to the MOTILE server running on a Unix host. The simple messages is translated into *selection*, *navigation* and *execution* of semantic codes which are organised in virtual keyboards. A *perl* script parses and returns elements of HTML from URLs. The users are continuously offered feedback on their actions via an echoServer, which uses a simple audio synthesiser to broadcast messages to a microwave radio. A headset is connected to the radio terminal carried by the user, thus affording non-obtrusive feedback through the audio channel. A separate server handles mail commands which it relays to *sendmail*.

The current version of MOTILE is implemented for Windows CE using Waba and Solaris servers, but any platform dependencies are external to MOTILE itself; the primary obstacles in this respect was finding drivers for Wireless LANs and an effective voice synthesiser.

The main contribution of the current MOTILE technique is twofold; First, it offers an input device platform on top of which to continue experimenting with new ways of operating mobile devices, and second, it demonstrates that the visual feedback channel taken for granted in the direct manipulation paradigm may indeed be challenged. Informal testing and evaluation of MOTILE report promising results.

We are currently in the process of setting up a proper evaluation of the system, thus far, mainly the authors have been experimenting with the system during development only. Besides establishing that the technical configuration works well, very limited "proof-of-concept" may yet be elicited from this. We have found, however, that typing, reading and sending email, "browsing" and selecting web-pages moving the mouse cursor works, albeit slowly and requiring some concentration (mental, rather than visual) compared to the desktop-based direct manipulation counterpart. An interesting avenue for further exploration is already established, namely to attempt using a combination of "intelligent profiling" based on use patterns, to re-use frequently types combinations, and "tangible bits" [14] to reduce the stress on the user during input operations. Getting audio feedback via the synthesiser and radio, rather than visual feedback, seems to work rather well.

DISCUSSION

We found that mobile computers used by the service staff, imposed unsuitable requirements considering the use situation. We also found that people, to cope with this often became engaged in disruptive, albeit "matter-of-factly" activities to "reconfigure" the situation to map these conditions: they had to "make place" for the mobile computer.

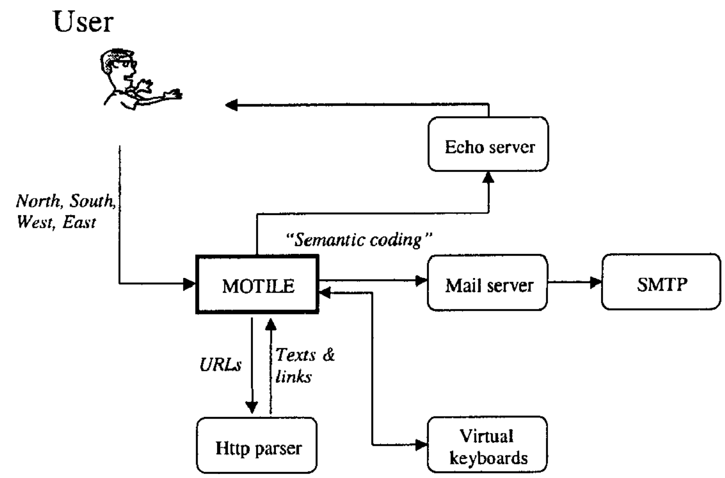

Figure 8. MOTILE.

"Making place"

Similar kinds of "extraneous activities," "work arounds," "articulation work," have been documented in the literature [e.g., 15, 16]. Thoresen [17], for instance, reports how staff need to take on "articulation work" due to the disparity between actual work practice and the assumptions of a workflow system.

Our finding relates to the studies of mobility and collaboration, conducted by Luff and Heath [2]. Luff and Heath argue that paper medical records are superior to computerised records in that they are "micro mobile." By micro mobility they mean "...the ways in which an artefact can be mobilised and manipulated for various purposes around a relatively circumscribed, or "at hand", domain" [2, p. 306]. The paper medical records are micro mobile in many ways, e.g., they can easily be shared, they are portable, they can be the focus of gestures and marks, etc. The medical records do not have these features: "The system is indeed part of the furniture, and as part of the furniture it demands orientation from the participants, rather than allowing the participants themselves the ability to ongoingly configure the artefact with regard to the shifting demands of the activity" [2, p. 307].

In a sense, this was also the problem encountered by the service engineers of our study. They found it hard to focus on the job, and could not easily adapt the computer support to the shifting demands. Instead, they had to do tedious reconfigurations of the entire work situation to make the mobile computer support work. Accordingly, the need for artefacts to be "micro mobile" is not only true in face-to-face interaction among people, but also in individual work tasks of mobile personnel.

Design strategies

The problem we documented in the empirical studies calls for new interaction styles for mobile computers. The user should not have to "make place" for the mobile computer, the use should simply "take place" in a way that is practical in the situation at hand. One strategy to approach the problem, which has become popular lately is to make the computer "context-aware." This means that the computer, based on sensors in the environment can adapt to the preferences of users. The technique has been used in both research and commercial systems, involving desktop as well as mobile computers. One example of a research system from the mobile domain is "the Cyberguide," which is a context-aware guide for tourists [18]. The Cyberguide, as all context-aware systems rests upon the idea that intelligible actions can bee defined in advance. Empirical investigations suggest this is not easy to realise in a practical way [e.g., 16, 19]. Too often, it seems, the outcome is exactly the problem documented in our study, i.e., that users have to "make place" for the technology to make it work. An alternative strategy is to provide users with a set of interaction styles from which they can easily choose the best suitable to the situation at hand. From such a viewpoint, we developed the MOTILE prototype introduced in this paper.

Other solutions to the problem

There has been made many contributions to the field of HCI research with regards to multi media and modal input. Sawhney and Schmandt [20] describe Nomadic Radio, a wearable system for providing background awareness for mobile users. It is thus distinguished from MOTILE, which relies on audio as a directed "foreground" feedback mechanism about the state of the work and available operations. In most other HCI and CSCW reports, audio is seen as a vehicle for input, whilst our concern in this domain is chiefly with audio feedback mechanisms. There has been many panels on this issue[2], but here the perspective is mainly one of structured output in combination with open voice input [21]. The project reported in this paper, on the other hand, aims to support, open audio output and structured tactile input. We have not been concerned with auditory cues [22], as such, although we of course see them as a useful complement to the design of MOTILE. Many more papers, of which the focus is input devices for drawing, pointing and dragging, further complies with the direct manipulation paradigm [23], and we have chosen not to go into these in any detail here. One particularly fruitful approach, we think, is to consider the integration or separation of input devices in terms of applications versus the mechanics of the system [24]. Rather than looking at perception as the key element, however, as Jacobs et al. [24] we have looked at the social practices involved in the mobile work which we aim to support. Thus, this, paper contributes to an already rich body of work in both HCI and CSCW, with a fresh perspective on the fundamental paradigms underlying the design of mobile applications.

Conclusions

This paper addresses the emerging issue of "mobile CSCW." We have reported empirical work on the topic, which suggest the need for new interaction styles for mobile computers. Current mobile computers rely too much on direct manipulation, which seems to demand too much attention of the mobile user to be useful.

The exploration offered in this paper has lead us to a preliminary reformulation of the problem: *The Direct Manipulation paradigm is exclusive*, i.e., one can only attend to one "landscape" at a time (driving while operating a device, or typing when having to monitor a potentially hazardous environment). Thus, a fairly general conclusion may be offered, namely that *complementing design principles are always needed in heterogeneous use context.*

MOTILE offers a complementing interaction style for heterogeneous use contexts, in particular those where tasks other than operating the mobile computer may be the most important, users' hands may be otherwise occupied, users may be involved in tasks "outside the computer" that demand a high level of visual attention, and users are highly mobile whilst performing the task.

As noted before, the mobile use context is indeed heterogeneous, thus the recommendations of this paper have to be considered in the light of the mobile use context researched. The empirical research gives implications for design of new interaction styles for mobile CSCW: no or little visual attention, and the use of audio feedback. These were considered in the design of MOTILE.

We plan to explore different ways to enhance MOTILE, e.g., "polar" as well as binary look-up, by which the user can scan a virtual much faster simply by pressing the pertaining button longer or harder, "pads" with physical scale and orientation, rather than buttons, by which the user can jump relative to the magnitude of direction changes, and semi-automated completion of input sequences based on the frequency of previous user actions. We will also conduct a thorough evaluation of Motile.

The empirical work of this paper clearly suggests the need for both empirical studies and design of new interaction styles for mobile CSCW.

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