Designing for mobility
- an integration approach supporting multiple technologies

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ABSTRACT

Based on an empirical study of a wastewater treatment plant we present an integrated prototype for PCs and PDAs. It supports getting an overview of the wastewater treatment process and making system information available in the environment outside the control room. The prototype is build on the understanding that support for mobile work must be realised through a combination of different technologies enabling users to meet the changing demands in a work situation. With the design we seek to reflect the position of the mobile device in the existing 'web of technology' and show how the concept of integration can be a driving force in design, allowing us to see heterogeneous devices as parts of a whole rather than independent entities. Furthermore, the prototype challenges the notion of working 'anytime, anywhere', which is presented as an ideal by many (communication)-technology companies today.

Keywords

Mobile computing, mobility, distributed work, integration, user interface design, "web of technology"

1 INTRODUCTION

The CSCW community has in recent years been criticised for neglecting to support mobility as a vital and integral part of collaboration in a distributed setting. Most systems designed to support cooperative, distributed work are 'workstation-centric' i.e. largely concerned with providing still more complex support tied to a personal computer, which makes them ill suited for supporting the mobile aspects of work (Bellotti & Bly 1996, Fagrell et. al. 1999, Heath & Luff 1998). These critical voices are meeting the challenge and, through excellent empirical studies, have pointed out important implications for design when supporting mobility in CSCW applications. However, what we find is missing from this discussion is the relation between the existing technology and the technology being introduced in the work setting. When looking to support mobile work by means of introducing new technology, e.g. a mobile device, we need to consider how this new technological artefact should relate to the existing technology as well as how it will affect the work practice. We refer to this relationship as 'the web of technology' and argue that if we neglect to take this into consideration in the design process, it poses a serious threat to the understanding that support for mobile work must be realised through a combination of different technologies, supporting:

"…an individual's ability to reconfigure him or herself with regard to ongoing demands of the activity in which he or she is engaged." (Heath & Luff 1998)

We report from an empirical study of a wastewater treatment plant where work is highly dependent on being able to move around on the plant area to get site-specific information in combination with using system information available only through a central PC. This type of mobility corresponds to what Bellotti & Bly (1996) identified as 'local mobility', where people move between buildings or rooms in a local environment. Furthermore, it carries aspects of both local and remote mobility (Heath & Luff 1998), in that the work require them to move around locations outside of the plant and still having contact to colleagues and being able to access information in addition to moving around on the plant itself. In this context, we have found the term 'integration' very useful. We use 'integration' to denote things being part of a whole without losing their individual identities, both on the technical level and more importantly in relation to the interface design.

Roman et al (1999) explores the challenges of integrating a PDA in a distributed environment. They argue the importance of using PDAs as 'enabling bridges' to services rather than treating the PDAs as isolated entities which seems quite similar to our view of integration. However, consistency in their system is supported by contents alone. We find that visual representation is an important element in maintaining a sense of integration across different devices.

We introduce a mobile device to support two vital aspects of the work, namely making system information available locally and providing the workers with an overview of the status of the process. Getting information when and where you need it has also been the focus of a number of research papers dealing with knowledge management in a mobile environment, e.g. (Fagrell & Johanneson 2000, Fagrell et al 1999). We see a number of similarities between these studies and our work, especially with regards to the problems of decontextualising information, and look towards it for inspiration.

We argue that when introducing a mobile device it is not necessarily the case that it should be possible to access or control all information available through the central system. On the contrary, our study shows that site-specific tasks require site-specific information and thus workers need locally relevant information to get their work done. Placing the mobile device in the web of technology led us to introduce it as an extension of the existing control and regulation system. It is necessary to emphasise that the information you get access to via the mobile device is in fact the information from the control system for the workers to trust it. Therefore the design reflects it being an integrated part of the control system rather than an independent device with the ability to access system information. Furthermore, we wish to emphasise that interface design on a mobile device cannot be reduced to down-scaling the interface design from the PC system, nor is it the reverse. The interface design must take advantage of the specific technologies. With our prototype, we debate how to present the information on both the mobile device and the desktop computer system without losing the sense of integration and overview. Björk et al (1999) also deals with presentation of information of heterogeneous devices or more precisely the need for "automatic on-the-fly transformations of existing web content to mobile formats". Based on focus-context techniques developed for traditionally sized screens, it is a fine example of the type of design we are arguing against.

In the following section we outline the case study and empirical findings and relate these to access to information spaces as they exist on the wastewater treatment plant. Based on a future scenario, we discuss the role of the mobile device in the work context and how this affects the user interface design for the new, integrated system. Then we present the prototype and discuss how insights from the empirical work and design considerations have been incorporated into the interface design. We report on the users' response to the prototype and conclude the paper with a general discussion of mobility in distributed cooperative settings and the notion of integration in supporting it.

2 CASE STUDY

The studied wastewater treatment plant (MR) is one of the largest and, technically, most modern wastewater treatment plants in Denmark. The purification process at the plant includes mechanical, chemical and biological phases. The resulting segmented sludge is put in fermentation tanks to generate gas, which produces enough electricity to run the plant. The digested sludge is pressed and taken away to an incinerator plant. MR was one of the first wastewater treatment plants in Denmark to implement automatic process optimisation for the removal of nitrogen. The automation has been possible due to the development of new sensor technology, which allows for on-line measuring and control of the primary parameters of operation. Not surprisingly, the process optimisation has radically decreased the use of chemicals. The plant has an estimated capacity of 220.000 person equivalents. However, it is constantly running at 110 - 150% over capacity because the plant has not been able to expand to match the increase in the city's production of wastewater.

The case study is part of a long-term research cooperation in the areas of HCI and CSCW involving researchers from Danfoss, the Computer Science Department at Aarhus University and the Art, Culture and Communication department at Malmö University College, and four wastewater treatment plants in Denmark and Sweden. We spent 40- 50 hours within a 5-month period doing participant observation at the site, following workers through their entire daily routine. Different researchers followed different workers, using hand-held video cameras or a digital camera to capture the events. We analysed the video, using the techniques described in Bødker (1996) and Buur & Søndergaard (2000). Video clips were presented for the plant employees at 3 feedback sessions/user workshops at MR. Furthermore, we compared the work practices at this site with data collected by other project researchers at the other wastewater treatment plants and held 3 project workshops emphasising design and evaluation with participation from all the cooperating parties.

2.1 Division of labour

MR employs a total of 8 people consisting of the manager, the foreman and six "waste water operators", who take care of the wastewater process per se. In addition, MR has a service contract with a group of electricians and a group of blacksmiths that are summoned to take care of problems relating to the electrical system and heavy machinery repair respectively. These groups of electricians and blacksmiths work for all 8 wastewater treatment plants in the county.

The manager and the foreman are responsible for the overall management of the plant and overlook the various experiments that are initiated to optimise the quality of the water being led out and the cost of cleaning it, e.g. through experiments with new types of additives like polymers. They are furthermore the representatives for MR when dealing with e.g. The Wastewater Treatment Office and other local council- and governmental offices, i.e. the larger wastewater treatment system of which MR is a part.

The remaining six employees work primarily in pairs, each of the three pairs being responsible for tasks associated with a specific part of the treatment process. Individual workers may temporarily take on other tasks, as when someone is ill, but the overall division of labour is quite stable. However, within these bounds they are free to ‘juggle’ the tasks as the situation demands. The levels of dynamics in wastewater treatment work are further explored in Bertelsen & Nielsen (1998).

2.2 The complexity of wastewater treatment

Wastewater treatment is a hugely complex, technical process and becoming familiar with the immense technical system that controls it is a yearlong learning process. The scope of this task has been very aptly put by one of the workers at MR as:

"I have been working here for four years and am starting to ‘know’ the plant, but I think it will take another two years before I know it well enough – where all the machines are, etc. For example, we have pipes running through this building and they are normally working fine so you can basically work here for years without knowing there’s a (throttle) valve up there [pointing]" (..) You never find out before something happens (..) We work with 50.000 components – you don’t learn about them all on your first day".

This example points out an essential aspect of work at a wastewater treatment plant, and most other process plants, namely the ability to 'see through' the chaos of information available by knowing how to filter it. This, however, is an ability that takes years for the workers to harness. The task is further complicated by the fact that most component specific information cannot be accessed locally but is available only through the central control system. We shall look into this in more detail in the following.

2.3 Central control and distributed work

The output from the staggering number of components is sent to a central computer, PC, on which the control and regulation system for the wastewater treatment process runs. The overall control of the purification process is thus centralised. Regulation of the wastewater treatment process takes place only through the control system in the control room. However, this stands as a glaring contrast to the way we observed work being done during our field study: the workers very rarely spent time in a control room more than five or ten consecutive minutes but were primarily working in the area because their daily routines depend on having direct access to the local environment and the components in it. The specific sites at the plant, like the primary clarifier, provide the workers with audio-visual information not measurable by the sensors e.g. the way the water looks and smells, the way a motor sounds while running and oil leaking from a gasket. We have seen countless examples during our field study where walking around in the environment contributes with valuable information, as the following examples show:

As part of his daily round, Bob was checking the area around the sludge tanks and noticed that the surface water in the tanks was brownish. He immediately proceeded to the building the water came from to check a pump he, rightfully, suspected to be malfunctioning because of the discoloration. He explained that if the water had not been discoloured, he would have checked the pump anyway because that building is part of his area of responsibility, but he would not have done so until hours later.

Thus, visual clues in the area prompts Bob to alter his routine in response to what he has encountered in the area.

Dan, who works in the building next to the lab, calls Robert, who is doing the daily laboratory tests, over to tell him that the contents of the primary clarifier looks strange today: it foams and is almost as grey as cement. They briefly discuss what could cause this and decide that the best cause of immediate action is for Robert to pay extra attention to the laboratory test results today.

In this situation, no immediate action is taken because even though the water looks odd, this alone does not provide enough information to determine a course of action. Robert needs the results from the laboratory, too.

This point to an important aspect of the work, namely that the information available in the area along with the information provided by the control system form the basis for how work is performed, and in most cases, any one source is not sufficient for deciding how to progress. However, at present the information obtained from walking around in the area is completely detached from the information from e.g. the sensors, which are only available in the control system. This makes the task of getting an overview of the 'state' of the process extremely complicated. To support the ability to ‘see through’ the chaos of the information it is of vital importance to provide such an overview. One of the aims of the prototype is to show how this may be accomplished by bringing the two bodies of information together in an integrated system.

3 DESIGNING FOR LARGE AND SMALL SCREENS

Our empirical findings show that how well a plant runs depends upon a vast amount of factors that mutually influence each other. All these factors make up what we call the overall information space of the wastewater plant. In other words, the overall information space of the plant contains all the information that constitutes the overview of the entire wastewater treatment process.

The different sites at the plant can be viewed as representing different places to access information. The variation in what kind of information is accessible and where it is accessible indicates that there are a number of smaller information spaces distributed at the plant. The examples from the case study illustrate that at a specific site at the plant, it is possible to access a definite amount of information. As we saw earlier the information can be accessed through multiple information sources, i.e. through the colour of the water, the smell, the measurements in the lab, or the information in the central computer system. Each of these sources reveals a larger or smaller part of the overall information space. They themselves represent in fact information spaces by providing information at the specific site.

To examine and discuss how a mobile device can be seamlessly integrated with a larger system, we need to develop a future scenario based on the daily work routine at the plant.

In the future scenario all the information that is currently available in the central system is still accessible through the PCs placed in the office building. The major difference from the current situation is the automation of the laboratory work and the utilisation of a mobile device for accessing system information. Online sensors will do all the measurements currently done in the laboratory and the data from the sensors will be send directly to the central system. When the worker walks his daily round at the plant he can access the data in the central system through a mobile device that he brings with him. This will provide him with updated information about the plant on the spot where he needs it.

3.1 The mobile device – a new access point

In the future scenario online sensors have replaced the work in the laboratory where the water is analysed today. This changes the current organisation of the information spaces at the plant because the worker will in theory be able to access all information available in the central system. But does the worker actually need to access everything when he walks his daily round? If we consider the theory of smaller information spaces being a part of the overall information space we will argue that since the worker brings the device with him on his round the information he needs will be site specific. Thus it is not necessary for him to access all information in the central system from his mobile device. Let us illustrate this by an example. Consider the situation previously described where the colour of the water is brown. When the worker notices this at his daily round he will in the future scenario be able to immediately access relevant information that might explain why the water is brown. In this particular situation he is at the sludge tank and needs information measured by the sensors at this specific site. The sensors measure what chemicals the water contains and that is exactly what the worker needs to know at this point. He does not need to access any information about for example the use of electricity at the plant. Instead he needs a precise overview of the current situation at the specific site - he needs access to this particular information space at the plant.

Thus the mobile device should provide access to an integrated, context specific part of the overall information space and not work as an alternative and independent entrance to this.

3.2 Presenting complex information

We now return to the question of how information should be presented on the mobile device and the central PCs? Two essential aspects affect this scenario considering the interface design. Firstly, how do we present complex information on large and small screens in unison, and secondly, how do we communicate the information in a way that supports the users' obvious need for moving around the area and use the non-system information available to them.

From our empirical study we have identified overview and integration as key features to be supported in the interface design. If we look at the user interface of the current system it is characterised by a large amount of detailed information. It has been developed for a normal PC monitor and is not suitable for a transformation to a small screen. There would simply be too much graphics squeezed into too little space on a small display and the information provided by the graphics would not be understandable (Jones et. al. 1998). The interface on the current system is a mix of geographically grounded and completely abstract information and it is not only inappropriate on any displays of smaller devices, nor does it provide the users with an appropriate conceptual model of the process. For this reason alone it becomes obvious why the approach to merely downscale a desktop interface design for a palm-top device must fail. It would simply not provide a sense of overview.

Recently developers have been working on how to transform information presented on the desktop computer to fit on a handheld device. As previously mentioned the WEST-browser is one way of making an already existing design fit into the small display of a handheld device. Another example is the PalmORB and 2K system, which similarly provide the user with a sense of consistency between the desktop PC and the handheld device. We do not believe that the solution in all cases is to develop a new interface design for the small device and let this exist in parallel with the interface design of the central system, with which it is supposed to be integrated. Instead we want to create a graphical match or a similar, compelling visual connection between the interface design on the large and small screens to obtain a sense of integration between devices.

A new graphical design for both the PC and the handheld would give us the possibility to communicate information not only through numbers and text but also through the graphical shape. The design should reflect that every distributed interface is a part of a larger whole to recreate a sense of the information provided is part of the overall condition of the plant.

The interface design should fit both the large and small screens. The graphical design should not only communicate the measured data in a strict functionalistic way. The connection between the large and small screens in terms of the interface design should be the use of the same fundamentally graphical shape. More delicate information may be expressed through, for example, the use of colours. The next question is now how do we translate our considerations on overview and integration into the actual design of the prototype?

4 THE PROTOTYPE

With the design of the user interface we aim at representing different views into the information spaces of the plant.

The prototype is implemented on both a PC and a PDA. The prototype was made for the PowerMac in Director and PhotoShop, and implemented on the Palm IIIx in Java with Waba.

We provide the following three views:

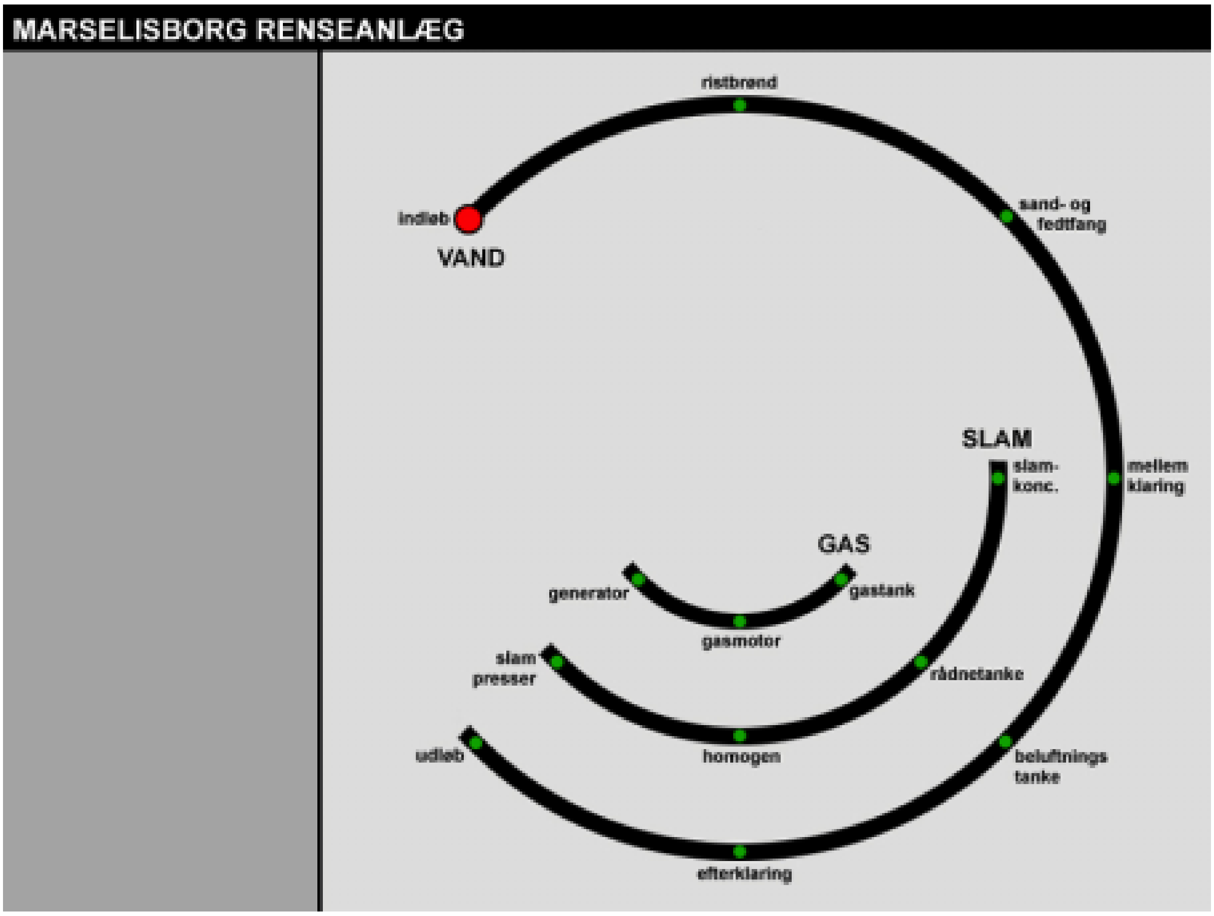

Figure 1. First view - PC Plant overview

The first view (see Figure 1 and Figure 2) is the 'plant overview' and it provides access to the three main phases of the wastewater treatment process, namely water, sludge and gas. Each important step in these three phases is indicated by a coloured dot – a green dot if everything is working fine, a red dot if the alarm on the sensor has been triggered. However, we use a PDA with a monochrome display and thus we can not provide the user with a coloured dot. Instead we illustrate an alarm on the PDA by showing small dashes from the dot (see figure 2). In this way the worker can immediately take note of the alarm through any view on the display. By pressing one of the dots on the circle it is possible to access the second view that provides more specific information about a particular step in one of the phases.

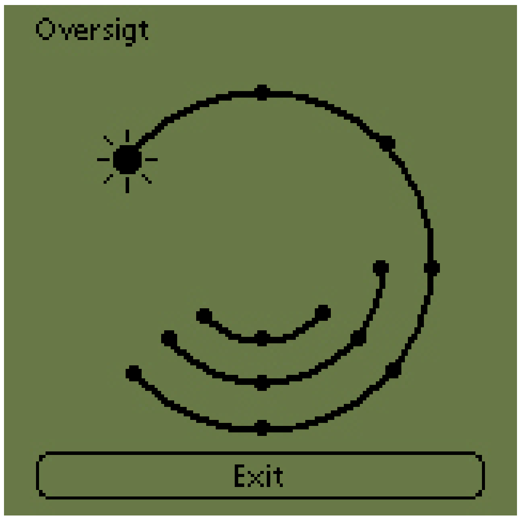

Figure 2. First view – PDA plant overview

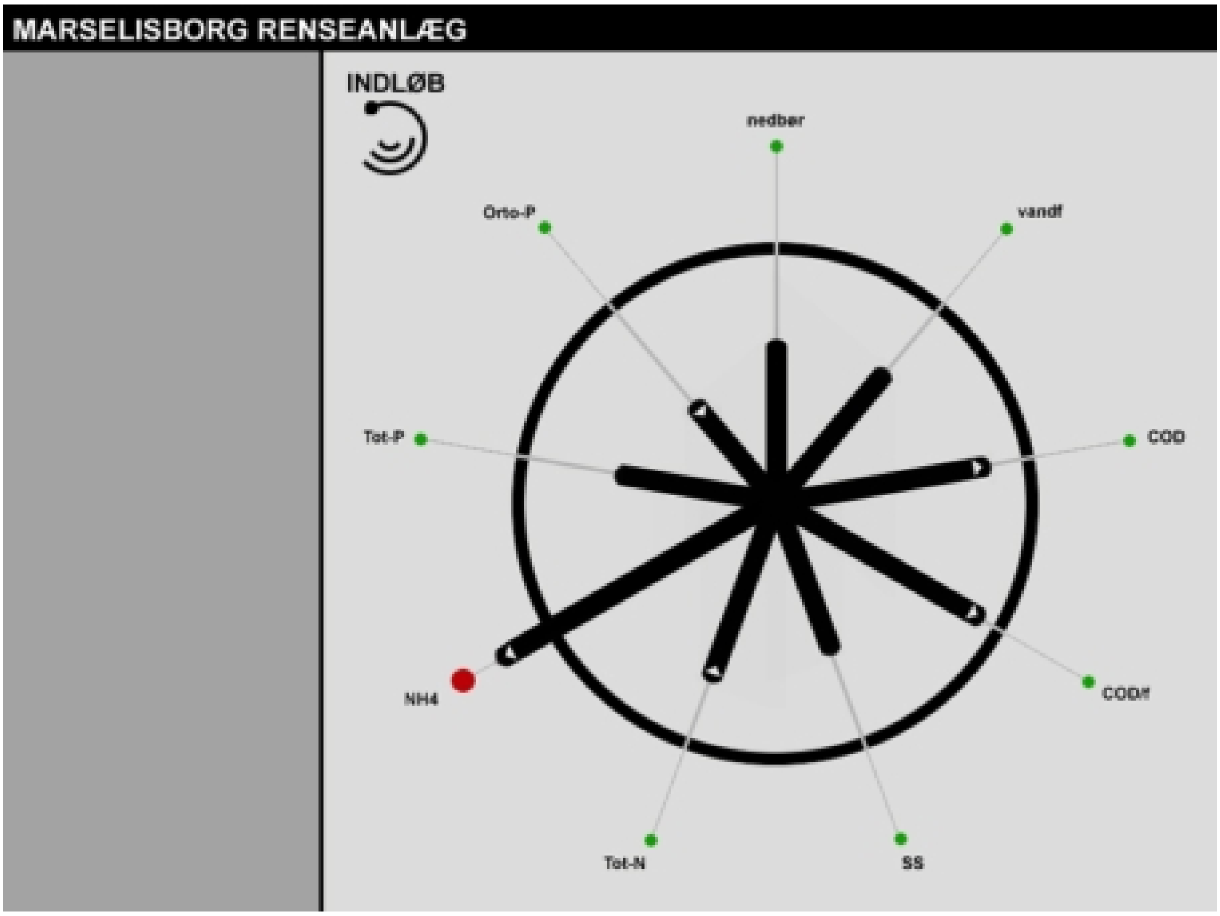

Figure 3. Second view – PC inlet water

The second view (see Figure 3 and Figure 4) provides access to the measurements done by the sensors at specific sites. In this case it is the inlet water (first step in the water phase in the outermost ring). This view represents the output from the sensor at the site of the inlet water. This view consists of 9 values corresponding to the fictitious online sensors at the inlet site. Again a coloured dot at each measurement is indicating if everything is working fine or if an alarm has been triggered. At the monochrome display the alarm is shown by the measurement-indicator that crosses the circle line when the measurement is beyond the threshold. By pressing one of these dots (on the PC display) or measurement-indicator line (on the monochrome display) it is possible to access more detailed information about the specific measurement.

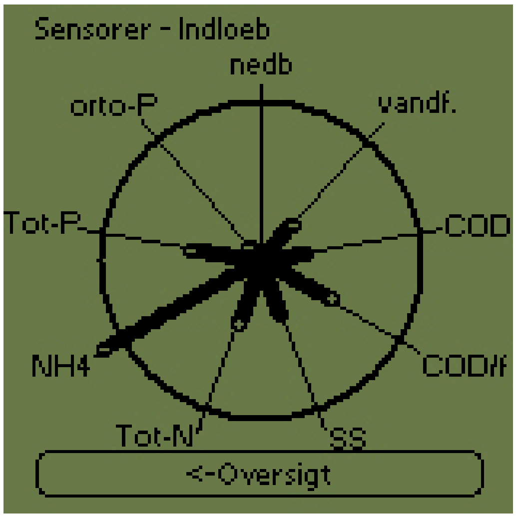

Figure 4. Second view – PDA inlet water

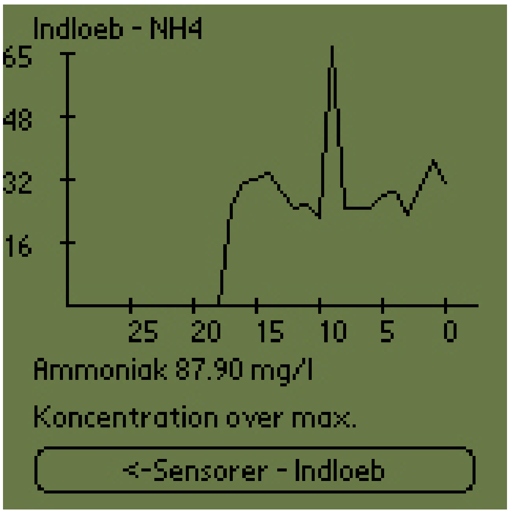

Figure 5. Third view – PDA single sensor information

The third view (see Figure 5) provides information from a single sensor. If one of the measurements in the inlet water e.g. the ammonium level has gone beyond the threshold value the worker can take a closer look at the development of this value over a certain time span and get more detailed figures concerning the present level.

4.1 Overview

As we have described earlier the work practices we aim to support rely on the ability of quickly getting an overview of the state of a process.

We found that the shape that could present the actual data in an efficient way and communicate a sense of overview was the circle. The circle is efficient when working with small screens because it is curved and it is practical when you want to show a linear process on a limited amount of space. Furthermore it is efficient when trying to show relations. The three phases represented on the first view have mutual relations: At a certain point in the water process (illustrated by the outermost ring) the sludge process starts (illustrated by the middle ring) and at a certain point in the sludge process the gas process starts (illustrated by the innermost ring). Furthermore the circle provides you with 'at a glance' overview. Consequently the processes at the plant in the first view are visualised through circular lines with mutual connections (see Figure 1 and Figure 2). The second view is based on the circle as well - nine measurements from the inlet water grow out from the centre of the circle, i.e., conceptually, out of the same water sample (see Figure 3 and Figure 4). The third view provides such specific information that using a regular system of co-ordinates creates it (see Figure 5).

4.2 Integration

Furthermore, choosing a graphically simple layout enables us to use the same layout on the mobile device as on the central PC. This brings us to the second key aspect addressed by the prototype design, namely designing for supporting a sense of integration between the mobile device and the PC. We want the design to show a clear link between the system on the PC and the mobile device. Using the same graphical representation for a collection of devices is a direct way of denoting integration between them. The design for the PC has empty space at the left of the screen as opposed to the design for the PDA. With this space we indicate that here is room for buttons, text, etc. that would provide the user with access to other parts of the information in the central system. The key issue in this prototype is that both the PC and the PDA are showing the same graphical representation on at least some part of the display in order to support the integration between the two.

4.3 Feedback from users

We presented the prototype at a workshop with participants from our collaborating partners and users from two of the four participating wastewater treatment plants. During the workshop we played through use scenarios with the users, bringing the mobile device with us out into the plant.

In terms of overview the reactions towards the overall design was quite overwhelming, especially from the managers from both wastewater treatment plants. They found that our design provided them with a much better overview of the state of the wastewater treatment process than the current control system interface with its strange mixture of geographically grounded information and abstract, process-oriented information. The new interface thus presented a more comprehensible conceptual model. The graphical design provided them with an overview that worked both on the PC and on the PDA. One thing they lacked, though, was a little more information on the PDA. In the first view (the overview of the processes) they needed some abbreviated names to mark the different sites at the plant just as it is provided on the PC interface. The transition between the desktop based system and the mobile device was conceptually smooth to the users because the same graphical design was used on both displays. This supported the understanding that they were bringing parts of the overall information space with them out into the field when they carried the mobile device with them to a specific site of the plant.

We also discovered that they did not need the third view (Figure 5) when they were at a specific site at the plant. They found it important to access the first and second view (Figure 1-4) where they could see whether there was an alarm or not and if there was what the alarm was about. But the third view provided too specific information which they instead preferred to access indoor in the warm office where they could sit down in front of the central PC and more comfortably examine the specific situation in detail.

5 DISCUSSION

We have presented a prototype that provides access to system information outside the control room. When providing a new entrance point into the overall information space, it is vital for us as designers to negotiate with the users how to prioritise the information, for example, which types of information must be available always and which may be available at a lower level. Throughout the study we have worked with the users to identify their set of priorities, which we have sought to implement in the prototype.

The feedback from the users indicates that in a specific situation like this when the workers bring a small device into the environment the information on the device and the contextual information in the environment will work together. This dynamic determines what kind of information it is needed to access where. Furthermore, the feedback workshops with the users made us realise that when they are outside, they need an overview of the process, not a detailed view of all the components. For the more detailed and cross-referential view, they prefer the PC system. This supports our understanding that the mobile device should not have access to all the information in the central control system because it is used for quite different tasks. This contradicts the general fascination with the idea that mobile technology will enable us to do anything, anywhere at anytime (see for example Palm, IBM & Nokia). This notion makes us consider the mobile device as an independent access point into the information space and does not allow us to place it in the existing web of technology. Wiberg & Ljungberg (1999) argues that "only a tiny part of service work is possible to perform anytime, anywhere. Most of the work is dependent on spatial factors" They narrow down the scope of anytime anywhere but the discussion about time and place still lacks an aspect. So far the discussion asks ‘when’ and ‘where’ but it does not ask ‘what’.

Mobility should be supported by the ability to access information on the move, but time, place and amount of information determine how it should be supported. The mobile device itself and its ability to access the information space should not define mobility. Instead, the amount of information needed should determine the mobile device. The PDA has its limitations. It proved to be useful at the plant because of the amount of information needed. But had the workers needed more information the PDA were maybe to small etc.

One of the main experiences from this project is that supporting wastewater treatment work or similar kinds of process control work must focus on providing the users with a wider range of entry points into the information. The technology should let them take advantage of both the superior overview provided by the desktop computer's large screen and support their skills at drawing valuable information from moving around in the environment, e.g. the sight and smell of the water and the sound of motors running.

The rapid development in all computer-related areas, particularly mobile technology, provides us with the technological basis for supporting mobility in distributed work. However, the design of such support is complicated by the lack of design principles, which has been the focus of much of the mobile literature, e.g. (Dix et. al 1998, Kristoffersen & Ljungberg 1999, Kristoffersen et. al 1998). It presents us with the task of dealing with and designing for a highly heterogeneous collection of devices with different physical attributes, using different formats and providing different services. Olsen (1999) describes this as ‘interacting in chaos’. Take as an example one of the latest advances, the WAP technology that makes it possible to access the Internet on mobile devices. In theory, this enables the user to order flowers, check plane schedules and download and read the complete works of Charles Dickens on his or her mobile phone. However, it is far from all of these tasks that are convenient to do through a mobile phone with its restricted display size. The mobile device is seen as an independent ‘information technology unit’ with universal access to information. This perspective adds to the information chaos we, as users of information technology have to deal with.

Thus we are now faced with the challenge of considering issues of e.g. diversity, inconsistency and integration (Johnson 1999). To transcend the chaos and create a sense of coherence in the access to the information space through heterogeneous devices, we see much promise in using the strong connection between placing new technological device in the existing web of technology and the notion of integration. By making this our starting point we are brought to consider the relationship between the different types of technology mediating the use activity as a natural part of designing technological support for use practice. In our case we needed to convey a strong sense of integration between devices, but in others the integration may be weak or non-existent. What is important is that we ask the question.

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