Localisation, Orientation and Recognition of Alarms

A comparison between three alarm systems in use

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ABSTRACT

This paper documents a study at three dialysis departments on the use of different alarm systems. The design of the alarm systems is to some extent in line with the visions of augmented reality and ubiquitous computing. Our study has raised a range of questions which we think are relevant for the research on how to embed technology in users' environment. We will address how the properties of the specific alarm systems, concerted in the local physical environment of the dialysis department, affords the localisation, orientation and recognition of alarms. In this paper, localisation is about the ways in which the nurses exactly locate where the alarm comes from and orientation is how the nurses orientate themselves towards the alarm in a more imprecise way. Recognition is about how the nurses notice that there is an alarm in the first place and if there are multiple alarms.

Keywords

Localisation, orientation, recognition, alarm system, dialysis department, ubiquitous computing, computer augmented environments

1 INTRODUCTION

Augmented reality represents a character of the design domain and a principal theme of some parts of the research within HCI and CSCW. Augmented reality, or Computer Augmented Environments (Wellner, Mackey and Gold, 1993), is an attempt to break away from the traditional desktop metaphor and the use of head-mounted monitors, data gloves and goggles in artificial or virtual reality. In 1990 Moran and Anderson also recognised the limitations of the traditional HCI paradigm and proposed a new design paradigm, the workaday world (Moran and Anderson, 1990). Their suggestion was to develop new design principles that could guide designers in embedding computers in users' environment more firmly in ordinary work practices. In recent years this attempt has mainly been represented by the concept of ubiquitous computing (Weiser, 1991), tangible bits, ambient media (Ishii and Ullmer, 1997; Fitzmaurice et al., 1995) and mobile/wearable computing (e.g. Spreitzer and Theimer, 1993).

This paper documents a study at three dialysis departments on the use of different alarm systems. The design of the alarm systems is to some extent in line with the visions of augmented reality and ubiquitous computing. They consist of a technology that is distributed in the environment to provide the nurses with information about alarms in many places at the department. Our study has raised a range of questions which we think are relevant for the research on how to embed technology in users' environment (e.g. ubiquitous computing and augmented reality), such as the integration of information in physical space (e.g. Streitz et al., 1998; Cooperstock et al., 1995) and issues on peripheral awareness (e.g. Pedersen and Sokoler, 1997; Bly et al., 1993; Sawhney and Schmandt, 1998). Considerations about indication and notification of alarms in this paper may also contribute to the body of design issues from the use of alarm systems in process control rooms, command centres and patient monitoring systems in intensive care (e.g. Van-Paassen and Wieringa, 1997; Mattiasson, 1999).

The starting-point for our discussion is the alarm systems designed intention - to inform nurses and patients about alarms. A study involving technology in use is a study that brings out questions in many perspectives. Aspects of work practice are central ones leading our thoughts in the direction of how labour is divided among the nurses, how they incorporate technology in their decisions and how the technology supports their collaboration. We have observed that the nurses are often in motion, moving from room to room, attending patients, handling medical tools, doing

administrative work and fetching materials. This character of work puts a demand on the design of these kind of systems in terms of how they should inform nurses about different alarms and engage their attention without interfering to much with their current work tasks (Tap and Svensson, 1999).

However, in this paper we will discuss how the properties of the physical environment are essential features of the way in which nurses deal with alarms in alarm situations. We will address how the properties of the specific alarm systems, concerted in the local physical environment of the dialysis department, afford the localisation, orientation and recognition of alarms. In this paper, localisation is about the ways in which the nurses exactly locate where the alarm comes from and orientation is how the nurses orientate themselves towards the alarm in a more imprecise way. Recognition is about how the nurses notice that there is an alarm in the first place and if there are multiple alarms.

2 BACKGROUND

For the last two years we have been involved in an ongoing research project in collaboration with the county council, the county hospital and a medical company. In this project we are interested in how medical staff and patients actually use different technological tools within dialysis treatment and how this understanding might influence the design and development of new technological tools for future applications.

Our field material is mainly based on observational studies inspired by traditional ethnographic methods, but in the examples presented in this paper we also use video-based interaction analysis (Ruhleder and Jordan, 1997). Our approach is also inspired by the Scandinavian approach of participatory design (Bjerknes et al., 1987; Greenbaum and Kyng, 1991). This research direction is based on the importance of getting a deep understanding of the social context in which the system is going to be placed. We are interested in how people actually go about doing their work and how they actually use information technology. We believe that an understanding of people's practical knowledge and practical circumstances may constitute good conditions for the design and development of new systems.

The study presented in this paper is based on ethnographic field studies at three dialysis departments. Video taped sequences at the departments were complemented with notes about nurses' engagement in the alarm situations not visible on the videotapes. Our understanding of the nurses' use of their alarm system has to some extent also evolved during the nurses' active involvement in workshops and design activities.

3 ALARM SYSTEM DESCRIPTIONS

Before we get into the comparison of the three alarm

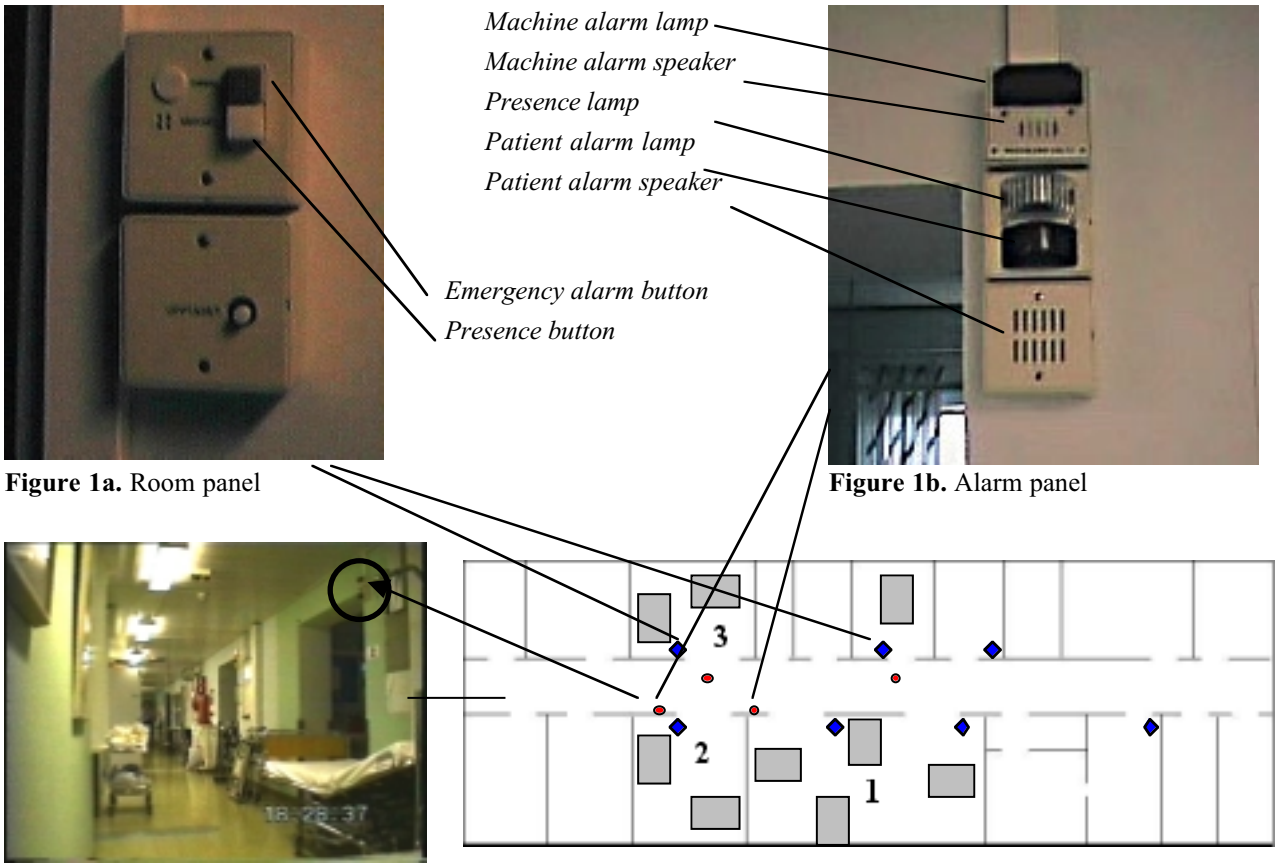


Figure 1a. Room panel

Figure 1b. Alarm panel

Figure 1. Alarm panel and room panel in alarm system A.

systems we will give a short description of the components they consist of and their functionality.

In the patient rooms in all dialysis departments each dialysis machine has its own alarm device which simultaneously indicates an alarm by sound, a flashing light on top of the machine and a textbox on a monitor. In addition, all patients have a patient alarm device beside their bed that they can use to get the nurses attention. A third feature is the use of an emergency alarm (described later in this section). Because of the building structure and the organisation of the dialysis departments the alarm indication in each patient room is not sufficient and is therefore propagated to other parts of the department. Each dialysis machine and patient alarm is connected to a distributed alarm system which provides the department staff with information about alarms in other rooms, and it is this part of the alarm system we will focus on in this paper.

All alarm systems described in this paper have the same purpose and features as those described above. In the following sections we are going to describe the distinctions between the alarm systems.

3.1 Alarm system A

At one of the dialysis departments the staff used an alarm system that was implemented in 1987. This alarm system is the oldest system of the three included in our study. Recently this department moved to another building with an entirely new alarm system, which is described later in this section (3.3 Alarm system C).

The alarm system has an alarm panel outside each patient room in the corridor and a room panel inside each patient room. The alarm panel in the corridor has three alarm lamps: a red lamp for the indication of a machine alarm, another red lamp for the indication of a patient alarm and finally a white lamp indicating the presence of nurses in the patient room (see figure 1b). Inside the patient room the room panel has two buttons: a red emergency button for emergency alarms and a white presence button for the indication of presence (see figure 1a).

When an alarm is activated on the dialysis machine the alarm lamp on the alarm panel outside the patient room starts to flash with a red light and the machine alarm speaker in the corridor sends out a sound. The alarm panel has the same indication intervals as the dialysis machine, which re-indicates the alarm signal each second until the alarm resets.

The second red lamp on the alarm panel, the patient alarm, turns red and a centrally positioned patient alarm speaker (see figure 1b) sends out one sound signal when the patient alarm button in the patient room is pressed (see figure 1a). This patient alarm is re-indicated every 10 seconds.

On the alarm panel the white alarm lamp is turned on whenever a nurse presses the presence button on the room panel. The purpose of this function is to enable nurses to inform other members at the department that

Figure 2a. Room panel

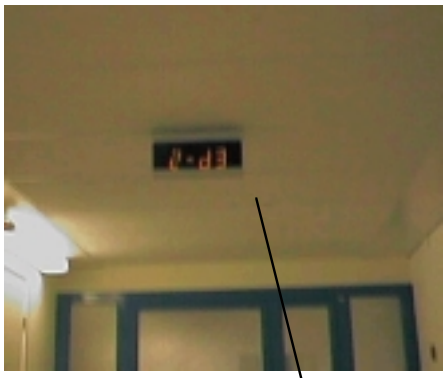


Figure 2b. Alarm panel

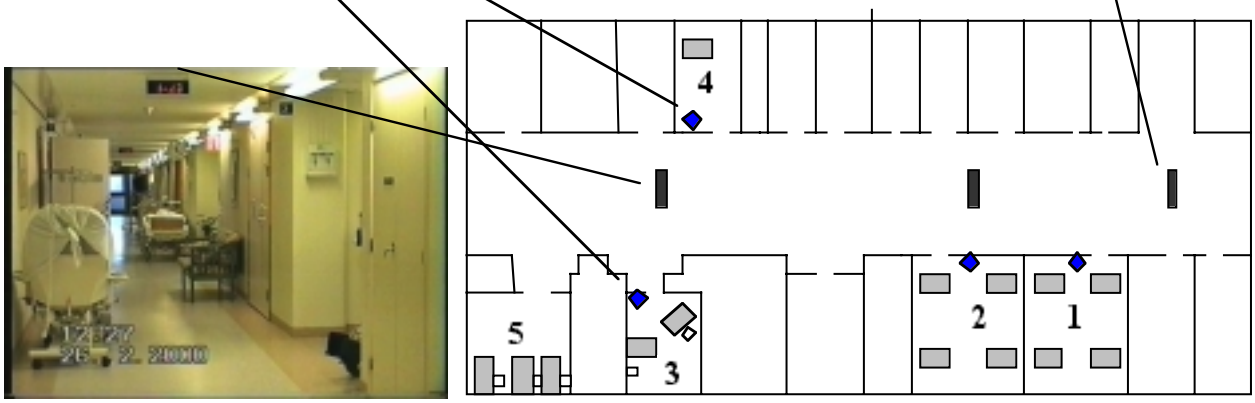


Figure 2. Alarm panel and room panel in alarm system B

somebody is present in the room. Another feature is the emergency alarm that a nurse activates by pressing the emergency button on the room panel. Also, if the presence button is pressed, pressing the patient alarm button will cause an emergency alarm. On the alarm panel in the corridor the emergency alarm is indicated with a red flashing light from the patient alarm lamp and a sound from the machine alarm speaker.

3.2 Alarm system B

The second alarm system is used at a dialysis department operating since 1996. As in the other alarm systems this one also consists of alarm panels in the corridor and room panels distributed within the department. What is different with this alarm system (and system C) compared to system A, is how the alarm indication is distributed and presented.

Along the department corridor, three alarm panels are mounted in the ceiling (see figure 2). Each alarm panel consists of a display and a hidden speaker (see figure 2b). In contrast to the older alarm system A, every alarm indication is distributed to all alarm panels. Inside each patient room the room panel is located just beside the entrance. These room panels have an alarm display, an emergency button and a presence button (see figure 2a). Other rooms at the department have a room panel too, but those panels do not have any emergency buttons.

The indication on the alarm panel gives the nurse information about room location, patient bed and alarm category. In case of a machine alarm from patient three in room two, the text "2-d3" ("d" stands for dialysis machine) will appear in the display on the alarm panel. If it is a patient alarm indication, the display would instead present the text "2-3". Both patient alarm and machine alarm are indicated with three beeps from the speakers. If there are two or more alarm indications at the same time, the display will show the text by altering them continuously. If the alarm is not reset after about 15 seconds, the alarm is re-indicated again with three sound signals.

If nurses want to be notified about the alarm through the room panels in patient rooms, they need to press the presence button. The purpose of this design decision is to allow nurses to decide if they want to get alarm indications from other parts of the department into the patient room. At the dialysis department nurses normally do not want to disturb the patient with this alarm indication.

When an emergency alarm is activated in this alarm system, the text on the display flashes and the speaker sends out an alarm sound that differs from the other and re-indicates each second until the alarm resets. The emergency alarm is activated either if a nurse presses the emergency button located beside each patient bed or if a patient or a nurse presses the patient alarm button when the presence button has already been selected (in the same way as with alarm system A).

3.3 Alarm system C

Less than a month before the writing of this paper the dialysis department at one of the locations (the department that used the alarm system A described in this paper) moved into new facilities in the main hospital building. While moving to the new department, both medical staff and patients have been facing new plan structures of the rooms, partly new organisation and routines and also a new alarm system.

Alarms are presented by the system through a display interface on alarm panels and room panels distributed within the department. The alarm panels are located in the ceiling in a couple of places in the corridor. These panels in the corridor have a white frame with space for a text field on the top and six numbers on the bottom of the display (see figure 3c). The text field and the numbers may be customised to suit a specific department. The three numbers to the left are displayed in green showing in what rooms the nurses have notified their presence. The three on the right are displayed in red and indicate different types of alarms coming from the patient rooms.

Apart from the corridor displays, there are room panels in every room of the department (see figure 3a). The room panels are all located by the entrance inside the patient room. The room panels have the size 10 x 10 cm and have two buttons and a small display (see figure 3a). The first button is green and nurses may push this button when they want to indicate their presence in a room. The second one is red and may be used as an emergency alarm to draw attention to the room from other nurses in the department. By pushing the presence button, they ensure that the room panel will show machine and patient alarms that are activated in any room in the department.

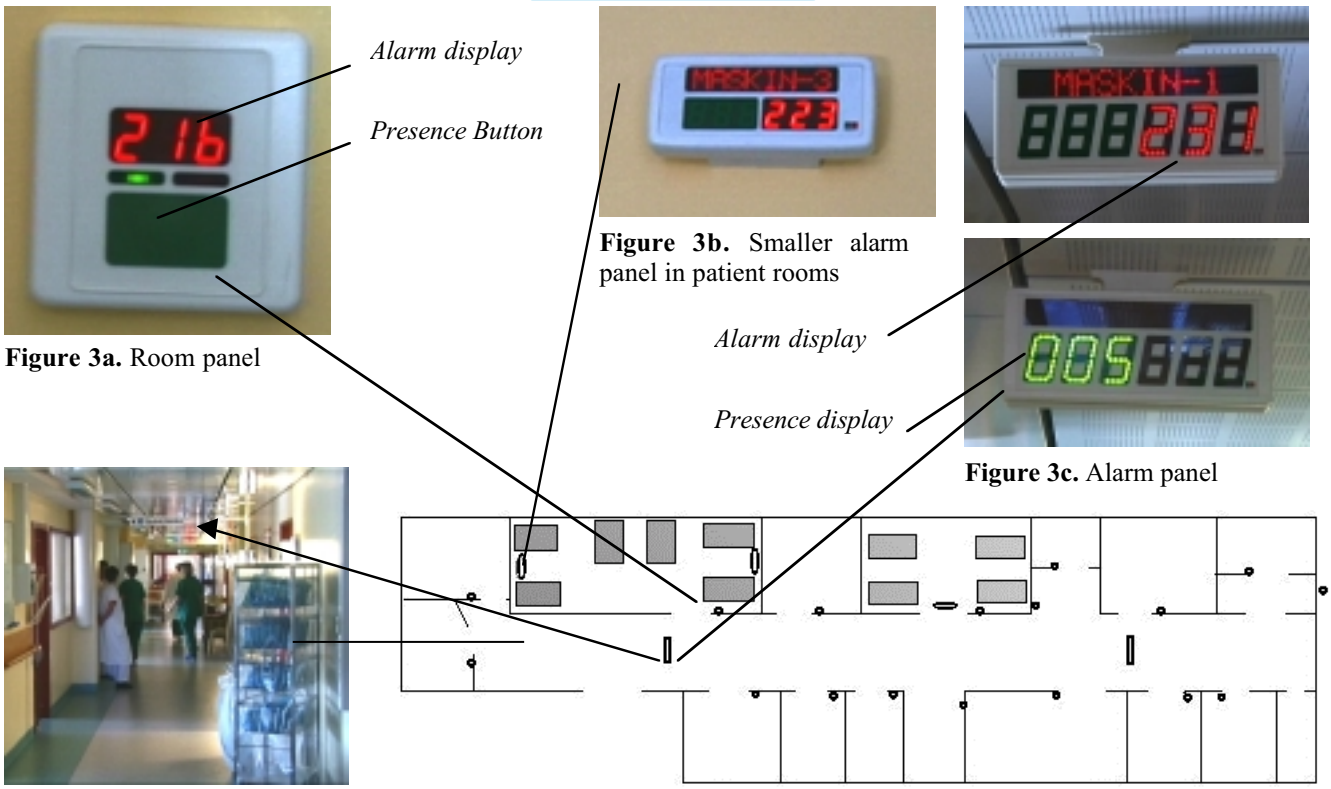


Figure 3a. Room panel

Figure 3b. Smaller alarm panel in patient rooms

Figure 3c. Alarm panel

Figure 3. Alarm panel and room panels in alarm system C

There is also another kind of smaller display placed in two of the patient rooms (see figure 3b). These can be seen as smaller copies of the larger alarm panels in the corridor and present just as much information as the ones in the corridor.

With advice from the producer of the alarm system, the head nurse of the department has organised the rooms and alarms according to different categories. All rooms that are not connected to patients, e.g. rooms such as nurses' office, the storage room, the medical storage, and so on, are indicated by a prefix of "00". The nurses' office is then named "003" and the lunchroom "005". All rooms that are somehow connected to patient rooms or rest rooms have the prefix 1. Patient room number one is then "110" and room number two "120". If there are two indications of presence at the same time, the display will show the two numbers by alternating them continuously.

When an alarm is activated, the right side of the display will show a number combination consisting of three parts - alarm category, room and bed number. For instance the combination "223" mean that there is a machine alarm (the first “2”) in room number two by bed number three. To emphasise more clearly which alarm that actually is triggered, the text field above the numbers on the display will either show "machine 3" or "place 3" depending on the type of alarm. Just like system A and B, the visual alarm is accompanied by a sound. This sound has a similar character to the sound in system B, i.e. a beeping sound that is distributed through out the department by a hidden speaker.

4 ALARM SYSTEM COMPARISON

There are of course several issues that are interesting to analyse in our case study, but in this paper we have chosen to focus on two topics related to the design of the different alarm systems. We will discuss what characteristics they have, how they differ from one another and what resource they offer to the users in the developing alarm situations. The first topic we have selected is about localisation and orientation – how the alarm systems indicate where the alarms are coming from. The alarm systems have different approaches that afford different kinds of use for the nurses. The second topic is a discussion about the different characteristics of the alarm systems in relation to how alarms are distributed and recognised.

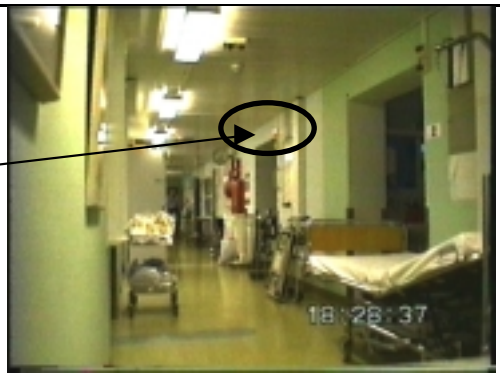
4.1 Localisation and Orientation

One obvious, important role of an alarm system is how it enables users to locate an alarm. The nurses needs to determine in what direction they have to walk and if the alarm is their responsibility. The alarm systems we have studied have solved this problem in rather different ways.

Let us first describe how alarm system A is designed to solve the problem. As seen in the system description, one alarm panel is placed in the corridor outside each patient room. When an alarm is propagated from the patient room to the corridor, the alarm lamp and the speaker placed outside that particular room becomes activated. Nurses standing in the corridor might locate the alarm quickly because of the direct relation between

the patient room and the alarm panel outside the room. They might also locate the alarm by the alarm sound from the speaker placed outside each patient room. From the office, the lunch room, or other parts of the department, the alarm system makes it possible for the nurses to hear if the alarm originates from far down the corridor or from a room nearby. This alarm system uses the physical placement as a way of orienting the nurses to the alarm source - both by sounds and visual effects.

The following example clearly illustrates the use of sound and visual orientation in alarm system A. This example also shows the implication of sound indications.

Time		Comments	
28:31	An alarm is activated in patient room one. The alarm lamp flashes on the alarm panel and the speaker sends out sound signals.	At this moment nurse B is in room one, nurse A and D in room two to the right and nurse C is in room three on the left side of the corridor.	
:37	Nurse A takes a couple of steps out into the corridor. Before he enters the corridor he turns his head toward room one.		
:39	The alarm panel continues to indicate the alarm from room one. Nurse A stops in the middle of the corridor and turns his body towards room one. At this moment Nurse C appears in the corridor from room three.	*Nurse B* *Nurse C* *Nurse A*	
:40	Also Nurse B takes a look in the corridor standing in the entrance to the patient room. Nurse A standing in the corridor points at nurse B.	Nurse B do not know the alarm is from her own room and nurse A points at her to indicate that it is her alarm.	

In the first part of the alarm situation it is noticeable how nurse A focuses his attention on room one already when he enters the corridor. Through the placement of the sound source, he immediately knows in what direction he is about to find the alarm indication. He turns around and looks at the alarm panel, notices nurse B in the entrance and points in her direction. However, although the alarm is activated in nurse B's own patient room (the dialysis machine also indicates the alarm by the patient bed) the nurse does not locate the alarm signal. In this alarm situation she obviously did not catch if the alarm signal was coming from the alarm panel outside her room or from the other two alarm panels in the corridor. The nurses have told us that they sometimes become desensitised by the repeating alarm signals in the corridor, the alarm indication from the dialysis machine and medical equipment, and noises from radio and television in the patient rooms.

As in alarm system A, the other alarm systems, B and C, also have alarm panels placed in the corridor. However, they do not enable nurses to locate the alarm by the physical placement of the alarm panels. Instead of orienting nurses towards the alarm by the physical placement, the other alarm systems have this information coded on displays. Both alarm system B and C use a display where a couple of letters and numbers state the localisation of the alarm (see section 3 Alarm System Description), e.g. "3-1" in alarm system B should be interpreted as an alarm from patient room three at bed one. Whenever a new alarm is indicated, the system both indicates the alarm on the display and sends out a short sequence of beeps.

In alarm system C, the code for the presentation on the display is partly based on the nurses' experience of the former system. For example, the alarm system at the old department (alarm system A), with its unspecific indication, made the nurses scan the room to find out where the alarm was before they could take action. The text in the text field has therefore been selected to minimise this problem. The problem, though, is that some nurses are used to standards outside the hospital environment. One of the nurses said on his third day at the new department, "it is stored in the bone-marrow that the first number in a row indicates the number of the room". This is not the case at the new department. Here the first number indicates the type of the alarm. Even if there is a clear logic to why the rooms have certain number codes and why the text field is showing a certain expression, there are still some questions to consider. First of all, the text field is situated on the top of the display. This, and the fact that it is a clear and unambiguous text in this field, makes that part of the display stick out compared to the rest of the display. The nurses have very quickly understood that there is an alarm going off at bed three in either room one, two, or three. The number combination on the right (underneath the text field) seems to be subordinated and requires, at this moment while the system is quite new, more of a conscious treatment.

Though alarm systems B and C do not use the physical placement, they support the nurses' localisation of alarms in a more specific way than alarm system A does. The displays on the alarm panels in alarm system A only identify the patient room, but in alarm system B and C the indication of patient bed is also visible.

The most apparent difference between the alarm systems is the possibility to hear what direction the alarm is coming from, as was possible with alarm system A. In the other two alarm systems, the alarm indication is replicated on all alarm panels. The only way to know where the alarms have its origin is to read the letters and numbers on the display. The sound is only used for getting the nurses' attention and not as guidance for localisation or orientation.

4.2 Alarm Recognition

The nurses do not only need to know where to go when an alarm is indicated. They also need to get notified that there is an alarm in the first place. It is also relevant to recognise if there is more than one alarm active at the same time. In this section we will discuss how these problems are solved in the different alarm systems. Let us first consider an example from alarm system B:

Time	Display	Sound	Comments
45:13	2-d1	3 beeps	New machine alarm indicated
:28		3 beeps	Alarm re-indicated by sound (2-d1 constantly
:46		3 beeps	visible on the display)
46:05	1-d3	3 beeps	New machine alarm indicated
:07	2-d1		
:10	1-d3		
:13	2-d1		Alternates between active alarms
:16	1-d3		
:19	2-d1		

Table 2. Example of alarm indications from alarm

When the first alarm is indicated (see table 2), there is a sound from the alarm panel and a description of the alarm is shown on the display. About every 15-18 seconds, the alarm is re-indicated with a sound. At first this is rather unproblematic, but at 46:05, when a new alarm is indicated, the problems begin to show. The only difference in indication from the alarm system is the new display indication "1-d3". The sound indication for the new alarm can be perceived as yet another re-indication of the "2-d1" alarm. The intervals between the beeps are the same as before so, the sound will not give the nurses a hint that a new alarm has been activated. They need to look at the display to get the information. Assume that a nurse glances at a display one second after the three beeps when the display information shows "2-d1". One possible interpretation from the nurse is that it was just another re-indication of the "2-d1" alarm. In this example, the nurse has to look at the display for about four seconds before she knows if the sound was indicating a new alarm or re-indicating an old one. If there are two active alarms, she has to wait for about seven seconds (worst case) to be sure. If the nurses are able to look at the display within 2-3 seconds (during the three beeps), the alarm indicated on the display is the actual alarm that causes the beeps.

The example above describes a kind of sequential notification that only allows one alarm to be visible at a single moment. With alarm system A, the design provides another kind of alarm distribution, namely parallel notification. The alarm panels in alarm system

A are independent of one another, so more than one panel can be active at one single moment. This has the effect that more than one alarm can be heard and seen at the same time – the nurses get not only an orientation towards the alarm, they also hear if there are multiple alarms. This can be useful when they are busy with other tasks, since they might continue with whatever they were doing and still know if there is more than one alarm and possibly also hear where it originates from. There are however some obvious disadvantages with the parallel distribution (as designed in alarm system A). Alarm system A is noisier than the other two, and, when adding the sound from televisions and phones, there are sometimes a hullabaloo of different sounds. This is more seldom the case when using system B and C, since only one alarm is indicated at a single moment. Also, the volume of the sound from system A is higher than with the other two systems.

5 DISCUSSION

Based on the analysis and description of the three alarm systems presented in this paper, we want to propose design considerations that can be useful for anyone developing similar kinds of alarm systems or technology embedded in users' environment. We will not make any absolute suggestions, since some of them might be in conflict with one another and you have to make a decision based on the local circumstances.

The principal theme in our analysis concerns how the alarm system and the properties of the environment afford localisation, orientation and recognition of alarms. This concern relates to Gibson's ecological approach on perception, and particularly the concept of affordance (Gibson, 1979). In our study we have seen that nurses make use of sound and visual effects in several different ways. The corridor displays in the two newer systems give the nurses exact information about the location of the alarm. In the older system, nurses could get the location of the alarm by looking down the corridor to see which lamps indicated alarms in direct relation to the patient room. Sound, on the other hand, may provide users with other information. In our study, we could observe that sound tells the users where to look. Sound has affordances that provide users with a peripheral awareness of events and other people (Gaver, 1997), allowing their attention to move back and forth between centre and periphery (Weiser, 1996). At more distant locations, the nurses can hear and orient themselves towards the alarm with the possibility of attending the current work task while being aware of the alarm indication at the same time.

Another issue related to the comparison between sound and vision is the properties of the technology distributed and embedded in the environment. As seen in alarm system A, there are many benefits of having the sound originating from the physical location of the alarm source. The problem, however, is the need for a rather high sound volume in order to cover the whole department. Instead of having a louder sound in the corridor, the nurses using alarm system B and C have the choice of deciding if they want to distribute the alarm indication to the patient rooms by using the presence button. However, this can be a problem, as we have seen in our observations. In one such case, two nurses were occupied with a patient who was about to get connected to the tubes from the dialysis machine. The nurses assisted each other inserting the needle into the patient, handing over the blood tubes and dealing with the dialysis machine. An alarm was then activated in patient room two. The nurses in ward four heard a couple of alarm indications from the corridor and realised that they had not pressed the presence button on the room panel, which otherwise would have made it possible for them to see the alarm indication on the display in the room. The situation was complicated further by the fact that they could not easily drop their work to press the button on the room panel or take a step out into the corridor to get more information. This is a typical problem to consider when designing in the field of ubiquitous computing – how to inform the user in a seamless and unobtrusive manner.

William Gaver has made an extensive study on the use of auditory interfaces (Gaver, 1986; Gaver, 1991) and points to the problems of using arbitrary sound mappings in intensive care units (Gaver, 1997). What we also have seen, related to this problem, is that an alarm in alarm system A sometimes ends the signal with a discordant sound. This is an interesting effect in the older alarm system that is not based on a conscious design decision but is rather due to the older technology being used. Although the closure sound could be seen as an unsuccessful design, we believe it is something one could use and deliberately include in the design of an alarm system. Especially if included in a system using sequential notification. By using a special sound as the prelude for a new alarm, and a closure sound when an alarm is terminated, one can imagine that the necessary attention focused towards the displays might be reduced. For instance, nurses could continue with their task and just by listening to the alarm indication conclude if it is a new alarm or a re-indication of an old one.

There is at least one more interesting aspect when comparing a parallel and a single distribution of alarms. By having a parallel distribution, the nurses get a feeling about how busy it is in the different patient rooms. With the single alarm indication, there is a possibility that many alarms will become invisible and unseen for the majority of the nurses. By including prelude and closure sounds to the sequential notification systems there, is a chance for the nurses of, at least, getting a feeling for the number of different alarms.

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