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ORIGINAL ARTICLE

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Supporting information access in a hospital ward by a context-aware mobile electronic patient record

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Abstract Context-awareness holds promise for improving the utility of software products. Context-aware mobile systems encompass the ability to automatically discover and react to changes in an environment. Most contemporary context-aware mobile systems aim to support users in private situations, for example, as tourist guides. Thus, we still lack an understanding of the impact of context-awareness in professional work situations. In this paper, we explore context-awareness for mobile electronic patient records through the design of a context-aware mobile prototype called MobileWard. The aim of MobileWard is to support nurses in conducting morning procedures in a hospital ward. MobileWard is context-aware as it is able to discover and react autonomously according to changes in the environment and since it integrates the ability to provide information and services to the user where the relevancy depends on the user's task. We evaluate MobileWard in two usability evaluations to assess the usefulness of the system and we find that context-awareness holds some promising opportunities, but that it also introduces some potential interaction problems when users are mobile and working in a professional environment. Implications and limitations of the proposed solution are further discussed.

Keywords Human–computer interaction · Context-awareness · Mobility · Mobile devices

1 Introduction

Context-awareness in mobile devices potentially provides users with new opportunities and ways for interacting with computing devices [1]. The automated adaptation to context makes it possible to present more usable services and information. With the diffusion of hand-held and mobile devices over the past years, context-aware mobile devices have the potential to influence all ways of communicating and interacting.

Mobile computing devices are increasingly supporting collaboration between people. Luff and Heath outline [2] the necessity for mobility in collaboration in various settings, such as health consultations, construction sites, and public transportation. As mobile technologies penetrate different kinds of use contexts, they propose new rationales, for example, mobile or cellular phones were originally aimed at supporting spoken communication between individuals, but they have now evolved to become technologies incorporating properties for reading mails, playing games, or taking pictures.

While collaboration in mobility seems important, studies of co-operative work technologies have found them to fail by the virtue of the systems' inabilities to support participants' awareness of each other's activities [3]. On the other hand, early studies in CSCW indicated that co-operating actors align and integrate their activities with those of their colleagues in a seemingly seamless manner [3]. It can lie concluded that context-aware mobile systems for collaboration should support this seamless integration of activities between actors. But most contemporary context-aware mobile systems aim to support users in more private situations, for example, when being a tourist [4, 5]. Little effort has so far been put into the investigation of context-awareness in professional work situations.

A context-aware mobile prototype called MobileWard is presented that aims to support nurses in conducting work tasks during morning procedures at a hospital ward. The design of the prototype is based on ethnographic studies at a ward where aspects of mobility and collaboration are critical in the use of the solution. The prototype is evaluated through a number of field-based and lab-based evaluations.

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This study shows that while context-awareness may be applicable to mobile systems in professional work situations; it still needs further investigations as it introduces new levels of complexity in the interaction.

2 Background

Before presenting the context-aware mobile prototype, we discuss some of the contemporary experiences of healthcare information technologies and outline understanding and definitions of context-awareness are discussed here.

2.1 Computer-supported collaborative work in healthcare

Computer-supported collaborative work (CSCW) issues play significant roles in the investigation of computer technology adoption in healthcare. Studies have focused on diverse issues concerning co-ordination and co-operation, for example, service integration challenges in electronic patient record (EPR) adoption [6], work practice issues of picture archiving and communication systems (PACS) [7, 8], and socio-temporal aspects of coordinating cooperative healthcare work [9]. We will use the term electronic patient records (EPR) for these software technologies [10]; other studies apply different but similar terms, for example, electronic medical records (EMR) [6] or electronic health records (EHR) [11]. The potential benefits of introducing computer-based technologies in healthcare, for example, achieve smooth collaboration between different services, has yet to be accomplished and studies remind of the potential pitfalls of relying only on technological solutions [12].

The increased interest in information technology adoption in healthcare is quite logical considering the global political and economic agendas. Growing demands for efficiency and effectiveness characterize contemporary healthcare services in both primary and secondary sectors. Major political priorities require increasingly patient-centered services, responsive healthcare services, and improved resource utilization. Historically, healthcare services have consisted of independent and autonomous units with few needs for sharing patient information, however contemporary healthcare services often require the integrated collaboration and sharing of patient information [11]. With this increased need for information sharing, the attributes of co-ordination and co-operation have been powerful drivers in the adoption of EPRs [6, 10]. Studies confirm that EPRs have become the technical embodiment of integration initiatives of services [11].

As CSCW technologies, EPRs are software systems assembling the information about histories of patients in a hospital or another healthcare service provider [11]. EPRs (and paper-based records) are not simply arbitrary collections of information, but they are highly structured documents, for example, structured chronologically, by source, by problem, or combinations of these [13]. EPRs exhibit different characteristics than paper-based records as they have no immediate problems with information-sharing. Paper-based patient records, on the other, are physical artifacts created and maintained typically by only one healthcare service and as such they do not facilitate effective sharing of information [1]. On the other hand, studies show that EPRs suffer from problems related to affordances as paper-based records better organize and structure social practices [14].

Despite the apparent problems, EPRs are currently being adopted in healthcare environments with the aim to replace existing paper-based patient records for better integration, sharing of information, and smoother collaboration between different healthcare services. EPRs will serve fundamental roles in the co-ordination of future work activities in many healthcare services involving different medical staff [7]. Considering the need for integration and sharing in healthcare services, a worldwide extensive focus on EPR has been currently found. For example in Denmark, the government has decided that by 2005 all Danish hospitals must have replaced the traditional paper-based patient records with EPRs [15]. However, it is up to the regional authorities to decide on the details of deployment. Thus, a number of pilot projects are currently in progress with the aim of designing, implementing, and evaluating EPR systems and prototypes.

Designing and evaluating EPR systems are huge challenges for the community raising a wide range of still unanswered questions. Brinck and York raise some of these questions, for example, where should the systems be located [16]? Who should enter the data? How does one make sure that input is complete and accurate? How are the different work processes in healthcare structured and co-ordinated? What is the most useful way of displaying and accessing the vast quantity of patient data? In the light of such questions, a number of research studies have been published in the literature about EPRs and how to meet challenges related to design and use of EPRs in healthcare, for example, information-sharing [11], support for co-operation [17, 18], and privacy [19].

While much of the research is based on studies on the use of traditional paper-based patient records, suggesting viable electronic counterparts, little research has been published based on studies that inquire into the use of the commercial EPR systems already in use. Studies show that CSCW EPRs suffer from severe usability problems making them difficult for medical staff to use [20, 21]. More healthcare systems including EPRs facilitate the daily routines of the medical staff poorly.

As outlined in the introduction, awareness in technologies could provide a viable solution for making software more usable enabling them to suggest more relevant information and services [22]. Schmidt et al [3]. wrote that awareness is a highly elastic English word that can be used to mean a host of different things. In this paper, context-awareness will be considered.

2.2 Context-aware mobile systems

Schilit and Theimer [23] characterize context-awareness as "... the ability of an application to discover and react to changes in the environment". This definition will be adopted in this paper due to its simple yet powerful expression. Furthermore, their definition has influenced a wide range of context-aware research over the past years [1, 22, 24]. In the following, some key concepts and understandings of context-awareness will be outlined in order to characterize the prototype. From the definition in Ref. [23], the key concepts of *environment*, *discover*, and *react* can be extracted.

Environment is a complex entity and defines the circumstances or surroundings assigned to an application's context. Environment can be understood in terms of entities denoting people, places, or objects that are relevant when using the application [25]. According to this understanding, a context-aware mobile system should be able to discover changes in any of these three entities, for example, when the system is moved from one location to another and thereby changing the place entity. Several studies apply context for environment [22, 24, 26–28], for example, Chen and Kotz define context as "... the set of environmental states and settings that either determine an application's behavior or in which an application event occurs and is interesting to the user" [24]. Abowd and Mynatt [22] apply a set of five questions to obtain what they call a good minimal set of necessary context. These are who, what, where, when, and why questions related to the context of the system. Again, their definition resembles the definition by Dey [25], but they further include temporal aspects surrounding the user (when) and reasoning for behaviors and actions (why).

Discover and react relate how the changing information in the environment is first discovered and secondly how this influences the system and the interaction. The two features are so closely related that they will be discussed together. Sensing information is a commonly applied technique for discovering changes in the environment [27]. Sensing relates to the entities found in the environment, for example, places and people, and many different technologies have been proposed for sensing, for example, global positioning systems (GPS) for spatial positioning in places or clocks for temporal positioning. Furthermore, different technologies have been applied for obtaining wireless communication in mobile systems, such as infrared, Bluetooth, and wireless local area networks (WLAN). Barkhuus and Dey [1] differentiate between three levels of interactivity in context-aware mobile systems: personalization, passive context-awareness, and active context-awareness. These interactivity levels suggest different degrees of user involvement in discovering and reacting; personalization is when the application lets the user specify their own settings, passive context-awareness is where the application presents context or sensor information to the user, but with no automatic updates, and active context-awareness is when the application autonomously changes the application according to sensed information. Kjeldskov [20] makes a distinction between spatial and temporal sensed information in the environment. Temporal information is patterns or events attached to time, whereas spatial information is physical (or virtual) positioning.

Most research studies on context-aware computing focus on development of technologies for context-awareness and design of context-aware applications and example applications are numerous [1]. Several mobile context-aware systems and prototypes have been proposed during the last years. Mobile tourist guides, for example [4, 5], are typical examples of mobile context-aware systems. Context-aware mobile tourist guides typically direct people from one physical location to another and they are able to point out and describe interesting properties of the context, for example, old buildings. Kjeldskov [20] proposes a different kind of context-aware mobile system and exemplifies a context-aware prototype where users typically would require different information at different locations in a movie theatre; in this prototype the context-awareness is facilitated by spatial and temporal indexes. Others have experimented with context-awareness for shopping assistance, for example, Bohnenberger et al. [30].

3 Mobile work at a hospital ward

The primary aim in this research study is to explore context-awareness in a mobile system in a healthcare environment. Therefore, the following two-step strategy of research methods is adopted.

First, the study is based on ethnographic methods for requirements specification, which has become highly recognized in the IS and CSCW fields [7]. The ethnographic study involved several observations of nurses conducting work tasks, two in-situ interviews with nurses, and several interviews with different members of the staff. The study was carried out over a period of 12 weeks.

Secondly, field-based and laboratory-based experiments were conducted [30], to evaluate the context-aware mobile EPR solution. This was done to facilitate both rigor and relevance of the identified results.

3.1 The gynecology and obstetric ward at Frederikshavn Hospital

The setting for this study is the gynecology and obstetric ward at the Frederikshavn Hospital (a medium-large regional hospital in Denmark). The ward provides treatment for female patients with diseases related the abdomen and the ward has capacity for 12 gynecological patients and 12 obstetrical patients. The length of an admission of a patient varies from a few hours to a few days. The ward work procedures include preparation of patients for surgery, treatment of abdominal illnesses, operations on various diseases, for example, cancer in the womb, treatment and observations of patients after giving birth. The ward is operating on a 24/7 basis and a typical day follows a standard schedule involving different activities. Based on experiences gained from another research study [21, 31], choice was to focus on the morning procedure. This procedure is carried out by the night shift and is usually done between 5 and 7 a.m. Through the analysis, it was found that the morning procedure can be understood in terms of a three-step procedure: plan, carry out, and follow-up.

1. The plan activity typically starts around 5:30 a.m. where two nurses and one assistant plan the upcoming morning procedure at an informal meeting. At this meeting, a patient is selected for the morning procedure; if the patient is scheduled for an operation the same day or has had previous critical values on blood pressure, temperature, or pulse. Typically, five to ten patients are selected for the morning procedure, and nurses are assigned to patients based on, for example, previous contact to the patients.
2. After the planning, the carrying out of the morning procedure involves nurses visiting the selected patients where they conduct tasks related to the current statuses and the diseases of the patients. The work involves measuring temperature, blood pressure, and pulse, and preparing patients for operations. All activities and measurements are documented in the patient records.
3. After the morning procedure, the day shift takes over the work with the patients at a morning meeting. Night shift nurses inform day shift nurses about patients' statuses and activities from the night shift. Typically, nurses will write down information on patients on pieces of paper.

3.2 A simple morning procedure scenario

The aim of the study is to support the morning procedure through a context-aware mobile EPR prototype. For illustrative purposes, the following outlines a typical morning procedure with two nurses.

The scenario description relates to Fig. 1 that roughly outlines the gynecology and obstetric ward. The letter legends in the text refer to the letters in the figure. The scenario is simple and many work situations would be more complex, but the scenario is included to highlight some of the frequent activities at the ward.

Ms. Hansen and Ms. Jensen, two nurses at the gynecology and obstetric ward, have just assigned nine patients for the morning procedure. The patients were assigned according to the nurses' previous experiences with the patients and their placements in the wards. Both nurses are in the staff office (A), and Ms. Hansen takes her survey of assigned patients. She walks to the lockers (B) to get instruments for the work, for example, a thermometer. On her way to the first patient, Ms. Hansen looks at the patient's medical record to see previous values and written notes. Ms. Hansen walks into ward 273 (C) where her first patient is placed; a single-bed ward. She talks with her patient before performing the assigned measurements; temperature and pulse. She notes the measured values on her patient scheme and on the bed graph. She leaves the ward and walks into ward 272 (D) where three patients are admitted, two of them are assigned for her morning procedure. The patient not assigned for her is sleeping while one of her assigned patients, Ms. Wood, is not in the ward. Ms. Hansen talks quietly with her patient and tries to work silently while measuring the temperature. She notes the values in her patient scheme and on the bed graph. Ms. Hansen leaves the ward and finds her final patient, Ms. Wood, in the corridor (E) sitting and reading in an armchair. She talks with Ms. Wood and measures her temperature in the corridor instead of going back to the ward. She notes the value in her paper scheme and returns to the reception (F). At the reception, she types in the values of all the patients from her morning procedure in the patients' medical records and in the care plan.

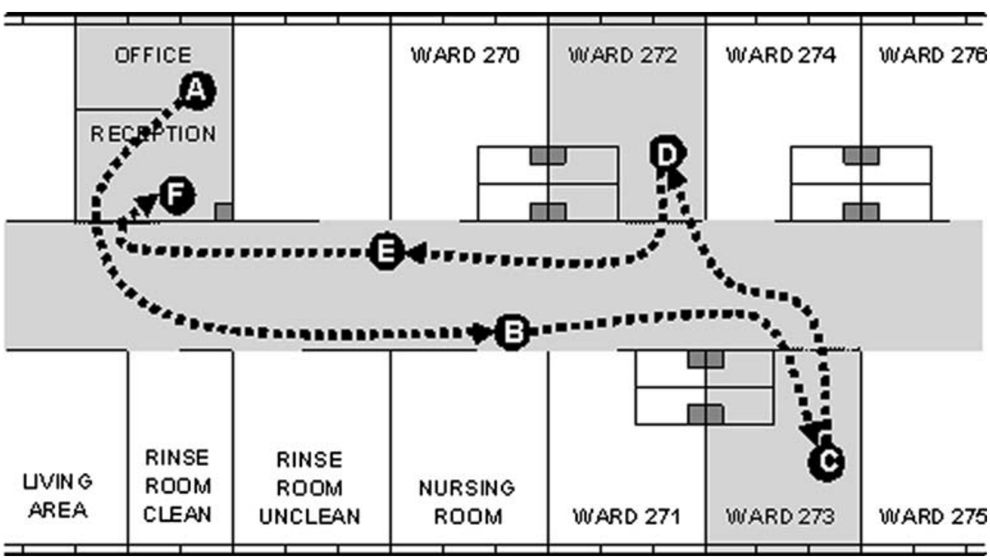

Fig. 1 Sketch of the gynecology and obstetric ward illustrating the morning procedure as outlined in the simple scenario. The *letter legends* refer to the letters in the text

3.3 Challenges

A number of challenges were identified that concerned being mobile in the above work situations. From the analysis, the following challenges are considered:

(a) The nurse frequently requires information at different locations. As illustrated in the scenario, nurses require information about patients when they visit the patients. However, patients are not committed to their beds at all times, as illustrated in the situation where the nurse meets a patient in the corridor. Thus, the nurses require access to the same information at different locations. Furthermore, when a nurse is requested at a certain ward and has to answer questions or perform unscheduled measurements unprepared, the nurse will need information. In such situations, the nurse can either try to rely on her memory of the patient's record, or she can go back to staff office and look up the information in the patient's journals.

(b) The nurse registers redundant information. As information is required at different locations, the nurse has to register the same information in different records. First, the nurse carries a record of measurements for each patient in which she notes down the new values. Secondly, she notes down the values on the bed graph located at the each bed in the ward. The latter registration ensures that other staff can access information at the bedside if required. Finally, the nurse transfers the values from all patients to the medical records of each patient. The redundant registration in this procedure introduces risk of errors; for example, situations where a wrong value can be registered leading to inconsistent information between the medical record and the bedside graph.

(c) The nurse notes down values by handwriting. The necessity of being mobile while working with patients makes it compulsory to write down information continuously. As a consequence, it is difficult (or even impossible) for the nurses to carry large equipment that would enable them to register information electronically. Thus, the nurse carries a notepad where she can write down information; this is done by handwriting. Handwriting introduces potential risks of misinterpretations and errors in medication and registration of values. Other research projects have identified the same problem, for example, confusion of medicine names [32].

4 MobileWard: a context-aware mobile electronic patient record

The above challenges at the gynecology and obstetric ward at the Frederikshavn Hospital suggest solutions that are mobile and integrated with the existing medical records. For this purpose, an experimental prototype on a hand-held device that could seamlessly support the morning procedure was designed. It was named the system MobileWard.

4.1 Definition and use of context-awareness

Based on the definitions of context-awareness (see Sect. 2.2), context-awareness is defined from Schilit and Theimer as "... the ability of an application to discover and react to changes in the environment" [23].

The understanding of environment is applied in terms of the entities people and places adapted from [25] and in terms of time adapted from [22]. Specifically, the folowing will be used:

– People include patients admitted to the ward. All patients will be modelled in the system and their statuses related to the morning procedure will be displayed in the interface; this includes upcoming scheduled measurements and previous measurements. The system will display which patients that are assigned to which nurses.
– *Places* include locations at the ward. The different rooms found in the ward are differentiated (for example, ward 272 and ward 273 in Fig. 1). Thus, the system will present different information according to physical location of the user.
– Time include the scheduling of upcoming operations of patients. As operations will influence activities around the patient, nurses would have to be notified when operations are planned and scheduled. Thus, time will influence presented information and services.

Considering the definitions of discover and react, we apply the active context-awareness level of interactivity, for example [1], where the application autonomously changes the application according to sensed information. Thus, changes of people, places, or time will automatically affect the user interface.

Furthermore, interface designs will incorporate a visual layout that enables finger-based interaction, as nurses would normally use the system while standing and while being at different locations. The use of pens for typing in information is therefore unsuitable. All interface elements should support finger-based interaction, for example, proper size of buttons.

4.2 Architecture

MobileWard is designed for and implemented on a PocketPC (Compaq iPAQ 3630) using Microsoft Windows CE V3 as the embedded operative system. The system uses a Wireless Local Area Network (WLAN) for communication between PocketPCs. The system was implemented in VisualBasic.

For the experimental prototype, we implemented some of the contextual sensing functionalities were through a control center. This control center was operated by the members of the design team and included the sensing of physical location, the barcode scanning of patients, and the trigger of temporal-oriented events. This approach was chosen to more quickly design an experimental solution that could be evaluated. For discussions on how to sense environments, see Bohnenberger et al. [29] or Schilit and Theimer [23].

4.3 Interface design

This section will present the interface design of MobileWard and explain how context-awareness has been built into the prototype.

Places relate physical location at the ward. At the top of each interface, the user can see the current physical location as interpreted by the system. The prototype pushes information according to the physical location of the user, so when the user is located in the corridor, information related to the patients are pushed (see Fig. 2a). When the user walks into a ward, the system automatically detects the change of physical location and presents information only related to the patients of that particular ward. This is illustrated in Fig. 2b. The system presents only information of patients at the ward where the user is currently located and it displays the position of the respective beds. Again, at the top of the interface, the user can see her physical location; for example, ward 276. When the user walks into a single-bed ward or into a ward occupied by only one patient, the system will present information on only that patient (see Fig. 2c). When the user walks back into the corridor, the system will once again provide an overview of all the admitted patients to the ward. Thereby, only relevant information is provided to the user by automatically adapting to the physical location.

People relate information of patients admitted to the ward. Before visiting assigned patients, the nurse often wants to go through the list of assigned patients and see specific information on each patient, for example, related previous measured values. The patient list interface shows the assigned (as well as unassigned) patients for morning procedure (see Fig. 2a). The list of patients is ordered by ward number and patients assigned for morning procedure is shown with a white background, while assigned patients for the current user are boldfaced (in the interface at the left of Fig. 2, Julie Madsen is assigned for morning procedure for the current user of the system). The indicators TP (temperature), BT (blood pressure), and P (pulse) show the measurements that have to be performed. The indicators are either presented with red text (value is still to be measured) or green text (value has already been measured).

The nurse can select to see more specific details of each patient while located in the corridor, for example, the interface presents the previous two sets of measured values of temperature, blood pressure, and pulse. Again, upcoming measurements of values are presented using the color coding illustrated previously. At the bottom of the interface, the nurse can activate the barcode scanner. This function must be activated in order to ensure that the data is attached to the right patient. After having scanned a patient, the nurse can type in measured values.

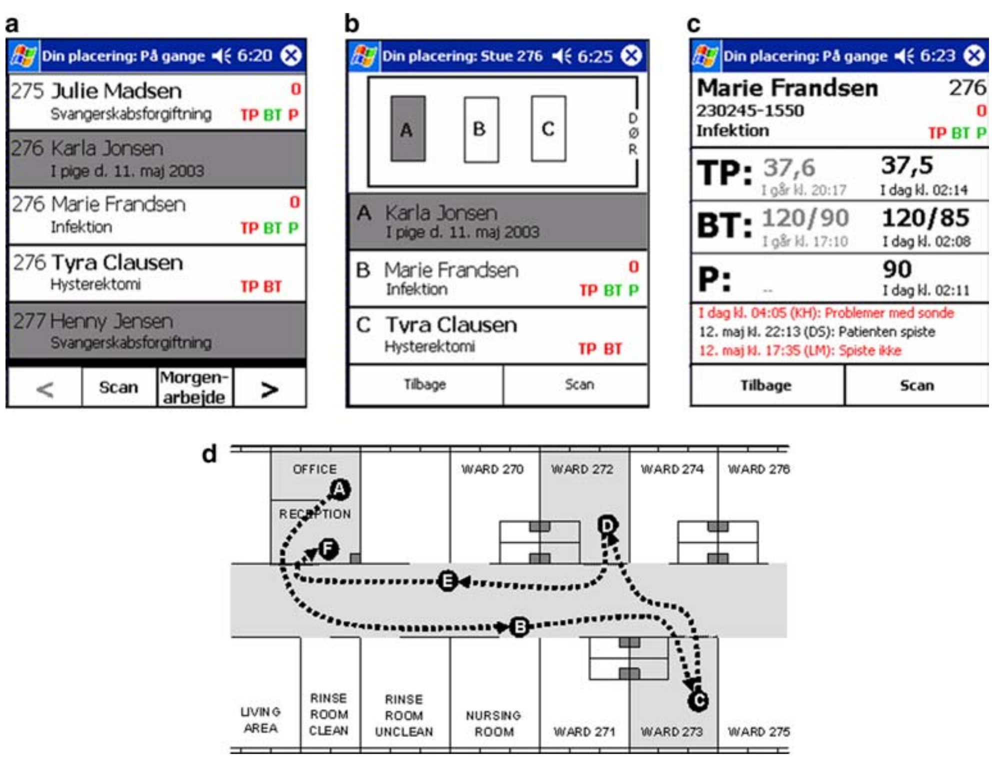

Fig. 2 Automatic adaptation to changes in the physical environment. MobileWard will show one screen when the user is located in the corridor and will change to a different one when the user walks into a ward

The system provides contextual information on previous measurements of values. Thus, the nurse is provided the opportunity to see whether, for example, the temperature for a given patient is rising or falling. Also, the history of these data can be used to determine the order in which the patients are visited during morning procedure.

Time relates scheduled upcoming operations for patients. For each assigned patient, the system provides information on coming tasks, already conducted tasks, and upcoming operations for patient. Above the three indicators of temperature, blood pressure, and pulse, an "O" indicates an upcoming operation (within 24 h), which usually requires that the patient has to fast and should be prepared for operation. MobileWard also combines the physical location of the user, current time, and upcoming schedules, as it will only alert the user when located in the corridor, in an empty ward, or in the office.

5 Evaluation

A number of usability evaluations of MobileWard were designed and conducted in order to evaluate the overall idea of context-awareness for mobile work. The system was evaluated in two different settings namely a laboratory study and a field study. The first study was conducted as a laboratory evaluation with the objective to evaluate MobileWard in a controlled environment where the use of the system was closely monitored. The standard experimental setup had to be extended to include mobility and context. The second study took place at Frederikshavn Hospital. The aim of this evaluation was to study the usability of MobileWard in supporting real work activities at a hospital ward involving real nurses and real hospitalized patients. Thus, the idea was that the work activities at the ward should control the usability sessions instead of assigned tasks.

In the following, (1) the experimental design of the evaluation and (2) the results of the evaluation are described. Further explanations of the experimental design can be found in Kjeldskov et al. [33].

5.1 Experimental design

Test subjects Twelve test subjects participated in the two evaluations where six subjects (four females and two males) aged between 28 and 55 years participated in the laboratory study whereas six test subjects (all females) aged between 25 and 55 years participated in the field evaluation. All subjects were trained, registered nurses employed at Frederikshavn Hospital and Aalborg Hospital. They had between 2 and 36 years of professional experience. All subjects were experienced mobile phone users but novices with the use of hand-held computers. All test subjects were frequent users of stationary EPRs and described themselves as semi-experienced or experienced users of IT.

Tasks All lab subjects received tasks to solve while using the system. The tasks were derived from the ethnographic study at the gynecology and obstetric ward and covered the duties involved in conducting standard morning work routines. This involved (1) checking up on a number of assigned patients based on information in the system from the previous watch, (2) collecting and reporting scheduled measurements, such as temperature, blood pressure, and pulse, and (3) reporting anything important for the ongoing treatment of the patients that should be taken into consideration on the next shift. The field evaluation did not involve any researcher control in the form of task assignments, but was structured from the work activities of the nurses in relation to conducting standard morning work routines.

Procedure Before the evaluation sessions, the test subjects were given a brief introduction to the system. This included the room-sensing functionality and the procedure for scanning patients' bar-code tags. In the lab sessions, the test subjects were instructed on how to operate the available instruments for measuring temperature, blood pressure, and pulse. Furthermore, the tasks required the test subjects to interact with three patients in the two hospital wards, and move between the two rooms through the connecting hallway a number of times. The lab subjects were encouraged to think-aloud (in the field if possible) throughout the evaluation explaining their comprehension of and interaction with the system. The evaluations lasted between 15 and 40 min and were followed by the test subjects filling in a questionnaire.

Data collection High-quality audio and video data from the laboratory study was recorded digitally. A tiny wireless camera was clipped on to the mobile device providing a close-up view of the screen and user-interaction (see Fig. 3, left). This was then merged with the video signals from the ceiling-mounted cameras. Motivated by the challenges of capturing high-quality video

Fig. 3 Wireless camera mounted on PDA (*left*), video images from the subject rooms (*middle*), and observer carrying and operating portable audio/video equipment (*right*)

data during usability evaluations in the field, a portable configuration of audio and video equipment was designed to be carried by the test subject and an observer, allowing a physical distance of upto 10 m between the two. The configuration consists of a tiny wireless camera (also used in the laboratory evaluation described previuosly) clipped-onto the mobile device and a clip-on microphone worn by the test subject. Audio and video is transmitted wirelessly to recording equipment carried by the observer (Fig. 3, right). In the test monitor's bag, the video signal from the clip-on camera can be merged with the video signal from a hand-held camcorder (picture-in-picture) and recorded digitally. This allows us to record a high-quality close-up view of the screen and user-interaction as well as an overall view of user and context. During the evaluation, the observer can view the user interaction with the mobile device on a small LCD screen and monitor the sound through earphones. For ethical reasons, there was no permission to film the hospitalized patients in the field study allowing only the video signal from the clip-on camera to be recorded

Data analysis The usability evaluations amounted to approximately 6 hours of video recordings depicting the 12 test subject's use of the system. All sessions were analyzed in random order by two teams of two trained usability researchers holding Ph.D. or masters in human–computer interaction. Each team analyzed the videos in a collaborative effort allowing immediate discussions of identified problems and their severity, adapted from Kjeldskov and Skov [34]. As a guideline for the collaborative analysis, each identified usability problem would be discussed until consensus had been reached. The two teams produced two lists of usability problems. Subsequently, these two lists were merged into one complete list. Again, this was done in a collaborative effort, discussing each problem and its severity until consensus had been reached. The usability problems were classified as cosmetic, serious, or critical according to the guidelines in Ref. [35], for example, critical problems were typically characterized by the fact that they prevented completion of a task.

6 Results

A total of 37 different usability problems were identified from the 12 laboratory and field sessions where 8 problems were assessed to be critical, 19 problems were assessed to be serious, and 10 problems were assessed to be cosmetic. Looking at the two different studies, it was found that the laboratory setting revealed more usability problems than the field setting. The six test subjects in the lab experienced 36 of the 37 usability problems whereas the six test subjects in the field setting experienced 23 of the 37 usability problems. A key reason for this difference in numbers of identified problems was the fact that none of the field subjects applied the integrated note-taking facility; this functionality caused several problems for the lab subjects. The following paragraphs will primarily outline results from an overall perspective leaving out discussions on differences between the setups. For further discussions of these differences please refer to Kjeldskov et al. [33].

Analyzing the identified problems further, it was found that some of the problems concerned the inherent complexity of context-awareness and automatic updating. Several subjects did not understand or could not see the status or mode of the system. This would sometimes lead them to attempting to type in measurements even though the system was not able to receive input. Thus, the subjects needed more information on status and mode. A number of additional problems concerned aspects of context-awareness, for example, the automatic update of the interface. The most common problem was that users got confused or believed they had done something wrong when the interface was updated automatically. One test subject was reading information on the device while walking into a ward and she got confused when the system suddenly changed the interface layout without notice or without having her trigger the event directly. Other subjects looked at the system while being in one room, walked into another room, and found that the interface had changed in the meantime. For some test subjects this caused confusion, but for other subjects it caused more severe problems as they could not locate or retrieve the previous information. This would lead to problems in conducting some of the work tasks.

Another observation extracted from the identified problems relates safety-critical issues and inherent complexity of the use situation. One problem identified in the field relates uncertainties expressed by some of the nurses about the validity of the data entered into the system, to what extent measurements had been correctly saved in the system. This issue relates to the evaluation taking place during real work in a safety-critical use context where errors cannot be tolerated. Also, one test subject did not know the semantics of the keyboard for typing in textual notes on patients. Actually, she felt insecure about the buttons "Tab," "Cap," and "Shift" as she would expect them to be "tablet," "capsule," and "shift medication."

Finally, problems concerning aspects of mobility and working conditions were identified, for example, a test subject was concerned about putting the mobile device in her pocket. She was afraid that she would accidentally click some buttons while walking and she stated that it would be impossible to carry the device in her hand at all times. Another problem related to mobility and working conditions was the fact that one test subject feared that the device could spread bacteria from patient to patient. Thus, she did not want to place the device on the patient's bedside table or on the bed. Furthermore, all subjects were informed to use either their fingers or the attached pen for device interaction, but only the lab subjects chose to use the pen and most of them experienced difficulties in placing the pen between tasks.

7 Discussion

MobileWard was designed as an experimental prototype with the aim of exploring context-awareness in mobile collaborative work. MobileWard is context-aware as it fulfils some of the definitions of context-awareness, for example, Schilit and Theimer [23]. MobileWard is able to discover and react to changes in the environment by sensing the physical location of the user. MobileWard integrates aspects of context-awareness focusing on both spatial, for example, different wards, and temporal issues, for example, time schedules. The evaluation identified a number of usability problems concerning context-awareness, safety-critical issues, and mobility.

Context-awareness has been hailed to hold promising features for improving the effectiveness and usability of information technologies [25]. As outlined, different perspectives and definitions exist of context-awareness for mobile systems. Schilit and Theimer proposed an early definition of context-awareness and state that context-awareness is the ability of an application to discover and react to changes in the environment [23]. A complementary definition is provided by Moran and Dourish stating that a system is context-aware if it uses context to provide relevant information and/or services to the user where the relevancy depends on the user's task [36]. Thus, key aspects concern changes in the context and the ability to provide relevant information according to such changes.

The study indicated and identified key challenges in meeting such definitions, for example, Schilit and Theimers [23] and Moran and Dourishs [36], as the system needs to react to changes in the context as well as present information or services that are relevant to the user's task. Situations were identified where the system reacted to a change in the context and presented the information relevant for the user's task, and situations were found where the system reacted to a change in the context and changed away from information that a user was reading. Both scenarios were linked to the same set of contextual rules that MobileWard was designed to react to. For the system to distinguish between these two situations, it would require a more advanced decision-making process and it is a question if the information required for a better suited decision can be sensed from the environment.

Several researchers talk about environment or context in context-awareness. Chen and Kotz define context as the set of environmental states and settings that either determine an application's behavior or in which an application event occurs and is interesting to the user [24]. Abowd and Mynatt use a set of five questions to obtain what they call a good minimal set of necessary context [22]. These are who, what, where, when, and why questions related to the context. Lieberman and Selker [37] state that context is everything, but the explicit input and output suggests a model of the context through the changing states of objects. Extending these understandings, Kristoffersen and Ljungberg [38] distinguish between physical and social context. MobileWard is designed to react upon changes primarily in the physical context and not in the social context. Modeling social context of MobileWard would allow the system to have a richer understanding of context. It is, however, still questionable whether such additional information would lead to a better chance of having the system present information or services that are relevant to the user's task, such as that suggested by Moran and Dourish [36].

Active context-awareness was chosen in level of interactivity, as we wanted to explore an extreme meaning of context-awareness. Barkhuus and Dey [1] conclude that this kind of interaction takes away the control from the user. The study confirms this finding and the lack of control sometimes lead to problems while carrying out assigned work tasks, as for example, the situation where a user reads the screen while walking into a ward and the information on the screen changes. However, most contemporary context-aware mobile systems aim to support users in private situations where this issue might not be a problem. Such systems include mobile tourist guides, for example, Pospischil et al. [5]. Context-aware mobile tourist guides typically direct people from one physical location to another and they are able to point out and describe interesting properties of the context. Furthermore, as local mobility is being dealt with [15], in a familiar environment, no spatial guidance is provided in MobileWard as most current context-aware mobile systems would. Kjeldskov [20] suggests a context-aware mobile system with spatial direction guidance where it is local mobility but in a potential unfamiliar environment. The environment at the ward would always be familiar to the users making direction guidance obsolete.

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