The Nurse Watch: Design and Evaluation of a Smart Watch Application with Vital Sign Monitoring and Checklist Reminders

Magnus Bang, PhD\textsuperscript{1,2}, Katarina Solnevik, RN\textsuperscript{3}, Henrik Eriksson, PhD\textsuperscript{1}

\textsuperscript{1}Department of Computer and Information Science, Linköping University, Sweden; \textsuperscript{2}SICS East Swedish ICT AB, Sweden; \textsuperscript{3}The Intensive Care Unit, Linköping University Hospital, Region Östergötland, Sweden

Abstract

Computerized wearable devices such as smart watches will become valuable nursing tools. This paper describes a smart-watch system developed in close collaboration with a team of nurses working in a Swedish ICU. The smart-watch system provides real-time vital-sign monitoring, threshold alarms, and to-do reminders. Additionally, a Kanban board, visualized on a multitouch screen provides an overview of completed and upcoming tasks. We describe an approach to implement automated checklist systems with smart watches and discuss aspects of importance when implementing such memory and attention support. The paper is finalized with an in-development formative evaluation of the system.

Introduction

The nurse watch has been a valued nursing tool since the early 20th century. Being predominantly employed in the United Kingdom, besides offering a time reference, it provides the nurse with a quick method of taking the 60-second pulse rate of patients using a pulse scale. Due to hygiene requirements, the watch is carried up side down on a chain (fob) and attached to the uniform for fast reference. The introduction of wearable technology such as wireless computerized smart watches from manufacturers such as Apple, Motorola and Samsung provide designers with a new set of possibilities to support medical professionals. For example, these developments make it possible to design and develop specialized nurse applications that run on smart watches. However, very few smart-watch designs for nursing have been presented.

Using checklists and reminders in clinical care have been shown to provide significant improvements in patient outcome and patient safety\textsuperscript{1}. Checklists can support standardized nursing care, aid workflow, and act as reminders of work-to-do\textsuperscript{2,3,4}. Moreover, studies show that appropriately-designed workplace arrangements and applications can offload cognitive demanding tasks and allow the clinician to focus on the important activities. Some studies, however, report that reminders have less significance to clinical outcome and routines\textsuperscript{5}. Nevertheless, studies have identified compliance problems with both paper-based and computerized checklists\textsuperscript{7} such as neglecting to use a checklist or not acting on a computerized reminder.

We have developed a smart-watch application and an adjunct Kanban task board to be used by ICU nurses during day and night shifts. The basis for the design was to approach a set of issues related to the use of checklists and reminders at a Swedish ICU. The goal was to improve workflow and patient awareness at the ICU. To direct the design, we applied the theoretical framework of Distributed Cognition\textsuperscript{8,9} to understand underlying aspects of checklists and reminders that are of importance when designing memory and attention support. This paper is organized as follows: First, we review research on checklists and their usefulness. Second, we discuss theoretical aspects of checklist and reminders based on the theory of Distributed Cognition. Third, the method section describes MODUS, the framework in which we have developed our approach as well as discussing how we elicited the requirements for the system. The remainder of the paper presents the smart watch app, its formative evaluation and discusses the pros and cons of the overall approach.

Background

Nurses have many responsibilities during day and night shifts. Numerous studies have demonstrated how reminders and alerts can be helpful in focusing the nurses’ attention on specific tasks. Reminders and alarms can be seen as decision-support tools\textsuperscript{10} designed to improve patient outcomes, reduce medical errors, and increase compliance with standards of care. A variety of formats have been devised such as paper-based and computerized reminders. Rind and colleagues showed that computer-based alerts and related changes in clinical practice had a respectable effect on preventing renal impairment and function of patients\textsuperscript{11}. Oniki and colleagues studied computer-generated reminders on charting omissions and they could show a clear decrease in charting deficiencies\textsuperscript{12}. The mid-day reminders
appeared to reduce deficiencies in the nurses’ charting and the reminders were helpful in focusing the nurses’ attention. Thongprayoon and colleagues showed that an electronic checklist reduced significantly provider workload and task errors.15 This study also suggested that electronic checklists are feasible in the ICU setting. Before we describe our approach to the design of reminders using smart watches and Kanban boards, let us discuss some theoretical aspects of checklists and reminders.

Distributed cognition of checklists and reminders

According to Norman, are there numerous cognitive aspects to the checklist14. First, without the list one needs to remember all tasks. On the other hand, when having a list, we need to remember little since the planning and remembering process was done in advance. At the time we enact the actions of the list, we do not need to repeat the planning and remembering process and this offloads cognition during execution. However, the use of a list also introduces new tasks: remembering to consult the list and reading and interpreting the tasks on the list. Naturally, having the physical reminder visible and upfront is important when relying on them for remembering tasks. According to Hutchins is this situation an example of Distributed Cognition; the computational task of remembering is distributed across time and across internal and external representations, which comprise a robust memory system.

Method

Requirements elicitation

The requirements elicitation and formative evaluation for the Nurse Watch were done iteratively and dynamically with a team of nurses using a Scrum methodology.15 This comprised software development, user demo, user feedback and subsequent redesign for four one-week sprints. Moreover, the head nurse and team redesigned and integrated a set of paper-based standard checklists and activities that were transformed to an internal XML format in the MODUS system. This transformation also comprised time stamping a set of nursing activities that previously not had been time aligned in the paper version of the checklist.

System development

The Nurse Watch was developed and integrated in MODUS, which is a comprehensive visualization environment and database system designed to support medical rounds and remote monitoring of patients in critical care. MODUS collects data from a set of Philips MP70 patient monitors, Braun Space Station Pumps and Maquet Servo-I ventilator systems as well as local picture and laboratory systems. This data is visualized on a motorized 46-inch multitouch tabletop during the round. Additionally, a smartphone application (Android) and Google Glass augmented-reality support remote monitoring of patients’ vital signs. The idea in this project was to add an unobtrusive new user interface to MODUS with a focus on nurses and their needs. In this project, we were able to reuse programming code from our Google Glass implementation and provide subset functionality to the watch. Moreover, we added a Kanban board to our multitouch tabletop to visualize all done and remaining checklist events on a timeline.

Formative evaluation

A formative evaluation17 was performed with seven experienced nurses and nurses’ aides of different ages and IT experience measuring task completion and subjective usability of the user interface of the Nurse Watch. All subjects had never used a smart watch before. Scenarios and eight test cases were developed covering all possible tasks and user interface components of the clock. The user evaluation was designed as a Wizard of Oz study18 that entailed simulated alarms and reminders triggered behind the scenes by our test staff. After a very brief introduction to the Nurse Watch the evaluated started and included a think-aloud methodology when the test subjects completed tasks in the scenario. After the initial test session subjects completed the SUS subjective usability questionnaire. The session was finalized with a brief interview on the feasibility of the overall approach.

Figure 1. The three-tier model of MODUS allows medical equipment such as patient monitors to communicate with the Nurse Watch via the MODUS app.
Result

The current version of the Nurse Watch was developed for the Motorola 360 smart watch\textsuperscript{35} in Java for Android and connected to a set of related systems in a tree-tier model. Figure 1 shows the software architecture. In the present implementation, the Nurse Watch communicates wirelessly via Bluetooth Low Energy to an assistant smart phone also worn by the nurse. A smart phone application manages communication via Wi-Fi with the underlying patient server and databases in MODUS where vital signs data and checklist are stored. Moreover, the smart phone application allows the user to set personal alarm threshold values for the own Nurse Watch. Figure 2 shows the Motorola 360 smart watch running the Nurse Watch application.

\textit{Nurse watch design features}

The Nurse Watch provides two primary features: (1) real-time vital-sign monitoring and (2) reminders of what to do. Navigating the Nurse Watch app is done by ordinary finger sweeps and clicks on the glass surface on the watch. Since this is a very small screen, we were forced to minimize the amount of information shown. Moreover, for patient-safety reasons, we decided to have the patient name and id highly visible on most screens even thought this takes up screen surface. The reason for this decision was to decrease the risk of introducing mode errors in terms of assessing the wrong patent based on information from the watch. Figure 3 shows the different user interface panes for vital-sign monitoring and reminders. Let us first discuss the vital sign monitoring part of the Nurse Watch.

The patient pane with vital signs is the primary home screen (see Figure 3, left). This screen is dynamically updated every other second. Scrolling up and down with the finger changes which patient is shown. What is presented is a subset of available patient parameters in the MODUS environment. To create a set of vital signs to be shown on the watch, the clinician chooses these parameters on a digital desk or PC using a drag and drop methodology. This activity allows the parameters to be sent and shown on the smartphone and on the watch. Additionally, the nurse can, using the adjunct phone app, set suitable alarm thresholds for the watch. Figure 4 shows the smartphone app for setting the alarm thresholds.

We implemented a two-level notification scheme in the Nurse Watch: vibration alarms and visual cues. Moreover, we decided to have two types of vibration alarms to notify the clinician on the level of urgency. Two consecutive vibrations denote an urgent alarm and indicate a violation of the threshold of a vital sign. A longer vibration is related to upcoming items on the checklist. Moreover, to clearly indicate what type of vital sign that was out of bounds, the color of the vital sign text changes to red and is flashing to make it stand out.

\textbf{Figure 2:} The Nurse Watch showing the breath rate of a patient. The additional vital parameters of the patient are automatically shown.

\textbf{Figure 3.} The user interface components of the Nurse Watch application. The app provides real-time monitoring of patients’ vital signs and deliver reminders on upcoming task. The nurse can classify a task as done (Swe., Avklarad) or postpone it (Swe., Skjut upp).
The Nurse Watch provides notifications on upcoming tasks. These are generated automatically in MODUS based on a time-stamped checklist in XML format that is executed in real time. As mentioned, the system generates a second level notification in terms of a longer vibration in the watch. The nurse can now directly view the task and classify it as completed or postpone it. The status of the task is then updated on the watch and on the Kanban board in terms of visual cues.

**The Kanban board**

Originally, Kanban boards were introduced in the manufacturing industry to support workflow and to provide an overview of the current work situation. In this project, we combined the traditional checklist with Kanban visualization. The idea is straightforward: every task on a checklist is time-stamped and visualized on a Kanban board. We developed a special pane for this in the MODUS system. The process is initialized when the patient is admitted to the ICU. Then, the head nurse chooses among a standard set of care plans/checklists in MODUS and these are shown on the Kanban board and are sent to the watch. Figure 5 shows a checklist visualized on the Kanban board. In MODUS are these tasks time-activated, which triggers the Nurse Watch of the responsible clinician.

**Formative evaluation**

The formative in-development evaluation revealed some user interface omissions in the first version of the nurse app prototype. The task completion rate for the eight primary tasks were 83 percent and this clearly indicated that there were problems with parts of the user interface. Primarily, two user interface problems were identified; glitches that were resolved in the finalized version of the Nurse Watch. One problem was an inadequate implementation of the alarm screen that required subjects to remember alarm types and patient names during navigation. A better design would have notified the nurse and allowed direct access to the corresponding patient and parameter screen. The second user interface issue was related to inconsistencies in how we displayed tasks as being done or not.

The SUS subjective usability scale measures several aspects of the usability of IT systems such as the need for support, training, and complexity of the user interface. The SUS mean score for the first Nurse Watch prototype was 70, which is regarded as OK but not exceptional. Particularly low scored a question on the comfort and security of the prototype. We believe that this result was due to the above discussed user interface issues combined with a very brief introduction to the new technology.

During the interviews the clinicians were generally positive towards the Nurse Watch and the overall approach. The nurses expressed that the user interface of the watch was easy to use and understand. The vital sign monitoring and the related threshold alarms were, by the lion part of the clinicians, seen as the most useful feature of the watch. Checklist reminders were also regarded as a useful function. However, a concern was on the relevancy of the reminder. One nurse stated, for example, that for it to be really useful, it should prompt only key medical tasks, not ordinary standard care task. Moreover, a suggestion was to include functionality to create own reminders that are displayed on the watch during the shift. All nurses expressed concerns regarding hygiene requirements and discussed how it could be worn to comply with these necessities. This discussion also included worries that the watch might reveal information to outsiders. Solutions included screen savers that blacken the display and ways to wear it on a chain (fob) in the pocket. One nurse expressed the need to have a tablet computer with the above-discussed features rather than a smart watch.
Discussion

Smart watches can become valuable tools in the healthcare environment. We have exemplified two primary features that can be useful – remote patient monitoring and reminders – that could improve situation awareness and support the memory of medical professionals. On the positive side is the unobtrusiveness of the device that might be its principal advantage in the healthcare environment, where nurses don’t necessarily want to carry bulky tablets or smartphones. On the negative side is screen size, which limits it usefulness as an interactive device. Moreover, energy consumption is still a problem even thought Bluetooth Low Energy is used for communication. Hence, a priority in development should be on applications that make the best out of the energy available on the platform. Related to the above is the reliability of the radio communication. This is still an issue and must be investigated further.

Many healthcare organizations have banned wristwatches because they have been identified being a transfer vector of healthcare associated infections. A possible approach to minimize this risk is to wear it with a chain hanging from the blouse or coat. However, this might impair user interaction. Software developers must account for how clinicians want to wear the device in order to find a suitable interaction scheme. Nevertheless, it needs to be washable, resist disinfectants, and have a liquid ingress protection reaching IEC 60529 level IP67.

Having automated data capture at the bedside with real-time patient monitoring feeds to devices such as smart watches introduce a set of general problems related to control and situation awareness. Traditionally, ICU nurses have the role of filling out the patient chart to record the vitals of the patient manually. Nowadays automated patient monitoring and recording systems, which risk setting the clinician out of the information and control loop, is increasingly taking this role. Therefore, vendors are requiring that the nurses in the ICU environment validate automatically collected data coming from the patient monitors. This problem also applies to the smart watches since an increased reliance on automated feeds may inflict on the formation on situation awareness. Hence, there is a difficult tradeoff that needs to be assessed between information feeds and direct information from the patient at the bedside.

Many studies have exemplified how clinicians create their own cognitive scaffolds as part of their practice. Common examples are the ubiquitous sticky notes that can be seen as external memories of work-to-do. Smart watch implementations should support flexibility and such cognitive practices. A problem here is that the smart watch is primarily an output device, which hamper the creation of small notes. A likely design solution is to create these notes with smart phones or tablets computers and use the watch for the reminder feeds.

A risk when introducing technologies that provide alarms is alarm fatigue. This is particularly apparent in the case of wearable technologies such as smart watches. For the Nurse Watch, we developed different alarms levels. This is probably only part of a solution to this problem. Since these are new devices, more research needs to be conducted on how smart watches affect alarm fatigue.

Conclusion

This paper presented a design and an evaluation of a smart watch platform for ICU nurses. Appropriately designed applications running on these unobtrusive devices can become important nursing information tools in the future. We exemplified two primary features – vital sign monitoring and work-to-do reminders – that were perceived by nurses to be useful in an ICU environment. Future work includes improvements to our alarm scheme and means for nurses...
to create their own reminders to support their personal memory practices. Full in situ studies are required to appropriately assess the feasibility and usefulness of smart watches in the clinical environment.

References