User-centered development of a pervasive healthcare application

Andreas Butz
University of Munich
Media Informatics
Munich, Germany
Email: butz@ifi.lmu.de

Antonio Krüger
University of Münster
Geoinformatics
Münster, Germany
Email: antonio.krueger@uni-muenster.de

Abstract— **We describe the user-centered development process of MARiS, a PDA-based mobile frontend to a hospital information system. It allows mobile access to patient records, and the documentation of diagnoses and treatments as they happen. While similar applications have been studied in research contexts, we developed a system which was tested with a considerable user base and which is currently in productive use in several German hospitals. For the system to become successful, we embraced a user-centered design approach. In this paper we discuss, how the initial system design was derived from user requirements and studies of the application environment, and how continuous feedback from daily use continually caused the initial design to evolve and eventually stabilize to what now is a successful commercial product.**

I. Why a mobile hospital information system?

The main focus of the work done in hospitals is and has always been to help and cure patients as good as possible. This goal is mainly achieved by careful medical diagnoses, well-chosen treatments and sufficient patient care. Administration of patients and keeping of exact patient records is only a secondary activity which is necessary to make these main activities possible.

Fig. 1. Traditional hand-written patient records

Patient records are traditionally kept in special cardboard folders which provide space to write on and can hold additional paper, such as printouts of laboratory results inside of them. With the rise of IT in general administration, also hospitals have started electronic administration of their patients' personal data, if only to facilitate efficient billing to the health insurance companies. Until today, many hospitals continue to keep their patients' medical records in paper form, since the richness and flexibility of this medium is hard to reproduce in IT systems. This manual bookkeeping includes medical diagnoses and monitoring, but also documentation of the treatments administered to the patient. These treatments are entered into IT systems for billing only once a day, or even less frequently. Many details of the treatments are lost in this delayed documentation process and items are forgotten, wrongly documented, or replaced by standardized entries.

With the globally increasing cost pressure in the health sector, hospitals face the need to treat more patients in less time. A reduction of the actual time spent for diagnoses, treatment and care endangers the result of the medical effort. Therefore, one viable way to face this pressure for efficiency, is to streamline the administrative parts of the work by providing more efficient tools for the keeping of the patients' medical records. Since the patient's personal data is already kept in the hospitals' electronic bookkeeping, this can be achieved in two steps: a) storing medical records along with this administrative data as much as possible, and b) providing a fast and simple access to these records, if possible right in the context of the actual treatment.

Another side effect of a more direct and efficient documentation of patient treatments are improved and more detailed and complete records for billing. By documenting their medical efforts better, hospitals can expect higher payments from the insurance companies, which further alleviate the cost pressure. This paper describes the development of MARiS, a mobile system for patient record access and documentation, which addresses exactly these issues. MARiS was developed by Eyeled GmbH[1], a German mobile solution provider with a strong focus on mobile user interfaces, and with the support of hsp[2], who provides health care solutions for the German market.

II. Related Work

Mobile computing in health care environments has received considerable attention during the last decade. According to [1]

[1]http://www.eyeled.de/
[2]http://www.hsp2000.de/

more than a 100 clinical trials have been carried out in the past 16 years, focussing on the whole range of mobile technology from larger portable computers, such as notebooks and Tablet PC to smaller handheld computers, such as PDA or small-scale PC with touch sensitive screens. Nearly every possible clinical department has been subject of trial studies in the past. Especially electronic diaries, that record patient data in-situ have been extensively investigated. Some of those trials include usage of mobile devices outside of the actual hospital, e.g. electronic diaries that help to keep track of eating disorders [2]. In our work, we focus on the usage of mobile devices inside hospitals with physicians and nurses as our primary users. In the past, experimental setups have been realized to facilitate the mobile access of x-ray images [3], the access and visualization of waveform data [4], and the realization of realtime monitoring of physiological information [5].

This body of related work can be divided into two classes: work that has concentrated on the technical aspects to connect mobile devices to the existing and usually stationary accessible HIS[3] infrastructure and work that has focussed on the integration of the mobile devices into the workflow of clinical routines. The first category has led to mobile systems that build on commercial platforms as extensions to traditional HIS and which investigate software concepts (e.g. usage of thin clients vs fat clients[6], [7] and the access to traditional databases[4]). The second class of related work is more research oriented and explores the use of new technologies, such as the combination of large displays and mobile devices as well as general usage patterns in hospital environments[8]. Research on usability issues of mobile technology in hospitals, however, is somewhat hard to find. In [9], based on ethnographic studies, a context aware distributed architecture is proposed that takes into account not only the location of staff and patients but also the role of tasks and the involved artifacts. Ethnographic methodologies have been applied in a ward to support the daily routines of nurses and to optimize their collaboration patterns[10]. The insights gained by this research projects could positively influence the design and deployment of commercial products. One explanation why this has happened rarely in the past, could be the cost and time intensive nature of the process. Another cause is the often encountered unfamiliarity of commercial HIS developers with the particular methodologies of usability engineering for mobile applications.

Although the need for mobile applications in health care environments has been propagated for more than 10 years, only a few commercial systems are in continuous use. We believe that this is mainly a mobile usability problem. A closer collaboration between mobile usability experts and traditional suppliers of HIS, bears the great potential to overcome these deficits. The work presented in this paper bridges this gap by taking into account existing HIS infrastructure as well as mobile usability aspects that help to facilitate the interaction with mobile devices in hospital environments. In contrast to most of the previous work, the presented mobile application has been in commercial use for over 2 years and has gradually evolved over time by applying strict user-centered design principles [11]. The involved team of mobile usability experts have kept close and ongoing contact with the various stakeholders from administration, the group of physicians, nurses and patients.

III. Application context and legal requirements

When we started to develop MARiS, two hospitals, located in south-western Germany, had expressed interest to get involved in the development and pilot operation phase. Both institutions had already started to introduce an electronic patient record system, but were unsatisfied with the fact, that records could only be modified on stationary computers. In both hospitals, we started with a single department, the one of internal medicine. These two departments represent an end user base of 15 doctors, 28 nurses and 177 patient beds.

One major aspect that came up already before development started, was that the hospital administration and staff were very sensitive to the protection of patient data against unintended use. In particular, they initially required that any mobile device containing patient records should not be usable outside of the hospital building or by unauthorized persons. This level of security would even have gone beyond the protection of current paper-based files, which could be stolen in an unobserved moment as well. We discussed the issue with legal parties within the hospital and finally settled for a password or PIN protection for access to any patient data. A strict limitation of the device operation to the particular building would have had so many costly technical implications that it might have prohibited the entire project. In fact, it was considered more important to create well visible access barriers such as a PIN instead of a technically strong encryption.

IV. Initial Design

In initial discussions with doctors and nurses, we tried to narrow the design space of possible devices as much as possible: Wirelessly networked Laptops or tablet PCs would have allowed to use the existing electronic patient record system without much modification, but were considered too heavy and cumbersome for regular use beyond the daily doctor's visit. Specialized, smaller devices were out of question for reasons of cost efficiency. Finally, PDAs were identified as the most promising target platform, since they combine a small form factor with a long battery life and immediate accessibility. We also decided to aim for a solution which did not require the mobile device to have permanent network connection, since this would have implied a wireless network installation in the hospital, and would also have reduced PDA battery life dramatically. The Palm Tungsten T3 PDA was chosen for its small form factor, robustness, and for the fact, that it also allowed to enter voice memos, which turned out to be important for text entry.

[3]Hospital Information System

[4]For example the commercial product MobiCare from the Dutch company ELMO ICT, http://www.elmoweb.nl/

Fig. 2. The target platform chosen for our mobile patient record system

Since documentation of medical diagnoses and treatments always includes considerable amounts of free form text, we proposed several ways to enter this text to our users. These included graffiti input and a screen keyboard, which are the standard means for text entry in PalmOS. Both of these were discarded for being too slow and cumbersome by the physicians. Their current work practice included the concept of dictation using a small voice recorder. These dictations were later typed in by administrative staff and the texts added to the patient record. It was therefore decided to use a similar dictation facility provided by the PalmOS PDAs as the only means of free form text entry. Voice recordings are stored on the PDA and transcribed by administrative staff as soon as they are synchronized to the server. We are currently experimenting with automatic text recognition and trying to increase recognition rate to the high standards required for accurate medical documentation.

A. Early end user involvement

In the first phase, we met with doctors and nurses and asked them to explain their current work procedure. Care was taken to record the basic units of information they dealt with as well as the activities they described, in order to derive an object-action interface model as described in [12] in the next phase. We also questioned them about their wishes and suggestions for improvement of the current work practice.

These initial consultations yielded a good insight into the users' conceptual model of their work practice. One major goal in the development of our mobile patient record system was to make the transition from the current, paper-based practice to the new system as smooth as possible. We therefore tried to preserve the existing conceptual models as much as possible.

One aspect of the whole interaction concept, which became clear already in this early phase, was that it would be important to streamline the mobile UI for maximum speed of access of different functionalities. In particular, this means that taking out the pen and interacting with it would in many cases slow down operation, and that it was desirable to have an interface which could entirely be controlled with the finger (implying big screen buttons) or with hardware buttons on the device, such as the 5-way navigator ring below the screen.

B. Object-action interface model

From the data collected in the first interviews, we constructed the hierarchy of information units shown in figure 3. The actual hierarchy is even bigger, but for the sake of this discussion, we would like to illustrate only those parts, which were influential for the design of the user interface.

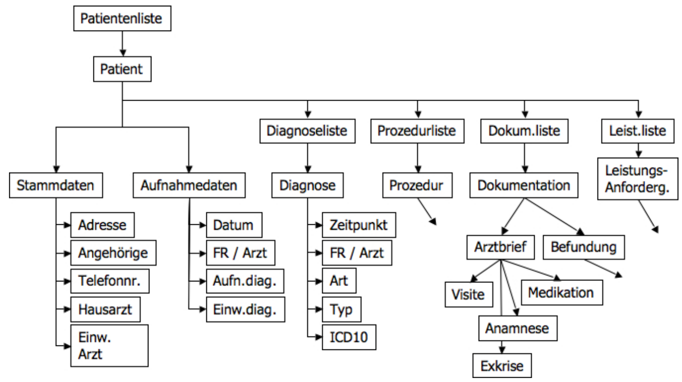

Fig. 3. A hierarchy of basic information units established from our first interviews (labels in German)

The set of actions associated with these objects turned out to be relatively simple and mainly included selection in the case of lists, adding and deleting items from lists, and entering, editing and displaying items. It also turned out that the hierarchy of information units used in the patient record domain contained a number of recurring patterns. Figure 4 shows how two of these patterns are repeated throughout the diagram.

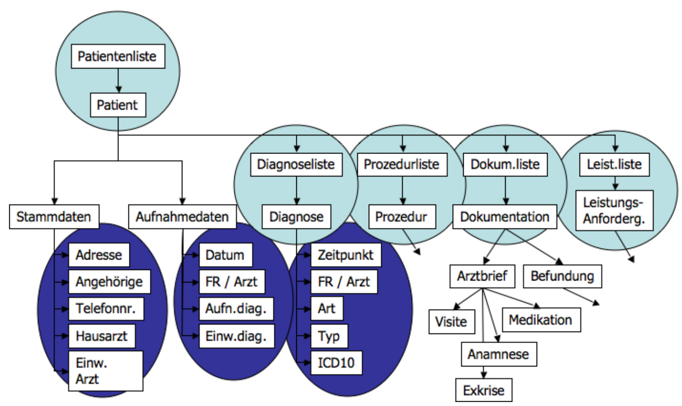

Fig. 4. Recurring patterns in the information hierarchy

The substructures underlaid in light color correspond to lists containing multiple items of the same kind. Examples for this are the main list of patients, as well as the list of diagnoses and the list of treatments for each patient. The structures underlaid in dark color represent basic objects of a more complex internal structure, as for example a patient's personal data set, or a single diagnosis, containing information on when, why, and how it was made.

C. Choice of concrete operators

From the hierarchy of information objects, we then derived the initial structure of the mobile user interface. For the sake of consistency, it was decided to represent the repeated patterns identified in the previous step by the same interface elements. In particular, this applied to the lists of diagnoses, treatments, ordered treatments and documentations for each patient. Additionally, from studying the work practice, we had found that it was essential to be able to jump back and forth quickly between all these lists belonging to the same patient.

In a first attempt to limit development efforts, we tried to use only interface elements provided by the operating system of our hardware platform, PalmOS, but we soon discovered that these elements were not powerful enough to provide all the functionality needed. The only UI concept PalmOS provides for collections of things of the same kind are list views which are used in applications such as the address book or ToDo lists. This kind of list view was used in the initial patient selection screen (figure 5). Nevertheless, we had to re-implement it entirely, in order to be able to integrate graphical symbols, dynamic database queries, and the kind of cursor highlighting we wanted. It can be navigated by pen or by the 5-way navigator button (scrolling up and down, selecting). Fast access to a particular name in this potentially long alphabetically sorted list is also provided by writing the first character in the Graffiti area below the screen.

Fig. 5. Patient list of MARiS

To switch between different lists, PalmOS applications usually go back through a menu or other structure, which needs several clicks and somewhat breaks the direct connection between these lists. From other operating systems and interface toolkits, the concept of register tabs is known. These provide a convenient way to switch between multiple almost full screen views with a single click and provide a permanent orientation by clearly distinguishing the actually selected tabs from the available alternatives. We therefore decided to implement register tabs on top of the widgets provided by PalmOS and then realized the patient view as such a collection of register cards (figure 6). The register tabs can be navigated by pen, but also using the 5-way navigator: pressing left or right switches between tabs, pressing up and down moved the interface focus up and down in the list belonging to the current tab, and pressing the select button opens the item currently in focus.

Fig. 6. Patient view in MARiS including register tabs for the different sublists

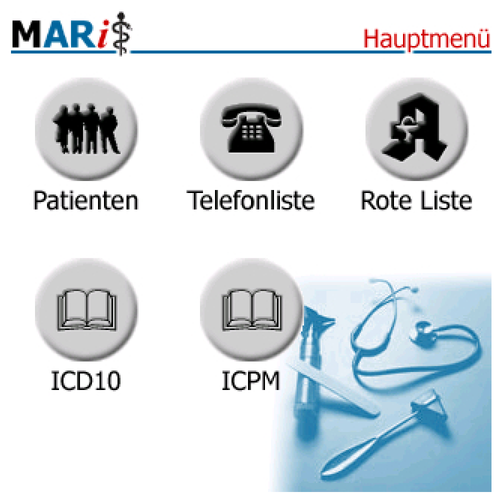

Fig. 7. Start screen of MARiS in the first design

D. Visual screen design

The actual visual design of the UI can make a big difference when it comes to practical usability, but also determines a general mood or atmosphere conveyed by the interface. We chose white as the principal color and black for regular texts, as well as different shades of grey and blue for interactive elements. This color scheme goes well with the hospital context, since it conveys a clean and medical atmosphere, and at the same time provides high visual contrasts and good readability. The atmosphere was further supported by visual elements alluding to the medical practice, as can be seen in figure 7.

V. PRACTICAL USE AND DESIGN ITERATIONS

When the first prototype of MARiS was operational, we started testing it in the actual hospital environment. Eight physicians used personal devices on a daily basis, and two more devices were in shared use by the nursing personnel. During ten weeks, we asked the physicians and nurses to note what they thought would need improvement in the interface.

A. Feedback on the initial prototype and design corrections

Feedback about our initial prototype was provided on different levels. Concerning technical usability of the interface, it was found that navigation using the 5-way navigator and the big screen buttons for finger usage worked very well. While the interface structure was mainly accepted without particular comments, users requested additional functionality to be integrated in the main menu, such as the voice recording and the synchronization functionality within MARiS, as well as a help button with a quick reference to the UI, in case they had forgotten about a certain detail. Other functionalities, such as the ICD10 and ICPM catalogue were considered less important at this level and therefore removed. Figure 8 shows an improved version of the start screen with different buttons and additional status information, but sacrificing the mood image from the first design (figure 7), which was considered worthless by the users.

Fig. 8. Start screen of MARiS in the second design

Concerning terminology, we were asked to adjust a few labels and abbreviations, to match the current work practice better. While these changes seemed to make the interface less understandable to outsiders and to our developers, it was confirmed by the physicians, that they would actually increased understandability by these expert users. In order to save screen space and provide more expressiveness at the same time, it was discussed to replace some labels by smaller pictorial elements, such as the chip card icon in figure 5 and to consistently use them throughout the interface. The chip card icon alludes to the actual chip card, which each patient in the German public health insurance system needs to have and which stores personal and insurance information. The rather subtle change in color of the icon signifies different insurance status, which is important for the billing process.

In other areas, our users had even more suggestions for interface elements alluding to their current work practice. When ordering an anesthetic procedure, for example, they had used a particular form before, which was in a characteristic yellowish color and contained a number of fields which had to be filled by black pencil strokes. Users working in this area suggested, that by providing a similar dialog in the corresponding part of the mobile UI, they would immediately recognize and remember this paper form and would feel more confident filling it out. Figure 9 shows this selection dialog using the tickmarks from the paper-based form.

Fig. 9. MARiS form for ordering a particular set of anesthetic procedures

Finally, some more general changes in the interface concept were requested. One change concerned the voice recording facility. While we had used a one to one copy of the operating system's built-in function for this, which just provided record and playback, our users felt that this was more limiting than their current work practice with portable voice recorders. Consequently, we extended the voice recording facility to include all functions of the traditional dictaphones. Voice recordings would also be immediately available with the patient record they belonged to, even before they were transcribed in the back office. Figure 10 shows the screen of this extended voice recording functionality with buttons for going back and forth in the recording, playing, modifying and ending it. For convenience, the PDA's physical record button on the side of the device doubles the function of the record button in the interface. One function that was included in the first design was the capability to add free form drawings in addition to voice memos or text. These drawings were meant to be used to denote locations of a particular diagnosis or treatment, which might be hard to express in words. Figure 11 shows the interface for this, which basically mimics the PalmOS built-in drawing program, but provides background templates for the human body and parts of it. During the initial testing phase

Fig. 10. Extended MARiS interface for voice recording

it was found that this functionality, although well meant, was hardly used. This can partly be attributed to the fact that the small electronic drawings did not have an equivalent in the previous work practice, where marks were made – if at all – on actual radiologic or photographic material. We therefore removed this functionality in the current productive version.

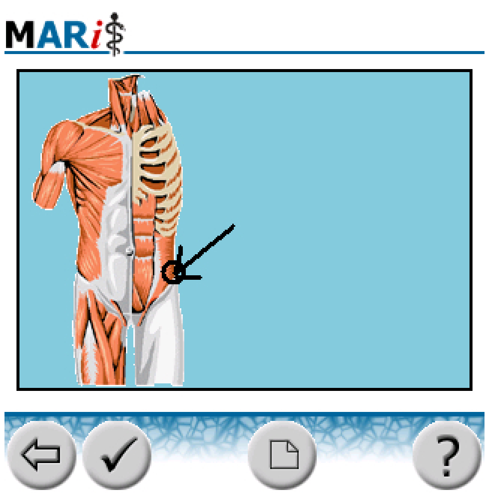

Fig. 11. MARiS interface for drawings, e.g., locations on the body

Finally, it turned out that the patient lists became too long to be handled by a simple list view for the initial selection of the patient in question. Since visits were mostly payed to each patient of a department in turn, a spatial grouping of patients seemed to make the most sense. We therefore added a patient selection by department, which first queried the department in a list view and then provided a ground plan of the selected department with patient icons located in the respective rooms. This graphical mapping was derived and updated automatically from the current patient database (figure 12). In further feedback rounds, however, we were told that this graphical solution went too far and was rather perceived as silly. We therefore removed the map-based selection, but kept the selection by department, which proved to sufficiently reduce the patient list.

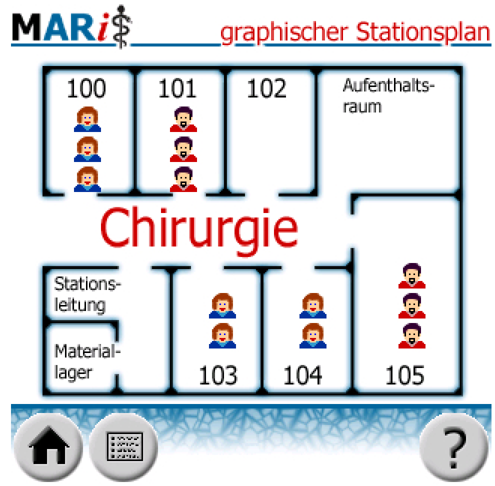

Fig. 12. MARiS interface for selecting patients by department and room

B. Further design iterations

In subsequent rounds of feedback, the changes became more subtle. The system was also used in more varied contexts. After a few more weeks of use it was found, for example, that physicians often had to switch back and forth between different screens to find changed entries or places, where requested information was still missing. In order to signal where something was missing, we suggested to use the register tab's color attribute, which was unused before. Figure 13 shows how a red register tab signals missing information in the corresponding register card.

Fig. 13. Colored and two-dimensional register tabs

We also found that in some application contexts, the application needed to display more data than a single screen could hold. We therefore extended the register tab concept to the second screen dimension and split more complex information into vertical register cards (figure 13). Although this concept moves further away from physical reality, it was intuitively understood by our users.

VI. Lessons learned

The development of MARiS showed that our user-centered design approach led to results which could not have been anticipated otherwise. We learned a number of lessons, both concerning the actual application, and the development process.

A. Lessons about the application

The hospital environment has a long tradition of established and developed work practices. When introducing new technology into such an environment, it is extremely important to closely look at these processes and to carefully design the interface in such a way, that it mimics existing procedure. This includes the actual process structure, but also terminology and familiar visual elements and symbols. An extreme example of this are the paper tick marks in figure 9. Later versions of of the application can then slowly start to move away from existing and accepted concepts by modifying and extending them towards the enhanced capabilities of the computer as a medium (see for example figure 13).

One other lesson from developing the MARiS UI was the fact, that not only the billing logics behind such a system can strongly depend on national variations in the health care system, but that also the actual visual elements of the UI do. Using the chip card symbol for health insurance status was only viable, because every member of the German public health insurance system owns one of these cards and immediately recognizes its shape. It would therefore probably be completely meaningless in other countries.

B. Lessons about the process

The successful development of MARis so far, would not have been possible without the continuous support of a good and enthusiastic user base. The user-centric design approach actually led to benefits on both sides and hence to a self-confirming effect: The MARiS application obviously benefits from the repeated end user feedback and the intense discussions. Users in turn felt that they were seriously involved in the development of the actual tool they were expected to use one day. This gave them a very positive attitude towards this new technology and helped to overcome technophobic tendencies which can sometimes be observed in relatively traditional and non-IT oriented fields such as health care.

If we were to do the project again from scratch, we would probably actually still intensify the design and feedback iteration process: In the project described here, all prototyping was done on the actual target platform and in the target programming language. We did not employ paper prototypes, since we felt that they would be too far from the mobile application scenario. In hindsight, we could probably have saved a certain amount of development efforts, by applying paper prototypes in a very early stage and identify, for example, issues related to terminology and symbols earlier on.

VII. Conclusion

We have presented the development process of MARiS, a mobile frontend to an electronic patient record system. In order to facilitate a smooth transition from current work practice to the new technology, we employed a strictly user-centered design approach. This approach produced an application which was in several ways unexpected and could not have been produced by a development team alone.

The MARiS system is currently in use by 5 German hospitals with 31 devices for physicians and 8 devices for nursing staff. In addition, we are running pilot test with three more hospitals, each of which uses 3-5 devices.

By increasing the quality of medical documentation and at the same time reducing the overall time spent for administrative work, MARiS certainly contributes to an increased quality of medical treatment in these facilities. MARiS also generated a financial effect through increased quality of the documentation used for billing. In those hospitals where MARiS is used on a permanent basis, the volume of documented and billed treatments increased noticeably and caused a financial payoff of introducing the system within hardly more than a year.

Acknowledgment

The authors would like to thank Martin Gisch and Wolfgang Wonner, who did the main development of MARiS, our development partner hsp, who provided access to the hospital information system and created the connection to our pilot users, as well as the staff of the hospitals of St. Wendel and Ottweiler, who provided most of the initial feedback on the interface designs.

References

[1] H. Bludau and A. Koop, *Lecture Notes in Informatics: Mobile Computing in Medicine*. Kllen Verlag, 2002.

[2] R. Percevic, M. J. Lambert, and H. Kordy, "Computer-supported monitoring of patient treatment response," *Journal of Clinical Psychology*, vol. 60, no. 3, pp. 285–299, 2004.

[3] D. Heiss, A. Knig, S. Endres, T. Pflger, K. Pfeifer, and K. Hahn, "Combined pacs and internet information system in a university medical center," *Neue Bildgebende Verfahren*, vol. 172, no. 6, pp. 542–552, 2000.

[4] M. Kroll, M. Sudyatma, and H.-G. Lipinski, "The mobile dicom internet portal serving dicom waveforms to j2me capable devices - a feasibility study," in *4. Workshop der GMDS Projektgruppe Mobiles Computing in der Medizin*. GI - Lecture notes in Informatics (LNI), 2004.

[5] S. Nelwan, T. van Dam, P. Klootwijk, and S. Meij, "Ubiquitous mobile access to real-time patient monitoring data," *Computers in Cardiology*, pp. 557– 560, 2002.

[6] J. Pollard, S. Rohman, and M. Fry, "A web-based mobile medical monitoring system," in *International Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications*. IEEE Press, 2001, pp. 32–35.

[7] J. Kjeldskov and M. B. Skov, "Supporting work activities in healthcare by mobile electronic patient records," in *Lecture Notes in Computer Science*, vol. 3101, 2004, pp. 191–200.

[8] J. Bardram and T. A. K. Kjaer, "Supporting local mobility in healthcare by application roaming among heterogeneous devices," in *Lecture Notes in Computer Science*. Springer, 2003, vol. 2795.

[9] M. Munoz, V. Gonzalez, M. Rodriguez, and J. Favela, "Supporting context-aware collaboration in a hospital: An ethnographic informed design," in *2806*. Springer, 2003, pp. 330 – 344.

[10] J. E. Bardram and C. Bossen, "A web of coordinative artifacts: collaborative work at a hospital ward," in *International ACM SIGGROUP conference on Supporting group work*. ACM Press, 2005, pp. 168–176.

[11] D. Norman and S. Draper, *User Centered System Design; New Perspectives on Human-Computer Interaction*. Lawrence Erlbaum Associates, Inc. Mahwah, NJ, USA, 1986.

[12] B. Shneiderman, *Designing the user interface: strategies for effective human-computer interaction*. Addison-Wesley Longman Publishing Co., Inc. Boston, MA, USA, 1992.