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Synopsis

Ubiquitous Health Care Systems: A New Paradigm for Medical Informatics?

Introduction

The concept of Ubiquitous Computing entered the world of computer science in the late 1980s and its introduction is often linked with Mark Weiser, Chief Technology Officer at Xerox's Palo Alto Research Center at that time [1]. One prominent definition he gave is frequently cited : „Ubiquitous computing names the third wave in computing, just now beginning. First were mainframes, each shared by lots of people. Now we are in the personal computing era, person and machine staring uneasily at each other across the desktop. Next comes ubiquitous computing, or the age of calm technology, when technology recedes into the background of our lives."

Since these early visionary days, miniaturization and improvement of computer, sensor and networking technology, development of new materials like intelligent textiles, smart paper, etc. and improvements of power supply helped to bring this vision at least partly into reality. Today several variants of „calm" and „receding" technology can be distinguished [2]

1. Mobile Computing: Making computer technology portable is the main objective of mobile computing. Using Personal Digital Assistants (PDA) or Smart Phones offers features like Internet and mail access or functionalities of office systems, etc. But these features are usually only a subset of stationary PC functionality. An important limitation of mobile computers is, that they are not aware of their changing environment, while being moved. Thus these devices are not able to adapt their services context sensitively.

2. Pervasive Computing: Permanently adapting a mobile computer and its services to a changing reality characterizes pervasive computing. A prerequisite of this is an active environment of devices able to recognize the emergence of a new device, whereupon the devices start to exchange information concerning their status and services.

3. Ubiquitous Computing: Ubiquitous computing, even though often used synonymous to pervasive computing, combines mobile and pervasive computing with the objective of surrounding the user with technology that unobtrusively provides him with information and services dependent of his environment and relevant to him in a particular context [3]. The computer as a single device with its rather cumbersome user interface consuming almost full attention of its user will vanish in this vision. Instead, intelligent user interfaces far beyond today's graphical user interfaces will enable the user to interact with his environment while simultaneously using IT-services.

The healthcare environment seems to be an ideal application field for ubiquitous computing. Where else is the paradigm of „Getting the right information, at the right time, in the right place" of greater importance than in healthcare? Three fictional scenarios, one from the perspective of health professionals, one from the perspective of patients in a home-care situation and one from the perspective of a health care institution may illustrate the potential of ubiquitous computing in health care.

Scenario 1: Assistance for health professionals

A clinician of a hospital department is on his daily round visiting inpatients together with other professionals of his interdisciplinary health care team. Each professional is wearing glasses including a display, a headset and a small tablet to write notices and receive additional pictorial information. Nearing the bed of an inpatient, all of them receive some spoken summarizing information specific to their profession concerning the status of the patient via their headsets and their glasses. The discussion of the case is accompanied by information given by the ubiquitous health care information system on demand or automatically via the headset or the tablet. When the system becomes aware of the discussion of some current laboratory findings it presents the corresponding progress curves automatically using the tablet in combination with other laboratory values that are relevant to assess the case. Diagnostic tests or therapeutic procedures are ordered using the headset, repeated by the system and finally authenticated with a simple „O.K.“ spoken by the clinician. Comments concerning possible interactions of a new prescription with an existing one together with some recommendations for an alternative are given immediately but inconspicuously via the headset of the clinician. This rather futuristic scenario points out the possible benefits of ubiquitous health care systems for health professionals: leaving the burden of cumbersome user interfaces behind to provide or receive necessary information whenever and wherever it is needed.

Scenario 2: Home care

The second scenario refers to a patient with a severe chronic health problem, e.g. after a heart and lung transplantation. After his hospitalization period the patient is back home but under continuous surveillance. Two times a week he has to do some training to strengthen his cardiovascular system. Instead of training at home he decides to go to the fitness studio in the neighborhood to do his training and meet some friends. He puts on a special T-shirt with miniaturized sensors integrated that unobtrusively record the ECG and other relevant parameters. He selects an ergometer bike, which immediately recognizes the patient's needs for a specific training program. In addition, the patient's Smart Phone recognizes the training situation. Using the headset the patient is wearing the Smart Phone asks him some questions to assess his subjective health status. The questions are part of the patient's personal clinical monitoring program. All data is collected by the Smart Phone and immediately transferred to a remote health professional, who keeps track of the patient. Again in this scenario the burden of using special medical devices or PC systems is reduced and the patient's life gets a little bit more „normal“.

Scenario 3: Socio-technical systems

The third scenario is a supra-individual one concerning aspects of self-organization of resources. Imagine a radiological department where the information system autonomously keeps track of the patients waiting or being examined to automatically update the schedule and resource planning. No manual data entry concerning patient logistics is needed. Each patient is equipped with a PDA and automatically gets informed if his examination is postponed to a later time or if he should move to another examination room.

Some aspects of these scenarios may still be science-fiction, but some important milestones have already been achieved. E.g. scenario three has been explored intensively in the EMIKA project of the University of Freiburg, Germany [4]. The technology needed for this scenario is already available and in use in other domains. Miniaturized RFID-chips (Radio Frequency Identification [5]) allow the wireless transfer of data within a limited area around a special RFID-reader. In the EMIKA-project, each patient was equipped with an individualized RFID-chip enabling tracking him within the hospital.

The special section „Ubiquitous Health Care Systems“ of this yearbook takes a closer look at current research in ubiquitous computing in health care. The paper by P. Lukowicz et al. [6] gives an overview of wearable technology; a basic technology of ubiquitous computing. The article by E. Coiera and R. Clark [7] suggests a concept to implement electronic consent of a patient for information exchange in an ubiquitous computing environment. The work by A.E. Carroll et al. [8] can be related to scenario one concerning the possibilities of PDA technology to improve documentation quality. The papers of C. Maiolo et al. [9] and I.M. Marks et al. [10] can be related to the second scenario focusing on supporting home care.

Basic technologies: Wearable systems

One popular instantiation of Ubiquitous Computing is wearable systems. Miniaturized electronic sensor systems invisibly integrated into clothes or small computers worn on the body and equipped with sensors for context awareness and a sophisticated user interface span the spectrum of possible devices. The recently published paper by P. Lukowicz et al. provides an interesting overview of current wearable technology and focuses on possible applications in health care.

To describe wearable technologies, respectively the technologies used to implement them, the authors suggest a 4-layer model for wearable system architectures. The layers are functional textiles (electrodes, data and power lines, etc.), embedded microsystems (sensors, power generation, etc.), attachable peripherals (display, keypad, etc.) and miniaturized appliances (mobile phones, PDA, etc.). Examples for every layer are given: conductive textiles, buttons with sensor and power generator functionality, displays that are integrated into glasses, and miniaturized computers integrated into a belt.

But what are meaningful applications of wearable technology in health care? The authors suggest the domains of monitoring, assisted living systems, mobile treatment and information management tools for health professionals. Besides adding valuable information sources concerning the health status of a person, miniaturization of *monitoring devices* are an important step to reduce the presence of a disease for a patient and his environment. First developments in medical informatics of wearable sensors combined with portable computer technology can be traced back to the year 1976 [11]. Current commercially available examples are devices for continuous measurement of blood glucose or measurement of a person's calorie balance. Additionally, ideas of *mobile treatment* like insulin pumps or pacemakers are already implemented. Sophisticated approaches integrate electrodes for muscle stimulation in textiles worn directly on the skin to help people with neuromuscular disorders. *Assisted living systems* are combining the technologies mentioned before with other techniques of ubiquitous computing to monitor the health status of e.g. elderly or impaired persons and to surround them unobtrusively with supporting information or functionality. The objective is to reduce the need for personal care and to keep the patients independent as long as possible. *Medical personnel* could be equipped with unobtrusive user interfaces like glasses with embedded monitors to receive support through context sensitive presentation of information needed to decide about a patient's status or about the treatment plan.

Wearable systems have enormous potential to improve the situation, especially of persons with chronic diseases or impairments who need continuously support or supervision. One important vision of ubiquitous computing in the field of health care, to surround these people unobtrusively with assisting technology, has no chance of acceptance without progress in wearable technology. Some developments in this field mentioned in the paper are rather motivated through a „natural“ trend of miniaturizing sensors and devices, but at least intelligent clothes is a research direction of its own. The rather short list of references to successful projects given in the paper of P. Lukowicz et al. leads to the impression that the research community concerned with wearable technology is rather small. Taking into account that the vision of wearable computing is more than fifteen years old, the question for reasons of this apparently restricted interest emerges. Are the technological barriers too hard to take? Is the real need for these technologies rather restricted? Or is the public awareness of the possibilities of these technologies not elaborated enough to enhance the funding of research in this field?

Safety and security: Consumer consent in an electronic environment

Ubiquitous computing in health care will need some exchange of information between the participating devices concerning the health status of a patient and this information exchange will be as unobtrusive as possible. But this kind of mainly transparent background data exchange has the inherent problem of ensuring privacy. Which information will be accessed by whom using which channel for which purpose? No patient or health professional will ever confide in ubiquitous computing if he cannot easily obtain a credible answer to this question any time he wants to. Every person should consistently get access to technological means allowing him or her to restrict this information transfer. This demand, emerging from the basic personal right of informational self-determination, is of actual relevance beyond ubiquitous computing. Every project concerned with electronic health records, whether designed for certain health care institutions or for trans-institutional health networks, needs to address this problem.

In their detailed paper, E. Coiera and R. Clarke give an excellent introduction to this problem domain. They introduce the concept of an e-Consent as the basic object defining permissions or denials for access to confidential patient information. Additionally, they suggest some basic design principles for any consent framework followed by an intensive discussion of possible forms of consent ranging from general consent (access is allowed generally) to general denial (generally no access is allowed). After discussing the possible functions of an e-Consent, i.e. their form and operational impact, ranging from just being informational to controlling access strictly by an access service, Coiera and Clarke propose a basic transaction model that decides if a transaction is permitted to be performed based on the consent rules deposited by the patient. Some further suggestions concerning the implementation of an e-Consent and a discussion of the impact of an e-Consent on clinical work close the paper.

The problem of patient controlled consent on transfer and processing of confidential patient information is related to the establishment of public key infrastructures, trusted third parties, institutional security policies and the functioning of policy bridging between institutions. These aspects are subject to intensive research and standardization activities including aspects of patient related access right management (see e.g. [12]). The work of Coiera and Clark may add substantial contributions to these developments.

Assistance for health professionals: PDA for documentation purposes

To provide clinicians with current information at the time and the place the information is needed is one golden rule of information logistics in medical informatics. Capturing clinical relevant data directly at the time and place of their creation without any delaying and error-prone transcription is the second golden rule. Enhancing the quality of data captured this way should be a positive side effect. The use of interconnected mobile computers like PDAs is a current way to implement these rules. Their suitability to support the delivery of clinically relevant information from and to the point of care has been examined frequently and a lot of research prototypes and commercially available devices have been developed. But are they in fact an appropriate means to enhance documentation quality?

Coming from the prominent 1999 report of the Institute of Medicine „To Err Is Human: Building a Safer Health System“ [13] with its remarkable results concerning a 50% rate of preventable medical errors of up to 98.000 patients that died of medical errors, A.E. Carroll et al. focus on the often published thesis, that information technology is an appropriate mean to reduce these errors. They conducted a before-and-after trial in a neonatal intensive care unit to explore changes in documentation discrepancies when a resident is using a PDA instead of paper based progress notes. Subject of the study were discrepancies in the documentation concerning three aspects: weight, medication and vascular lines. Only the weight documentation revealed a significantly better result for the PDA concerning the number of documentation discrepancies. The other two dimensions showed no significant changes.

The authors come to the conclusion that the results did not reveal a clear improvement in documentation and the PDA would fail to provide a clear benefit. This is surprising due to three reasons. Beside the fact that the results of the study point in the other direction, the conclusion does not take into account the potential of electronically available data for following activities especially in the context of quality assurance programs. Thirdly, the study design has some weaknesses, most of them discussed by the authors themselves.

One aspect worthy of being discussed would have been the integration of plausibility testing features into the PDA. A PDA can realize advantages concerning the quality of manual documented data only when providing active control of the entered data with respect to completeness and correctness. Replacing only the pure documentation functionality of a paper based record by a PDA has hardly any advantages. The same good or bad documentation habits would produce the same good or bad documentation quality, whether with or without electronic support. In the study conducted by Carroll et al., where one year lies between the two study periods, changing documentation habits may have had more influence on the results than the technical intervention.

A further open question concerns the optimization of user interface design with respect to the simplicity of the data input task. A cumbersome user interface may have negative effects especially with respect to omissions. This is true all the more for those data the clinician believes are not really relevant. Interestingly, the omission rates of medication and vascular line documentation in the study are higher for the PDA. Generally the results of such studies have to be interpreted very carefully, because they are extremely sensitive to user interface quality. Just a few minor alterations in user interface design are sufficient to transform a former usable system into an instrument that, if used at all, produces a horrible error rate. A suggestion is to include a statement of a human factors engineer into every study of this kind.

Home care I: Home telemonitoring for patients with severe respiratory illness

One of the most promising visions of ubiquitous computing in health care is the unobtrusive surveillance of patients with severe chronic diseases at home reducing the need for face-to-face medical visits or hospitalization. Relevant data characterizing the state of health of the patients can be used by watchdog applications or remotely accessed by health professionals who are allowed to adapt therapy or surveillance in a timely fashion in case of deteriorations of the patients health. A lot of telemedical approaches have been developed to realize improvements this way for different diseases. A prominent example with a lot of telemedical applications is the surveillance of people suffering from diabetes (see e.g. [14] or www.ist-inca.org).

The paper by C. Maiolo et al. presents a study concerning the application of this approach for patients with respiratory illness compared with traditional health surveillance based on hospital visits. To assess the effectiveness of the telemedical approach the number of hospital admissions and acute home exacerbations were considered. The study is organized into two phases each of 12 months length with a study population of 30 patients receiving long-term oxygen therapy. In the first phase the patients were observed traditionally with visits in the hospital every three months. In the second phase a telemedical system for monitoring pulse-oximetry data was additionally installed in the patients home to measure arterial oxygen saturation and heart rate twice a week during the night with immediate data transmission afterwards. The remote health professional accessed these data the next day to adapt monitoring or therapy plans. 27 patients completed the two phases with the result of significant lower hospital admissions and a significant lower number of acute home exacerbations in the telemedically supported phase. The authors conclude that beside the better outcome of the telemedically supported home-care, the costs of treatment can considerably be reduced through the reduction of hospital stays.

The paper impressively supplies evidence that telemedical services can be a mean to improve home-care while simultaneously reducing costs. The development of smaller medical sensors possibly integrated into clothes or things of daily life and interconnected in a wireless fashion would complete the vision of ubiquitous computing for this home-care scenario.

Home care II: Computer-aided self-help for anxiety and depression

Computer-aided home-care for psychiatric patients: Having the popular image of intensive and individual face-to-face therapy in mind, this seems to be the least unusual. The paper by I.M. Marks et al. presents an impressive example of effectively extending the psychiatric face-to-face therapy of a clinician by means of computer applications. The four applications presented were developed for phobia and panic, for depression and anxiety and for obsessive-compulsive disorders. They were designed to provide immediate computer-aided cognitive-behavioural self-help therapy, i.e. the patients use the systems as needed and where needed without being supervised by a clinician. The applications can be accessed in different ways using a stand-alone PC, the Internet or the telephone in the case of the interactive voice response systems.

Marks et al. describe a pragmatic evaluation study of their systems. For 15 months they offered 355 patients with very chronic, moderately severe problems the combination of computer-aided and face-to-face therapy. To measure the effects, the 210 patients found suitable for the intervention therapy were assessed with respect to their disease severity using self ratings before and after the at most twelve weeklong therapy combination. For 108 patients that passed the therapy, all data needed to assess the system effects were available. For three of the four systems the patients' health state improved significantly, one system was at least assessed useful. The authors conclude that with this apparent effective therapy combination the workload on clinical therapists can be massively reduced enhancing the throughput per therapist with positive effects concerning the costs of treatment.

Of course the interpretation of the results should be done carefully, because the study is not a randomized controlled trial comparing the outcome of traditional face-to-face therapy with that of computer-aided therapy. But the authors stress this problem in detail referring to several randomized controlled trials that mainly support their results. To sum it up the results can be interpreted as being very promising concerning the possibilities of computer-aided therapy in psychiatry.

Conclusion

The vision of ubiquitous computing needs further research on technologic issues like miniaturization, spontaneous networking with sufficient bandwidth, improvement of power supply of mobile devices, shielding of devices like pacemakers from the extremely growing use of RF-networks, etc. But some other important problems have to be addressed beyond these technologic aspects. Ubiquitous computing inherently implicates unobtrusive technology working autonomously in the background. Taking into account that even nowadays, where the computers are relatively „touchable“, the mistrust concerning automated data processing and information exchange is very high, to what amount this mistrust will evolve when hundreds of even invisible devices are exchanging information of the perhaps very personal and confidential kind? Beside this Big-Brother anxiety, the feeling of loosing control while being part of anonymous machinery may emerge especially when thinking about home care scenarios.

The papers presented in this section are a valuable contribution to some aspects of these questions and it will be very exciting to see how this extremely promising field will evolve.

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