Experimenting with ubiquitous computing technologies in productive environments

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Ubiquitous computing techniques are ideal tools to bring new solutions to environments which are otherwise quite resistant to rapid change. In this paper we present techniques to carry out experiments in the very heterogeneous environment of a hospital's decision making conference, the ''tumour board''. Introducing the concept of surface interaction we demonstrate how information from various sources such as X-ray film, slide presentations and projections of CT scans together with oral comments and typed notes can be captured and made available for surgeons' use in the operating theatre, without interfering with the ''old'' way of holding the meeting and without putting any extra burden on the hospital staff.

Keywords: ubiquitous computing; medical informatics; user centred design; human computer interaction

Ein Ansatz zum Erproben ubiquitärer Informationstechnik in produktiven Umgebungen.

Ubiquitäre Informationstechnologien sind geeignete Werkzeuge, um innovative Lösungen in Umgebungen einzuführen, die in der Regel eher konservativ sind und in denen Neuerungen sonst häufig auf Widerstand stoßen. In diesem Beitrag stellen die Autoren einen Ansatz vor, der es ermöglicht, die Wirkung neuer Technologien in der heterogenen Umgebung eines Krankenhauses zu untersuchen. Hierzu wird eine typische Konferenzsituation, das so genannte ,,Tumor-Board'', in der das medizinische Personal über Patienten spricht und Entscheidungen über Therapien und Vorgehensweisen fällt, betrachtet. Die Autoren führen das Konzept der Interaktion mit Oberflächendaten (z. B. Videoausgaben für die Projektion oder Datenströme von der Tastatur) ein und zeigen, wie damit Daten von verschiedenen Quellen wie Röntgenfilmen, digitale Folienpräsentationen oder CT-Daten zusammen mit mündlichen Kommentaren aus der Diskussion in der Konferenz aufgezeichnet und später dem Chirurgen im OP zugänglich gemacht werden können. Der Ansatz zeichnet sich dadurch aus, dass die traditionelle Vorgehensweise bei der Entscheidungskonferenz beibehalten wird und dass durch die Aufzeichnung keine zusätzliche Arbeit für das beteiligte medizinische Personal entsteht.

Schlüsselwörter: ubiquitäre Informationssysteme; Medizininformatik; benutzerzentriertes Design; Mensch-Maschine-Interaktion

1. Introduction

Ubiquitous computing ideas and prototypes have been around in research labs for several years. Still it is very difficult to find real deployments in productive environments. Even experiments where ubiquitous computing technologies are integrated with productive real-world are rare (*Davies et al., 2005*). In our case study we look at how the flow of information, work process interaction, communication processes as well as decision making practices in a hospital environment can be enhanced with new technologies. We aim to introduce novel technologies, known and investigated in ubiquitous computing research, into a complex work environment without disrupting established work processes.

The paper is organized as follows. First we provide details about the application domain and the overall setting in which the research is conducted. In this context we look in detail on requirements and conditions. Then we discuss potential improvements that became apparent during the contextual analysis. For a subset of these improvements we present technical solutions, based on the novel introduced concept that combines surface interaction, implicit interaction and time synchronisation. In the final part of the paper we show how this could improve the current work practice in the concrete setting introduced in this paper.

2. Application domain and setting

We focus on interaction processes between medical personnel that are anchored in medical images. Examples of such images include digital X-ray still-images, video sequences recorded using ultrasound, voxel visualisation of CT-images, and digital angiograms. The use of digital images in hospitals has become the norm, and while there has been extensive research on the individual image storing and rendering technologies, little has been researched on the way of using them together for decision making (*Stytz, Frieder, Frieder, 1991; Wong, Huang, 1996; Parisot, 1995*). Three important stages are at the centre of our investigation: image creation (e.g. radiology), image discussion, diagnosis, and decision making (e.g. tumour board meeting), and the use of images (e.g. during surgery in the operating theatre). In this paper we will discuss the use of images for diagnostics and decision making in the setting of a multidisciplinary daily meeting in more detail.

2.1 Tumour board and later use of images

The tumour board is a regular morning meeting in a hospital lecture theatre that serves multiple purposes. In this meeting leading medical personnel (e.g. head professors in radiology, surgeons, and anaesthetists), assistants (e.g. assistant professors), support staff (e.g. nurses), and students come together to discuss patients and treatments (such as surgeries) for the upcoming day. It is the central place for communication between people concerned with the medical treatment of patients. The meeting is strictly organized and the time for each patient is very limited, usually less than 8 minutes.

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In total 5–15 patients are discussed. Such face to face discussions are of great value as the information needs of people in different roles in the medical system and between organizations vary a lot (*Prabuddha, Thomas, 1998*).

For each patient, background information and a brief summary of his medical history is presented using information from the hospital intranet database. Then the current reason for hospital treatment is introduced. In the context of this treatment usually several examinations have already been performed, typically by a radiologist. This includes conventional X-ray imaging (individual still images), CT scans (series of cross sectional images) and ultrasound images as well as angiograms (motion pictures). Source for these images may have been the in-house radiology department or cooperating doctors outside the hospital. A radiologist presents the material, while an assistant switches between the sources and shows the requested images or video sections. The visual material is the central source of information for the discussion, however, it is made usable by the oral comments of the radiologist. During the discussion an expert types notes (keywords only), these are stored in the hospital intranet system as an extension to the patient's electronic record. A patient's case is completed by an agreed procedure for immediate and future treatment which is also recorded in the database. Currently all participants come together in one location, however, including remote resources and experts using telematic services is anticipated, such approaches have been advanced significantly over the last years (*Tsiknakis et al., 1997*).

One typical use of the information recorded and the images of the patient is in preparation of and during surgery. The surgeon can access the notes taken in the discussion as well as all images in the record on a terminal in his office and during the operation in the operating theatre. However, he or she has only access to the raw set of images and the short notes taken. There is no link between the notes and the images.

2.2 Technologies used in the tumour board

During this meeting a wide variety of technologies are used. The images are presented from heterogeneous sources, such as a document camera, overhead projector, from VHS video tape and from different computers displaying still and motion pictures (e.g. DICOM-format images, (*DICOM, 2006*). The visual information is presented with a video projector. A person is manually choosing video sources for the projector to show what is required at the moment of the discussion. The person explaining the diagnostics (usually the radiologist) uses a conventional laser pointer (which is not connected to a computer) to point to and highlight findings that can be seen in the pictures. In addition to the medical images, data from the electronic patient record stored in the intranet can also be projected. An overview of this set-up is presented in Fig. 1.

2.3 Conditions and requirements

Overall the tumour board scenario is a productive and critical environment for experimentation, very unlike a laboratory environment. Even with the full cooperation of the hospital it is very difficult to introduce new software into their system and infrastructure. Providing new software, especially for a decision making process may impact the results of this process as reported in (*Alberdi et al., 2005*). For all experiments, changes, and improvements to be made a foremost condition is not to disrupt the process.

In particular the following 4 points became central constraints to our work.

- *Work in the productive environment during normal operation*: The research is carried out in a productive environment. It is not meaningful to do tests under lab conditions in a restricted environment, as many of the challenges arise only for the real environment. A replication of the infrastructure in full scale is not realistic and would not make sense as especially the involvement of the medical personnel is an essential issue for the design of a new system. Time pressure on people working in the hospital environment is massive and scheduling additional meetings is not acceptable.
- *No changes to the currently used system*: Changes to the current system (e.g. installation of new software on productive machines) are not welcome as they may disrupt the systems. Additionally many of the systems in use, even so they are PC-based, are specifically tailored (e.g. by a manufacturer of a medical device) to the application running. Adding software may violate the contract or risk malfunction of the system. Therefore one important requirement was to add as little new software as possible to existing systems during experimentation.
- *Work with heterogeneous systems*: The software and hardware infrastructure is highly heterogeneous, especially with regard to imaging devices and medical appliances. Even so there are common exchange formats (e.g. PACS, DICOM) the systems still differ to a great extent. There is research that investigates the interoperability on a semantic level (*Ingenerf, Reiner, Seik, 2001*) of electronic exchange. However, in the environment we investigated images and movie formats ranged still from printouts (visualized with a document camera) to VHS tapes and to digital movies in MPEG4. The experience shows that heterogeneity can

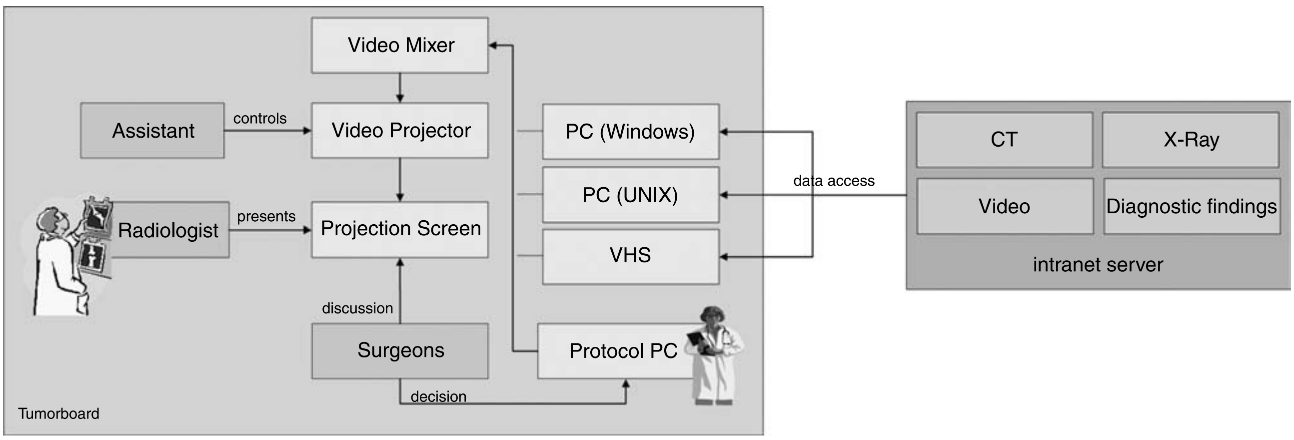

Fig. 1. Heterogeneous technology set-up and data flow during the tumour board

be regarded as given in productive environments (e.g. due to competition between manufacturers, update circles of software and hardware, external relations). In the experimentation phase it is therefore a basic requirement to work with heterogeneous systems.

- *Keep experimental machines outside the hospital's intranet*: The hospital's IT infrastructure is very sensitive with regard to privacy and security. Patient records, lab results, and communication between medical personnel are secret and hence need to be protected. There are laws that request certain standards when handling this data. These privacy and security concerns make it obvious that a further requirement is, to aim to have experimental machines outside the hospital's intranet.

It appears that these points are more generally applicable to research and prototyping in professional and productive environments and that they are not restricted to the medical domain.

3. Expected improvements

At the start of the project one central goal was to ease the use of medical images by the surgeons during operations. One shortcoming of the current solution is that the medical images are presented and discussed during the tumour board, but this information is not tightly integrated with the images. Hence, access to the information and the arrangement of the images, as presented in the meeting, is afterwards difficult and time consuming. In our research we address issues related to accessing an image collection related to a specific patient and the improvement of individual images.

3.1 Improving access to the image collection of a single patient

In many cases there exists a collection of medical images for one individual patient. In these collections some images are of greater value to understand a certain medical condition than others. In other cases a whole set of images has to be consulted to understand a condition and to anticipate a certain treatment (e.g. surgery). For CT data the images are very similar for neighbouring slices. Overall our interviews with professionals and radiologist revealed that it is not economically doable to annotate all images individually (even if this would be technically feasible (*DICOM 2006*)). This is especially the case for data that results from CT. Additionally, for many patients these annotations would not be used in further treatment.

Current practice is that one specialist (e.g. the radiologist) creates a report referencing written text and images (and in some cases movies). This report is then used by another specialist (e.g. the surgeon). In cases where further information is required a meeting between both parties is arranged and the case is discussed in more detail. Within the tumour board an extremely brief version of this communication takes place and the report is orally condensed to the very essence but providing the chance for posing questions and for discussion. This process that takes place during the meeting can be compared to producing a short movie from a vast amount of raw material.

Our approach aims at preserving the ''ad hoc media production'' of the essence of a case and making it the entry point to the material available. For this we want to record the composed materials (usually between 1 and 7 minutes) and make it accessible in small chunks (e.g. 10–30 seconds) that provide information based on a specific diagnosis or highlighting a particular issue.

3.2 Improving individual images

For improving individual images we mainly regard two mechanisms. First we want to ease the manual and explicit addition of annotations to images and movies. Here one central problem is the annotation of sets of images that are very similar (e.g. a set of CT images that show neighbouring slices). So far there is no support for annotation of the whole set, each image must be treated individually and this is not sensible with regard to time and cost. Second, we are adding implicit annotations to images. With implicit annotations we describe information that has been automatically extracted from the usage of the image. Parameters of interest are how long did the radiologist look at this picture, which regions were looked at, which pictures were looked at while writing the report, or where did the radiologist point to during the presentation. This information can be gathered from monitoring the software that is used to visualize images and additionally by tracking mouse and eye-gaze of the user. Additionally, meta information created in the meeting (meeting notes) can be attached automatically to the corresponding image.

4. Technical approach and solution

Using a user-centred design approach we investigated the technical feasibility of the anticipated improvements described in the previous section. We had several sessions observing the current work process and the project team consisting of experts from the medical domain as well as of researchers in computer science. Overall we followed human centred usability process, similar as suggested in (*Holzinger, 2005*).

4.1 Basic principles

Based on the technical requirements outlined in chapter 2 and the results from our user centred design approach we suggest the following principles for creating experimental infrastructures:

1) *The existing functionality should be available unchanged*
Especially in safety-critical situations this is very important. Our research prototypes are created with this in mind. Therefore new functionality is added without removing ''the old ways'' of doing things.
2) *No extra work load in standard situations for personnel*
The use of the experimental systems during normal work situations should not create an additional burden to the user. The ''prime players'' (in our case the head of the medical school and the leading medical professors) should be able to use the system as they always did.

It is obvious that those basic principles collide with ideas for radical changes. In our experience, however, it is not a fundamental problem to preserve the current system and to add new components, as will be described later. Related research suggests that changes in the user interface may introduce risks of mal operation (*Besnard, Cacitti, 2005*) and this is especially critical in our setting.

4.2 Concept: surface interaction, implicit interaction and time synchronisation

The basic concept of our approach is surface interaction; this combines the idea of implicit interaction (*Schmidt, 2000*) and collaboration with surface representations (*Olsen et al., 1988*). With surface interaction we describe capturing and using information that is created on the very interface between the user and the machine. An example of a surface media stream is projected output from various sources. When information is projected this is independent of the sources where it comes from (e.g. at the projector the operating system, type of appliance, or software used does not matter). An example of an input media stream is the stream of keyboard events created while taking notes, or the recording of a speech during a discussion.

Additionally we look at what implicit information can be captured in a given situation. Such information may include who is present-

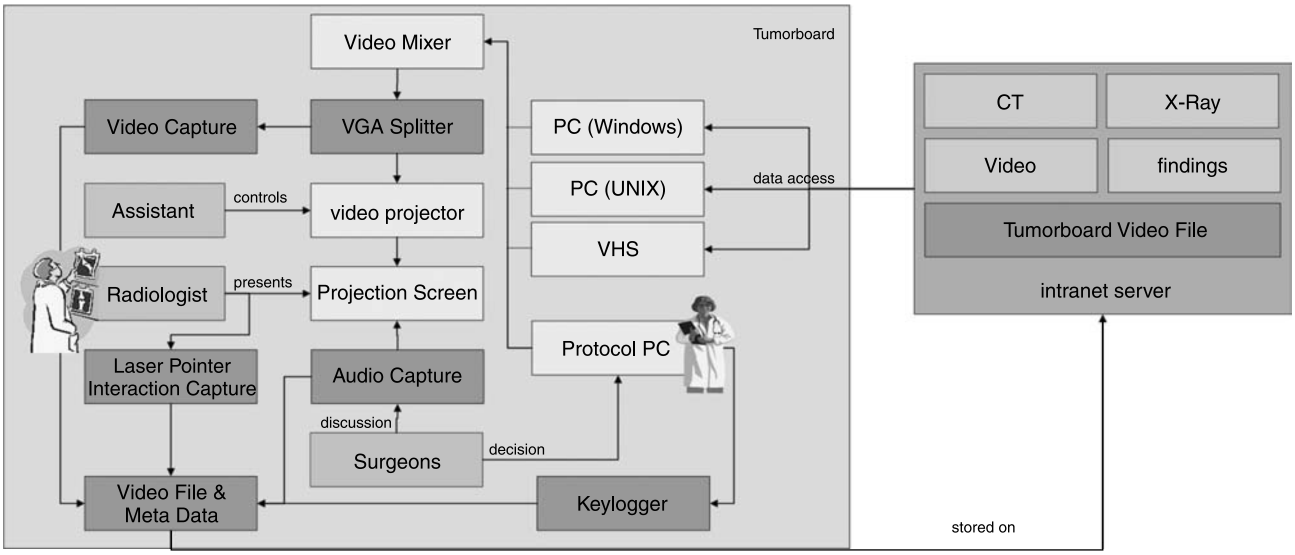

Fig. 2. Surface interaction, implicit interaction and time stamping applied to application domain

ing, where is a person looking at, and what is the noise level (e.g. as an indication for side discussions).

To make this information accessible it is central that it can be correlated. E.g. a typical question may be what was the discussion and consensus reached when this CT-image series was presented during the meeting? To facilitate this all input and output events are time stamped. Using these time stamps cross navigation between different media types can be achieved.

In the remaining part of the paper we show how our approach is applied to the setting introduced in the beginning of the paper.

5. Towards a new tumour board system

Following the concept outlined above we are currently implementing a new system to support the communication in the tumour board, as well as the preparation and use of the material needed there. Figure 2 shows the basic architecture. The components that are added are highlighted. A major concern in our work is that the system and its operation is understandable to the users to prevent further problems that result of wrong mental models (*Besnard, Greathead, Baxter, 2004*).

To acquire the output stream we intercept the output signal between the video mixer and the input to the projector. To allow the projection and to have the signal available for capture at the same time we introduced a video splitter. Simultaneous to the projection the output stream is digitized and stored. During the presentation the audio is also captured using several microphones. To capture the input stream on the computer that is used to write the protocol we investigate two options. One is to use a keylogger software that logs all key events with a time stamp. The other is to use a hardware keylogger, which is a device that is plugged between the keyboard and the computer. The software solution is more flexible but has the drawback that software needs to be installed on the productive system. The hardware solution is designed for offline use.

During the presentation we are interested in the actions of the presenter as well as those of the discussants. Currently, we experiment with options to capture the laser pointer on the surface that is used by the presenter. Information, such as where is the presenter pointing in an image or to what images is he or she pointing at can be attached as meta information to the data stream.

Even though we have the full support of the medical teams involved, it was one central design criteria not to change the way the systems are used. It is obvious that the laser pointer could be replaced by a wireless mouse, however, this would introduce several problems, e.g. what if the data is played in from VHS tape or from a specific imaging appliance? Similarly, we observed that in some instances the assistant of the presenter used the mouse on the computer to manipulate (e.g. move, zoom) the images while the presenter pointed to specific regions in the image. This simple example shows that in many cases capturing surface interaction may be the better and more generic way.

The captured information will be combined together. The system output movie captured will be segmented according to the information from the other media streams (keywords in the log from note taking, key events from the video mixer, or pauses in the captured audio). In this way the segmented video is an easily accessible excerpt of the patient information and becomes the entry point to more in-depth information on the patient.

6. Discussion and conclusion

In our research so far we have seen that user centred design, even if one wants to create a system with little user interface, is essential for creating useful systems. Many ideas that are appealing and interesting in the context of a research lab do not work in the real world. Not investigating the real world (e.g. contextual enquiry and workplace observations) will most likely waste resources as lab developments are often not transferable into the real situation of use, especially in a system and user interface context.

Even though it is very difficult to experiment within a productive high-tech environment (and a medical hospital is only one example) we believe that surface interaction is a powerful approach to do research. Using surface interaction, implicit capture, and time stamping is a generic approach that is noninvasive to existing systems and does in general not put extra burden on the personnel. Using this approach heterogeneity is easier to master and the risk for disrupting the overall service is minimized.

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