Designing Usable Ubiquitous Computing

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ABSTRACT
This paper demonstrates that in order to design successful ubiquitous computing, designers must consider concurrently both the end user interactions in the context of use and the suitability of the technology and its underlying infrastructure. We describe methods used to create more useful collaboration and communication between users, designers and engineers in designing ubiquitous computing systems. We tested these methods in a real domain in an attempt to create a system that is affordable, minimally disrupts the end-user's workplace and improves human-computer interaction.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Evaluation/methodology, input devices and strategies, prototyping, user-centered design.*

General Terms
Design, Human Factors

Keywords
User-centered design, participatory design, interaction design, ubiquitous computing, multimodal interfaces.

1. INTRODUCTION
It has been more than a decade since Mark Weiser's seminal article "The Computer of the 21st Century" [6] defined a vision for the now familiar term "ubiquitous computing". Although computers have achieved ubiquity in the form of wired and wireless devices such as mobile phones, PDAs, screens, and embedded microprocessors, in many cases they have not blended into the background to seamlessly support human activity in the way envisioned by Weiser. Some users have successfully adopted stand alone items like PDAs, modifying their practices in order to take advantage of new technology and sometimes integrating them with other devices.

However, far too often, the leap from adoption of single machines to adoption of multiple machines operating as a ubiquitous computing environment has been less than ideal. As Weiser pointed out, the problem of designing ubiquitous computing is not due to technical challenges alone but demands the "very difficult integration of human factors, computer science, engineering, and social sciences." These problems are manifest in infrastructure costs, deployment difficulties, user training needs and uptake difficulties (due to systems being designed from a technical vision, rather than designed to meet the needs of particular work practices). In order to explore these issues for ubiquitous computing, it is necessary to consider both end-user interactions, practices and capabilities (such as the ability of end users to integrate devices into their practices) and the characteristics of technology and its underlying infrastructure. This suggests that rather than develop a complete concept for a ubiquitous computing environment and then build a decontextualised prototype, a participatory bootstrapping approach is needed. In such an approach designers reveal the capabilities and characteristics of technology and technical infrastructure to end users in intelligible ways (end users often find the details of infrastructure both mundane and baffling) and end users try out and explore the possibilities for such technologies to enhance their practices in the context of their work environments.

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2. DESIGNING TECHNOLOGY
There are many examples of ubiquitous computing systems which seem to have an implicit assumption that usability and technical systems design are separate from one another. While these systems demonstrate useful technologies and potential scenarios for their use, they lack a sense of user involvement and have generally not explored how they will be embedded into practice.

2.1 Augmented offices
Work carried out by the Xerox Research Centre Europe imagined what a future office may be like [1]. Their aim was to create an "affordable enabling infrastructure", with a basic assumption that technology in their scenarios would be both inexpensive and readily available. While this assumption may hold true, it would be instructive to explore the scenario from the point of view of the end user through participatory design. An example scenario given by the researchers describes a user attempting to print a document. RFID tags embedded into the paper would allow the user to locate their document quickly and efficiently. If a user attempted to print a document when a large file was already being printed, the option to initiate a negotiation of printer priority would be available. The printer would initiate a phone call to the owner of the large print job to facilitate this.

A participatory design approach might explore business users impressions and experiences in locating a job by RFID tags, examine what expense was considered worthwhile, reveal what other things they might do with technology such as RFID tags, examine the logistics of tagging each piece of paper with an RFID tag, examine user privacy issues, examine under what circumstances office workers would be happy to be interrupted from their work to negotiate time on the printer and so on.

2.2 Networked surfaces

A recurring theme in ubiquitous computing research is the idea of networked surfaces. Research into this field has investigated using the surface of everyday furniture such as desks, note-boards, etc, as a means of communicating between sensors and other machines. This allows the devices to both receive power and to communicate without requiring bulky components within their own package to facilitate this independently. Conceptually, this fits nicely with ubiquitous computing's ideals. However many examples given by the Pin&Play project [3] use the surface only as a source of power and not communication. Lifton and Paradiso's Pushpins [4] have a range of only approximately ten centimetres. Thus there are several factors that could be explored through particpatory design. For example, by engaging participants one could examine the context in which such surfaces would be used, which items use the surface for communication, which simply need it for power, how other technologies such as wireless technologies compare, how communication range issues affect usability, other imagined use of the surfaces, costs, etc.

2.3 Interactive rooms

There have been a number of projects that aim to empower entire rooms with computing abilities. By embedding these computers into most of the furniture and walls, computing abilities are argued to be ready-at-hand. For example, the i-LAND project [4] makes use of tables as scanners, desks as collaborative spaces and walls as computer screens. While this technology has successfully made the transition to a commercial product, it comes at significant cost. Having been built as a specific technological platform and product for a generally perceived use, its users must either find specific problems that fit the technological product or adapt the technology to meet user practices and contexts.

3. CREATING COMMUNICATION

We have attempted to create effective communication channels between users, designers and engineers through a series of design activities. These activities have supported a better understanding of the context of use for the designers and engineers while the users acquire a knowledge of how new systems will impact their workplace. These activities are not 'one-off', but rather a part of an iterative cycle of learning. The basic concept behind these activities is to allow users to reveal details of their work practice in conjunction with the designers revealing technological potential.

3.1 The dental surgery

Our research has focussed on studying the domain of a dental surgery. This environment exhibits a rich combination of both human interaction and instrument use within a complex social environment. Dentists are turning to computers to help manage patient records, to assist during procedures, for patient education and to display digital x-rays and pictures taken by intra-oral cameras. The majority of dentists in Australia have a computer in the surgery. However, during a procedure, a dentist must adhere to infection control standards. Primarily, the dentist must remain clean by wearing gloves. These gloves are then removed in order to use things like a keyboard and mouse which are not easy to disinfect or sterilise. This makes use of a traditional computer interface extremely disruptive.

During our research, we approached both dentists within private practice and students at a local dental school. These provided slightly different viewpoints on their interaction within the surgery. Dentists within a private practice are accustomed to 'four-handed dentistry', while the students are more independent as they share their assistant with other students.

3.2 The dental school

We undertook an ethnographic study at the dental school which lasted two months consisting of six visits. It was during this time that we gained an insight into how the school functioned and of the work practices of the students and staff. We used interviews as a springboard for organising design events and creating prototypes.

3.2.1 The digital pen

At the dental school there are a large number of students working concurrently. In addition to this, the chairs are shared across sessions, so a single chair may be used by up to four different people in a single day. Although the dental school plans to completely convert to digital records, the number of chairs and the sharing of equipment make this a slow transition. As an interim step in this process, we investigated the possibility of using a digital pen made by Logitech.

The pen is the size of a large ballpoint pen (see figure 1) and writes normally with ink. However, when used in conjunction with digital paper[1], all strokes of the pen are recorded individually, available for download to a computer. Instead of having an individual machine at each chair, having docking stations instead would allow a central computer to receive all records and catalogue them. This system solves several problems that we identified.

Figure 1: Logitech io digital pen.

Firstly, such a system would solve distribution and filing problems. Currently at the dental school, a record must be recorded on a cleanable laminate sheet or throwaway piece of paper. It is then transcribed by the student to the official record. This record then has the procedure transcribed to a computer by a

[1] The paper is obviously physical rather than digital; however it is imprinted with a fine grid of dots that reflect infrared light. The pen uses a camera to track its position using the dots.

receptionist. If a different department requires a copy of the record, it must be photocopied first. Having a central digital copy would allow anyone to print a copy of the record at any time.

Secondly, this system would allow users to continue using their existing work practices. Keeping a good record is extremely important as their work must be assessed by supervisors and signed off. While it is technically possible to use a computer to allow sharing of a single patient's record between different students, and there are possible authentication techniques for signing off work digitally, we observed that many students would take the record to the supervisor in another clinic or a different part of the room. This is far better facilitated by a paper record.

Finally, using a pen (as opposed to a keyboard and mouse) takes into account infection control procedures. It was observed that students would take a normal pen, swab it with alcohol and then wrap it in glad wrap. The glad wrap was all that was required to protect the pen from major infection. The digital pen used is sufficiently packaged to allow cleaning.

All of these details were not immediately obvious to us during our study. Contextual interviews and discussions with the dental students about technology and potential future work practices revealed these problems.

With this possible interface to a digital patient record, we obtained a digital pen and created a digital paper version of the dental record (figure 2). This looked identical to the record with which they were familiar, so when we trialled it with them they knew the location of data entry points and used it without difficulty.

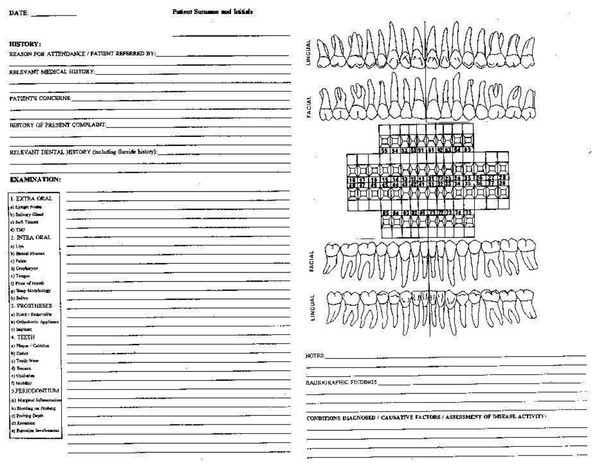
DATE: Patient Surname and Initials
HISTORY:
REASON FOR ATTENDANCE / PATIENT REFERRED BY:
RELEVANT MEDICAL HISTORY:
PATIENT'S CONCERNS:
HISTORY OF PRESENT COMPLAINT:
RELEVANT DENTAL HISTORY (including fluoride history):
EXAMINATION:
LINGUAL
FACIAL
FACIAL
LINGUAL
NOTES:
RADIOGRAPHIC FINDINGS:
CONDITIONS DIAGNOSED / CAUSATIVE FACTORS / ASSESSMENT OF DISEASE ACTIVITY:

Figure 2: The dental record used

Through using a basic prototype system, immediate constraints of a complete system became apparent. For example, we identified to the staff the ability to edit the record and adjust individual pen strokes after downloading it. Immediately the lecturer pointed out the legal requirements that void this as a feature. Knowing this greatly affects our system design: it is more important to have the record easily transferable to the computer than the ability to edit the digital copy. Implementing the ability to edit would both increase development time and be unsuitable for users.

It is also interesting to note that when we first approached the lecturer with the system in mind, they were not enthusiastic. However once a basic prototype was built and they were able to explore the possibilities of the technology for themselves, they began to imagine future use contexts and to question the limits of its use. Once the user felt they were part of the design process, their contribution increased dramatically.

3.2.2 Multimodal interfaces

In a separate investigation [2], we identified the possibility for a multimodal interface (e.g. speech, gesture) to the computer to facilitate interactions with a computer based record, whilst reducing the amount of time required to drive the interface and the workarounds needed to maintain infection control standards. To explore the design of this interface, we ran a design activity with various dental students. This activity aimed to help identify the different ways that information can be represented usefully and useful methods of accessing this information. Our aim was to gain an understanding of which representations and modalities worked well and why.

In order to achieve this, we asked one student to simulate the computer interface, while the other completed an examination on one of the research team members. By varying the way that information is made available and is input to the system, we hoped to identify effective attributes of new interface modalities.

It is extremely important to keep the users involved in the selection of technology. For example, when testing the use of speech and gesture with two of the students, the following conversation took place:

> Student 1: "One more question – is she meant to be telling me where she wants me to write? Usually we just listen to them talk and write."
>
> Student 2: "It's easier for me to just say… 'Medical history – nil sig' so the heading, where I want to write it, and what I want written I suppose."
>
> Student 1: "Cause see how she's talking to him, saying do you use fluoride toothpaste, do you do this, do you do that, and then turning to me and going 'fluoride toothpaste, this' [Student 1 gestures while she's saying this]. Usually while she's saying that I'd be doing that anyway."
>
> Researcher: "Okay, so have you guys done that before, where you're filling out the patient record for someone else?"
>
> Student 2: "Yeah, yeah, if we've got a spare session then we always do it for someone else. The only difference is if someone like a dental assistant or someone is assisting you, like I said, they sort of automatically know where to put it approximately, so there's no repeating any information or anything like that."
>
> Student 1: "Say [Student 2] will be looking the mouth, she'll go through and say 'Yep, quadrant 1 is fine, there's this here', and she'll just say it as she's going and I'll just write it wherever it should go."

Without actually having the users test a possible interface first, we would not have realised they are accustomed to dictating to others for their records, as it was never observed during our study. Furthermore it showed us the most efficient method (in their current work practice) of collecting the data: they know the layout of the record and they know the order the procedure should run in.

With this contextual information, all that may be required for collection is speech recognition and minor contextual clues from the dentist's speech or activities to confirm where the information is placed in the record.

From interviewing dentists in private practices we discovered that existing speech recognition programs relied on training and could only be used by a person who had trained with the program. This type of recognition was used entirely for converting raw speech to text. However, what was found through these activities was that many abbreviations were used. In addition, there was implied knowledge that whoever was filling out the form would know that something would need to be written. For example, "intra oral, nil sig" would mean to ignore all entries under intra oral as there were no problems in that area.

This may explain why comparatively few dentists currently use speech recognition. In addition, there is also a lack of understanding as to what speech recognition can actually offer as detailed in the following conversation:

> Lecturer 1: "So presumably at some stage, I mean we'll end up with voice activated computers so you can actually dictate your treatment plan. But does it respond to any voice? I don't know much about this at all, or is it specific voice activated?"
>
> Researcher 1: "The voice recognition we've been playing with works with anyone, but you can only say really specific phrases, you can't just talk regularly and have the computer understand you. If you want to do that you have to train for a particular person, so there's a trade off there, and the training takes pretty much a day."
>
> Lecturer 1: "So the reality is to voice chart, is not to provide a whole series of charting as you heard the students do when they have a new patient and go through every tooth, that would be more complicated than just a phrase, like "examination" or "periochart"."

3.3 Private practice

After several ethnographic studies at a private practice, a fellow research member prototyped a 'sensing table'. This came out of discussions with the dentist regarding breaks in their concentration from driving an interface. It was envisioned the table could decide which chart was necessary given the instruments in use. An initial prototype using load sensors was demonstrated to the dentist. Immediately problems we had not considered were found. From watching the dentist at work, it appeared they always had unique instruments for different procedures. However, there is overlap we did not observe, and it is not possible to derive the context of the procedure simply by knowing the tools in use. Through further interviewing we discovered that by combining which tool was being used with the location of tools (through RFID technology) the ambiguity is reduced and thus our design was refined further.

4. FUTURE WORK

The activities we have completed so far have not told a full story. It is necessary to take what we have learned from these initial design sessions and apply it towards exploring the methods of interaction and representation of information further.

While the first activity seemed to identify speech as the most essential modality, this may simply be because of the affordances of the paper patient record. Our next activity will allow the record to be completed by selecting written phrases through gesture. This is a technique used by some existing dental software, but so far there has been little research into the trade-offs of each method and their various combinations. During our activities, the students used minimal amounts of gesture which consisted only of pointing. We aim to identify whether this is because gestures are not a viable interface or if it is because they are not afforded by their current information representation.

It is hard to say where the design will proceed after this activity. Details that reveal themselves during these activities have the potential to completely change the course of our design. However, through undertaking a sufficient number of participatory activities and framing the design problem from several different perspectives, the better combination of modalities will emerge.

Workshops that explore the constraints and possibilities of specific interface technologies and infrastructure technologies are also planned. For example, if the interface is wireless, a spatial model of the surgery will be used to help map out 'hot' and 'cold' zones, range, privacy issues, etc, in order to illustrate issues in wireless design to the dentists and to reveal issues from the dentists' perspective.

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