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Design Requirements for Ubiquitous Computing Environments for Healthcare Professionals

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Abstract

Ubiquitous computing environments can support clinical administrative routines in new ways. The aim of such computing approaches is to enhance routine physical work, thus it is important to identify specific design requirements. We studied healthcare professionals in an emergency room and developed the computer-augmented environment NOSTOS to support teamwork in that setting. NOSTOS uses digital pens and paper-based media as the primary input interface for data capture and as a means of controlling the system. NOSTOS also includes a digital desk, walk-up displays, and sensor technology that allow the system to track documents and activities in the workplace. We propose a set of requirements and discuss the value of tangible user interfaces for healthcare personnel. Our results suggest that the key requirements are flexibility in terms of system usage and seamless integration between digital and physical components. We also discuss how ubiquitous computing approaches like NOSTOS can be beneficial in the medical workplace.

Keywords:

Ubiquitous computing; augmented reality; healthcare environments; collaborative work, tangible user interfaces.

Introduction

Recent advances in sensor and wireless technologies make it possible to create novel types of interfaces to computers. These developments have resulted in renewed interest in the area of ubiquitous computing [1]. The concept of ubiquitous computing involves attempts to make computers available through physical tools in the work environment and to make them 'smarter' through the process of computer augmentation [2]. The idea is that people will prefer to interact with computer technology that includes ordinary tools as interfaces instead of choosing to use the windows and buttons of stationary computers.

Ubiquitous computing solutions are particularly attractive in the medical workplace because they may allow medical professionals to abandon static keyboard and screen-based routines for more natural and mobile interaction with computers via familiar workplace tools such as paper forms [3]. These solutions may prove to support both normal workflow and humans' information processing methods more appropriately than present graphical user interfaces (GUIs) and desktop systems.

Ubiquitous computing is still at an early stage of research and development, and very few work environments have been described.

The BlueSpace research project at IBM is an attempt to develop a smart cubicle that combines multiple technologies to activate the physical environment. For example, BlueSpace includes an omnipresent display that can transform any surface (e.g., walls and tables) into a computer system and touch screen [4]. McGee and colleagues have developed an enhanced work environment that can respond to and interpret natural language and the physical location of sticker notes on a chart [5]. Also, related to our research is a system called Manufactur, which is a collaborative augmented reality environment for architectural design work [6,7]. Manufactur integrates physical objects into the digital domain with the aim of tracking the way that users organize paper materials.

Our work is devoted to design of the next generation of computer-augmented workspace solutions for medical professionals [8]. We have developed the NOSTOS ubiquitous computing environment [9], which is based on the ordinary tools and collaborative routines at an actual emergency room (ER) in a middle-sized hospital in Sweden [10]. The experimental system encompasses a range of software and hardware technologies, such as sensors and digital-paper tools to activate the physical workspace and make it the interface to the computer domain. The overall goal of our project is to retain existing paper-based routines and tools, and to augment them and connect them to the digital domain and network to facilitate everyday administrative tasks such as record keeping.

Currently, little is known about how to design computer-augmented work environments, and the need for information is especially pronounced in the context of developing support for the administrative routines of collaborating healthcare professionals. In this paper, we draw conclusions about the results of our workplace study and the design of NOSTOS to formulate a set of requirements for future ubiquitous computing in medical work environments. We illustrate the requirements by showing how we approached them in the NOSTOS environment.

Augmenting physical workspaces

Related to the ubiquitous computing approach is augmented reality [2] where technology enables users to retain familiar physical tools and interaction techniques and at the same time gain functionality of computers. The interest is how we can blend digitization into ordinary physical tools and environments to make them work more efficient and provide easy of use to gain advantages from both worlds.

The rationale for physical interfaces

The graphical user interface approach of today is a direct descendant of the Xerox Star interface of the late 1970s and early 1980s [11]. The Star interface replicates tools of a physical office, hence the metaphors used in the system refer to the office environment (e.g., 'desktop' and 'folder'). Researchers have criticized this interaction model in that it does not effectively support co-located teamwork. For example, the screen of a desktop system is small, which makes it difficult for several users to work simultaneously, and, along with that, it is impossible to quickly hand over a document to share information. Consequently, this solution and model imposes unnecessary tasks on the collaborating personnel.

Rather recently, researchers in the fields of sociology and cognitive science have studied the roles that everyday objects play in the workplace [12,13]. These investigations have shown that professionals depend heavily on the *tangible properties* of objects to align collaborative work efforts and to sustain memory. People actively manage their workspaces to create orderliness and structure to increase the effectiveness and robustness of tasks. For instance, a strategy that is often used to control and monitor a complex work process is to arrange objects in space so that they reflect the state of the process [14].

The mentioned findings are clearly corroborated by our studies of clinical case management routines in an emergency room [10]. Medical professionals assemble their physical workplaces to be rich information spaces that support the teamwork and workflow [15]. For example, we observed that clinicians arranged patient folders on a desk to create a division of labor, enhance workflow memory, and display the tasks to be conducted. Our analysis also revealed that the flexible and powerful information processing properties of paper materials were difficult to capture in GUI. Furthermore, we noted that physical objects such as paper documents were involved in the delegation of tasks and responsibilities in the clinic. For instance, the act of handing over a document from one person to another represents an exchange of responsibility for the task related to the document.

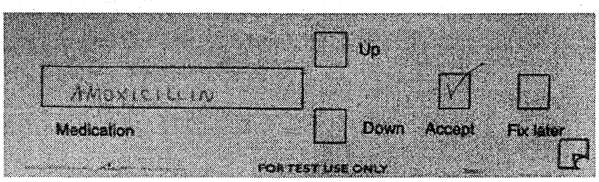

Figure 1 - The experimental paper form. Users tick with the digital pen on designated areas of the form to get feedback and control the system.

Current efforts in medical informatics have been focused on replacing physical information objects such as paper forms with their digital counterparts. However, we feel that this type of substitution will make it necessary for clinicians to both cope with and bypass the virtual GUI solutions. We believe that physical interfaces can provide the additional properties needed to support collaboration and unleash the power of clinical administrative computing. Before we ponder issues related to the design of physical interfaces and computer-augmented environments for healthcare professionals, let us consider technologies that can be adopted to add computational power to the healthcare environment and its artifacts.

Approaches to workplace augmentation

Several different technical approaches can be used to amplify ordinary physical tools and environments with functionality from computer technology. A common method is to superimpose computer-generated imagery onto existing objects by means of projector technologies. In principle, this makes it possible to display output data on any surface, such as a desk or walls.

Radio frequency identification (RFID) technology can be used to connect objects to the digital world [16]. RFID tags are small, batteryless electronic chips that contain unique identifiers (e.g., IP addresses). The identifiers can be detected from a distance by use of a reader and antenna, thus the technology can be used to track tagged objects in physical space. However, a limitation of present RFID solutions is that they often work at a range of only about 10 cm (depending on the size of the reader and tag antennas). With these techniques, it is possible to create a new class of physical interfaces called tangible user interfaces (TUIs) that act as specialized input devices to computers [17]. For example, Ullmer and colleagues developed a TUI for controlling video recorders that utilizes small wooden blocks that serve as physical icons (phicons) for the containment, transport, and manipulation of media [18].

Digital pen technology [19] allows ordinary sheets of paper to serve as an input interface for data capture. The tip of the pen is equipped with a tiny camera that scans paper printed with a pattern to capture the pen strokes. This approach enables the design of active paper applications such as e-mail, improved sticker notes, and forms that can be sent instantly to the computer over a wireless network.

In the remainder of this paper, we discuss how the mentioned technologies can be combined to create an active environment [20] that supports medical professionals by aiding them in their administrative tasks and, in particular, by allowing them to be more mobile and flexible than is possible with the computer interface designs that are available today.

Research Approach

We have previously applied a cognitive perspective [21] in an empirical investigation of routine teamwork performed in an emergency room in a middle-sized hospital in Sweden [10]. For a period of one month, we used ethnographically-informed methods [22] to study the supporting properties of physical objects and to determine how overall computerization could be achieved. We made participatory observations on a surgical team working day and night shifts. The final stage of this study was devoted to ascertaining how paper materials such as forms, folders, and sticker notes were used to align collaborative activities and offload cognitively demanding tasks. The outcome of the study was a set of requirements and a physical interaction model. Subsequently, we developed NOSTOS, which is an experimental computer-augmented work environment designed to support the practices that we had observed in the ER [9].

Results

Let us now consider requirements for computer-augmented environments for healthcare professionals and give examples of how these requirements can be dealt with in the NOSTOS environment.

Mobility and flexibility—tangible user interfaces

We found that ordinary paper technologies supported many tasks in the ER we studied, and in many cases paper constituted a powerful information-processing tool. Paper forms are robust and mobile and offer a good data-capture solution, since a single paper form can hold much more information than its electronic counterpart. Moreover, paper is flexible, thus it can be used for many tasks, for instance as a tool for collaboration. Consequently, we wanted to maintain the properties of paper in NOSTOS and combine them with the benefits of computer technology to get the best of both worlds.

Our solution was to combine digital pen and RFID technology to create a TUI. In NOSTOS, clinicians use digital pens (i.e., the Anoto system) and write on enhanced paper forms to record medical data directly into the computer domain. We created special paper forms and widgets to control the system, and the digital pen is used to write and tick on the form to interact with the system. Figure 1 shows a special paper form.

Our experiments revealed the following shortcoming of this paper-based approach: there is limited user feedback, because it is difficult to determine whether the pen and the software applications actually captured and correctly interpreted what was written. To overcome the feedback problems, we designed two approaches that provide feedback by means of *auditory* and *visual* cues that are channeled through external devices such as earphones and walk-up displays. Both the auditory and the visual systems were written as thin clients that were responsible for sending feedback to the appropriate devices, for processing pen strokes, and for accessing the underlying system. A character recognition engine and a set of string-matching algorithms (i.e., Soundex and Bestmatch) interpret the pen strokes.

A Bluetooth-enabled mobile headset provides the feedback in the auditory approach. For example, a clinician can write a medication on the form and the system sends its interpretation of the text as an audio message to the earphones. To confirm that the interpretation is correct, the user marks the *Accept* box on the form, and the system once again verifies the selection in the earphone. To 'scroll' in a list of items, the user ticks the up and down areas of the form. Furthermore, we added an option (i.e., a Fix later box) for situations in which the system cannot interpret the text appropriately. In the visual cue approach, user fills in a value on the paper form, and feedback from the system is given directly on a walk-up display. Figure 2 shows the walk-up display. To confirm the system's suggestion, the user simply ticks the Accept box, as in the auditory approach, and an accept message is shown on the display.

Attaching RFID tags to patient folders, forms, and sticker notes makes it is possible to determine the positions of these objects in physical space, thus in principle they could serve as a TUI (Figure 3). For example, special functions, such as sending a fax, can be achieved by placing a document at designated spots (near an antenna). We found that this approach also was useful when we developed an improved desk.

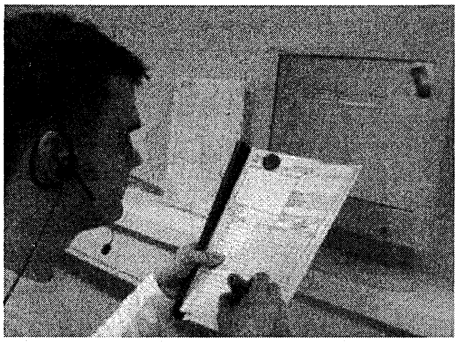

Figure 2 - The walk-up display provides feedback so that users can check the correctness of stylus input

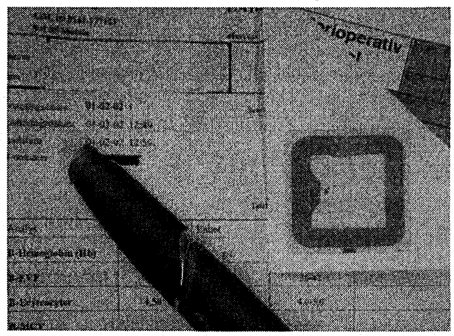

Figure 3 - RFID tags are attached to objects such as documents and folders to track their position on the digital desk.

Collaborative work and awareness—the augmented desk

We observed that clinicians placed patient folders on a desk in an arrangement that supported teamwork and awareness of the activities by functioning as a shared display of the number of patients and triaging. Human information processing at the desk was rather effective and flexible. For example, the triaging could be changed merely by placing a folder in the appropriate place within the arrangement. However, a drawback of this particular collaborative model was when case folders were missing from the desk, for example, when a physician examined a patient and needed the folder. In this case, the representation of the amount of patients and triaging became unsound.

We wanted to explore the possibility of tracking the physical interactions at the desk and to ascertain whether we could improve the representation.

We developed a digital desk, in principle, by placing a moving RFID antenna underneath a deskboard. We used a standard serial RFID reader (RS-232) and attached RFID tags on the folders, which allowed us to determine the positions of the individual folders on the desk. Furthermore, we mounted a projector system above the desk to enable overlaying of computer-generated imagery.

With this setup, clinicians can still organize their workplace so that it will support awareness and workflow, and it will reduce their information processing tasks. For example, NOSTOS automatically keeps track of triaging as follows: staff members place folders in a row on the digital desk as before computerization. Thus, there is no need for clinicians to explicitly enter the triaging into a system. The representation of patients is also kept sound, for example, if one folder is missing on the desk, the NOSTOS projector system will show a virtual representation of that particular folder. Moreover, since the desk serves as a TUI, users can place documents and folders at designated spots to send messages such as faxes. The digital desk is illustrated in Figures 4 and 5.

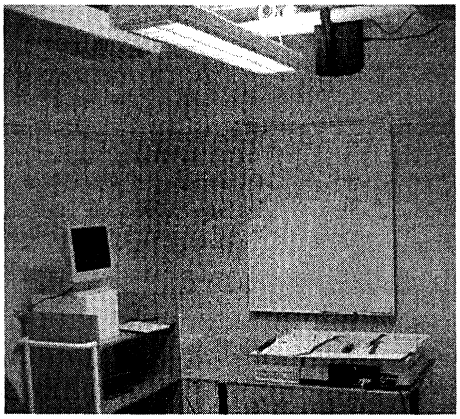

Figure 4 - The digital desk and walk-up display of the NOSTOS environment.

Discussion

The problem with feedback that we mentioned above emphasizes a general question that arises when designing computer-augmented environments that are intended to bridge the physical and digital worlds: how can we ensure the consistency of information between paper documents and their computerized counterparts? We addressed that issue by allowing users of NOSTOS to get feedback to check that written pen strokes had been correctly interpreted into digital text by the system.

However, future systems must be able to handle inconsistencies between physical and virtual documents and it is also important to develop means for users to check and resolve inconsistencies. Nevertheless, active communicating paper displays or lightweight tablet computers with direct accesss to the underlying databases could be part of the solution to this problem.Considering medical environments, matters of confidentiality will be an issue for developers. When the environment per se constitutes the computer interface, system messages can, in principle, be channeled everywhere, for example to embedded speakers. Naturally, this means that sensitive medical information can be overheard. We addressed this problem by using headsets and walk-up displays in NOSTOS to avoid breaches of privacy. However, researchers are currently developing means that support privacy such as speakers that can transmit sounds to designated spots to avoid overhearing, and such solutions are clearly suitable for the medical domain [23].

Flexibility was one of the major incentives for developing computer-augmented clinics, because teamwork is more appropriately supported by the physical interfaces than by the present GUI equivalents. Flexibility is also a key issue in the design of the computer-enhanced environment. Naturally, medical staff members should have the flexibility to freely move around and use documents in ways that support them and the system should not respond and interpret these actions as computer commands. The active environment needs to be designed in ways so that personnel know where and how functionality is embedded into the milieu. However, there is always the danger that we will overengineer our environments and provide unnecessary functionality that can impair flexibility.

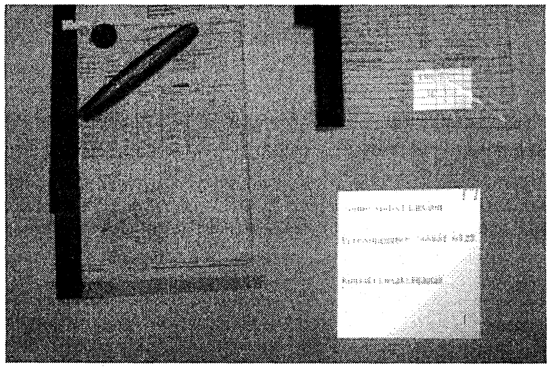

Figure 5 - NOSTOS superimposes virtual sticker notes and folders on the desk to provide messages and indicate when the physical folders are missing on the desk.

Personalization and adaptability are related to flexibility, and these requirements are important in the design of computer-augmented environments. It should be easy for medical professionals to configure parts of the active computational work environment to match the local routines and activities. For example, the entire clinical environment could have a setup mode in which the staff members in charge can designate physical parts of desks and walls to be fax areas and special display functions.

Conclusion

We have discussed a set of design requirements for ubiquitous computing environments aimed at helping healthcare professionals and their administrative tasks. Moreover, we have given examples of how physical interfaces and sensor technologies can be used to develop active clinical work environments. We suggest that the tangible properties of the physical interfaces are advantageous in the medical workplace, because they provide flexibility and they support crucial collaborative functions. We are currently evaluating parts of our system in cooperation with clinicians. Our goal is to find a physical interaction model that is appropriate for medical administrative work. Analogous to NOSTOS, we believe that future clinical ubiquitous computing environments must include a combination of several technologies such as IP-enabled paper forms, digital pens, ordinary desktop computers, tablet computers, digital desks, and activated binders, as well as devices such as smart paperclips and wearable displays, which are connected to the networked environment and work as an ensemble.

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