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Some Usability Issues of Augmented and Mixed Reality for e-Health Applications in the Medical Domain

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Abstract. Augmented and Mixed Reality technology provides to the medical field the possibility for seamless visualization of text-based physiological data and various graphical 3D data onto the patient's body. This allows improvements in diagnosis and treatment of patients. For the patient, this technology offers benefits and further potential in therapy, rehabilitation and diagnosis, and explanation. Applications across the whole range of functions that affect the health sector from the physician, the medical student, to the patients are possible. However, the quality of the work of medical professionals is considerably influenced by both usefulness and usability of technology. Consequently, key issues in developing such applications are the tracking methodology, the display technology and most of all ensuring good usability. There have been several research groups who extended the state of the art in employing these technologies in the medical domain. However, only a few are addressing issues of Human-Computer Interaction, Interaction Design, and Usability Engineering. This paper provides a brief overview over the history and the most recent developments in this domain with a special focus on issues of user-centered development.

Keywords: Human–Computer Interaction, Augmented Reality, Mixed Reality, Visualization, User-Centered Development, e-Health, Medicine

1 Introduction

The concept of Mixed and Augmented Reality provides the fusion of digital data with the human perception of the environment: using computer-based rendition techniques (graphics, audio, and other senses) the computing system renders data so that the resulting rendition appears to the user as being a part of the perceived environment. Most applications of this paradigm have been developed for the visual sense, using computer graphics technology to render 3D objects and presenting them registered to the real world. The difference between Augmented Reality (AR) and Mixed Reality (MR) is in the degree of virtualization: in AR the real world is the main operating framework, with a limited number of virtual objects added into the display, hereby solely augmenting the real-world view of the user. In MR, the emphasis of the virtual environment is much larger, which can manifest itself either in a larger number of virtual objects or in having the virtual environment (VE) as the dominant interaction framework.

Both paradigms have interesting applications in the medical domain: AR can be used to visualize complex 3D medical data sets (e.g. form ultrasound or NMR scans) in a direct projection on the patient, hereby allowing the physician to examine simultaneously the data and the patient. This can be taken a step further in tools for surgery, where the imagery can support the procedures to be undertaken. MR technology on the other hand can be used for off-line simulation and training, with the option to use virtual patients to simulate complex surgical procedures.

R&D has been carried out for enabling the use of AR and MR in combination with information and communication technology (ICT) in the medical area since the early 1990s. This paper gives an overview over the development and the current state of the art, highlighting specific examples of such e-health applications.

2 Basic Concepts of AR and MR

At the core of AR and MR technology is the seamless fusion of the perception of the real world with the computer-generated data. In order to achieve this, it is important that the system hardware supports this fusion. For the visual sense, this can be achieved with a head-worn display which is placed into the field of view of the user, who hereby sees both simultaneously the real world and the display. For such a system to be called “AR” or “MR”, it is essential that the information shown in the display is registered with the real world, which means that when the user changes the viewing direction, the content of the display also changes, in accordance with what the user sees. This is necessary to create the impression that the display content is in fact connected to the real world. Other types of displays are hand-held see-through displays, which can be used to overlay information onto the background. A different approach is to use projective displays, which project the information directly into the environment. This approach relies on walls or environmental structures which are relatively close to the projector and have reflective surfaces. Uneven complex surfaces cause problems in the projection approach, as the projection has to be corrected for the user’s position and depends on the shape of the surface.

For achieving a seamless mix of the perception of the real world together with the computer-generated graphical information, AR and MR systems need to track the user’s viewing direction and position. This can be achieved with a variety of technologies: active IR illumination in connection with IR tracking cameras can be used to track the user’s head pose; computer vision techniques can be applied to track the user’s position and orientation either from the captured images of the user’s environment, captured by a head-worn camera, or from cameras in the environment, pointing at the user. For medical applications it is not crucial that the tracking is done ubiquitously: since medical procedures are generally performed in a designated area or room, it is acceptable to employ technologies which rely on certain infrastructure available at the location, such as markers, projectors, reflectors or similar.

3 Medical Applications of AR and MR

The paradigm of AR and MR is very well suited for the medical domain, as the fusion of 3D medical scan data with the view of the patient will have benefits in diagnosis (through on-patient visualization) and performance support in general. Specifically, AR can be used for support of surgery, while MR and Virtual Reality (VR) are very suitable for simulation without the actual patient. Any of these technologies can be used for training of physicians and medical students, as they improve the situational and spatial awareness of the practitioner. Further on the patient also can be supported by a variety of applications through this technology.

3.1. Visualization of Ultrasound

The research group of Andrei State at University of North Carolina (UNC) has developed medical visualization applications using AR since 1992. Their first project dealt with passive obstetrics examinations [1]. Individual ultrasound slices from a pre-natal fetus were overlaid onto the video of the body of the pregnant woman – both live image streams were then combined using chroma-keying. Since the ultrasound imagery was only 2-dimensional in nature, the overlay resulted only in a correct registration from one particular viewing direction. An improvement was introduced with the volumetric rendition of the fetus. The original real-time ultrasound rendition proved to produce blurry images [2], but the introduction of off-line rendition allowed to render the volumetric data at a better quality at higher resolution [3]. As a further development, UNC used AR for ultrasound-guided needle biopsies for both training and actual performance [4]. Based on the experiences and practice of this technology, the group at UNC has also contributed to development of technology components for such systems, e.g. improvements of the video-see-through head-worn display [5] and tracker accuracy improvements. They have moved their system into actual performance of minimally invasive surgery (e.g. laparoscopic surgery [6]) and are working towards improvements of their system for being used in everyday practice.

3.2. Visualization using CT scans

Stockmans [7] demonstrated how CT scans can be used within a 3D visualization package to determine how very complex bone deformities within arms may be corrected as effectively and as accurately as possible. The technique involved determining how wrist joint mobility could be improved by correcting and re-sighting the forearm bone. The software used a virtual skin mesh and an accurate representation of joint movement to view various strategies for the operation. After the operation had been completed and recovery had been taken place it was possible to match the final result with the previous virtual visualization to determine the success of the operation. The software proved to be a valuable tool in decision making, preoperative testing and surgical planning.

3.3. Simulation for Training

MR technology does not need the human patient to be present, as it deals more with off-line simulation and employs more virtual reality (VR) technology. This makes it very suitable for training. One example of such a simulation for training is the birth simulator developed by Sielhorst et al. at the TU München [18]: a complete scale model of a woman's womb is designed as a torso, and a set of birth pliers is providing haptic feedback to emulate the forces when extracting the baby. With the head-worn display, the person to be trained can have an X-ray view into the body torso to get a better learning experience.

Another application of MR technology is training paramedics for disaster situations: Nestler et al. are developing a simulation of "virtual patients" [31], to train paramedics for large-scale disasters. In this simulation, the paramedics learn to deal with the various possible injuries of disaster victims and to apply first aid procedures. These virtual victims are simulated on a large multi-touch table-top in which one patient at a time can be displayed in full size. In this application, tracking precision is not very relevant, but solely the fact that procedures are applied correctly.

A different application of MR in the medical area could be the information of patients, as demonstrated in the VR-only system developed by Wilkinson et al. [9]: this system is designed to educate patients about the upcoming surgery procedures. In a study, this system has been used in a game and demonstrated to be able to reduce children patients' fear of an upcoming hand surgery, as with this system they were able to become more informed about the procedures. This concept could be expanded to use MR or AR technology, to show the procedure directly on the patient's hand.

3.4. Surgery and AR

Surgery is a very complex application for AR: life and death of the patient depend on precise registration of the data for the surgeon to perform the operation properly. The technical requirements for this application have been investigated by Frederick [12] from CMU. A more recent review of surgery and AR has been published by Shuhaiber [10] in 2004. His conclusions pointed out that these systems are still not yet practical in clinical applications, but hold a promising future by providing a better spatial orientation through anatomic landmarks and allowing a more radical operative therapy.

The German government funded the project MEDical Augmented Reality for Patients (MEDARPA) [13], which has the goal of supporting minimally invasive surgery. In this system, AR and VR technologies are used to improve the navigational capabilities of the physician. The system was being evaluated at 3 different hospitals in Germany (Frankfurt, Offenbach, Nürnberg) as a support for placing needles for biopsies (bronchoscopy) and interstitial brachytherapy (to irradiate malignant tumors). In addition, the system also was intended to be used with a surgical robot, to allow a more precise alignment of the incision points.

For computer-aided medical treatment planning, Reitinger et al. [20] present a set of AR-based measurement tools for medical applications. Their Virtual Liver Surgery Planning system is designed to assist surgeons and radiologists in making informed decisions regarding the surgical treatment of liver cancer. By providing quantitative assessment in measuring e.g. distance, volume, angle and adding automation algorithms, it improves the way of performing 3D measurements.

3.5. Therapy/Rehabilitation

Riva et al. [21] expect the emergence of “immersive virtual telepresence (IVT)” and see a strengthening of 3rd generation IVT systems including biosensors, mobile communication and mixed reality. This kind of IVT environments are seen to play a broader role in neuro-psychology, clinical psychology and health care education.

While VR therapies (like e.g. provide in the project NeuroVR [24])and exposure in vivo have proven to be effective in treatment of different psychological disorders such as phobia to small animals (like spiders or cockroaches), claustrophobia or acrophobia, AR offers a different way to increase the feeling of presence and reality judgment. Juan, M.C. et al. [23] have developed an AR system for the treatment of phobia to spiders and cockroaches.

Concerning mental practice for post-stroke rehabilitation Gaggioli et al. [25] present a way of applying augmented reality technology to teach motor skills. An augmented reality workbench (called “VR-Mirror”) helps post-stroke hemiplegic patients to evoke motor images and assist this way rehabilitation combining mental and physical practice. An interesting project for healthy living basing on computerized persuasion, or captology, combined with AR technology is the “Persuasive Mirror” [30]. In an augmented mirror, people get help to reach their personal goals like leading a healthier lifestyle by regular exercise or quitting smoking.

3.6. Education / Edutainment

Nischelwitzer et al. [22] have designed an interactive AR application for children, called “My inside the body Book (MIBB)”. In a physical book, the human alimentary system is described by interfacing reality and virtuality. In order to be able to interact with the content, buttons were mounted at the bottom of the book. The possibility to examine organs of the human body from different perspectives showed the positive potential of AR for the area of learning. From this result we also envision that for example a medical encyclopedia could be designed for medical students, for example to provide 3D information on anatomy.

4 Technical Issues

4.1. Registration and Tracking

For registration of the data overlay, seamless tracking is essential, to keep the view of the data registered with the patient's body. For medical applications, precision is especially important in order to match the data (e.g. CT or NMR scans [11]) to the patient's body precisely for enabling a correct interpretation and diagnosis. One difficulty is that the human tissue is not rigid and often does not have distinctive features. For camera-based tracking, one can attach markers to the body, to provide fiducial markers as visual anchor points.

The calibration effort should be very small, as the physician needs to focus on the patient and not on the technology. Tracking approaches need to be resistant to possible occlusion, as the physician may need to manipulate instruments [17].

The MEDarpa system [13] employs different tracking methods: an optical tracker is used for tracking the display and the physician's head. The instruments themselves are being tracked by magnetic tracking systems, to avoid problems with occlusion through the display.

4.2. Display Technology

Today the AR/MR community and the end-user have the possibility to choose from a variety of display technologies which best suits their application demands. Different optics can be used as information-forming systems on the optical path between the observer's eyes and the physical object to be augmented. They can be categorized into three main classes: head-attached (such as retinal displays, head-worn displays and head-mounted projectors), hand-held and spatial displays. [26]

Head-worn displays (HWD) provide the most direct method of AR visualization, as the data are directly placed into the view and allow hands-free activity without any other display hardware between the physician's head and the patient. However, they were in the past often cumbersome to wear and inhibited the free view and free motion of the surgeon. Latest research and design tries to bring HWDs (especially the optical see-through type) into a social acceptable size like e.g. integrated into sun- or safety-glasses and has already resulted in some available prototypes. This creates the expectation that in the near future, light weight and low-cost solutions will be available [28][29]

Video-see-through (VST) displays have a lower resolution than optical see-through (OST), but are easier to calibrate. The overlay can be generated by software in the computing system, allowing a precise alignment, whereas an OST system has additional degrees of freedom due to the possible motion of the display itself vs. the head.

The group of Wolfgang Birkfellner from TU Vienna has developed the Varioscope [19], a system which allows visualization of CT data through a head-worn display, with the goal of pre-operative planning. In the design of this display, care was taken to produce a light-weight and small device which would be suitable for clinical use.

Alternatives to HWDs are hand-held or tablet displays, which could be mounted on a boom for a hand-free process. In general, these displays are semi-transparent to allow optical see-through of the patient's body without the need for a separate camera.

The MEDarpa system [13] did not use head-worn displays, but instead developed a novel display type which is basically a half-transparent display. This display can be freely positioned over the patient, providing a "virtual window" into the patient by overlaying CT and MRT data from earlier measurements into the view [14]. This requires that both the display and the physician's head are being tracked.

Most of these examples show that the prediction and model of an e-Assistant [27] is step-by-step becoming true and will be available soon with ongoing miniaturization process of devices, improvements in technology, and becoming available to the users.

4.3. Interaction

Similar as for visualization, the variety of interaction possibilities is large (unless the display does not have an integrated interaction device). Different interfaces like traditional desktop interfaces (e.g. keyboard, mouse, joystick, speech recognition), VR I/O devices (e.g. data glove, 3D mouse, graphics tablet etc.), tangible user interfaces (TUI), physical elements and interfaces under research (like brain computer interface (BCI)) can be used. Further research also concentrates on medicine and application-specific user interfaces.

5 User-Centered Development Issues of AR for Medicine

The quality of the work of physicians is considerably influenced by the usability of their technologies [32]. And it is very interesting that in the past many computer science pioneers have been tempted to ask “what can the computer do?” instead of asking of “what can people do?” [33]. It is obvious that medical procedures can greatly benefit from improved visualization, navigation, interaction and from enhanced decision support [34]. By the application of User Centered Development Processes (UCDP) it is possible to study the workflows of the end users and to involve them into development from the very beginning. However, a serious threat is that medical professionals have extremely little time to spend on such development processes. One possibility is to make them aware about the potential benefits and to demonstrate how this technology solves specific problems for their daily routine [35].

It is essential that the developers of AR applications for the medical domain must understand not only the technology they support and the limitations of the techniques they use, but also the medical professionals, their workflows and their environments. Consequently, Usability Engineering Methods (UEM), which includes the end users in the development from the beginning, are becoming more and more important [36]. However, although approaches for the application of User Centered Development have been around for most of the time [37], in practice today, a gap still exists between these theories and practice. Either software engineers concentrate on software development, or usability experts concentrate on design, they rarely work together [38].

Basically, standard UEMs can be applied for AR environments. However, when looking for differences, we found several adapted methods, although mostly for *evaluating* the usability of AR applications – not User-Centered Development. For example, Hix developed checklists of criteria for assessing VE design and adapted methods for evaluating usability of standard user interfaces for Virtual Reality applications [43], while Kalawsky [45] created a questionnaire audit of VE features derived from a usability checklist for GUIs. Several experimental studies have assessed the effectiveness of different interactive devices (e.g. [46]) and haptic interaction in collaborative virtual environments. A principal difference in assessing user interaction with VEs in comparison with traditional user interfaces is the sense of presence created by immersion in virtual worlds. Assessment of presence has primarily focused on measuring the effects of VE technologies on a person’s sense of presence via questionnaires. Slater et al. [47] concluded that presence itself was not associated with task performance. However, measures of presence have concentrated on user perception of VE technology and have not considered the impact of errors. Errors can disrupt the sense of illusion, and hence impair perception of the presence.

Freeman et al. [44] defined presence as “the observer’s subjective sensation of ‘being there’ in a remote environment”, while Lombard and Ditton [48] investigated presence and immersion, and defined presence as “the perceptual illusion of non-mediation [which] involves continuous (‘real-time’) responses of the human sensory, cognitive and affective processing systems”. The effects of being immersed have been investigated in a variety of VE system configurations. More recent work has examined presence in collaborative VEs from the viewpoints of self and perceptions of others' presence. Although considerable previous research has been carried out in fully immersive VEs and into how users interact with objects in such VEs, such work has concentrated on head-mounted display (HMD) -based systems. Few studies have investigated fully immersive CAVE systems or Interactive WorkBenches (IWBs), apart from the work of Blach et al. [49] who concluded that realistic perception and interaction support were important for effective interaction in CAVE environments.

While evaluation methods and techniques have acknowledged the importance of presence [43], they have not included techniques for measuring it, apart from simple ratings of the "naturalness" of an environment. One of the weaknesses of questionnaire-based assessment is that people's ratings may be biased by their experience.

Summarizing, the user experience within AR is essential, any problems in interaction can reduce the illusion of presence thereby reduce the advantages of AR [39].

Several researchers made serious concerns about the use of AR (e.g. [40]: The already present information overload can result or be accompanied by a sensory overload; end users, especially in the medical domain might find themselves overwhelmed by the wealth of experience they find in the AR; and most of all: Either too little experience with technology per se, or lack of acceptance. Social effects (beliefs, attitudes and feelings) should not be neglected.

Some interesting questions for further research could be:

- Which interaction metaphors are most appropriate in AR for the medical domain?
- Which influences do AR applications have on performance of the end users in the medical domain?
- What are the effects of adaptation that people might have to make cognitively to believe in and cope within an AR environment?
- How will multimodal interaction through a number of input and output channels enhance or detract from the reality/Virtuality experience?

In comparison to standard HCI work, in AR we must deal with physical interactions, social interactions and cognitive interactions. It is definitely more difficult to isolate variables to investigate them in controlled trials, and there are less constraints on performance, which lead to a lower predictability of behaviors to set up field observations or experiments [39]. According to Dünser et al. [41], for a successful development of AR systems all research domains involved have to be considered and integrated properly with a user-centered design focus. As AR and MR technology is going to be used more and more outside of laboratory settings and becoming integrated in everyday life, the systems need to:

- be more accessible,
- be usable for the everyday end-user,
- follow the notion of pervasive and ubiquitous computing,
- implement the basic ideas of social software,
- be designed for use by users who lack a deep knowledge of IT systems [42].

6 Summary and Outlook

Augmented and Mixed Reality technology has a promising potential to be used in medical applications, as it provides seamless integration of data visualization with the patient's body. This allows improved methods for medical diagnosis and treatment. The technological hurdles of displays and registration are still not completely solved for realistic clinical application in a regular medical environment, but progress in various projects is encouraging. With the special focus also on the user-centered development issues and research on AR and MR design guidelines, the future success for various e-Health applications in the medical domain has promising perspectives. Of specific interest are developments of smaller and lighter head-worn displays, with a larger field of view and higher level of detail. More attention needs to be paid to the actual usability of such systems, avoiding a sensory overload and making the visualisation experience more controllable. Such systems could benefit from an integration of other related HCI technologies in the domain of ubiquitous computing, using speech and gesture recognition for a multimodal interaction with the medical information system.

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