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7 Virtual Reality in telemedicine

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Abstract. Virtual Reality (VR) can be considered as the leading edge of a general evolution of present communication interfaces involving the television, computer and telephone. Main characteristic of this evolution is the full immersion of the human sensorimotor channels into a vivid and global communication experience. Since telemedicine is principally focusing on transmitting medical information, VR has the potential to enhance this function. Particularly VR can be used in telemedicine as an advanced communication interface, which enables a more intuitive mode of interacting with information, and as a flexible environment that enhances the feeling of physical presence during the interaction. In this chapter, the state of the art in VR-based telemedicine applications is described. This technology is now used in remote or augmented surgery, and surgical training, which are critically dependent upon eye-hand coordination. Recently, however, different researchers have tried to use virtual environments (VEs) in medical visualization and for the assessment and rehabilitation in neuro-psychology. The chapter also discusses technological, ergonomical and human factor issues and specific guidelines are presented for expanding the use of VR in telemedicine.

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7.1 Introduction

A Virtual Environment (VE) is an interactive, virtual image display enhanced by special processing and by nonvisual display modalities, such as auditory and haptic, to convince users that they are immersed in a synthetic space [1]. In a different fashion, virtual reality (VR) is an application that lets users navigate and interact with a three-dimensional, computer-generated environment in real time [2].

Virtual reality, is not only a hardware system [3]. But also an emerging technology that changes the way individuals interact with computers. It can be described as "...a fully three-dimensional computer-generated 'world' in which a person can move about and interact as if he actually were in an imaginary place. This is accomplished by totally immersing the person's senses...using a head-mounted display (HMD)" or some other immersive display device, and an interaction device such as a DataGlove or a joystick [4, p. 111]. However, it is the user immersion in a synthetic environment that characterizes VR as being different from interactive computer graphics or multimedia. In fact, the *sense of presence* in a virtual world elicited by immersive VR technology shows that VR applications may commonly differ fundamentally from those associated with graphics and multimedia systems [5].

Virtual environments provide a unified workspace, which allows almost complete functionality without requiring that all functions to be in the same physical space. According to Ellis [1, p. 17], VEs can be defined "...as interactive, virtual image displays enhanced by special processing and by nonvisual display modalities, such as auditory and haptic, to convince users that they are immersed in a synthetic space." Less technically, a virtual world can be described as an application that lets users navigate and interact with a computer-generated 3-D environment in real time. The system has three major elements: interaction, 3-D graphics, and immersion [2].

According to Bricken [6] the essence of VR is the inclusive relationship between the participant and the virtual environment, where direct experience of the immersive environment constitutes communication. In this sense, VR constitutes the leading edge of a general evolution of present communication interfaces involving television, computer and telephone [7]. The main characteristic of this evolution is the full immersion of the human sensorimotor channels into a vivid and global communication experience [8]. In fact, VR provides a new methodology for interacting with information [9]. Since telemedicine is principally involved with transmitting medical information [10], VR has the potential to enhance the telemedicine experience. The two principal ways in which VR can be applied are *interface*, which enables a more intuitive manner of interacting with information and *environment*, which enhances the feeling of presence during the interaction [9].

Many VR applications have emerged in entertainment, education and military training [11]. Nevertheless, the considerable potential of VR in medicine has been recognized only recently. These and similar applications share three common attributes, which offer significant advantages over current tools [12]:

- *Content***.** Until the last decade, computers were used to control numbers and text by entering numbers and text using a keyboard. Recent direct-manipulation interfaces have allowed the manipulation of iconic representations of text files, or two-dimensional graphic representations of objects, through pointing devices such as the mouse. The objective of direct-manipulation environments was to provide an interface that mimics object manipulation in the real world. The latest step in that trend, virtual reality systems, allows the manipulation of multi-sensory representations of entire environments by natural actions and gestures.
- *Feedback*. VR systems are capable of displaying feedback in multiple modes. Thus, feedback and prompts can be translated into alternate senses. The environment could

be reduced to achieve a larger or general perspective (without the "looking-through-a-straw" effect usually experienced when using screen readers or tactile displays). Sounds could be translated into vibrations while environmental noises could be selectively filtered out.

- *Method of Controlled.* Current alternate computer access systems accept only one or at most, two modes of input at a time. A computer can be controlled by single modes such as pressing keys on a keyboard, pointing to an on-screen keyboard with a head pointer, or hitting a switch when the computer presents the desired choice. Present computers do not recognize facial expressions, idiosyncratic gestures, or monitor actions from several body parts at a time. VR systems open the input channel mor widely: VR systems have the potential to monitor movements or actions from any body part, or from many body parts simultaneously. All properties of movement, not just contact of a body part with an effector, could be monitored.

Recently, some research projects have begun to test the feasibility of using VEs in medicine. Applications of this technology are being developed for health care in the following areas: surgical procedures (remote surgery or telepresence [11, 13], augmented or enhanced surgery [14, 15], and planning and simulation procedures before surgery [16, 17]); medical therapy [5, 18, 19]; neuro-psychology [20-25]; preventive medicine and patient education [26]; medical education and training [27, 28]; visualization of massive medical databases [29] and skill enhancement and rehabilitation [30]; and architectural design for health-care facilities [31]. This paper highlights recent and ongoing research related to the application of VEs and related technologies in telemedicine. The paper also discussed advantages and limitations of VR as a telemedicine tool.

7.2 The VR technology

7.2.1 Technical tools

A three-dimensional computer-generated environment enables the user to move about and interact as if he actually were *in* it. This effect is achieved by totally immersing user senses in the VE via both a head-mounted display (HMD) or some other immersive display device, and an interactive device such as a DataGlove or a joystick [4, p. 111]. The VE may be displayed on a desktop monitor, a wide field-of-view display such as a projection screen, or a head-mounted display. A virtual environment displayed on a wide field-of-view display, which is fixed in space, is called partially immersive virtual reality. A fully immersive virtual reality environment utilizes a head-mounted display, with a head position sensor to control the displayed images so that they appear to remain stable in space when turning the head or moving through the virtual environment. A see-through head-mounted display and head position sensor may be used to augment the user’s experience of the real world by superimposing space-stabilized computer-generated images of virtual objects on the user’s view of the outside world [32].

7.2.2 Low cost VR

Due, in large part, to the significant advances in PC hardware that have been made over the last three years, low cost VR systems are approaching reality. While the cost of a basic desktop VR system has not changed much, the functionality has improved dramatically, both in terms of graphics processing power and VR hardware such as head-mounted displays (HMDs). The availability of powerful PC engines based on Intel's Pentium III, Motorola's Power PC G4 and Digital's Alpha processors, and the emergence of reasonably priced 3D accelerator cards allow high-end PCs to process and display 3D simulations in real time.

A standard Pentium Celeron 533 Mhz with as little as 64 Mb of RAM can offer sufficient processing power for a bare-bone VR simulation, an 800 Mhz Pentium III/Athlon with 128 Mb of RAM, can provide a convincing virtual environment, while a dual 800 Mhz Pentium III XEON configuration with OpenGL acceleration, 256 Mb of RAM and 32 Mb of VRAM running on Windows NT, can match the horsepower of a graphics workstation.

Immersion is also becoming more affordable. For example, Virtual I-O (USA) now has a HMD that costs less than $800 and has built in head tracking. Sony distributes its basic Glasstron headset for about $600 without headtracking. Two years ago HMDs of the same quality were about 10 times more costly. A HMD with VGA quality produced by Sony is now about $2,000. However, this price will probably decrease during the next five years.

Presently, input devices for desktop VR are largely mouse- and joystick-based. Although these devices are not suitable for all applications, they can keep costs down and avoid the ergonomic issues of some of the up-to-date I/O devices such as 3D mouses and gloves. Also, software has been greatly improved over the last three years. It now allows users to create or import 3D objects, to apply behavioral attributes such as weight and gravity to the objects, and to program the objects to respond to the user via visual and/or audio events. Ranging in price from free (Alice WTK - http://www.alice.org) to $6,000, the toolkits are the most functional among the available VR software choices. While some toolkits rely exclusively on C or C++ programming to build a virtual world, others offer simpler point-and-click operations for simulation.

7.2.3 The Virtual Reality Modelling Language

A further attempt to spread the diffusion of low-cost VR comes from the development and increasing diffusion of the *Virtual Reality Modelling Language* (VRML). The VRML is a file format and run-time description of 3D graphics for use on the World Wide Web. It includes interaction and animation elements as well as interfaces to scripting languages, thereby providing more general simulation behaviors and interfaces in network services [33]. Today VRML worlds can be scripted with Java and JavaScript, both of which are familiar to most web programmers.

The first version of VRML (1.0) allowed the creation of virtual worlds with limited interactive behavior. These worlds can contain objects that have hyper links to other worlds, HTML documents, or other valid Multimedia Internet Mail Extensions (MIME). The second version of VRML (2.0), available now, allows the user for richer behaviors, including animations, motion physics, and real-time multi-user interaction.

VRML2.0 was designed and implemented in 1995, and it has been an International Organization for Standardization standard since 1997 (called VRML97). VRML97 is the only existing open standard for describing 3D graphics on the web, though several proprietary packages with similar capabilities exist. The development and maintenance of VRML97 are overseen by the Web3D Consortium whose members include Sun, Microsoft, SGI, Apple and Intervista.

The first step in viewing a VRML document is retrieving the document itself. The document request comes from a Web browser, either a VRML browser or a HTML browser. Users send their request to the Web browser, and the Web browser forwards the request to its intended recipient. The Web server that receives the request for a VRML document attempts to fulfil the request with a reply. This reply goes back to the VRML browser. Once the VRML browser has received the document, it is read and understood through visible representations of the objects described in the document. Each VRML scene has a "point of view," which is called a *camera:* you see the scene through the eye of the camera. It is also possible to predefine viewpoints. All browsers feature some interface for navigation, so that you can move the scene's camera throughout the world. A VRML world can be *distributed,* that is, it can be spread across the Web in many different places. In the same way that an Internet Web page can be composed of text from one place and images from another, a VRML world can state that some parts of the scene come from *this* place, while other parts come from *that* place.

This means that VRML files are often loaded in stages. First, the basic scene description is loaded. Then, if this refers to *nested* (scene within a scene) descriptions, the browser loads these after the basic scene has been loaded. Typically, computer speeds are not quite as fast as we would like. Similarly, modems are not as capable as the demands we like to make upon them. Hence, there is usually some delay in loading a VRML world. It rarely appears immediately, or all at once.

VRML can show you where objects will appear before they have been downloaded. Before the object appears, it is shown as an empty box of the correct dimension (called a *bounding box),* which is subsequently replaced by the actual object when it is read. Called *lazy loading,* this allows the VRML browser to take its time, when it has no other choice, loading the scene from several different places, while still giving you a correct indication of what the scene will look like when it is fully loaded [33].

Since a variety of open standard VRML authoring tools are now freely available on the Web, hardware changes in PCs have accelerated the deployment of VRML on the desktop. Available PCs meet the requirements for moderately complex VRML97 worlds. Specifically, almost all desktop PCs sold since mid 1998 have been shipped with a 3D graphics accelerator. In addition, VRML97 browsers are now standard in IE5.0 (Intervista WorldView) and Netscape4.6 (CosmoPlayer). Plugin browsers are available for earlier versions of these software packages.

Much of the power of VRML over other 3D technologies is that 3D worlds can be integrated into standard 2D web page descriptions. Given that the web page is a very familiar "front-end" to the Internet, and that VRML scripts can access the capabilities of Java scripting, games developers and on-line shopping providers have been quick to recognize the potential of hosting thousands of users within a controlled 3D environment.

The general experience of VRML worlds on the Internet will be vastly improved over the next few years as basic technologies such as 2nd generation graphics accelerators and network technologies such as Asymmetric Digital Subscriber Line (ADSL) become available. Up to now, applications of VRML for telemedicine VR are available in visualization [34] and training [35].

7.2.4 Human factors

The introduction of patients and clinicians to VEs raises particular safety and ethical issues. In fact, there are well-documented side-effects of exposures to virtual reality environments which could lead to problems [36] including:

- symptoms of motion sickness;
- strain on the ocular system;
- degraded limb and postural control;
- reduced sense of presence;
- the development of responses inappropriate for the real world which might lead to negative training.

However, the improved quality of the VR systems has drastically reduced the occurrence of simulation sickness. For instance, a recent review of clinical applications of VR reported instances of simulation sickness are few and nearly all are transient and minor [37].

Nonetheless, patients exposed to virtual reality environments may have disabilities that increase their susceptibility to side effects. Precautions should be taken to ensure the safety and well being of patients, including established protocols for monitoring and controlling exposure to virtual reality environments. Strategies are needed to detect any adverse effects of exposure, some of which may be difficult to anticipate, at an early stage.

According to Lewis & Griffin [36] exposure management protocols for patients in virtual environments should include:

- Screening procedures to detect individuals who may present particular risks.
- Procedures for managing patient exposure to VR applications to ensure rapid adaptation with minimum symptoms.
- Procedures for monitoring unexpected side effects and for ensuring that the system meets its design objectives.

Unfortunately, the effect of VEs on cognition is not fully understood. In a recent report, the US National Advisory Mental Health Council [38] suggested that "research is needed to understand both the positive and the negative effects [of VEs]... on children's and adult's perceptual and cognitive skills." Such research will require the merging of knowledge from a variety of disciplines including (but not limited to) neuropsychology, educational theory and technology, human factors, medicine, and computer science.

Ergonomics plays an important role in the development of effective telemedicine tools. In this area, the achievement of certain performance criteria may be the main objective of VR-based telemedicine applications [39]. For instance, virtual environments designed for surgery must realistically represent the real task that is being simulated. An important aspect of such simulation can be the measurement of performance to assess likely competence in the real task. As noted by Lewis and Griffin [36], “the introduction of artifacts by the virtual environment which affect the performance of the task are likely to reduce the effectiveness of the training or lead to negative transfer of training to the real environment” (p. 41).

This leads many researchers to explore the characteristics of visual-motor co-ordination tasks in virtual reality systems and simulators. Most of these kinds of studies have focused on the effects of lags between the sensing of head, limb or control position and the movements of images on the display [40, 41]. Lags of a similar order to those present in many practical systems have had a significant effect on the tracking, manipulation and reading tasks [42]. Studies have also demonstrated the benefits of stereoscopic displays to provide depth cues to aid the manipulation of virtual objects in three dimensions, such just as it is called for in surgical simulation. Moreover, the VR system should minimize the total delay between head position sensing and the presentation of a suitable image. This may involve the choice of suitable position sensors and the minimization of synchronization errors [43]. Similarly, the system update rates should be maximized. Minimizing the visual delay and maximizing update rates should reduce both the probability of simulator sickness symptoms and minimize the interference with the user’s interactivity with the environment. This is especially important where the effectiveness of the application depends on the performance of a visual-motor task as in many VR-based telemedicine applications. Significant delays and low update rates may lead users to adopt unnatural movement strategies. This would subsequently interfere with the transfer of training for a real task [36].

Interaction plays an important role in VR, indeed, the essence of VR is the ability to interact in a three-dimensional computer-generated environment. Some clinical applications may simply call for subjects to be present in an interactive virtual environment. For example, applications are being developed to desensitize subjects in anxiety-provoking situations. The effectiveness of such applications is likely to be strongly dependent on the sense of presence within the virtual environment that is felt by the subjects. More than the richness of available images [44, 45] the sensation of presence depends on the level of interaction which actors have in both real and simulated environments [46]. Normally, a certain amount of freedom of movement is needed in order to adapt to the needs of a changing environment. That is why a good VR system must grant a certain amount of freedom of movement to the actors who move in it. As noted by Ellis [47] the key questions for a VR designer are: “ Can [the users] accomplish the tasks they accept? Can they acquire the necessary information? Do they have the necessary control authority? Can they correctly sequence their subtasks?” (p.258). In fact, the successful implementation of a VR-based telemedicine system will depend directly on the answers to these kinds of questions. In this sense, emphasis shifts from quality of image to freedom of movement, from the graphic perfection of the system to the actions of actors in the environment. "Experience of space will depend more on the mode of locomotion than on the visual and acoustic images. The reality of a surface will be in its implications for action (e.g., does it impede locomotion) rather than in its appearance (e.g., does it look like a wall). In this approach, the reality of experience is defined relative to functionality, rather than to appearances" [48].

7.3 Telemedicine applications of VR

7.3.1 Surgical procedures

The leading field in VEs have is surgery. VR-based telepresence systems are used in surgery to manipulate equipment at remote sites. Its advantages are clear. For instance, a specialist can help a local surgeon by remote connection, or surgeon to perform complex operations where the local provider is in a rural setting, a ship at sea, an airplane in flight, or even a space station. Besides solving the distance problem, telepresence offers other benefits, such as minimizing the exposure of surgeons to infections and potential trauma [49]. One of the first applications in this field comes from SRI International of Menlo Park, CA. This company designed its Green Telepresence Surgery System (TeSS) to allow surgeons to participate in battlefield operations from sites removed from the front line [50]. The system consists of a remote operative site and a surgical workstation that offers to the surgeon 3-D vision, dexterous precision surgical instrument manipulation, and input of force feedback sensory information. This is done through real-time 3D video vision using two color CCD video cameras on the remote surgical unit and a stereo display on the surgeon's workstation (the surgeon wears passive polarized glasses). The instrument handles are under the surgeon's display mirror to maintain hand-eye coordination.

The surgeon using this system operates on a virtual image, and a robot on the battlefield reproduces the surgeon’s movements. The coupling between the surgeon and the machine has been shown to work from 150 yards away with a fiber-optic connection. The next goal for the military is to replace the fiber-optic connection with a wireless signal [50, 51]. However, a challenging issue for all telesurgical applications is time delay between “master” and “slave” sites. The computation delay ranges from a few milliseconds to 10-100 ms induced by computer networks, to delays of seconds or more induced by multiple satellite communication links [52]. These delays can induce loss of teleoperator fidelity and task performance as well as dangerous instability of operation [53]. So, therefore, any tele or remote surgery will be limited to a few hundred miles until a new method to compensate for latency is discovered.

Recently, supervisory staff at medical schools has been using TeSS for training. Third-year medical students with no prior operative experience were mentored exclusively through use of TeSS. During these lessons, medical students were alone in the operating room, and the teaching surgeon was in an entirely separate room. The remote interaction was facilitated by the two monitors and a fast ethernet connection [54].

A more advanced attempt in using a VR-based telemedicine system for surgical simulations comes from the Manchester Visualization Center [55]. Using VRML and JAVA to render the 3D models, the authors created simulations of ventricular chatheterisation accessible through Internet. Early in their training, trainees in neurosurgery need to gain an appreciation of the ventricular system and how to cannulate it in an emergency. The flow of cerebrospinal fluid can be obstructed in the ventricles by several pathological processes leading to hydrocephalus.

The pressure within the ventricles can rise leading to loss of consciousness. The ventricular system can be cannulated in the operating theatre, fluid drained and a potentially lethal rise in pressure relieved.

In the VE the user can move the virtual cannula to the entry point on the 3D patient. The cannula is then placed with the correct orientation. Finally, it is inserted through the virtual patient and into the ventricular system.

The authors are also exploring the possibility of allowing multi-user collaboration. Using the Deep Matrix software [56] as a base platform, researchers have extended the simulators to allow a single instance of one simulator to be accessed by several users over the Internet. Any change in the VRML word produced by one user is propagated to all the other participant web browsers. This enables the teacher to explain to a remote audience how a procedure should be performed.

A similar approach - VRML plus JAVA - is used by the Department of Neurosurgery in the Leeds General Infirmary, UK, to train surgeons in the treatment of trigeminal neuralgia. Specifically, the teletraining system simulates the insertion of a needle in Percutaneous Rhizothomy [57]. The collision detection between the instrument and patient is critical to this simulation. Hence, the VE provides a pair of linked views: one from the eye of the surgeon and one from the viewpoint of the needle.

The different parts of the procedure - marking anatomical landmarks, orienting the needle and inserting it - are all simulated by the application. The simulator is freely available on a public access Web site (http://synaptic.mvc.mcc.ac.uk/home.html).

In neurosurgery, the operation should be planned very carefully since VR based telemedicine tools can play an important role. In fact, there is a trend to stereotaxy a tumor before an open operation is planned. This process can now be undertaken using a telemedicine link between the surgery center and the pathology department where the tissue specimens are analysed [58]. Digital holography would facilitate the three-dimensional visualization of the trajectory [59].

In 1989, video technology was employed for the first time by a team of surgeons to perform a laparoscopic cholecystectomy (removal of a gallbladder). Since then, the use of minimally invasive therapeutic techniques has become standard. About 90% of all cholecystectomies performed in the last years have been done using laparoscopic techniques [60]. This surgical method is well suited for telemedicine.

For instance, the European Institute of Tele Surgery located in Strasbourg, France, is developing the World Electronic Book of Surgery, a VR-based tele-education tool for the training of laparoscopic operating techniques [61]. This tool use high-speed access, constant updating, and use of video and 3D animated computer graphics to provide online real time learning tools.

A surgical telementoring suite was also developed by the Department of Surgery at the University of Hawaii in collaboration with the Tripler Army Medical Center. The system, currently used for the teaching of laparoscopic cholecystectomy, produced comparable results to in vivo lessons [62].

7.3.2 Medical visualization and consultation/diagnosis

Telemedicine VEs allow remote information visualization. Usually, data visualization is performed slice by slice, or by using volume rendering on costly graphics workstation. However, the recent development of Internet technologies, the dramatic improvements of rendering capabilities on PC's and the diffusion of the VRML standard make three-dimensional visualization based upon client-server architecture possible [35].

Through remote 3-D visualization of massive volumes of information and databases, students can understand important physiological principles or basic anatomy. For instance, VR can be used to explore the organs by "flying" around, behind, or even inside them. In this sense, telemedicine VEs can be used both as didactic and experiential tool, allowing a deeper understanding of the interrelationship of anatomical structure that cannot be achieved by any other means, including cadaveric dissection.

The number of developed applications in this area is very large. For instance Westwood and colleagues [63] reported more than 10 different educational and visualization applications. A typical example is Anatomic VisualizeR, a VR enhanced multimedia application used in medical school anatomy and high school biology classes [64]. However, state-of-the-art VR and high speed networks have made it possible to create an environment for clinicians geographically distributed to share immersively massive medical volumetric databases in real time. One of the most successful systems in this area is the one developed by the VRMedLab at the University of Illinois at Chicago. This research group has developed a tele-immersion program that allows clinicians to interact with the same volumetric models, point, converse and see each other through an ATM network [65]. Participants are depicted by virtual representations (avatars) which have their head and hand tracked so that they can convey natural gestures such as nodding and pointing. Moreover, the system allows the users to fly through space using a joystick, and to interact with objects in the space using a tracked wand. Participants can pick, delete or move any of the objects and speak to each other using a virtual intercom system. A more advanced research project was developed at NASA in the “Virtual Collaborative Clinic” project at NASA’s Ames Research Center. It used the high bandwidth Abilene network (9920 Gbps) for multicasting in real-time complex images (1200000 polygons) generated on a central graphic server at NASA [66]. To allow interaction with remote sites, the project used a combination of client-side (local) low resolution rendering (20000 polygons) during object manipulations and multicast image distribution for single frame (static) image display. To achieve these outstanding results, the project used a 39Mbps bandwidth through satellite communication.

As we have seen before, another typical use of visualization applications is the planning of surgical and neuro-surgical procedures [58, 59]. The planning of these procedures usually relies on the studies of series of two-dimensional MR (Magnetic Resonance) and/or CT (Computer Tomography) images which have to be mentally integrated by surgeons into a three-dimensional concept. This mental transformation is difficult, since complex anatomy is represented in different scanning modalities, on separate image series, usually found in different sites/departments. A telemedicine VR-based system is capable of incorporating different scanning modalities coming from different sites providing an interactive three-dimensional view. Within the Virtual Collaborative Clinic project NASA researchers developed Cyberscalpel, a VR based telemedicine surgical system for planning and practice [66]. To plan the operation of a patient with cancer of the jaw, the upper and lower jaws were reconstructed using Cyberscalpel starting from a CT scan. The scan was reduced to 20000 polygons, and the final model used to prove how fibular bone could be sectioned to mimic and replace the jaw pieces. The display of the Cyberscalpel was multicast to the participant Virtual Clinic clients during this procedure.

Generally, remote three-dimensional interactive models play a major role in different areas ranging from medical education, clinical visualization and medical research. The opportunity for international collaboration in medical conferences is another potential application now being explored [67]. Interaction and participation using VEs might alleviate some of the stiltedness of current videoconferencing capabilities. However, even if many of these applications could be developed, their actual use in this area is still limited by both technology-related factors - such as lack of high visual fidelity or price/performance issues - and design-related factors - such as poor interface and sensory overload.

7.3.3 Neuro-psychological assessment and rehabilitation

The first VR system specifically designed for the assessment and cognitive rehabilitation of cognitive functions in persons with acquired brain injuries was developed in Italy [21, 68]. Using a standard tool (Wisconsin Card Sorting Test--WCST) of neuropsychological assessment as a model, these researchers have created a virtual building wherein the person uses environmental clues in the selection of appropriate choices (doorways) to navigate through the building. The doorway choices vary according to shape, color, and number of portholes. The patient is required to refer to the previous doorway for clues to make the appropriate next choice. After the choice criteria are changed, the patient must shift the cognitive set, analyze clues, and devise a new choice strategy. The parameters of this system are fully adjustable so that training applications can follow initial standardized assessments. Although this VE was not developed as a telemedicine tool, the authors are now trying to develop a new Internet version using VRML. This VE will be used to document failures in everyday life coping in a patient with an anterior thalamic stroke [69].

Probably, the first VE in this field for remote use comes from the research group from Politecnico di Milano, Milan, Italy. Within the EC funded VREPAR project (HC 1053), this group developed a VE for the study of the relationship between visual sensory information and the control of movement being performed in patients with movement disorders [70, 71]. The system was developed to allow the clinician to acquire from a remote site - through a TCP/IP connection - different data about the characteristic movements of the patient. The preliminary results obtained from the Milan group [70] demonstrated that this approach is suitable for testing both, the effectiveness of various types of visual control and individual performances in manipulation. An initial therapeutic application could be the assessment and rehabilitation of patients suffering from spinal cord injuries.

A similar tool was developed by Greenleaf Medical in collaboration with the Center for Telecommunications Education and Research at the University of Alabama [72]. In response to different VR stimuli, the patient is instructed to grip an electrodynamometer in front of a camera so that the health care provider can verify that the patient is holding the device correctly in the desired hand. The data are sent to a remote client (hospital) using the Internet TCP/IP protocol through a fast ASDL (Asymmetrical Digital Subscriber Loop) or CATV (Community Access Television) line.

From the VREPAR 2 project (HC 1055) comes the Body Image Virtual Reality Scale (BIVRS), an assessment tool designed to assess cognitive and affective components of body image [12]. It consists of a non-immersive 3D graphical interface, through which the patient can choose between 9 figures of different size varying from underweight to overweight. The software was developed in two architectures. The first runs on a single user desktop computer equipped with standard virtual reality development software. The second, developed using the VRML and QuickTime VR format, is freely accessible via Internet (http://www.psicologia.net) [73].

The possible use of remote VEs for telepsychiatry has emerged in the last year. Use of videoconferencing in the mental healthcare surged in Norway [74] and USA [75] during the last ten years. The results from videoconferencing trials revealed that this approach could provide insight that is valuable to the learning process [74]. Given the successful results obtained in a less immersive medium, it can be assumed that the use of immersive VR would further strengthen the assessment and rehabilitative process [76, 77] because of the ability to immerse the patient in a life-like situation that she/he is forced to face. As noted by Miller & Rollnick, [78] people are "more persuaded by what they hear themselves say than by what other people tell them" (p. 58).

Moreover, the use of VR enables the therapist to present a wide variety of controlled stimuli, and to measure and monitor a wide variety of responses made by the user. Both the synthetic environment itself and the manner in which this environment is changed by the user's responses can be tailored to the needs of each client and/or therapeutic application. Finally, VR is highly immersive and can cause the participant to feel "present" in the virtual, instead of real, environment. It is also possible for the psychologist to follow the user into the synthesized world.

Future applications of remote VR for telepsychiatry are expected to appear in the near future for the treatment of phobias and eating disorders [37] starting from existing research in this area [79, 80]. In fact, almost all the VEs developed in this area were developed using VR toolkits that support the Internet. Hodges *et al.* [81, 82] report on a project that makes use of VEs to provide acrophobic patients with fear-producing experiences of heights in a safe situation. A similar research was conducted by Lamson [83], who used a VE to treat 44 subjects with acrophobia.

In a more recent work Hodges *et al.* [84] verified the possibility of using a virtual reality airplane for exposure therapy in the treatment of fear of flying. North *et al.* [85], too, presented a case study of a 42 yr. old male who was afraid of flying. He was recruited for virtual reality therapy. Using a helicopter simulation, the authors exposed the patient to anxiety producing stimuli in progressively challenging situations. North *et al.* [86] also verified the possibility of using VEs in the treatment of agoraphobia. In a controlled study, the experimental group exposed to VR therapy reported a significant improvement [86]. A similar approach is used by Botella *et al.* [87, 88] in the treatment of claustrophobia and by Carlin et al. [89] in the treatment of arachnophobia.

Riva *et al.* [90] are using the Experiential Cognitive Therapy (ECT) an integrated approach ranging from cognitive-behavioral therapy to virtual reality (VR) sessions in the treatment of eating disorders. In particular, using both on-line and off-line VR sessions, ECT seems to be able to address both body experience disturbances and motivation for change [91].

7.4 Pros and cons

7.4.1 Added value

Remote virtual environments and related technologies add value to health care at least in the areas of improved services, and savings in material resources [92].

- *Improved Services*. Virtual reality can lead to improved surgical results. Examples include the use of laparoscopic simulators for training [93], the development of applications that simulate human response to medication for example, simulator systems helping to train anesthesiologists [94], and the development of imaging tools that guide surgical tools through brain tissue to the site of a tumor [95]. Advantages offered by telepresence systems include enhancing task performance in remote manipulation through increased positioning resolution or range, allowing controlled application of extremely large or small forces, improving operator perception of the task; and facilitating manipulation in hazardous environments by isolating the environment from the operator, or manipulation in clean environments also by isolating the operator from the environment.
- *Non-Renewable Resource Savings*. Finally, the use of simulators saves precious resources such as cadavers and animals. By allowing medical personnel to train using simulators, the demand for non-renewable resources can be drastically reduced. The trainee can practice over and over using a realistic, virtual environment without reducing the supply of non-renewable resources.

In this sense, VEs can offer a new human-computer interaction paradigm in which users are no longer simply external observers of images on a computer screen, but are active participants within a computer-generated three-dimensional virtual world. VR can add, delete, or stress details to better help clinicians perform basic functions from remote sites.

Proving more detail, VR systems offer at least two advantages over traditional telemedicine tools. VEs are capable of displaying feedback in multiple modes. Thus, feedback and prompts can be translated into alternate senses, to improve the awareness of the clinicians. For instance, sounds can be translated into vibrations. Finally, VR systems open the input channel: VR systems have the potential to monitor movements or actions from any body part, or many body parts simultaneously. All properties of movement, not just contact of a body part with an effector, can be monitored. Particularly, VR allows the manipulation of multisensory representations of the entire environment by natural actions and gestures. These unique features can provide the patient with specialized, safer treatment techniques for problems that previously were expensive or impossible to treat.

7.4.2 Limitations

Several current virtual environment applications in health care have problems that limit their effectiveness. Specifically, at least three technical problems limit their actual application:

- *Cost.* Although some attempts have been made to use PC-based virtual reality systems, most of the existing VEs are based on RISC platforms whose cost is beyond the reach of the average therapist.
- *Lack of reference standards*. Almost all applications in this sector can be considered "one-off" creations tied to a proprietary hardware and software, which have been tuned by a process of trial and error. This makes them difficult to use in contexts other than those in which they were developed.
- *Non-interoperability of systems*. Although it is theoretically possible to use a single virtual reality system for many different applications, none of the existing systems can be easily adapted to different tasks. This means that two different departments within

the same organization may find themselves having to use two different VR systems because of the difficulty of adapting one single system to their different needs.

7.5 Conclusions

Nonetheless, remote VEs can have a strong effect on health care. As we have seen, the key characteristic of VEs is the high level of control of the interaction with the tool without the constrains usually found in computer systems. VEs are highly flexible and programmable. They enable the therapist to present, from a remote site, a wide variety of controlled stimuli, and to measure and monitor a wide variety of responses made by the user.

As we have seen, one of the most promising areas of application of remote VEs is surgery: improved cameras, HDTV, head mounted displays, and stereoscopes have advanced the sensing and displaying of vision. However, there have been few developments in the area of tactile feedback. The ability to feel tissue is important. Procedures that require palpitation, such as artery localization and tumor detection, are extremely difficult when the only form of haptic exploration is in the form of forces transmitted through long, clumsy instruments. As noted by Moline [92], "The ability to remotely sense small scale shape information and feel forces that mesh with natural hand motions would greatly improve the performance of minimally invasive surgery and bring a greater sense of realism to virtual trainers" (p. 21). Also, time delays between master and slave sites represent a significant challenge for researchers in this area. These delays can induce loss of teleoperator fidelity and task performance as well as dangerous instability of operation [53]. Therefore, until a new method of compensation of latency is discovered, any tele or remote surgery will be limited to a few hundred miles. However, these limitations do not prevent VR-based tele-education systems for surgeons. In fact, Internet based surgical simulators represent one of the most promising areas of this technology.

Another key issue is safety. Some users have experienced certain side effects, during and after exposure to virtual reality environments [42]. The symptoms experienced by these users are similar to those which have been reported during and after exposures to simulators with wide field-of-view displays [96]. These side effects have been collectively referred to as "simulator sickness" [41] and are characterized by three classes of symptoms: ocular problems, such as eyestrain, blurred vision and fatigue; disorientation and balance disturbances; nausea. Exposure duration of less than 10 minutes to immersive virtual reality environments may result in significant incidences of nausea, disorientation and ocular problems [97]. Even if the latest VR tools have less or no side effects [32, 37], future researches have to confirm these results.

To spread the use of VR in telemedicine, further research is required. Professionals in this field must share information about their experiences in order to expedite suitable development work in this field.

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