VIRTUAL REALITY IN REHABILITATION OF SPINAL CORD INJURIES: A CASE REPORT

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Abstract: Advances in Information Technology offer new opportunities for rehabilitation. In particular, the immersion capability provided by a synthetic environment could be exploited to design novel assistive devices.

In virtual reality (VR) users navigate and interact with 3-D, computer-generated environments that are highly flexible and programmable, enabling the therapist to present a variety of controlled stimuli and to measure and monitor responses. VR provides a powerful means of increasing levels of environmental interaction in a highly controlled and structured manner.

In this paper an overview is given of the design issues of a VR-enhanced orthopaedic appliance used in rehabilitation of a person with spinal cord injury.

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1. Introduction

Advances in Information Technology are creatng new opportunities for rehabilitation, helping people to reduce the impact of motor or sensor limitations.

The use of rehabilitation robotic enables disabled users to interact with their environments via manipulator-like mechanisms which respond to their commands (Meredith, 1996). Moreover, virtual reality (VR) enables users to navigate and interact with 3-D, computer generated environments (Riva et al., 1997). The immersion capability which provides a synthetic environment could be exploited to design novel assistive devices. (Kuhlen & Dohle, 1995; Meredith, 1996)

In this paper an overview is given of the design issues of a VR-enhanced othopaedic to be used in rehabilitation of persons with spinal cord injury (SCI).

Physical therapy is usually a major part of the treatment program in SCI rehabilitation (Buck, 1992). However, long-term physical therapy is very demanding and requires strong motivation in patients. We believe that Virtual Reality (VR) can foster this motivation. In VR, a computer synthesises a three-dimensional graphical environment from numerical data (Riva & Mantovani, 1999). Using visual and auditory output devices - usually head mounted displays - human operators can experience the "virtual environment" (Riva, 1997). Further, because input devices sense the operator's reactions and motions, the operator can modify the synthetic environment, creating the illusion of interacting with the environment (Riva, Wiederhold, & Molinari, 1998).

VR is highly flexible and programmable. It enables one to present a wide variety of controlled stimuli and to measure and monitor responses made by the user (Riva, 1998; Riva et al., 1997). Both the synthetic environment itself and the manner in which this environment is modified by the user's responses can be tailored to the needs of each client and/or therapeutic application (Glantz, Durlach, Barnett, & Aviles, 1996). Moreover, VR is highly immersive and can cause the participant to feel "present" in the virtual environment. In this sense, VR provides a powerful means of increasing levels of environmental interaction in a highly controlled and structured manner .

There are ***three*** important characteristics of VR systems that can broaden rehabilitation of individuals with paraplegia (Riva, 1998):

- ***How They Are Controlled***: Current computer access systems accept only one or 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 recognise facial expressions, idiosyncratic gestures, or monitor actions from several body parts at a time. Most computer interfaces accept only precise, discrete input. Thus, many communicative acts are ignored and the richness of human communicative gestures are lost. VR systems open the input channel; as they have the potential to monitor movements or actions from any body part , or many body parts at the same time. All properties of a movement, not just contact of a body part with an effector, could be monitored.

- *Feedback*: VR systems can display feedback in multiple modes; thus, feedback and prompts can be translated into alternate senses. The environment could be reduced to achieve a larger or overall 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. Vision is the primary feedback channel of present-day computers; frequently, a displayed message is further distorted by text representation. It is very difficult to represent force, resistance, density, temperature, pitch, etc., through vision alone. For the individual, multimodal feedback ensures that the visual channel is not overloaded.

-*What Is Controlled*: 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 multisensory representations of entire environments by natural actions and gestures.

2. System design and implementation

To investigate the possible use of VR in SCI rehabilitation we have developed a prototype orthopaedic appliance for walking and rehabilitation comprising:

- a semi-rigid exoskeleton for support of the bust and the lower limbs;
- a virtual reality system.

The test-bed application, designed to be easily tailored to the needs of different users, is used to reproduce the feeling of an excursion to the mountains. The expected end-user cost of the appliance, including the adaptation process required to match the specific physical characteristics of each SCI patient, is about 15000/20000 $.

The exoskeleton

The gait-inducing exoskeleton, patented worldwide, was designed and developed by Ferrati Benito, President and CEO of Ferrati Electronic, an Italian IT company based near Milano. It is composed of a compressed air operated semi-rigid sling (Figure 1) for supporting the bust and the lower limbs of the patient, together with a framework designed as stable rest and support for the user.

The sling is equipped with small actuators (micro cylinders), activated by compressed air, which move the lower jointed part of the sling in accordance with the human gait . The micro cylinders are operated by the patient by means of a two-button interface located on both sides of the framework grips: pressing the left button, the left leg moves forward; pressing the button on the right, the right leg moves forward. The framework has grips on both sides, wheels for moving on the floor and inside are located both the PC used for the virtual experience and the compressed-air delivery means.

The virtual reality system

The VR-enhanced orthopaedical appliance uses a Thunder 400/C virtual reality system by Virtual Engineering of Milano-Italy. The Thunder 400/C is a Pentium II based immersive VR system (400mhz, 64 mega RAM, graphic engine: Matrox Millenium II 8Mb WRam) including an HMD subsystem.

A head mounted display (HMD) with 40° H and 30° V field of view (50° diagonal) provided the visual display. The HMD, developed by Retinal Displays Inc. - Los Altos (CA) - for Virtuality (UK), displays 800 lines of 225 pixels (180,000 active dots) to each eye and uses LCD technology (a full color AMLCD panel). The provided head tracker was used to sense head rotation.

The virtual environment used in the study was developed by Virtual Engineering using VRT 5.51 from Superscape Ltd. (UK). The environment reproduces the feeling of an excursion to the mountains, by simulating a stroll through a mountain path. To increase the realism of the experience, actual images of Alpine scenery were used together with sounds and voices typical of a natural environment.

The virtual environment moves in sync with the patient's steps: each motion ahead is activated by the buttons located on both side of the framework.

3. Case report

The first VR-enhanced orthopaedical appliance was developed for Nicola, a 26-year old male individual with complete paraplegia resulting from a car crash that occurred 4 years ago (Figure 2).

Two experimental sessions were conducted. Each session consisted of two fifteen-minute system trials separated by a ten-minute pause. During each trial, Nicola walked through the virtual path to the peak of a snow-covered mountain. However, during the second trial, a virtual runner was added, and the patient competed with him to reach the peak of the mountain.

Before and after each session Nicola rated his emotional and physical state using a questionnaire (Riva, 1996) consisting of 20 bipolar adjective pairs with six levels of intensity.

There were no side effects or simulation sickness in our patient. Only during the first session Nicola reported an increased level of fatigue together with a slight pain in the left ankle.

The adjective ratings revealed slightly improved levels of in self-confidence, will, increased relaxation and activity. Nicola also declared subjective improvement in his sense of well-being, mood and quality of sleep. The improvement in the sense of well-being can be also verified by higher scores both in mood-related adjectives (likeable-unlikeable and happy-unhappy) and in state-related adjectives (fast-slow and dynamic-static).

4. Conclusions

Although there is much potential for the use of immersive virtual reality environments in clinical rehabilitation, some problems have limited their application. During and after exposure to immersive virtual reality environments some users have experienced side-effects similar to those which have been reported during and after exposure to simulators with wide field-of-view displays (Regan & Price, 1993). These side-effects - collectively referred to as "simulator sickness" - are characterised by three classes of symptoms: ocular problems, such as eyestrain, blurred vision and fatigue; disorientation and balance disturbances; nausea (Riva et al., 1998). Exposure duration of less than 10 minutes to immersive virtual reality environments has been shown to result in significant incidences of nausea, disorientation and ocular problems (Regan & Price, 1994). We found no such effects.

The possile advantages of a VR system of this nature will have over traditional rehabilitation devices are:

- ***increased patient motivation:*** Adjustment to a new life style is certainly problematic for many individuals with paraplegia. It takes considerable motivation to participate in demanding therapies. For many patients with SCI walking again, even if wearing an exoskeleton and only for a few minutes, may be an enormous emotional boost.

- ***the ability to adapt the characteristics of the rehabilitation environment to the needs of different individuals***. VR can offer great flexibility in the adaptation to the patient's individual problems, improving the efficacy of the rehabilitation process. In fact, both the synthetic environment itself and the manner in which this environment is modified by the user's responses can be tailored to the needs of each client and/or therapeutic application. Moreover, individuals with SCI can explore living environments in VR prior to negotiating the environment from a wheelchair in the real world. For example, an individual's home could be put into a VR program and presented from the level of a wheelchair. In this way, a patient with paraplegia could prepare a meal in virtual reality, or use the toilet, or get into bed. The VR system could provide feedback on how safely his/her virtual behaviors were conducted and the likehood of success in the actual environment estimated. Rehabilitation therapies could then focus on improving any deficiencies and maximizing the patients' likehood of success in the home and community.

Of course these results are preliminary. Also, the cost of the VR system used in the study, even if affordable for departments or hospitals, is still high for a single user.

From a clinical view point, issues to address in the future are: further testing of the device using controlled clinical trials; a follow-up study to check the persistence of the positive effects on mood and how to integrate the use of the orthopaedical appliance into the usual rehabilitation process. However, at this stage, a number of obstacles exist which have impeded the development of active research specifically testing persons with SCI. These obstacles include problems with acquiring funding for a new treatment modality, the relative lack of familiarity with the technology on the part of researchers in these fields and, last but not least, the lack of reference standards. Almost all of the existing VR applications can be considered "one-off" creations tied to their development hardware and software, which have been adjusted in the field by a process of trial and error. This makes them difficult to use in contexts other than those in which they were developed.

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Figure 1: The sling equipped with small actuators (microcylinders)

Figure 2: The patient during the second VR session