Virtual Reality Based Rehabilitation and Game Technology

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ABSTRACT
Virtual Reality technology is currently part of advanced physical rehabilitation therapy. However, several questions remain unanswered: Can this technology improve or even substitute the traditional methodologies? Can it really influence the nervous system or does moving within a virtual environment just motivate the individual to perform? In this paper we present the state of the art, the new advanced technology available and the most promising applications in this field. Finally we will introduce our research as a case study in the area.

Keywords
Rehabilitation, Therapy, Virtual Reality, Motor Disorders, Game Technology

INTRODUCTION TO VIRTUAL REHABILITATION

Following an authoritative description of traditional rehabilitation therapy of motor disorders [1] *it is by its nature repetitive, and repetition tends to "decouple" the mind, and reduce patient's motivation*. In other words: it is boring.

There are several universally accepted definitions of Virtual reality (VR). One of the most clear was provided in [2]: *VR is an immersive, interactive, 3-dimensional computer experience occurring in real time*.

Virtual reality has the ability to simulate real-life tasks [3] and comes together with several evident benefits for rehabilitation:

1) specificity and adaptability to each patient and disease;
2) repeatability;
3) ability to provide patient engagement;
4) tele-rehabilitation and remote data access;
5) capability for precise assessment;
6) safety.

VR offers the possibility to be precisely *adapted* to the patient's therapy and to be specific. VR environments can provide realistic training for the patient in different scenarios and phases of the rehabilitation.

Repetition is crucial for the re-learning of motor functions and for the training of the cortical activity. This task has to be connected with the sensorial feedback on every single exercise.

Patient *motivation* is fundamental because active cooperation of the patient is needed to achieve a more functional outcome of the therapy. Motivation can be improved by assigning a serious game format to the therapy. In this way the training activity becomes more attractive and interesting [4, 5].

Remote data access is a fundamental requirement, especially for rural patients, since they do not have to travel to urban clinics.

In addition, VR represents a precise tool for the *assessment* of the therapy during each session. The (tracked/saved) data can be used by the rehabilitation specialists for monitoring and managing the therapy [6].

By using VR in conjunction with Human Computer Interfaces (HCI) the training of daily life activities can be much improved in terms of time and quality. This approach permits a realistic and ergonomic training in a safe, interactive and immersive environment. In particular, VR provides the user with the possibility to perform tasks with a degree of safety which is normally not possible in the traditional rehabilitation. VR provides the rehabilitators with the possibility to influence qualitatively the training program, even in real-time. Another evident benefit is the patient's engagment which is a key factor in rehabilitation (especially for children).

Examples of interfaces able to interact with VR are mice, joysticks, haptic interfaces with force feedback and motion tracking systems.

Several researches have shown that, during VR rehabilitation, the movements are very similar to those used in traditional therapy. Although they appear to be a bit slower and less accurate, [7, 8] show that they are anyway appropriate for rehabilitation. Finally, [9] have proven good results in executing the movements trained in VR in reality. In [10], [11], and [12] good results are shown in improving of motor skills for post-stroke rehabilitation of functional deficits in reaching, hand function and walking, respectively. A personal computer based desktop VR system was developed in [13] for rehabilitating hand function in stroke patients. The system uses a tracking system based on gloves to exercise four parameters of hand movement: range, speed, fractionation, and strength. Their results show that each patient showed improvement on most of the hand parameters over the course of the training and that some of the subjects have re-learned difficult functions of daily life like buttoning a shirt.

Some of the significant studies on the application of robotics and VR for rehabilitation purposes shall be introduced briefly. In [14], results were presented obtained from the comparison of a training with a robot-virtual reality system with a robot alone on the gait of individuals after stroke.

[15] presents a development of an advanced upper extremity prosthesis with the potential to restore full motor and sensory capability to upper extremity amputee patients. In addition, a GUI interface for patient training and therapeutic applications was developed during this research. The Rutgers Arm [16] is one of the first prototypes composed of a PC, a motion tracking system and a low-friction table for the upper extremity rehabilitation. The system has been tested on a chronic stroke subject and has shown improvements in arm motor control and shoulder range of motion (Fugl-Meyer [17] test scores). The same group has developed the Rutgers Ankle [18] for the lower extremity rehabilitation. It is a haptic/robotic platform, which works with six degrees of freedom, driving the patient's feet movements (Fig. 1, up). The tests of the Rutgers Ankle system have shown that the group of patients trained with the robotic device coupled with the VR demonstrated greater changes in velocity and distance than the group trained with the robot alone [19]. Most of the gait rehabilitation systems currently used for therapy are based both on treadmills and body weight support. The state-of-art in rehabilitation using virtual reality (VR) and robotics is provided by Lokomat® and Armeo® (from Hocoma) for the lower and the upper extremity, respectively (Fig. 1 down left and right).

These two systems are validated by the medical community and used in several rehabilitation centers [20]. Both are completed by an augmented feedback module which extends the conventional hardware with a computer and a large monitor with acoustic stereo feedback together with software for the interactive training tasks. This option provides various engaging virtual environments to motivate your patients, adjustable level of difficulty and intensity according to the cognitive abilities and the specific needs of each patient.

Low Cost VR based Rehabilitation using game technology

Recently there has been an explosion of new technologies: especially low cost gaming devices based on optical tracking systems, radio frequencies, infrared cameras, and haptics are accessible to almost everybody.

Considering the general trend to decrease the costs for the health systems all over the world one question comes up urgently: can low-cost gaming technology serve the needs of at least not severely injured patients with motor disorders?

In terms of costs and deployment logistics it is evident that a transition of the rehabilitation from traditional hospitals or clinics to home environments can be a winning challenge [21].

Many research groups have started the exploration of the use of such systems like Nintendo Wii® or more recently Kinect® as tools for rehabilitative therapy, including occupational and physical therapy.

An exploration of researches and low-cost programs is presented below.

An example of tele-rehabilitation can be found in [22], where a home-based tele-rehabilitation system based on low-cost haptic devices (game pad and joysticks) is described. The system focuses on a series of virtual reality therapeutic exercises for upper limb motor rehabilitation. It provides effective visualization and quantification of the patient's motions and associated pathologies. Therapists can access remotely the collected data.

Figure 1: Successful examples of applied technologies for rehabilitation. They are all based on robots/exoskeletons and VR. Upper left: Rutgers Ankle, lower left Armeo® and right Lokomat®.

Sony PlayStation2® was successfully used as low-cost VR system in home environment by [23] to improve sensory/motor recovery on an individual two years poststroke with residual sensorimotor deficits.

Sony PlayStation3® was used for tele-rehabilitation of children with hemiplegia togheter with 5DT 5 Ultra (five sensor) glove for the hand tracking, a computer, display, keyboard and a mouse [24].

The release of the Wii® Fit (software) and Wii Balance (platform) has stimulated new researches. The system eBavir is a low-cost balance virtual rehabilitation system based on the Wii® balance board.

[25] has presented a comparison of the feasibility, safety, and efficacy of virtual reality using the Nintendo Wii gaming system (VRWii) versus standard rehabilitation to evaluate arm motor improvement. They have shown that gaming technology represents a safe, feasible, and potentially effective alternative to facilitate rehabilitation therapy and promote motor recovery after stroke.

Another reference research group in the field is working about virtual rehabilitation using Kinect® [27]. In particular they are developing a high level library (the Flexible Action and Articulated Skeleton Toolkit) which can be used upon the open source library OpenNI [28] to produce virtual rehabilitation software.

Case Study: the HYPER project

We are currently working on providing a VR rehabilitation platform for the HYPER project [29]. This research involves different results in neurorobotics (NR) and motor neuroprosthetics (MNP), both for rehabilitation and functional compensation of motor disorders.

The project focuses its activities on new wearable NR-MNP systems that will combine biological and artificial structures in order to overcome the major limitations of the current rehabilitation solutions to Cerebrovascular Accident (CVA) and Spinal Cord Injury (SCI).

VR, an important part of the complex system, was initially based on radio frequency tracking technology. This solution offers good tracking performances but it suffers from the use of many cables.

Considering the patient's needs it is therefore not an optimal solution. Therefore we are now exploring a new wireless and inexpensive technology: Kinect®.

First results (see Fig. 2) are very promising and even if the accuracy of the tracking has to be measured exactly it seems that for this type of application the needs in terms of accuracy are not highly demanding. Additionally the tracking system appears to be robust enough to track the patient and the related robotic exoskeleton or neuroprosthetic devices on both upper and lower part of the body.

A limitation to be considered is that the Kinect® IR tracking suffers when the subject is illuminated strongly by the sun light. This is, however, a merely technological limitation which can be overridden.

Finally, a further part of our research concerns the conjunction between a Brain Computer Interface and virtual reality in order to create a good diagnostic and personalized environment in which it is possible to study the brain signals as answers to external (VR) stimuli or to assess the progress of the patient in the rehabilitation therapy.

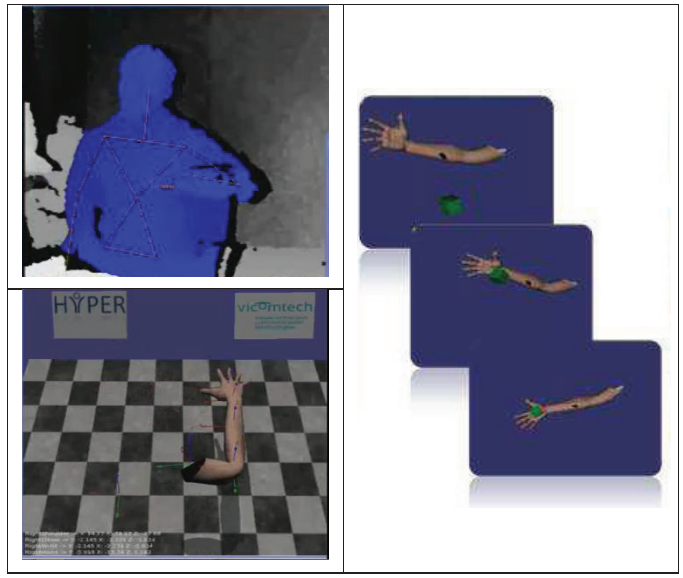

Figure 2: Snapshots of simple VR scenes: reaching, moving and grasping a virtual object. Kinect® is used for the tracking of the upper part of the patient body

CONCLUSIONS

This paper reviews the state of art, advantages and perspectives of Virtual Rehabilitation used in various forms of therapy. The recent introduction of new technology, originally developed for game purposes, provides a number of challenges and increases the possibilities of Virtual Rehabilitation to gain wide acceptance.

We have presented, as a case study, the first development status of an advanced system that combines VR based on game technology with a hybrid NR and MNP system for functional compensation of motor disorders.

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