Virtual Reality in Rehabilitation

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1. Stroke and rehabilitation

Rehabilitation means different things in different cases. In this chapter, the term is referred to as post-stroke treatment for recovery purposes. According to the World Health Organization, 15 million people suffer stroke worldwide each year [The Internet Stroke Center; and Patient @UK stroke]. In the United States, stroke is the leading cause of serious, long-term disability and also the third leading cause of death [NIH post-stroke rehabilitation]. Though the effect differs on survivors, stroke might leave patients with brain damage, paralysis or some dysfunctions such as limb's stiffness and tightness and losing balance. These effects may seriously weaken survivors' capabilities of controlling movements, using languages, and memorizing, thus, leaving them with residual disabilities. Proper rehabilitation is essential for helping stroke survivors progressively rebuild capability and relearn skills that have been lost due to brain impairment. The aim of rehabilitation is therefore to maximize activity and quality of life. Although short and intensive rehabilitation is critically important following a stroke, continuous and repetitive rehabilitation is essential to help survivors achieve the best possible long-term outcomes with the goal of reaching the highest possible level of independence in daily living activities which require skills of mobility, communication, and social interactions [Stroke and rehabilitation education]. Basically, rehabilitation employs the same technique as that used for teaching new skills.

As an ongoing process, repetition in rehabilitation is to maintain and refine the learned skills for a long period of time typically in months or years after the stroke. The right direction is provided by specialists since symptoms and disabilities following a stroke vary greatly depending on such factors as the part of the brain affected, the time elapsed between the stroke and the treatment, and the extent of the damage. Progress and recovery are therefore unique for each person due to the complexity of individual cases. Although rehabilitation centers with trained professionals and facilities are ideal for stroke survivors to regain their living skills, certain situations, such as transportation and financial problems, may prevent them from accessing to the centers. In such cases, self-directed rehabilitation may be continued at home. However, self-directed exercises at home often lack professional guidance and quantitative feedbacks. To circumvent these problems, an innovative rehabilitation system allowing guided self-training in home settings will be beneficial to many stroke survivors.

2. Virtual reality in rehabilitation

To develop an innovative system of home-based rehabilitation, the new trend is to rely on the virtual reality technology because of its inherent ability to simulate real-life tasks [Adamovich et al., 2005; Boian et al., 2002; Yang et al., 2008]. Virtual reality (VR) is a young and growing field. It allows users to interact with virtual objects in a near natural way through different interface devices using their natural senses of vision, audition and taction. The interaction makes users feel immersed in the virtual environment as if they are surrounded in a real world [Burdea & Coiffet, 2003]. The growing technologies along with concomitant system cost reductions have benefited many fields such as education, medical training and health care, manufacturing, military, and entertainment. An advantage of virtual reality is that it allows individuals to easily vary training parameters and to explore effective scenes that may be difficult or unsafe to construct in the real world. Furthermore, a fully immersive virtual environment mimics reality exceptionally well. VR is especially useful for systems which depend heavily on visualization and experimentation for practicing. As more advanced technologies are developed, new applications ensue. The virtual reality based rehabilitation training is one of the advancing and emerging research fields.

Compared to the traditional rehabilitation method, the VR based system has several advantages, which include the ability for individual setups, ease of adjustment, capability of measurement and performing feedback, and the inclusion of stimulus features. The software based rehabilitation exercises are easier and faster to setup than utilizing the traditional rehabilitation facilities. Individual practice sessions can be customized to suit individual needs according to different dysfunctions and injury levels through computer programming.

Specific software programs may be developed for measuring, quantifying, evaluating, and data storage. With the inheriting simulation capability, virtual reality can bring the physical world into the controlled environment. Therefore, the virtual reality based system can implement performance analysis from different aspects, and give the feedbacks to users in real time. Preliminary analyses and useful results can be stored in the computer as references for specialist. The specialist may then adjust training parameters and levels for appropriate self-practicing according to the need of individual patients. It is also possible to develop a system for tele-rehabilitation to allow services from a remote location, while patients remain in their home settings [Holden et al., 2007]. The specialist may provide professional guidance remotely to avoid the drawbacks of self-training in rehabilitation.

As mentioned earlier, an important factor in rehabilitation is repetition. Users may easily experience boredom for keeping on practicing the same exercise without any stimulus. To attract their attention during the repetitive training session is an important element for increasing the training efficiency and obtaining successful recovery results. It is straightforward to develop either real-life or game-like exercises to attract users by providing interesting scenes and challenging tasks for competing with the computer or other users.

3. Representative work on virtual reality based rehabilitation

Several studies have demonstrated the effectiveness of virtual environments in the treatment of motor skills impairments.

3.1 Upper extremity function rehabilitation by imitation

Holden and colleagues at the Massachusetts Institute of Technology developed a virtual environment based tele-rehabilitation system for improving upper extremity function for patients with stroke [Holden et al., 2007].

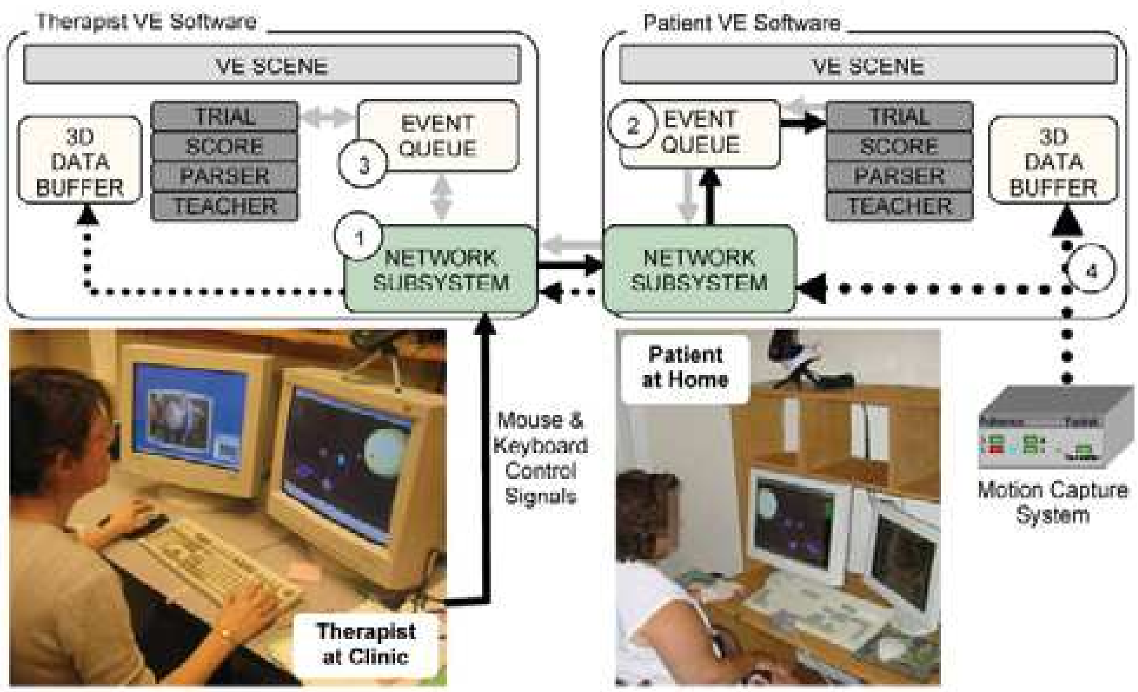


Fig. 1. Schematic of the home-based virtual reality tele-rehabilitation system. Patient and therapist can see and hear each other via a teleconferencing link on a monitor. Motion capture equipment transmits information about patient's arm movements to the virtual reality display. Therapist in the clinic controls the software and views the same virtual scene as that displayed to the patient in her home (second monitor). Video camera allows the therapist to remotely view any part of the patient's workspace. [Holden et al., 2007]

The system (Fig. 1) is to help stroke patients regain upper extremity function through tele-rehabiliation. It employs 2-3 Polhemus sensors attached to the patient with one on the back of the hand, one on the upper arm, and an optional sensor on a held object to capture the motion of the upper extremity. With an algorithm model, the software can generate a "virtual upper extremity" of the arm that infers shoulder, elbow and wrist locations and orientations according to individual setups. The patient can sit in front of a computer with two monitors-one for the virtual environment scene and the other for the videoconference image of the therapist. With the small sized movement parameter data transmitted through the network, the practicing procedure can be synchronously remodeled, viewed and

controlled by the remote therapist. This real-time remodel feature along with the videoconference can provide a rich interactive training program.
The training procedure is to help patients relearn the upper extremity function by imitation. In theory, this should facilitate motor learning by assisting the patient's motor planning process in a natural way. Several "learning by imitation" examples are available [Holden et al., 2001, 2005]. Fig. 2 shows an example of standard training scenes, and Fig. 3 displays additional scenes designed for individual needs. Fig. 4 shows an example of the score calculation and parameters adjustments for different aspects of the patient's performance (e.g., spatial elements, speed, timing, and velocity profile). The score representing the "match" with the teacher's trajectory is displayed in real time for each patient.

The left column shows the virtual reality scene.
The right column shows a schematic of the subject's movement in the real world that the scene is designed for training.
Top panel: Mailbox scene, for learning to reach into into the workspace
Middle panel: SleevePull, training a hand-to-body movement. The score indicator is for showing previous movement at below target performance level.
Bottom panel: Clock, for training repeated reciprocal movement (supination/pronation).

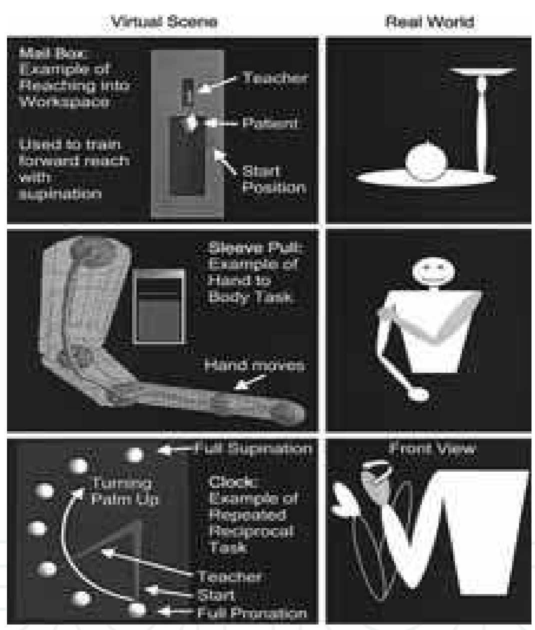


Fig. 2. Examples of three standard training scenes used by all subjects [Holden et al., 2005]

Top panel, scenes used for subject 1 to enhance control of wrist extension, without (left) and with (right) grasp.
Bottom panel, customized scenes used by subject 2. Left: scene allowed practice of elbow extension with shoulder flexion and adduction. Right: practice of isolated shoulder external rotation in neutral flexion/abduction with elbow flexion.

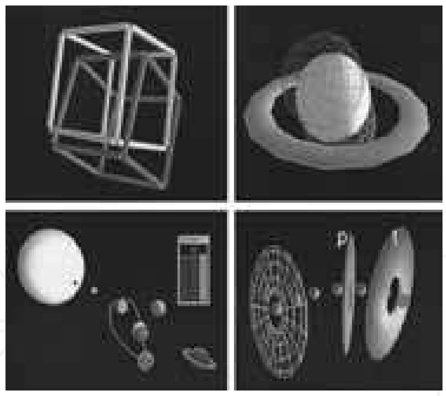


Fig. 3. Examples of additional scenes designed for individual needs[Holden et al., 2005]

Results of the clinical study on subjects with stroke showed significant improvements in upper extremity function following 30 1-h virtual reality treatment sessions as measured by three standard clinical tests: Fugl–Meyer test of motor recovery, Wolf motor test (WMT), and shoulder strength test. Grip strength (GS) showed a trend toward improvement. These changes were maintained, for the most parts, at four-month follow-up.

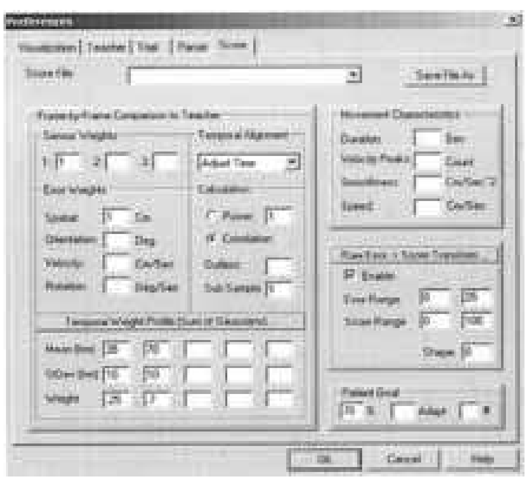
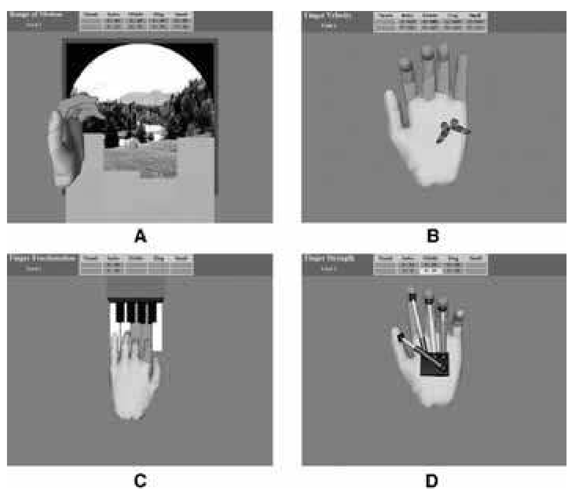


Fig. 4. Score-preferences panel in which all score settings are accessed[Holden et al., 2005]

3.2 Rehabilitation with specially designed hardware

Researchers at Rutgers developed several systems for post-stroke patients. One system is virtual reality based hand manipulation rehabilitation with two versions [Adamovich et al., 2005; Morrow et al., 2006]. The first version utilizes CyberGlove and Rutgers Master II-ND haptic glove. Based on this work, a second version of a low cost hardware is setup with a modified Xbox that runs the training practices. A P5-glove is used to measure the flexion of all fingers as well as the wrist 3D position. The experimental system set up is shown in Fig. 5. Game tasks used for stimulating users' interests are to train finger motions with respect to speed, range, fractionation and strength. Examples of training scenes are displayed in Fig. 6. Their pilot study seems to indicate that this virtual reality based rehabilitation application may improve hand function in chronic hemiplegic patients.

Fig. 5. Overall view of the experimental low-cost finger training system [Morrow et al., 2006]



(A) range of motion, (B) speed of movement, (C) finger fractionation, (D) finger strength
Fig. 6. Screen snapshots of four VR exercises [Adamovich et al., 2005]

Another system of "Rutgers Ankle" is for patients with lower-extremity dysfunction [Boian et al., 2002; Deutsch et al., 2001; Lewis et al., 2003; Whitworth et al., 2003]. The main component is a Stewart platform haptic interface that reads foot position and orientation for applying resistant forces. The system also includes the low-level servo control of the platform and the high-level software such as graphical user interface for rehabilitation [Deutsch et al., 2001]. Fig. 7 displays the hardware setup and Fig. 8 shows two virtual reality exercises. From the testing studies taken by chronic post-stroke individuals, it appears that some improvements have been made through the system training.

(a) the rehabilitation system setup showing the PC monitor and the web-based monitoring display

(b) the Rutgers Ankle device

Fig. 7. The VR-based ankle rehabilitation system [Boian et al., 2002]

(a) the airplane exercise

(b) the boat exercise

Fig. 8. Virtual reality exercise simulations [Lewis et al., 2003]

3.3 Hand motor recovery systems with Phantom haptics

Four VR based hand rehabilitation applications (virtual phone dialing, virtual writing, virtual painting, and tele-hockey game) are illustrated below. All were developed by Yang and associates at Purdue University Calumet [Kim et al., 2006, 2007; Yang et al., 2007, 2008].

3.3.1 Virtual phone dialing

Phone dialing is an important part of routine daily life. A virtual phone dialing training application was developed to train users to dial the telephone numbers within a specified period of time [Yang et al., 2008]. The system focuses on training hand movement with precision, speed, and appropriate pressing force. The Phantom premium 1.0 haptic device provides users with feedback as if they were touching the buttons on the real phone. The haptic is represented with a virtual hand along with a virtual phone and other graphic features in the user interface. Once a training session starts, the user needs to press eight buttons chosen by the system randomly within a specified time period. Fig. 9 shows a training scene.

Fig. 9. Virtual phone dialing [Yang et al., 2008]

3.3.2 Virtual writing

Writing requires a fine motor skill which involves hand movement adeptness together with a coordinated hand-eye movement. Different hand-writing training systems have been developed for different purposes such as learning of writing Chinese characters, Japanese calligraphy, or following writing trajectories [Avizzano et al., 2002; Saga et al., 2005; Teo et al., 2002].

The developed virtual writing system is to help recover hand motor skills through real time guiding forces from the Phantom Premium 1.0 haptic device - [Kim et al., 2006, 2007]. The haptic device guides the user's hand to follow the preset English letter trajectory. The guiding force calculated with the developed algorithm is proportional to the distance deviated from the trajectory. The algorithm recognizes the 26 letters based on two categories (straight and curved strokes) and calculates forces accordingly [Yang et al., 2008]. Users may choose any one of the 26-English alphabet letters, and the letter with pre-drawn trajectory will then be displayed on a virtual paper. The system analyzes several training parameters of force, completeness, and correctness in real time. The results are recorded in the database for future reference. Fig. 10 shows a practicing scene of writing letter A in the virtual environments.

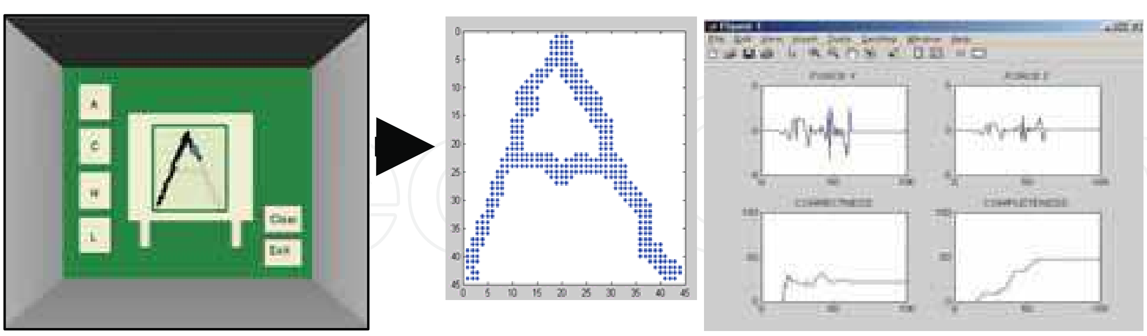


Fig. 10. Virtual writing with real time performance feedbacks [Kim et al., 2007]

3.3.3 Virtual painting

Virtual painting is for improving hand control precision and movement speed. The virtual environment includes mainly a virtual flower composed of thousands of triangle meshes and other graphic user interface features such as buttons, and color options. The Phantom Premium 1.0 haptic device is represented with a virtual pen in the environment. It is developed as a game exercise. Once the user presses the "start" button, a random triangle will be flashing and waiting for the person to paint on the screen and make color changes. The position and time spent on implementing each task is shown to the user as well as recorded in a database for future reference. According to individual needs, levels of tasks can be set with different speed and pedal size. To provide the user with the more realistic touching feeling, a new collision detection algorithm was developed with an efficient triangle management[Yang et al., 2008].

Fig. 11. shows a practicing scene with a virtual flower and a virtual pen. The user is in control of starting and stopping training times. The painted part and the duration of the exercise are shown throughout the training session.

Fig. 11. Virtual painting [Yang et al., 2008]

3.3.4 Tele-hockey game

A tele-hockey game scene was developed for hand motor skill training. It is mainly for stimulating users' interests in a game environment. The virtual scene includes one hockey ball controlled by the system plus two others controlled by users. Each user controls one virtual ball and competes with each other for hitting the ball controlled by system. Two haptic devices-Phantom Omnis are used to give users force feedbacks when they hit the virtual hockey ball. Different levels of difficulty may be set upon request. To avoid accidental scoring by uncontrolled hand shakings from some users, the system is able to filter out the unintentional hitting incident and record only the real practicing results including precision rate and speed [Yang et al., 2007]. Fig. 12 shows a practicing scene.

Fig. 12. Virtual tele-hockey game [Yang et al., 2007]

Volunteered normal human subjects have tested the above four training practices. Based on feedbacks, additional features, such as audio alert, the calculation of guiding force to hand in virtual writing, and adjustment of different levels of difficulties for different needs, have been included in the development. Clinical testing has not been performed for any of these systems, and thus no clinical data are available at this time.

4. Conclusions

In view of the examples presented, it is clear that different virtual reality based rehabilitation systems are useful for different purposes, since no one system can cover all aspects of rehabilitation. For example, a therapeutic environment for gesture analysis and recognition [Camurri et al., 2002] is useful for Parkinson's patients, whereas a web-based tele-rehabilitation system may be suitable for arm and hand therapy for stroke patients [Reinkensmeyer et al., 2002]. Virtual reality is valuable for not only motor rehabilitation but also for others such as psychological and cognitive rehabilitation [Rose et al., 2005; Takacs et al., 2007], as well as orthopedic rehabilitation [Akay et al., 2001; Burdea et al., 2008].

It is encouraging that virtual reality technologies have been successfully employed for helping the skill recovery of post-stroke patients. The advantages of combining virtual reality with rehabilitation have now been realized by the rehabilitation community. However, there is still insufficient clinical testing data to ensure the efficiency and safety of virtual rehabilitation for widespread clinical acceptance. Furthermore, whether virtual reality really influences the nervous system or whether moving within a virtual environment just motivates the individual to perform remains to be answered. Continued efforts and studies are needed for making progresses in this field.

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Population ageing has major consequences and implications in all areas of our daily life as well as other important aspects, such as economic growth, savings, investment and consumption, labour markets, pensions, property and care from one generation to another. Additionally, health and related care, family composition and life-style, housing and migration are also affected. Given the rapid increase in the aging of the population and the further increase that is expected in the coming years, an important problem that has to be faced is the corresponding increase in chronic illness, disabilities, and loss of functional independence endemic to the elderly (WHO 2008). For this reason, novel methods of rehabilitation and care management are urgently needed. This book covers many rehabilitation support systems and robots developed for upper limbs, lower limbs as well as visually impaired condition. Other than upper limbs, the lower limb research works are also discussed like motorized foot rest for electric powered wheelchair and standing assistance device.