Occupational Therapists' Evaluation of Haptic Motor Rehabilitation

Ruba Kayyali[1], Atif Alamri[2], Mohamad Eid[2], Rosa Iglesias[1],
Shervin Shirmohammadi[1], *Senior Member, IEEE*, Abdulmotaleb El Saddik[2],
Senior Member, IEEE, and Edward Lemaire[3]
[1] Distributed and Collaborative Virtual Environments Research Laboratory
[2] Multimedia Communications Research Laboratory
[3] Faculty of Medicine, The Rehabilitation Centre
University of Ottawa, Ottawa, Canada
rkayyali@discover.uottawa.ca, atif@mcrlab.uottawa.ca, eid@mcrlab.uottawa.ca,
riglesias@discover.uottawa.ca, shervin@discover.uottawa.ca,
abed@mcrlab.uottawa.ca, elemaire@ottawahospital.on.ca

Abstract - **Haptic-based virtual rehabilitation systems have recently become a subject of interest. In addition to the benefits provided by virtual rehabilitation, the haptic-based systems offer force and tactile feedback which can be for upper and lower extremity rehabilitation. In this paper, we present a system that uses haptics, in conjunction with virtual environments, to provide a rich media environment for motor rehabilitation of stroke patients. The system also provides Occupational Therapists (OTs) with a Graphical User Interface (GUI) that enables them to configure the hardware and virtual exercises and to monitor patients' performance. We also present an analysis of the system by a group of OTs from the Ottawa General Hospital, Rehabilitation Center. The OT's feedback, both the positives and negatives, and the results of the assessment test are also presented.**

I. INTRODUCTION

On average, a recovering stroke patient receives one to two half hour sessions a day with an OT [1]. This short time is not enough for a stroke patient to recover at sufficient speed. Therefore, virtual rehabilitation proposes to use Virtual Reality (VR) technology to alleviate this problem by allowing patients to perform rehabilitation exercises using a computer, probably at home, allowing more frequent and repetitive practice, leading to faster recovery. This has been a research subject for over a decade [2, 3], where it has been shown that virtual reality could be beneficial for patients' rehabilitation. VR supplies an interface to the real world and a synthetic environment, which can be seen as an extension of the current computer imagery technology. This synthetic image system supports a VR application to recreate an essential scenario for rehabilitation activities.

At the same time, the haptic technology or haptics has been recently employed in many VR applications. Haptic, which is derived from the Greek verb "haptesthai" meaning "to touch", refers to the science of touch and force feedback in human-computer interaction. Haptic-based virtual rehabilitation offers the potential to create systematic human testing, training and treatment environments that allow precise control of complex dynamic 3D stimulus presentations, behavioral tracking, performance measurement, data recording, and analysis [4]. Furthermore, the incorporation of haptics in VR-based rehabilitation systems opens up many applications and possibilities, such as haptic guidance and augmented feedback.

Recently, much research that involves VR and haptic devices has been conducted in medical rehabilitation and tele-rehabilitation to enhance patients' motor and cognitive skills, in a repetitive and progressive manner. However, there is still a gap between the design of such systems and their usage with real rehabilitation patients. OTs need better control and configuration of such systems in order to, for example, select the amount of time delay, angle, zoom, difficulty, and other parameters that will be used as a form of tracking of the patient's progress. But more importantly, current haptic systems have hardware limitations, as we will see, that need to be overcome to make them practical for motor rehabilitation.

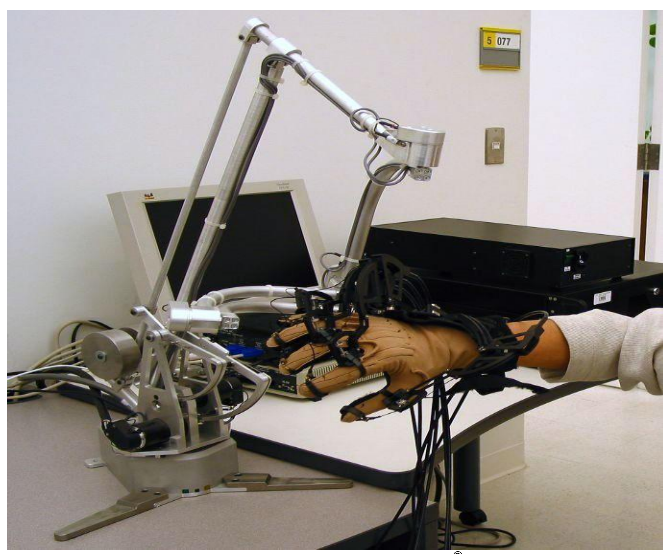

Figure 1: Immersion's CyberForce® System

In this paper, we present a haptic virtual rehabilitation system whose goal is to assist patients who suffered from a stroke, acquired brain injury, muscular sclerosis, paraplegia and upper extremity amputees. The system uses the CyberForce system from Immersion Corporation, shown in Figure 1 [5]. This specific hardware was chosen because firstly it measures the position and orientation of each finger, the wrist, the palm orientation, and simulates objects' weight by exerting downward force. Secondly, currently the CyberForce System is the only commercially available hand exoskeleton system; although we believe other systems could be available soon. The system's requirements were the result of several consultations with the Rehabilitation Center of the Ottawa General Hospital and the Discover Lab at the University of Ottawa. As a result of these consultations and trials, a GUI was designed so that OT's can supervise and control a patient's rehabilitation session. This interaction allows the OT to load a specific virtual exercise with parameters tailored for a patient. Finally, the system was evaluated by seasoned OT's who had experience patients with upper extremity weaknesses, a deficit within range of motion, any hand or cognitive deficits. The findings are reported in this paper.

II. RELATED WORK

There are extensive research and publications in the field of haptic-based virtual rehabilitation. In terms of lower extremity, the work reported in [6] and [7] explains that some of the patients' ankle muscles capabilities were improved when introducing haptic effects using the Rutgers Ankle haptic interface. For upper extremity, several attempts have been made to incorporate haptics for arm and wrist motor function rehabilitation [8, 9, 10]. In addition, many other systems were developed to help in the recovering of patients' hand motor function using the CyberForce system [11, 12, 13], the Rutgers Master II [14, 15], and the Phantom haptic interfaces [11, 16].

In our previous work [12, 13], the initial version of a VR system was developed to include a set of exercises that relied on force feedback mechanism. These exercises were obtained by incorporating common tests that OT's have been using, such as the Jebsen Hand [17] and the Box and Block test [18]. The system also included a set of exercises that allowed for the manipulation of small objects, as well as employing gross motor skills. However, the system lacked a human-computer interface that allowed for interactions between the OT's and the system itself. The system was also tested using healthy people. In this paper, we investigate the importance of haptic VR-based exercises, implement a GUI for OTs, and evaluate the system by seasoned therapists.

III. THE REHABILITATION SYSTEM

The system's requirements were the result of extensive analysis of the general specifications of virtual rehabilitation exercises. Exercises such as "lift a cup", "squeeze ball", and "arrange cubes" have already been explained in [12] and [13] and integrated into the new system. Moreover, we explain a new exercise, "3D Maze" with different difficulty levels. The virtual rehabilitation system incorporates a GUI for OTs to easily setup the system for each patient, choose the virtual exercise and help in monitoring patient's data.

The new 3D Maze exercise essentially consists of a cylindrically shaped object that would be used to traverse a path within a maze from the starting point until the end point. The maze itself is a simple 3D structure, built using mesh cube objects. The following requirements, which were used to tailor exercises, were requested by the OT's:

- Ability to vary the angle of the maze from 45° to -45° the horizontal axes.
- Several levels of complexity.
- Ability to track the speed of patients as they move the stick.
- Ability to alter the weight of the stick being moved through the maze.

The main objective of the 3D-maze exercise is to increase the motion range of patients, along the horizontal and vertical planes. This exercise also allows patients to increase hand's steadiness and eye-to-hand synchronization. The number of collisions between the stick and the maze walls is computed. Five different difficulty levels were designed, some of which are shown in the Figures 2, and 3.

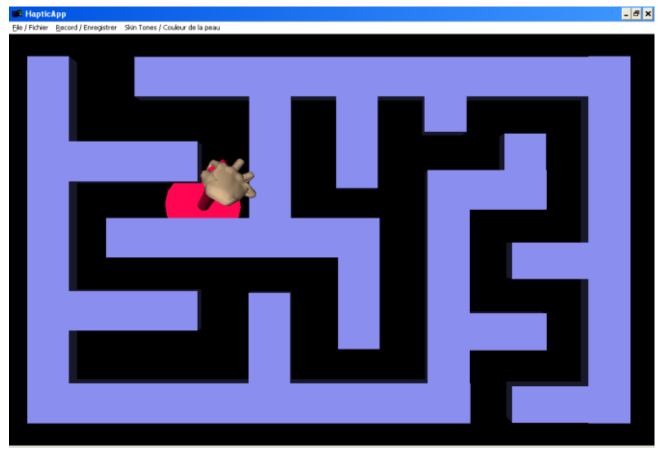

Figure 2: Maze Exercise Level 4

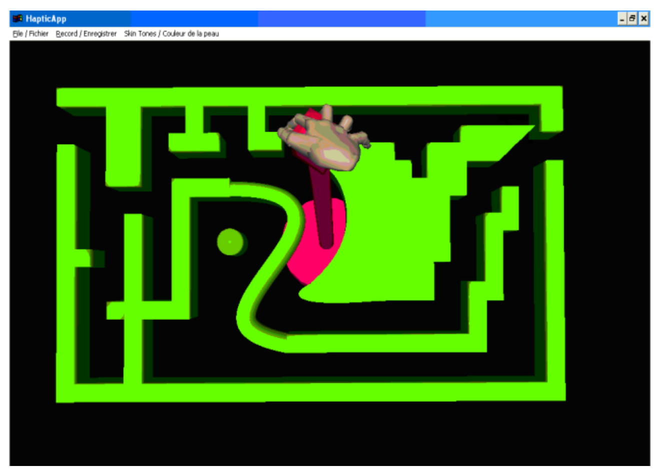

Figure 3: Maze Exercise Level 5

The maze stick was designed as a long, cylindrical object that had a disc attached at one end, and a cube attached at the other end where the stick is virtually "held" during the exercise. This seems to provide more realistic grasp for the patient.

Speed tracking is another important requirement in measuring a patient's performance. The haptic devices currently employed in the VR system do not provide a means of measuring the speed of the hand as it moves. We addressed this issue by using a spherical ball. The patient starts the exercise but, after a specified time delay, the ball begins to traverse the path of the maze. Once the ball collides with the stick, this means that the patient is moving too slowly and the OT can determine if a longer time delay is needed.

The GUI designed for the OT's is shown in Figure 4. Throughout the GUI, OTs were able to configure the system in about five minutes. This time included putting on the device glove/actuators and configuring the hardware. The GUI allows therapists to perform the setup steps in an easy-to-follow manner. It also provides OTs with the ability to view the results of analyzing the data collected from each exercise, although as a preliminary phase of this study this was not evaluated by the OTs. The data recorded throughout the exercises provide information about the X (width), Y (length), and Z (depth) position of the hand on the screen, the angles of each finger (metacarpal, proximal, and distal joints angles), and the time elapsed to complete the exercise.

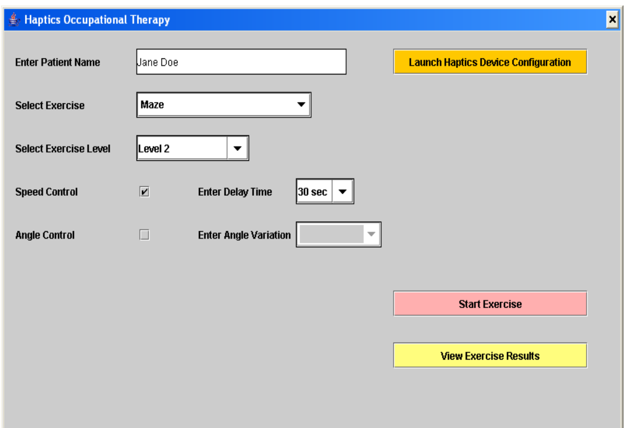

Figure 4: Therapists' Graphical User Interface (GUI)

The CyberForce system consists of three pieces of hardware: the CyberGlove, CyberGrasp and the CyberForce armature [5]. It should be noted that Immersion Corporation provides a standard glove size (the CyberGlove) (Figure 1) that fits most hand sizes. The CyberGrasp provides force feedback to the fingers via actuators and has a weight of 350 grams, which is considered to barely be a significant weight. The CyberForce is a robotic armature made of stainless steel that simulates objects' weight. Any actual weight to be exerted on the arm is done through the armature that has barely any significant weight. Furthermore, the hardware itself can be configured to exert a desired weight on the user's arm. This weight varies from 1N to 25N, and can be set by OTs.

IV. EXPERIMENTAL RESULTS

To test the system, we opted to use the experience and knowledge of 5 OTs from the Ottawa General Hospital Rehabilitation Centre aged between 20s and 60s. The goal was to collect their assessment and feedback for the VR system, so that all aspects of the system, including the hardware, software and graphics, were properly scrutinized. Each OT was given ample time to try the system, by going through the initial set-up phase and then attempting the cup or 3D maze exercises. The feedback was collected from each OT during their trial and later on, through individual interviews. After spending one working day examining and using the system, the therapists' feedback can be summarized as follows:

- The hardware itself poses problems, where a patient may be unable to get the actual hardware on, due to neurological damage the hand might suffer from.
- It was found that adjusting the size of the CyberGlove, in addition to the calibration, was necessary.
- The calibration procedure for the hardware may be difficult to meet, due to the motor function damage in the hand.
- Although they previously agreed to build 3D maze exercises, after their trial they showed the more suitability of using exercises based on daily common actions.

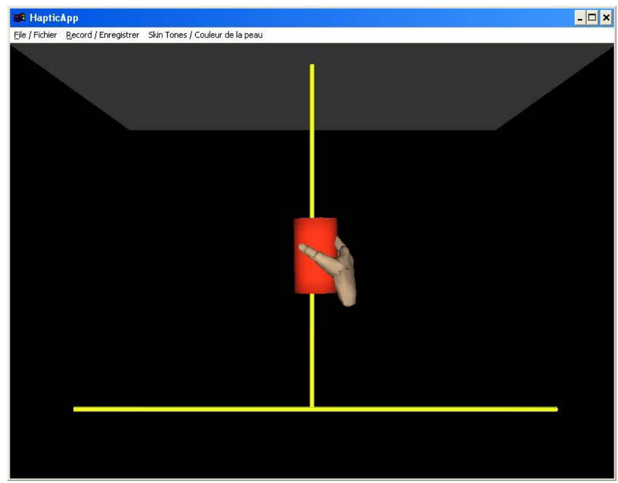

Figure 5 Cup Exercise: Cup moves along the yellow axes.

- The Cup exercise described in [12][13] and depicted in Figure 5 was very well received. The therapists appreciated this exercise as it allowed the patient to do a daily common task.
- The simplicity of the exercises was praised, as well as the GUI, especially the naming conventions that would not imply any belittling of the patient (Level 1 to 5).

A. *Observations*

While observing the OT's performing the exercises, certain obstacles and issues were discovered, with the most significant listed here:

- Some of the therapists had difficulty viewing the exercises as 3D objects, where the virtual environment spreads further along the horizontal plane than can be seen by the computer screen.
- Some of the therapists began to experience slight symptoms of arm fatigue while performing the maze exercises, especially when the arm was held up unsupported for a long period of time. This fatigue would be significantly higher for a patient.
- As mentioned, the maze exercises did not seem very interesting to the OT's. According to them, focusing on

exercises that provide the patients with everyday common situations would be a better goal.

- It should be noted, however, that the idea of increasing the difficulty of an exercise based on the progress of the patient was well-received.
- However, the OT's admired the ability to modify an object's weight in the virtual environment and to see the change reflected by the haptic device.
- Further observations were directed to the actual hardware, where some of the OT's complained about a slight pain due to the actuator's thimbles. The apparent cause of the pain was the diameter of the thimbles which, even at the largest possible size, were yet too tight for some therapists.
- Another problem was with the configuration of the hardware needed in determining the appropriate centre of the workspace. The CyberForce system is limited in its workspace by the length of its armature. Visualizing the centre point proved to be somewhat difficult for some of the OTs.
- The workspace was also limited by the lengths of the electric cords, which is another issue to be considered.

V. CONCLUSIONS

In this paper, a haptic 3D virtual rehabilitation system for upper extremity rehabilitation using the CyberForce system was proposed. This system includes a GUI for therapists to setup the system for each patient, choose a virtual exercise and the difficulty level. Two different virtual exercises were incorporated: lifting a cup and navigating a maze.

This system was evaluated by a team of occupational therapists. While many benefits were observed, the results also prove that the system still requires further improvements. The main area of concern lies in the haptic device itself more than in the details of our designed system. This suggests that there is a need for haptic hardware makers and rehabilitation specialist to work together to produce better haptic devices. The tests also revealed that exercises need to be more realistic, by providing patients with a virtual reality environment that resembles their own daily lives rather than simple exercises. We will now be concentrating on designing further exercises that would help the patients in their common daily activities, which include eating and drinking actions and so on. These new exercises will provide more practical rehabilitative aids to patients. Moreover, other haptic devices will be studied, such as the FCS HapticMaster, which provides larger and more stable force feedback.

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