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Daily-Life Exercises for Haptic Motor Rehabilitation

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Abstract - Haptic-based virtual rehabilitation systems have recently become a subject of interest. In addition to the benefits provided by virtual rehabilitation, they offer force and tactile feedback which can be crucial for many 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 with a human-computer interface that allows for easier set-up, more facilitated interaction with the system, and provides a more autonomous means for the progression of the patient. The system had been modified, after thorough analysis by a group of experienced occupational therapists. The result is a new set of exercises and a more advanced user interface, as will be presented.

Keywords – Haptics, Motor Rehabilitation, CyberForce System, Occupational Therapy

I. INTRODUCTION

On average, a recovering stroke patient receives one to two half hour sessions a day with an occupational therapist [5]. 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 subject of research for over a decade [17-18], where it has been shown that virtual rehabilitation could be beneficial for rehabilitation patients. 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. VR 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.

At the same time, the haptic technology 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 devices are evolving and getting cheaper, more flexible, and more compact in size. In general, haptics provide an excellent addition to VR due to the force feedback and tactile input/output that is essential to many rehabilitation patients.

There have been several proposals for implementing haptic-based virtual rehabilitation systems, most provide the patient with the time needed and the intensive exercises that are designed to target the patient's 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. Occupational Therapists (OT's) 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.

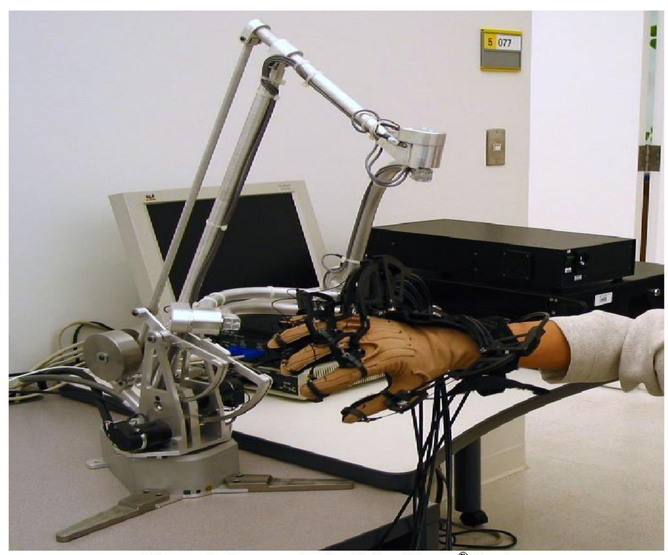

Figure 1. Immersion's CyberForce® System

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. This specific hardware was chosen because it measures the position and orientation of each finger, the wrist, the hand in general, and simulates objects' weight by exerting downward force. 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. The initial implementation was also placed under the analysis of a group of five occupational therapists that provided thorough feedback and further amendments to the design of the system. As a result of these consultations and trials, the graphical user interface was modified to include further details, tailored for each specific exercise, as well as a new list of exercises derived from common daily activities.

II. RELATED WORK

There exists extensive research and publications in the field of haptic-based virtual rehabilitation. In terms of lower extremity, the work reported in [7] and [10] 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 [11, 13, 16]. In addition, many other systems were developed to help in the recovering of patients' hand motor function using the CyberForce system [4, 9, 14], the Rutgers Master II [8, 12], and the Phantom [14, 15] haptic interfaces.

In our previous work [4, 9], 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 [2] and the Box and Block test [3]. The system also included a graphical user interface that allows the OT to launch a specific exercise with parameters tailored for a specific patient However, the system was tested using healthy people and never subjected to the scrutiny of OT's. In this paper, we present the analysis of the initial version of the VR system, by a group of OT's who had experienced patients with upper extremity weaknesses, a deficit within range of motion, any hand or cognitive deficits, and overcome the listed shortcomings by designing new tests and exercises, improving upon the graphical user interface for the OT, and re-evaluating the system by the OT's themselves.

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 "the cup", "squeeze ball", and "cubes" have already been explained in [4] and [9]. We began by designing a new exercise, "3D Maze" that is meant to become more difficult as the patient progresses [19]. The 3D Maze exercise was designed with the objective of helping a patient increase his or her range of motions, along the horizontal and vertical planes, and to teach better eye-to-hand synchronization. It was also intended to help the patient develop the psychological ability of strategizing how to complete a certain task. Five different difficulty levels were designed, one of which is shown in the Figure 2.

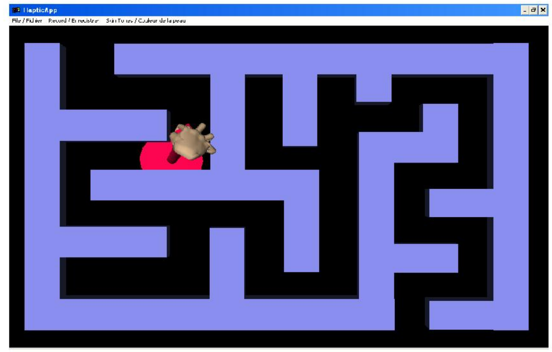

Figure 2. Maze Exercise Level 4

A user interface was also designed for the OT's. The interface allows the therapists to perform all the required steps for configuring the entire system in sequential order. It was thus demonstrated that the setup time for a new patient would be an average of five minutes, including the time taken to wear the device and configure the hardware itself.

A. Analysis of the Rehabilitation System

The system was subjected to analysis by a group of five occupational therapists from the Ottawa General Hospital Rehabilitation Centre aged between 20s and 60s, volunteered their time to assess the effectiveness of the VR system, and the implemented exercises. The aim of the therapists' assessments was to collect as much feedback for the VR system as possible, such 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 any of the exercises, all with the help and supervision of two of the team members. The feedback obtained provided a foundation on which to base the future improvements and amendments to the VR system. The opinions and after-thoughts of the OT's are summarized as follows:

- The Maze exercises did not seem very interesting to the OT's. It seemed as though concentrating on exercises that provide the patients with everyday common situations would be a better goal. This would imply actions such as eating exercises and drinking exercises that use cups and mugs, exercises that give the ability to hold a shopping bag, etc.
- Some of the actions done while performing the maze exercise, are not based on daily, common actions that even a healthy person would perform.
- The hardware itself poses problems as some patients' hands could be suffering from neurological.
- Size adjustments with the CyberGlove and the CyberGrasp were sometimes necessary, in addition to the calibration stage.
- The configuration process for the hardware may be difficult, due to the motor function damage in the hand.

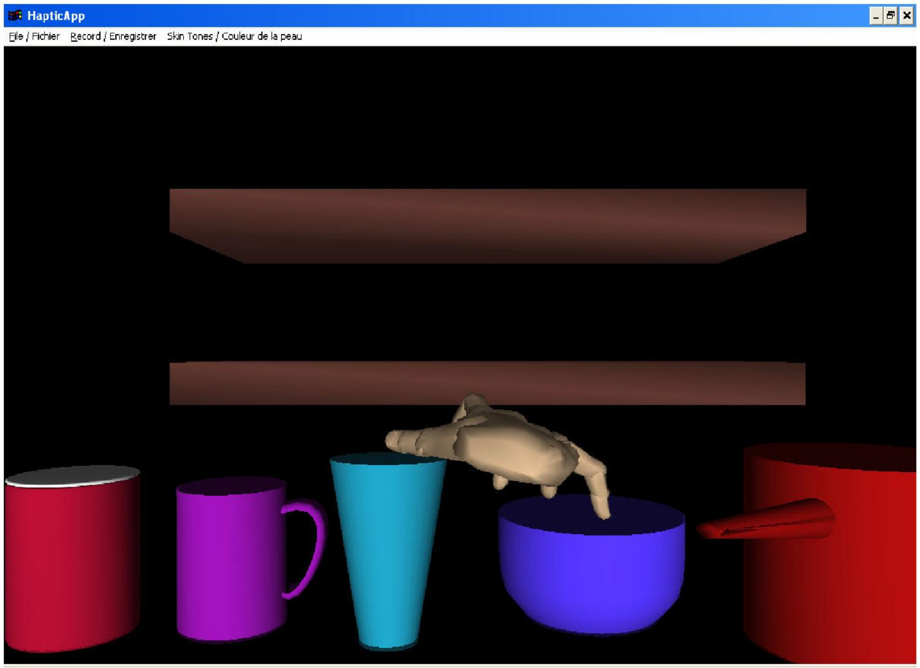

Figure 3. Shelf Exercise

- The simplicity of the exercises was praised, especially in selecting exercises and naming conventions that would not imply any belittling of the patient.
- The therapists were also impressed with the amount of time it took to set up the hardware on each user, and configure the device.
- The OT's admired the ability to modify an object's weight in the virtual environment and seeing the change reflected by the haptic device.

IV. IMPROVEMENTS AND NEW EXERCISES

As a result of the above test results, a new set of exercises has been proposed. These exercises are intended to concentrate on providing the patients with more common daily activities, such as eating, drinking, etc. A new set of requirements was gathered from the OT's, on which we based our new designs. Further amendments and improvements were also required for the user interface. The requirements mainly consisted of the following:

- Ability to vary the angle of the main components of each exercise from 45° to -45° the horizontal axes.
- Several levels of complexity.
- Ability to track the velocity of the patient.
- Ability to track the number of collisions a patient makes, if suitable to the exercise.
- Ability to alter the weight of the items being moved throughout the exercise.
- Provide feedback information to the occupational therapist.

A. Shelf Exercise

The Shelf exercise essentially consists of two shelves, fixed in place within the virtual environment, and a set of common items that can be found in all kitchens. The purpose of the exercise is to have the patient pick up the items, placed alongside the shelves, and place them on the shelves. The items themselves range in size and weight, and are made distinguishable through the use of appropriate colors. A sample of the exercise can be seen in Figure 3.

As the patient progresses, the difficulty of the exercise can be advanced by increasing the respective weights of each of the items, as well as placing obstacles on the shelves.

B. Tea Exercise

The Tea exercise provides a patient with a common daily activity. The current design of the exercise includes several levels of difficulty, with each advanced level including a heavier tea pot. Future designs will include the ability to pour an actual liquid into the cup, as well as calculating the accuracy of the pouring action by determining the amount of spilt liquid. The exercise also allows the patient to lift the teacup, separate of the saucer. This also helps the patient learn to perform more delicate tasks which include the use of the thumb and index finger only. The following figure, Figure 6, provides a sample of the exercise.

C. Soup Exercise

The Soup Exercise is derived out of a basic daily activity that comprises of the user bringing a spoon shaped object from within a bowl of liquid, to his or her mouth. The intent of the exercise is to allow the patient to practice performing such a precise, yet simple, action that (s)he would require during daily activities. The exercises consists of a bowl of liquid and a spoon, as can be seen in Figure 4.

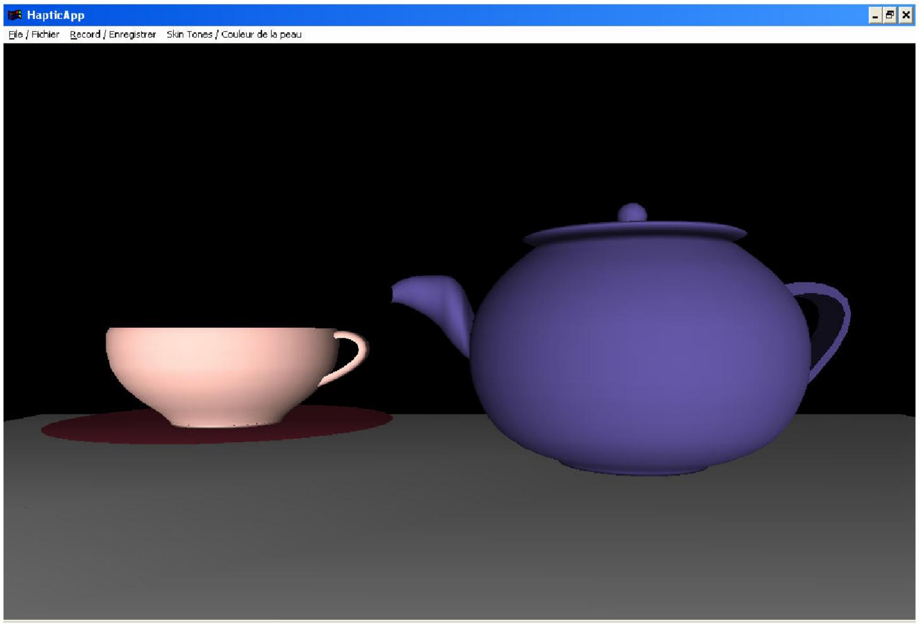

Figure 4. Tea Exercise

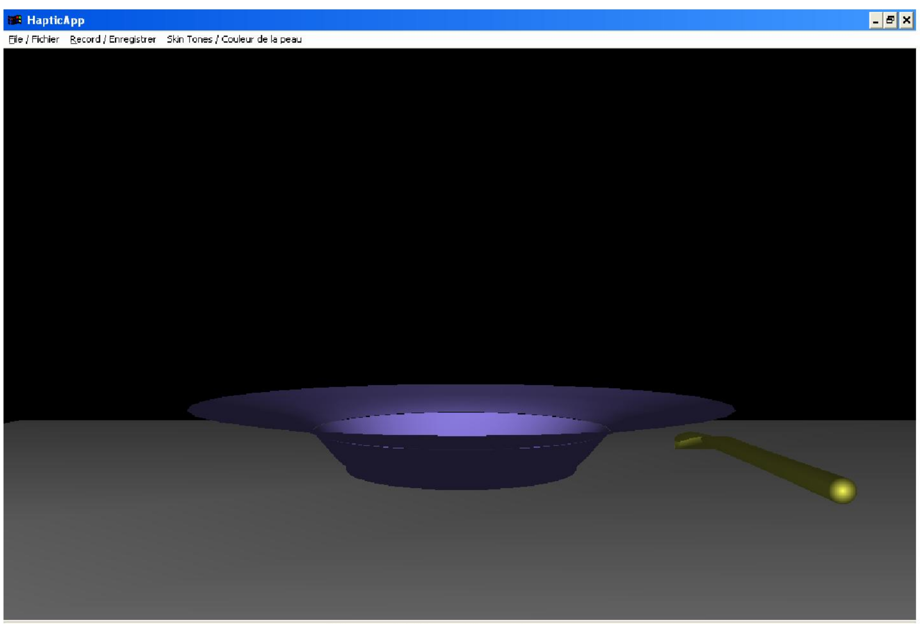

Figure 5. Soup Exercise

D. Eating Exercise

The Eating exercise resembles the Soup exercise in concept. It comprises of a plate with several food items, such as carrots, peas and potatoes, and a knife and fork. The items are designed using basic mesh objects, and the food items have been made to vary in size and shape. The intent of the exercise is to allow patients to practice the action of picking up small items using a fork. This is meant to help patients gain better motor skills that would aid them in their daily lives. Future alternatives of this exercise will include cutting actions, using the knife, of various food items.

E. User Interface

After gathering the feedback from the OT's on the exercises and the new system requirements, we concluded that further amendments would be needed to the user interface. The new interface still contains similar features to the initial one, in allowing the system configuration steps to be performed in chronological order. The main window of the user interface can be seen in Figure 7.

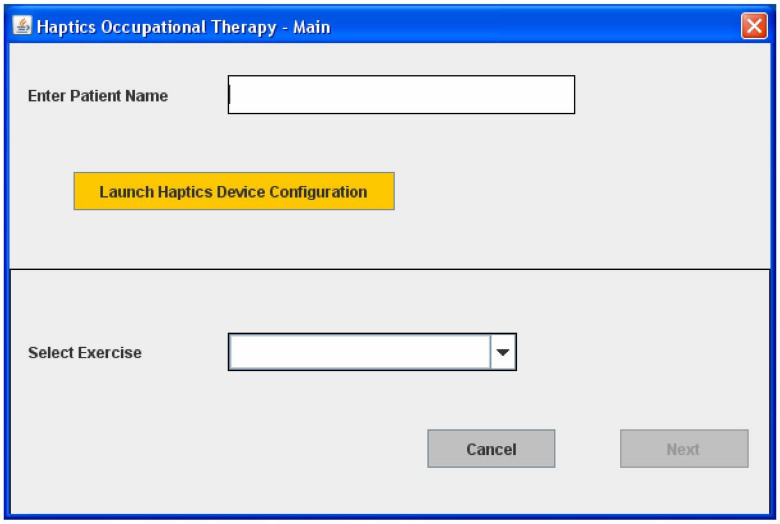

Figure 6. Therapists' Interface Main Window

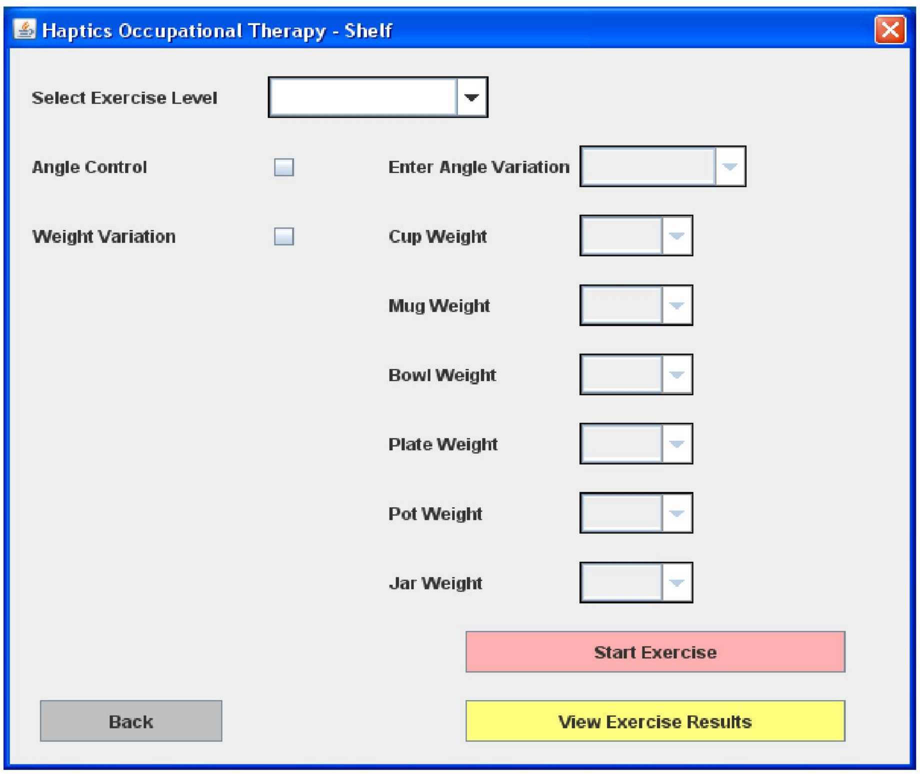

Figure 7. Therapists' Interface: Shelf Exercise Window

Furthermore, it also includes further tailoring of the interface that depends on the exercise being selected by the OT. For example, after selecting the Shelf exercise from the main window and clicking on the "Next" button, the window to follow would be customized to include a list of all the objects to be moved throughout the exercise, and the ability to modify their default weights. This can be seen in Figure 8. This allows the OT's to modify each exercise and tailor it to the progress of each patient

V. FUTURE WORK

There is yet some work to be completed in order to fulfill all the requirements of the Virtual Rehabilitation system. The main task to be completed is a complete system evaluation to be done by the OT's. This will provide a new basis for the system from which further improvements will be made. Other tasks to be done will include the following:

- Devise a means of automatic patient progression through the performance evaluation report for an exercise.

- Enhance the Soup and Tea exercises to provide the patient with liquid graphics, pertaining to the liquids (i.e. tea and soup) involved in the exercises.
- Enhance the Eating exercise to allow for the physical cutting of volumetric objects.
- Provide various difficulty levels to the Eating, Soup and Tea exercises.
- Improve the current framework to support animation within the virtual environments.

The hardware aspect of the system still remains an issue still remains an issue and other hardware possibilities are still under study. The FCS HapticMaster is still a valid option, as well as the PHANTOM Premium 3.0 Haptic Device, when used in a combination of two or more of the device. Further collaboration with the occupational therapists' team will be needed to determine the best possible hardware option to be used.

VI. Conclusions

This paper presents a new set of exercises designed for a Haptic 3D Virtual Rehabilitation system for upper extremity rehabilitation, using Immersion's CyberGlove / CyberGrasp / CyberTouch, as a result of a system evaluation by a team of occupational therapists. Many improvements to the system were made, such as to the user interface, and many of its benefits were retained. As per the evaluation tests, the new version of the system includes more realistic exercises that provides patients with a virtual reality environment that resembles their own daily lives rather than simple exercises. The new system's exercises concentrate on actions that would help the patients in their common daily activities, which include eating actions, drinking actions, etc. These new exercises will be subjected to further evaluation by the occupational therapists to prove their practicality as rehabilitative aids to the patients. The main area of concern continues to lie in the haptic devices 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. For the purpose of the implementation of this system, other hardware alternatives are still being debated.

References

[1] M. McLaughlin, A. Rizzo, Y. Jung, W. Peng, S. Yeh, W. Zhu, and the USC/UT Consortium for Interdisciplinary Research, "Haptics-enhanced virtual environments for stroke rehabilitation", Proceedings of the IPSI, Cambridge, MA. 2005.

[2] R.H. Jebsen, N. Taylor, R.B. Trieschmann, M.J. Trotter, and L.A. Howard, "An Objective and Standardized Test of Hand Function," Archives of Physical Medicine and Rehabilitation, pages 311-319. June 1969.

[3] V. Mathiowitz, G. Volland, N. Kashman, and K. Weber, "Adult Norms for the Box and Blocks Test of Manual Dexterity," The American Journal of Occupational Therapy, pages 386-391. 1985.

[4] I. Shakra, M. Orozco, A. El Saddik, S. Shirmohammadi, and E. Lemaire, "Haptic Instrumentation for Physical Rehabilitation of Stroke Patients", In proceedings of the 2006 IEEE International Workshop on Medical Measurement and Applications Benevento, Italy, April 2006.

[5] P. Rijken and J. Dekker, "Clinical Experiences of Rehabilitation Therapists with Chronic Diseases: A Quantitative Approach," Clinical Rehabilitation, vol. 12, pp. 143-150. 1998.

[6] G. Burdea and P. Coiffet, Virtual reality technology, Hoboken, NJ: John Wiley & Sons, 2003.

[7] R. F., Boian, J. E., Deutsch, C. S., Lee, G. C., Burdea, and J., Lewis, "Haptic Effects for Virtual Reality-Based Post-Stroke Rehabilitation," Proc. of 11th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2003.

[8] D., Jack, R., Boian, A.., Merians, M., Tremaine, G., Burdea, S., Adamovich, M., Recce, and H., Poizner. "Virtual reality-enhanced stroke rehabilitation" IEEE Transactions on Neurological Systems and Rehabilitation Engineering, Vol. 9, pp. 308-318, 2001.

[9] A., Alamri, R., Iglesias, M., Eid, A., El Saddik, S., Shirmohammadi, and E., Lemaire, "Haptic-based Exercises for Post-Stroke Patient Rehabilitation," submitted to IEEE Workshop on Medical Measurement and Applications,Warsaw, Poland, 4-5 May, 2007.

[10] J., Deutsch, J., Latonio, G., Burdea, and R., Boian ,"Rehabilitation of Musculoskeletal Injuries Using the Rutgers Ankle Haptic Interface: Three Case Reports", in proceedings of EuroHaptics 2001 Conference. UK, July, 2001.

[11] R., Colombo, F., Pisano, S., Micera, A., Mazzone, C., Delconte, M., Carrozza, P., Dario, and G., Minuco, "Upper limb rehabilitation and evaluation of stroke patients using robot-aided techniques," proceeding of 9th International Conference on Rehabilitation Robotics, Chicago, June, 2005.

[12] R., Boian, A., Sharma, C., Han, A., Merians, G., Burdea, S., Adamovich, M., Recce, M., Tremaine, H., Poizner, "Virtual Reality-Based Post-Stroke Hand Rehabilitation", in Proceedings of Medicine Meets Virtual Reality 2002 Conference, CA, January, 2002.

[13] R., Loureiro, F., Amirabdollahian, S., Coote, E., Stokes, W., Harwin ,"Using Haptics Technology to Deliver Motivational Therapies in Stroke Patients: Concepts and Initial Pilot Studies", in proceedings of EuroHaptics 2001 Conference. UK, July, 2001.

[14] S., Yeh, A., Rizzo, W., Zhu, J., Stewart, M., McLaughlin, I., Cohen, Y., Jung, and W., Peng,"An integrated system: virtual reality, haptics and modern sensing technique (VHS) for post-stroke rehabilitation", proceedings of the ACM symposium on Virtual reality software and technology', New York, 2005.

[15] J., Broeren, A., Bjorkdahl, R., Pascher, and M., Rydmark, "Virtual Reality and Haptics as an Assessment Device in the Postacute Phase after Stroke", CyberPsychology & Behavior, Vol. 5, No. 3, 2002, pp. 207-211.

[16] J., Furusho, C., Li, Y., Yamaguchi, S., Kimura, K. Nakayama, T., Katuragi, T., Oguri, U., Ryu, S., Suzuki, and A., Inoue,"A 6-DOF rehabilitation machine for upper limbs including wrists using ER actuators", in proceedings of IEEE International Conference of Mechatronics and Automation, 2005.

[17] A. A. Rizzo and J. G. Buckwalter, "Virtual Reality And Cognitive Assessment And Rehabilitation: The State of the Art", in Virtual Reality in Neuro-Psycho-Physiology, pp. 123–146. Ed. Amsterdam, The Netherlands: IOS,1997.

[18] G. Riva, "Virtual Reality in Psychotherapy: Review," CyberPsychology & Behavior. Vol. 8, No. 3,pp. 220-230, June 2005.

[19] R. Kayyali, A. Elamri, M. Eid, R. Iglesias, S. Shirmohammadi, A. El Siddik, E. Lemaire, "Occupational Therapists' Evaluation of Haptic Motor Rehabilitation", in proceedings of the EMBC Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Lyon, France 2007.