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Haptic Instrumentation for Physical Rehabilitation of Stroke Patients

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Abstract - The recovery of hand functions in post-stroke patients relies on the length of therapy that is available to them. Rehabilitation exercises supervised by occupational therapists are characterized by repetitiveness and a constant increase in intensity. However, due to resource limitations, facilities and time allocated to recovering stroke patients restrict the maximum level of rehabilitation that can be attained. Various efforts have therefore been spent into rehabilitation themes set in virtual environments, sometimes using haptic devices, in order to create affordable stand-alone systems that patients could use at home. This study carries forward in that direction by implementing hapto-virtual reality based exercises for the purposes of hand rehabilitation. In this paper, we present a haptic-based rehabilitation system that can be set in the patient's own house to provide him/her with treatment that is not restricted by time and facilities and that offers continuous evaluation of the patient's improvement.

Keywords – Medical Instrumentation, Physical Rehabilitation Systems, Haptic Application in Medical Systems, Medical Virtual Environments.

I. INTRODUCTION

For Recovering stroke patients are typically seen for half hour sessions, once or twice a day; hardly enough time for a patient to recover, especially that it is decreased to once or twice a week when seen as an outpatient. The time elapsed from admission to discharge is around 42 days [8]. At the Ottawa General Hospital, an average length of a rehabilitation session for a patient runs for typically an hour. This number is double that of an average session length in a US private healthcare facility. A patient is seen for around 25 times a week. Not only will a haptic-based VR system allow a patient all the required time to recover by providing intensive exercises that are repetitive in nature, which is necessary for recovery [10], but it will do so by providing this service from the comfort of the patient's home and consequently allow for continuous evaluation of performance.

The process of implementing a framework that aims to induce haptic-based post-stroke rehabilitation in virtual settings requires a delicate balance between ambition and reality that is dictated by available resources and time restrictions. An ideal situation would see such work through to the shores of realizing a framework that provides a patient with a personalized station at home, where the patient can log in at pre-determined times that were set by the therapist and perform the appropriate rehabilitation exercises, have the recorded data stored then analyzed by an intelligent context-aware mechanism in order to adjust the intensity/difficulty of the exercise. The data repository for each patient will be updated accordingly and the results of each session will be sent to the responsible doctor or occupational therapist. That would be a full realization of the ambitions of people involved in hapto virtual reality based rehabilitation. Although progress in this field is bound by available resources and equipment, a framework with the potential to realize the final objective needs to be possess two attributes: 1) Incorporate simple rehabilitation exercises that provide a patient with the means to train a stroke-afflicted hand, and 2) Provide a continuous evaluation system that analyzes recorded patient data from an exercise. The resulting evaluation will help a therapist to detect vital signs about the patient's status and provide him/her with in-depth information about minute details about the hand, like the trouble with a certain finger for example.

An intelligent system that provides Operational Therapists (OTs) with behavioral-based analysis of patient's data will only help them in devising better solutions and rehabilitation schemes depending on a patient's personal preferences and needs. Also, such a system will provide OTs with enough material to deduce certain patterns displayed by certain groups of patients that might in turn open the door to new hypothesis in hand rehabilitation. Finally, engaging a patient in haptic-based virtual reality exercises will maintain the motivation necessary to complete the repetitive exercises on a daily basis with the same level of enthusiasm and hence produce consistent data that will materialize into highly accurate analysis. This is in addition to the instant feedback that will help OTs in designing therapy that is unique to each patient [1].

In this paper, we present our Hapto Virtual Reality based prototype for Physical Rehabilitation. Our system incorporates the two attributes mentioned above, and takes into account tests that occupational therapists have been using in practice for a long time. We also present our experimentations and preliminary results. The rest of this paper is organized as follows: section II discusses related work in the field, while section III presents our proposed framework. Section IV describes the experiments and the results, followed by section V which wraps up the paper by discussing future work.

II. RELATED WORK

Substantial research that involves Virtual Reality and Haptics has been carried out in therapy and rehabilitation. These can generally be categorized into two groups: Virtual Reality, and Haptics.

A. Virtual Reality

Visual stimulus is very important in many tasks of perception. Virtual environments provide an interface to the real world and closer realistic 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 for the precise control of complex dynamic 3D stimulus presentations, within which sophisticated interaction, behavioral tracking, and performance recording and analysis is possible [8]. McLaughlin et al have developed an immersive motor rehabilitation system with force feedback interaction. Their system is based on a stereoscopic Head Mounted Display (HMD) as mechanism of visual interaction. A VE is presented in order to establish a closer contact between patients and medical staff as main objective [9].

B. Haptics

Linguistically, the word haptic is derived from the Greek verb “to touch” or to handle. It now refers to the expanding discipline that is associated with the study of touch through human computer interaction. Haptic technology has developed rapidly and has been the center of attention of many research communities. As a result, concerned vendors have thrived on creating haptic-related products to be deployed commercially, in development, and for research purposes, as well as serving as prototypes. Virtual environments are strongly linked with haptic-based applications. Such environments require the visual sensory channel to produce more realistic sensations. To handle the complexity of the graphical representation and its haptic interactions demands a system to be flexible to different formats and different levels of resolution. In addition to the graphic management handling, the complex calculations for the haptic rendering aspect require an efficient and intelligent algorithm able to learn and understand the requirements for the user application.

Most of previous efforts exhibit a theme of exercises that are more or less similar. However, in our framework, we incorporate tests that occupational therapists have been using for a long time, such as the Jebsen Hand [5] and the Box and Block test [6]. Working with seasoned therapists, we set out to overcome technological obstacles such as manipulating small objects (like a spoon for feeding) to the best of our abilities with the current state of haptic software and hardware. As a result, we have built a system that, in addition to matching existing rehabilitation standards, accommodates future expansions that will be allowed by advances in technology.

III. PROPOSED FRAMEWORK

The framework consists of four components: A Sensory component, a Haptic/Software Simulation component, an application component, and a Haptic/Behavioral Data component. The sensory component of the system is embedded within the haptic and visual interfaces. Tactile and kinesthetic stimuli are provided by the CyberGrasp system, which consists of CyberGlove, CyberGrasp (exoskeleton based), and the CyberForce instruments. These make high-accuracy joint-angle measurements, generate force feedback on the fingers, and make six-degrees-of-freedom measurements of the hand movements, respectively. The CyberForce also creates the feeling of the weight of an object, thus allowing a patient to feel gravity. The system’s software component responsible for haptics simulates the complex calculations involved in the haptic rendering process loop, maintains synchronization with graphic rendering, and recording haptic behavioral data for further analysis.

Currently we are testing our framework with volunteers from the University of Ottawa. The testing sessions involve taking the volunteers through a set of exercises that involve moving a cup, squeezing a stress ball with varying stiffness, navigating a maze with a small cylindrical stick, and most lately, arranging a set of eight colored cubes according to surface color. Hitherto, we have analyzed results from the cup and cubes exercises and will present the findings in the next section. We are analyzing results from the other two exercises and will present our findings in a later paper. Fig.1 and Fig. 2 below depict the view that a subject had of the cup and cubes exercises respectively. Fig.3 shows the cubes exercise without the virtual partition. We found that the partition improved the subjects’ depth perception and provided for a smoother trial.

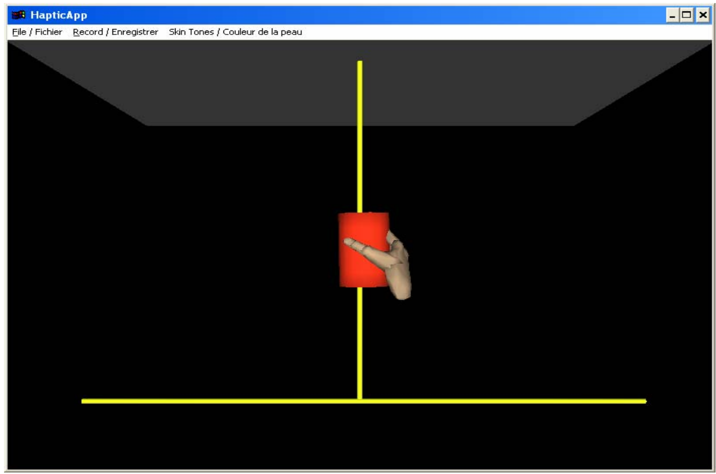

Fig. 1. Cup Exercise: users have to move the cup along the x or y axis

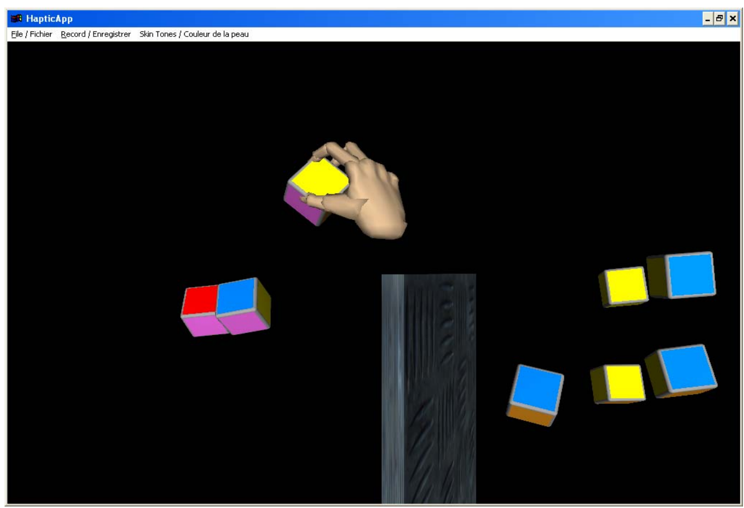

Fig. 2 Cubes Exercise: users need to move the cubes from the left part of the screen to the right part of the screen following a given pattern

Fig. 3 Arranging cubes in an arbitrary way to test the grip of the user

IV. EXPERIMENTS AND ANALYSIS

In analyzing the results from the cup and cubes exercises, we were interested in the finger idle time for each of the five fingers for each subject. This provided us with an insightful look at the performance of each finger.

Figures 4 and 5 show the finger idle time during the cup and cubes exercises respectively for subject 2. The graphs show that the gap in idle time between the index and pinky fingers is considerably large. Being that these two fingers are the edge finger that hold an object (excluding the thumb, which has a different positional orientation than the other fingers), this might insinuate a weaker or improper grip of subject 2.

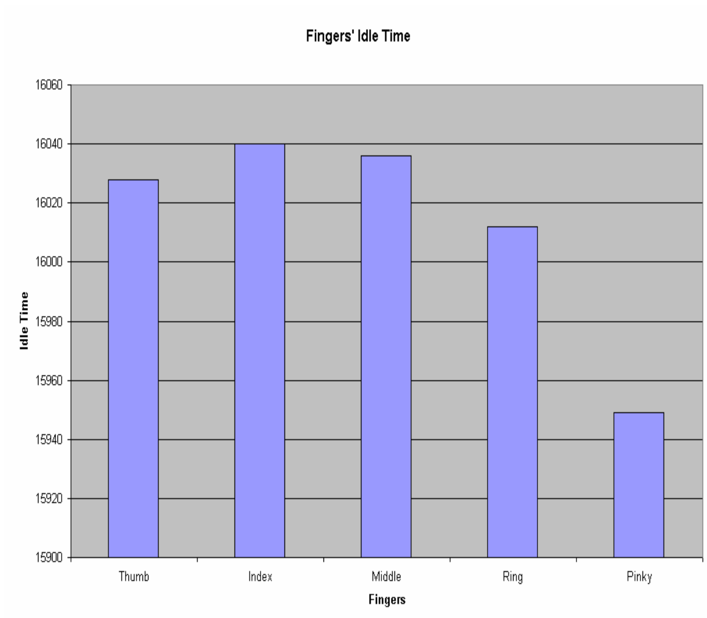

Fig. 4. Finger Idle Time for Cup Exercise, Subject 2

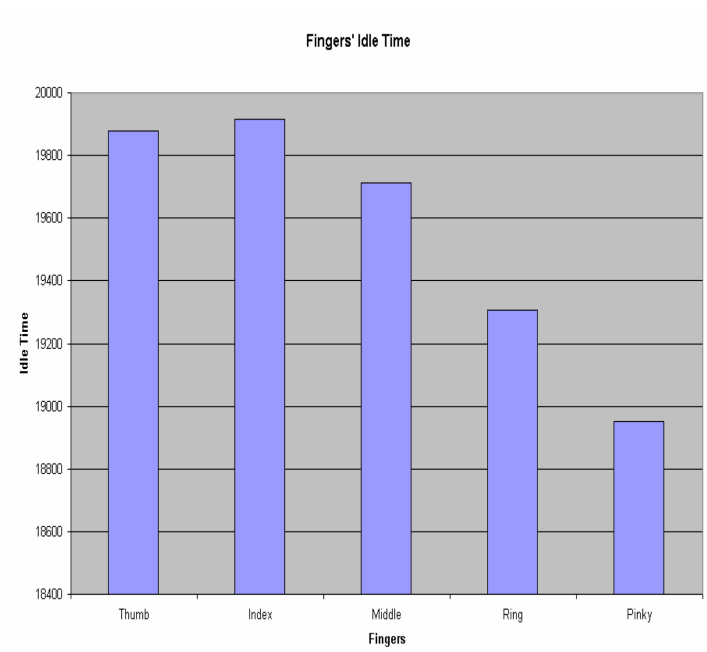

Fig . 5 Finger Idle Time for Cubes Exercise, Subject 2

By studying the finger idle times for all the other subjects for the cubes exercise, subject 2 ranked second highest. Tables I and II show the finger idle times for the fingers for the five subjects for the cup and cubes exercises respectively. The last row in each table shows the percentage of the time difference in idle time between index and pinky of the total exercise time. Subject 4 showed the highest idle time for the cubes exercise. That same subject ranked second in the cup exercise. In conclusion, it can be inferred that subject 2 had the weakest grip. Subject 4 was found to be right in subject 2's neighborhood.

Table I. Cup Exercise for all Subjects, Idle Times (sec)

Subject	1	2	3	4	5
Index	5608	16040	8541	3345	6323
Pinky	5600	15949	8496	3174	6298
Difference	8	91	45	171	25
Total Time / ms	5867	16147	8668	8253	6407
Difference : Total Time	0.136	0.564	0.519	2.072	0.390

Table II. Cubes Exercise for all Subjects (sec)

Subject	1	2	3	4	5
Index	22509	19916	13087	16651	13606
Pinky	22524	18950	12903	15861	13488
Difference	15	966	184	790	188
Total Time / ms	22773	21454	13763	20202	14583
Difference : Total Time	0.066	4.503	1.337	3.911	1.289

An operational therapist would probably see more drastic changes and higher values for difference of idle times between different fingers. Overcoming that gap in a patient would be a target and also a continuous evaluation of performance. As the above analysis showed, a therapist can combine results from two different exercises to draw analysis about the same patient. Also, comparisons among different patients with similar degrees of affliction (from stroke) could provide the therapist with a granular view of a patient's status. Details about each finger can help the therapist devise 'personalized' themes for a rehabilitation course by accommodating the special needs and habits of a patient.

V. FUTURE WORK

Future work would see us completing analysis for the other exercises and drawing more conclusions based on certain aspects pertaining to hand performance. We would almost certainly cross diagnose among two or even three exercises to compare performance. We hope to improve the equipment to a certain level as to start testing with patients. Improving the settings to make the apparatus less bulky and hence more comfortable for patients would result in fairly accurate evaluation.

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