VR Aided Motor Training for Post-Stroke Rehabilitation: System Design, Clinical Test, Methodology for Evaluation

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ABSTRACT

This paper describes interdisciplinary work on developing a virtual reality (VR) aided motor training task for post-stroke rehabilitation on functional deficit of the upper extremity: static reaching. Patient-specific and human-centered design of the VR system was addressed from the physical therapist’s perspective. The two main features of the system were that it could actively drive the human kinetic behavior based on the therapist’s rehabilitation goals and capture the patient’s kinetic performance in an accurate way. A three-month clinical trial of this VR task was conducted with five post-stroke patients. To analyze the collected data, a methodology was proposed to visualize the patient’s current status and progression over time based on three kinematics measures: performance time, movement efficiency, and moving speed. Results from the analysis clearly reveal the current status of the patient’s hand and arm movement with respect to his/her range of motion, comprising pitch, yaw and arm length. Further, evidence of progress was found and visualized quantitatively over a series of practice sessions. Along with several conventional behavioral assessments at three points: pre-training, mid-training and post-training, the patient’s progress was identified as well. Finally, human factors, such as perception of difficulty, confidence of movement, and system usability, were measured and studied.

CR Categories and Subject Descriptors:
H.5.2 [Information Interfaces and Presentation]: User Interfaces - Evaluation/methodology, Haptic I/O, User-centered design
J.3 [Computer Applications]: Life and Medical Sciences – Health

Additional Keywords:
Virtual reality, rehabilitation, physical therapy, human factors, human computer interaction

1 INTRODUCTION

Stroke is the leading cause of serious, long-term disability among American adults. Each year over 700,000 people suffer a new or recurrent stroke, and nearly 500,000 (71%) survive with some form of enduring neurological disability. Upper extremity (UE) motor impairment is a common consequence of stroke and often produces significant challenges for patients as they engage in everyday instrumental activities of daily living. However, research has shown that such lost UE function can be recovered or improved via systematic, repetitive and task-oriented motor training. Virtual reality (VR) aided motor training is an emerging therapeutic modality that can serve to deliver UE motor training tasks within consistent, yet modifiable simulated functional environments that mimic real world challenges. As well, game features can be integrated into the VR training to enhance motivation and promote therapeutic focus and adherence.

2 DESIGN OF VR SYSTEM AND CLINICAL EXPERIMENT

Among the numerous VR tasks that we have created and tested for UE training aims, the “Static Reaching Test” is designed to require patients to reach for multiple virtual targets in 3D peripersonal space with synchronized forearm and hand movement on their paretic side (Fig. 1). Target positions in 3D space are positioned in a semi-sphere zone that is calibrated to each patients current range of motion (Fig. 2).

A clinical test using this VR task (along with 3 others) was conducted with five post-stroke patients at USC. Each subject attended 12 two-hour training sessions to practice the four VR UE tasks. Specific to the Reaching Task, three kinematic measures are derived: movement efficiency (ME), movement speed (MS) and performance time (PT), based on continuous capture of the hands 3D position across all trials. In addition to examining performance change over time, we explore various methods for efficiently visualizing this type of data.

3 METHODOLOGY: VISUALIZATION OF PERFORMANCE AND PROGRESSION

We propose a methodology to visualize the performance and progression via VR data collected from a series of practice sessions. In other words, the goal is to look for any significant correlation existing between task parameters and kinematic measures. 2D pitch-yaw maps with specific arm length ratio are
developed and are used as a base to visualize kinematic measures. 3D performance maps are developed to visualize performance (current status). 3D progression maps are developed to visualize progression (change of status).

4 TEST RESULTS AND DISCUSSION

Since a huge amount of data was collected, subject 103 is selected for case study and representing test results.

4.1 Visualization of Performance: Arm Length Ratio 60%

For all three kinematic measures, 3D performance maps are developed in Fig. 3 and labeled with different color to indicate the level of current status where red stands for “Excellent”, blue stands for “Good” and green stands for “Fair”.

4.2 Visualization of Progression: Arm Length Ratio 60%

3D progression maps for all three kinematic measures are developed with different labeling color to indicate the level of progression where red stands for “Significant”, blue stands for “Minor” and green stands for “None”.

4.3 Progression versus Various Arm Length Ratio

For each arm length ratio, we calculate the percentage of zones for each progression level, as shown in Fig. 4. Progression of each kinematic measure at different arm length can be seen from it.

5 CONCLUSION

A VR aided upper extremity motor training system is designed well both in patient-specific need and in therapy perspective. An important feature the system equipped is the capability to actively drive human kinetic behavior via a combination setting of environmental parameters.

It is successfully applied to a clinical pilot test on five stroke patients. Data of human’s kinetic behavior is captured accurately and quantitatively via the clinical test.

Representative kinematics measures: PT, ME and MS are defined suitably to represent kinetic features. Methodology is proposed to visualize the performance and progression on a base of kinematics measures.

The case study clearly reveals the patient’s current status of hand arm movement with respect to his/her motion range composed of pitch, yaw and arm length. Further, progression is found and visualized quantitatively over a series of practice sessions. Study shows that progression appears mostly in zones with lower performance. The results of physical assessments also show the behavioral progression that it is in compliance with the results from VR training.

Finally, human factors such as perception of difficulty, confidence of movement and system usability are measured quantitatively. Analysis shows that the VR system does keep challenged to the patient. Thus, the patient does perceive a similar difficulty from the beginning to the end over the test period. Further, with the decrease of confidence on movement, it reveals that the patient does perceive the existing deficit on his/her upper extremity limbs via the VR system. It might make the patient more humble and motivate the patient to participate the therapy more.

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Fig. 4. Progression of each kinematic measure versus various arm length ratio