2017 IEEE/ACM International Conference on Connected Health: Applications, Systems and Engineering Technologies (CHASE)

Quantitative Assessment and Validation of a Stroke Rehabilitation Game

Mengxuan Ma[1] , Rachel Proffitt[2] , Marjorie Skubic[1]
[1]Department of Electrical Engineering and Computer Science, [2]Department of Occupational Therapy
University of Missouri
Columbia, MO, USA
mmrnc@mail.missouri.edu, proffittrm@health.missouri.edu, skubicm@missouri.edu

***Abstract*—We explore a quantitative assessment for a Microsoft Kinect-based stroke rehabilitation virtual reality (VR) video game, Mystic Isle, by evaluating three assessment metrics of player hand movement-- maximum range (extension), peak velocity and mean velocity. We also analyze the left-right hand symmetry by visualizing trajectories of both hands throughout the game. Assessment metrics obtained by the Kinect-based game have been validated using a Vicon motion capture system. The percentage errors of maximum range and mean velocity are less than 10%. The peak velocity metric is more sensitive to noise and sampling rate with a percentage error up to 18%.**

Keywords—stroke rehabilitation game; assessment; validation

I. Introduction

Stroke is one of the leading causes of long-term adult disability, affecting approximately 795,000 people each year in the U.S. [1] People who suffer from a stroke can recover through rehabilitation. Stroke rehabilitation involves various physical activities like range of motion exercises, aiming to build up the muscle strength and capability. In recent years, technology-assisted physical activities have been introduced and developed for stroke rehabilitation [2], such as Microsoft Kinect-based virtual reality (VR) video games, not only motivating patients to exercise more, but also enabling easier quantitative assessment. Some metrics for the upper extremity assessment have been proposed to evaluate the movement quality in Kinect-Based VR games [3]. However, few of them have been validated by gold-standard motion capture systems. In this work, we provide quantitative assessment for the rehabilitation game, Mystic Isle [4] by evaluating hand maximum range (extension) as well as peak and mean velocity metrics, and then validated their accuracy with a Vicon motion capture system [5].

II. Mystic Isle Rehabilitation Game

Mystic Isle is a virtual reality Kinect-based video game which targets balance training and upper limb reaching exercises for people with orthopedic and neurological injury or impairments, including stroke [4]. The player is placed on a 3D virtual island (Fig.1 left). The background, game objects, and tasks change with the player's move on the island. During the game, the player is asked to move around the island to collect objects marked with the color red [4]. When the player successfully reaches the colored target, he/she will gain a point, and the target will disappear.

The skeletal data of each frame is also recorded and stored in the local computer. To discriminate healthy and pathological conditions and to assess clinical changes over time, we quantitatively measured the hand movement quality. People with neurological injury will perform the movements with relatively larger velocity peaks than healthy people [4]; thus, we collected hand peak and mean velocity metrics. The estimated velocity is the ratio of the hand position distance and the time difference between two frames based on Kinect skeletal data. The peak and mean velocities are the maximum and average values of the velocity estimates. Stroke patients may also have a decreased range of motion. To analyze the hand movement symmetry, we acquired maximum extension of both hands by computing the distance from the hand joint to the center of the shoulders using data captured from the Kinect skeleton model and displayed trajectories of both hands.

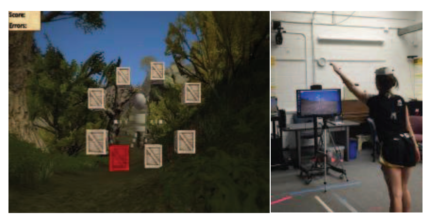

Fig. 1. The player collects targets in the VR rehabilitaion game, Mystic Isle

III. Results

A. *Quantitative Assessment of Hand Movement*

We evaluated the player's hand movement by estimating hand extension and hand peak and mean velocities and by analyzing the symmetry of hand trajectories.

1) *Hand Extension and Velocity*

Four persons were asked to play the Mystic Isle game with the same game settings; their hand extensions and velocities were evaluated using Kinect skeletal data. Players 1 and 2 are stroke patients. Players 3 and 4 are healthy players (Table I). The left and right hand maximum extension of the stroke players are very different. For example, Player 2's right hand has a 26 cm larger extension than the left hand. For healthy Players 3 and 4, both hand extensions are almost the same. The stroke players also have relatively larger hand mean velocities, and their peak velocities are 20 times more than their mean velocities.

2) Symmetry Analysis of Hand Trajectories

People with stroke may have decreased range of motion on one or both hands; the symmetry can be illustrated by plotting the hand trajectories as 2D and 3D graphs. Fig. 2 shows 3D graphs on the left, in which the temporal sequence is illustrated by color according to the color bar (from red to blue). The graphs on the right are 2D plots in which the left hand trajectory is shown in black and the right hand trajectory shown in red. The top row shows the hand trajectories of a healthy player. The reaching space of the left hand is symmetric to the right hand's. In contrast, the bottom row shows the hand trajectories of a stroke patient, which are clearly asymmetric. The left hand has a much larger extension range than the right hand.

TABLE I. HAND MAXIMUM AND MEAN VELOCITY AND EXTENSION

	Left Hand			Right Hand		
	Max (m/s)	Mean (m/s)	Ext. (m)	Max (m/s)	Mean (m/s)	Ext. (m)
Player1 – stroke	11.81	0.37	0.86	19.73	0.34	0.95
Player2 – stroke	10.61	0.46	0.63	23.93	0.43	0.89
Player3 – healthy	2.12	0.13	0.78	1.92	0.15	0.79
Player4 – healthy	2.55	0.21	0.80	2.02	0.20	0.82

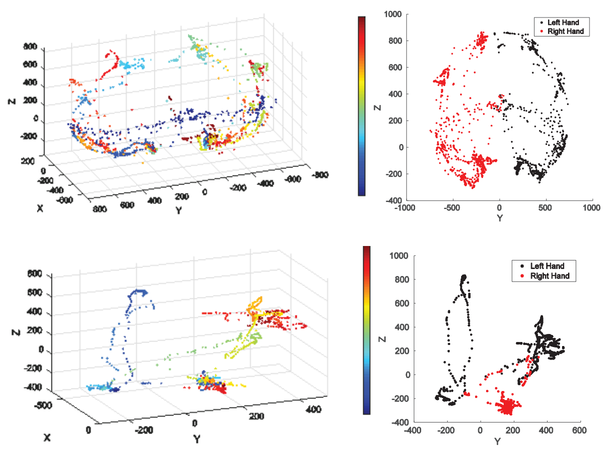

Fig. 2. Left and right hand trajectories of a healthy player and a stroke patient. Top left: healthy player in 3D space. Top right: healthy player in Y-Z plane. Bottom left: stroke player in 3D space. Bottom right: stroke player in Y-Z plane.

B. Hand Extension and Velocity Validation

The Vicon system provides a validated solution designed specifically for accurate motion capture. By placing reflective markers on the human body [5], it can be used to give real-time positions of body movements. To evaluate the accuracy of the Kinect skeletal model in terms of assessing players' hand movement quality, we conducted an IRB-approved study in which ten participants were recruited to play a short 10-minute video game shown in Fig.1 right. We recorded the players' movements using both Kinect and Vicon systems. Each player was asked to collect the game targets using 6 different types of movements, as listed in Table II. Subjects sat on a chair in 'sitting close' and 'sitting far' movements and stood in the other cases. In the 'close' type movement, the targets are close to the player. In the 'far' type movement, the targets are farther away, requiring the player to lean forward. In the 'step' type movement, the player took a necessary step to reach the targets. In the 'game' movement, the player was asked to perform grabbing and dragging motions on targets. To validate the accuracy of the maximum range (extension), the distance between the hand joint and the center position of shoulders was computed separately in X (depth), Y (lateral), Z (vertical) directions and in 3D space from both filtered Kinect skeleton data and Vicon data. Then the mean percentage error and standard deviation of ten subjects were calculated (Table II). The average percentage error of the X dimension is larger than Y, Z and 3D space, but they are less than 10%. The peak and mean velocities were validated by comparing the mean percentage error and standard deviation between results obtained from Kinect and Vicon data. The error of peak velocity is 14-18% and the error of mean velocity is less than 10%. Note that the Vicon data are sampled at 100 Hz, whereas the Kinect data are sampled at a maximum of 30 Hz.

This project was supported by the NIH/National Center for Advancing Translational Sciences (UL1 TR00048) and the University of Missouri Institute for Clinical and Translational Sciences.

TABLE II. PERCENTAGE ERROR(%) OF HAND EXTENSION, VELOCITY

Type	X	Y	Z	3D	PK_V[a]	MN_V
	Left Hand Maximum Range (μ ± σ) in %				Left Hand Velocity (μ±σ) in %	
SI_C[b]	6.5±4.0	4.3±3.5	7.0±5.6	3.9±3.1	15.4±7.1	7.9±5.0
SI_F	6.0±4.4	3.8±2.5	5.7±4.2	4.5±2.7	15.4±6.4	9.9±2.8
SD_C	2.8±2.3	2.4±2.1	3.2±1.4	2.9±2.5	17.0±13.4	5.9±1.3
SD_F	5.9±5.1	2.0±1.6	2.2±2.5	2.2±2.5	15.1±10.5	4.7±2.8
SD_P	5.3±3.4	2.1±2.3	2.4±2.4	4.0±3.2	17.2±13.8	4.1±2.3
Game	3.3±2.2	3.5±2.4	3.3±2.3	3.6±3.4	15.3±10.6	3.3±2.6
	Right Hand Maximum Range (μ ± σ) in %				Right Hand Velocity (μ±σ) in %	
SI_C	6.7±4.7	4.3±2.1	6.5±4.2	4.1±1.9	14.5±5.1	8.2±4.0
SI_F	6.6±4.0	2.8±1.7	6.1±3.2	3.9±2.4	15.1±6.1	9.6±6.1
SD_C	4.0±2.0	3.4±1.7	5.5±3.7	3.2±3.2	18.0±14.1	7.4±4.7
SD_F	6.4±5.8	3.4±2.9	4.9±2.6	4.2±3.9	18.4±10.7	5.8±3.5
SD_P	9.0±5.2	2.5±1.4	5.3±4.0	5.6±4.0	18.6±13.4	3.1±2.0
Game	8.3±4.8	7.8±5.1	3.7±2.0	5.1±3.7	17.8±13.5	4.6±4.0

a. PK_V means peak velocity and MN_V means mean velocity

b. SI means sitting type. SD means standing type. C, F and P means 'close', 'far', and 'step' type.

IV. DISCUSSION

In this paper, we presented the hand extension, and peak and mean velocity results of the Kinect-based rehabilitation game, Mystic Isle, and validated their accuracy by comparing the results captured from Kinect and Vicon systems. The goal is to assess rehabilitation progress using game play. Peak velocity is more sensitive to noise with a percentage error up to 18%; error rates for other metrics were less than 10%. The accuracy could be improved by exploring a better filtering method. A larger study is also planned for future work.

REFERENCES

[1] "Rehabilitation Therapy After A Stroke". Stroke.org. N.p., 2017. Web. 30 Mar. 2017.

[2] "Stroke Rehabilitation: What To Expect As You Recover From Stroke - Mayo Clinic". Mayo Clinic. N.p., 2017. Web. 30 Mar. 2017.

[3] de los Reyes-Guzmán, A., Dimbwadyo-Terrer, I., Trincado-Alonso, F., Monasterio-Huelin, F., Torricelli, D. and Gil-Agudo, A., 2014. Quantitative assessment based on kinematic measures of functional impairments during upper extremity movements: A review. Clinical Biomechanics, 29(7), pp.719-727.

[4] Proffitt, R. and Lange, B., 2015. Feasibility of a Customized, In-Home, Game-Based Stroke Exercise Program Using the Microsoft Kinect® Sensor. International Journal of Telerehabilitation, 7(2), p.23.

[5] "Vicon Clinical Science". Vicon. N.p., 2017. Web. 30 Mar. 2017.