Progress Monitoring in Upper Limb Stroke Rehabilitation by Using Muscle Activation and Hand Speed

H L Lee¹, Wan Khairunizam¹, Basri Noor Cahyadi¹, Wan Azani Mustafa², Syed Zulkarnain Syed Idrus³

¹School of Mechatronic, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia
²Faculty of Engineering Technology, Kampus Sg. Chuchuh, Universiti Malaysia Perlis, 02100 Padang Besar, Perlis, Malaysia.
³Center of Excellence Geopolymer and Green Technology, Universiti Malaysia Perlis, 01000 Kangar, Perlis, Malaysia.

hailing1018@hotmail.com

Abstract. Nowadays, Virtual Reality (VR) technology is commonly used in the rehabilitation to increase the motivation of the stroke patients do the exercises, however, very few researches to monitor the rehabilitation progress has reported. VR based rehabilitation is interesting because could motivate stroke patients in their long-term rehabilitation process. This research is to evaluate the progress monitoring of the subject after conducting three sessions of rehabilitation exercise. Five male and female healthy subjects were selected to do the rehabilitation game. Three VR games are designed for the subject to perform three different movement sequences. The selected upper limb characteristics are muscle activation and hand speed. An Electromyography (EMG) is used to measure the muscle activation through an electrical activity of the muscle, while a Kinect sensor is used to measure the hand speed. The experimental results show that the proposed upper limb characteristics are able to be used for monitoring progress in the rehabilitation.

1. Introduction
According to the World Health Organization, stroke is the leading cause of deaths in the last fifteen years and it becomes the second biggest killer in the year 2016 [1]. Stroke often results in a large number of disabilities and it is the main cause for the loss of body function in people above the age of 60 [2].

In recent year, VR technology is applied to a home rehabilitation to make rehabilitation more enjoyable for stroke patients. VR training may use video game platform or interactive “exergaming” systems such as the Xbox Kinect [3,4]. It is interesting and can motivate stroke patients in their long-term rehabilitation process. However, the evaluation of the rehabilitation is necessary to know the efficacy of the rehabilitation [4,5]. The movement sequence should be designed to cover specific functional movements such as pointing, grasping and reaching. The desired goals for the rehabilitation is to help stroke patients increase the movement speed, the accuracy, the efficiency, and the range of movement [6,7].

This paper presents the performance evaluation of upper limb stroke rehabilitation exercise by using the VR game. The paper is organized as follows. Session 2 presents the related researches. Session 3 presents the proposed methodologies. Session 4 presents the result and discussion and Session 5 presents the conclusions of the works.
A non-clinical rehabilitation exercise might bring further impairment to the stroke patient. Hence, the previous researcher proposed the ideal arm movement sequence for the upper limb rehabilitation [8–10]. Each movement sequence consists of warm-up and cool-down exercises. The exercise is assessed by EMG, where the muscle activities of biceps and triceps are measured. The signal feature is extracted to observe the activation of different muscle during the rehabilitation task. The study is necessary to ensure that the rehabilitation exercise is safe and useful for the stroke patient to carry out.

In [7,9], the movement sequence exercise is proposed, and the upper limb movements are measured by a Kinect sensor. The Kinect sensor functions as a recorder for the position of the hand and the trajectories are analyzed [4]. A survey to the subject is conducted to rate the VR game which the result reveals that the potential for the rehabilitation games. The participants give feedback that the VR game is fun and interesting.

VR is a digital environment, which can be entirely controlled by a particular party. VR has become a popular platform among researchers and rehabilitation specialist in replacing conventional stroke rehabilitation, which is repetitive and boring. It is an effective way of establishing a variable and stimulating environment, allowing the patient to engage in meaningful and motivating therapeutic activities. Rehabilitation by using VR games may have some advantages than traditional therapy. VR games can allow people to practice daily activities that are cannot be practiced within the hospital environment. In addition, several VR game features might be able to attract patients to spend more time in the therapy [4,7].

2. Methodologies
The workflow of the research is shown in Figure 1. The game was designed to allow the subjects to focus on the rehabilitation. The EMG system was set up for the muscle activation monitoring purpose. Ten subjects were selected to perform the game in three sessions. The 2-D position of the hand was recorded by using the Kinect sensor. The analysis of the EMG signal is to evaluate the muscle activation and the analysis of 2-D position is to evaluate the speed of the hand.
2.1 VR Game
Three VR games were designed by using the game engine Unity software. Each game had different movement sequences. These movement sequences were designed to achieve the rehabilitation criteria’s which were warm up and cools down [5][8]. Figure 2 (a), (b) and (c) show the movement sequence patterns.

Figure 1. The workflow of the research

Figure 2. The designed game patterns (a) Game #1 (b) Game #2 (c) Game #3
2.2 **VR Environment**

VR environment was built to offer the subject a new experience in interacting with the game. The VR environment was built up by using a Kinect Xbox One (Microsoft Kinect Sensor), a projector, a projection screen, and a personal computer as shown in Figure 3.

![Figure 3. The VR environment](image)

The preliminary experiments were carried out to investigate a suitable distance between the Kinect sensor and the subject. Three distances of 1.5 m, 1.75 m, 2 m were investigated. Game #3 was used in the investigation. Game #3 consists of four targets and had the widest range of movement. The hand movement of the subject was tracked and recorded in 2-D position once they start the game. The subjects were asked to perform three trails of this game.

2.3 **EMG System**

The EMG system used was the Delsys Bagnoli-8 EMG System with a personal computer that was installed with EMGworks® software as shown in Figure 4.

![Figure 4. EMG system](image)
3. Experiment Setup

Five male and female healthy subjects were selected to do the rehabilitation game. The subjects were shown a demo video before they start the rehabilitation. The skeletal muscles that involve in the measurement were deltoid, biceps, and triceps muscles. The skin surface of these muscles is managed by referring to the guidelines of SENIAM.

The subjects were requested to perform the maximum voluntary contractions (MVC) test that consists of two functional tasks. Each task was repeated twice. After completed the MVC test, the subjects start to play the three VR games, and each game was repeated five times.

3.1 EMG Signal

The EMG signal was sampled at 2000 Hz. An inbuilt bandpass filter from 20 to 450 Hz was set up to remove the movement artifacts from the signal. The raw signal acquired was transformed into the time domain. A signal full-wave rectification was carried out to change the negative polarities of the raw signal into positive to produce a higher average output voltage. A 5th order Butterworth low pass filter with a cut off frequency of 6 Hz was utilized to capture the envelope of the EMG signal [6,11].

A normalization process was carried out to obtain % MVC. The normalization technique is described by using Equation 1. % MVC represents muscle activation of the subject.

\[
%\text{MVC} = \frac{\text{Filtered EMG Signal from VR Game}}{\text{Maximum Filtered EMG Signal from MVC Test}} \times 100\% \quad (1)
\]

3.2 Two-dimensional (2-D) Position of the Hand

The distance and velocity traveled by the hand were measured by using Equation 2 and 3.

\[
\text{Distance} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (2)
\]

\[
\text{Velocity} = \frac{\text{distance}}{\text{time}} \quad (3)
\]

4. Results and Discussion

4.1 Investigation the optimum distance from the Kinect sensor and subject

Figure 5 shows the distances traveled by the hand in performing the Game #3. The deviation of the distance traveled by the hand increases when the distance of the subject from the Kinect sensor increases. The smallest deviation represents the optimum distance. Hence, the smallest deviation between the Kinect sensor and the subject is 1.5 m, which is position #1.
4.2 Muscle Activation Analysis

Figures 6, 7 and 8 show the performance of the muscle activation for the deltoid, biceps and triceps muscles in 2 sessions, #2 and #3 respectively. Figures 5, 6 and 7 show the results for Game #1, #2 and #3, respectively.

For Game #1, the performance of biceps and triceps muscles are 10% increases, while the deltoid muscle has no changes. For the Game #2, the biceps muscle improved 20%, the deltoid muscle improved 10% and the triceps muscle has no changes. For Game #3, deltoid and triceps muscles improved 20% and the biceps muscle has no changes.

Figure 5. Hand distance traveled for performing Game #3

Figure 6. Muscle activation for Game #1

Figure 7. Muscle activation for Game #2
4.3 Hand Speed Analysis

Table 1 shows the hand movement speed for Game #1, #2 and #3. All subjects have increased the hand movement speed by comparing to the previous sessions of the rehabilitation. For Game #1, the hand movement speed has increased from 3.23 m/s in session #1 to 5.16 m/s in session #3. For the Game #2, the hand movement speed has increased from 3.51 m/s in the sessions #1 to 4.89 m/s in session #3. For Game #3, the hand movement speed has increased from 3.82 m/s in the sessions #1 to 5.20 m/s in session #3.

Table 1. Hand movement speed for Game 1, 2 and 3

|       | Speed (m/s)         |
|-------|---------------------|
|       | Session #1 | Session #2 | Session #3 |
| Game #1| 3.23       | 4.33       | 5.16       |
| Game #2| 3.51       | 4.42       | 4.89       |
| Game #3| 3.82       | 4.62       | 5.20       |

5. Conclusions

This work proposed the investigation of the upper limb rehabilitation in the VR environment. According to the preliminary experiments, the optimum distance between the Kinect sensor and the subject is 1.5 m. The distance is used to conduct the progress monitoring of the rehabilitation experiments.

From the experiments, Game #3 performed at most for the improvement of the muscle activation. Hence, it can be concluded that the movement sequence pattern for Game #3 resembles the most ideal motion sequence pattern for stroke rehabilitation. Moreover, Game #3 has the criteria of the warm-up, progressively move and cool down as suggested by the previous researchers. Besides, Game #3
produces the highest movement speed. Hence, it can be concluded that the movement sequence pattern for Game #3 has an efficient range of motion.

References

[1] Anon 2018 The Top 10 Causes of Death World Heal. Organ.
[2] Anon 2018 Disease Burden and Mortality Estimates World Heal. Organ.
[3] Tanaka K, Parker J, Baradoy G, Sheehan D, Holash J R and Katz L 2012 A Comparison of Exergaming Interfaces for Use in Rehabilitation Programs and Research J. Can. Game Stud. Assoc. 6 69–81
[4] Pedraza-Hueso M, Martín-Calzón S, Diaz-Pernas F J and Martínez-Zarzuela M 2015 Rehabilitation Using Kinect-based Games and Virtual Reality Procedia Computer Science vol 75 pp 161–8
[5] Semblantes P A, Andaluz V H, Lagla J, Chicaiza F A and Acurio A 2018 Visual feedback framework for rehabilitation of stroke patients Informatics Med. Unlocked 13 41–50
[6] Yeh S C, Stewart C J, Margaret M and D Parsons T 2007 Evaluation Approach for Post-Stroke Rehabilitation Via Virtual Reality Aided Motor Training Ergonomics and Health Aspects of Work with Computers (Berlin, Heidelberg: Springer Berlin Heidelberg) pp 378–87
[7] Cahyadi B N, Khairunizam W, Muhammad M N, Zunaidi I, Majid S H, M.N R, Bakar S A, Razlan Z M and Mustafa W A 2018 Analysis of EMG based Arm Movement Sequence using Mean and Median Frequency 2018 5th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI) (IEEE) pp 440–4
[8] Suhaimi R, Talha K S, Wan K and Ariffin M A 2015 Design of Movement Sequences for Arm Rehabilitation of Post-Stroke 2015 IEEE International Conference on Control System, Computing and Engineering (ICCSCE) (IEEE) pp 320–4
[9] Majid M S H, Khairunizam W, Ikram K, Jing L M, Sahyudi B N, Zunaidi I, Ariffin M A, Bakar A S and Razlan Z M 2018 Performance Evaluation of a VR-Based Arm Rehabilitation Using Movement Sequence Pattern 2018 IEEE 14th International Colloquium on Signal Processing & Its Applications (CSPA) (IEEE) pp 123–8
[10] Kamps A and Schüle K 2005 Cyclic movement training of the lower limb in stroke rehabilitation Neurol. und Rehabil. 11 259–69
[11] Suhaimi R, Aswad A R, Adnan N H, Asyraf F, Wan K, Hazry D, Shahriman A B, Bakar J A A and Razlan Z M 2014 Analysis of EMG-Based Muscles Activity for Stroke Rehabilitation 2014 2nd International Conference on Electronic Design (ICED) (IEEE) pp 167–70