Design of arm movement for upper limb after stroke rehabilitation using enhanced VR-based

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DECLARATION OFTHESIS

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LIST OF ABBREVIATIONS

EMG	-	Electromyogram
DA	-	Deltoid anterior
DL	-	Deltoid lateral
BB	-	Biceps brachii
TB	-	Triceps brachii
AOM	-	Amount of movement
VR	-	Virtual reality
VE	-	Virtual environment

Reka Bentuk Aturan Pergerakan Tangan untuk Pemulihan selepas Strok bagi Bahagian Atas Anggota Badan berteraskan Alam Maya yang Dipertingkatkan

ABSTRAK

Setiap tahun, 15 juta orang dari seluruh dunia menderita dari serangan strok. Hampir 6 juta orang meninggal dunia dan lima juta orang selebihnya menjadi cacat. Menurut National Stroke Association of Malaysia (NASAM), strok adalah penyebab ketiga kematian di Malaysia selepas penyakit jantung dan kanser. Strok boleh menyebatkan kecacatan yang serius termasuk kehilangan kebolehan melihat atau bercakap, kelumpuhan otot dan kekeliruan. Otot yang terjejas boleh diubati dengan penggunaan intensif dan pergerakan aktif bahagian yang terkesan untuk merangsang kembali otot yang lemah dan perlahan-lahan membangunkan fungsi motor yang membolehkan penderita mendapatkan semula pergerakan terhadap bahagian yang terkesan. Terapi strok konvensional adalah mahal pada masa yang sama kurang menarik. Oleh itu, sistem alam maya (VR) menjadi fokus untuk penambahbaikan pemulihan strok dengan memberi pesakit strok kemungkinan penglibatan dalam tindakan, pada masa yang sama menawarkan banyak kelebihan lain seperti pengurangan kos terapi, penilaian yang lebih realistik, dan boleh disesuaikan mengikut keadaan pesakit. Kini, ramai penyelidik membangunkan pemulihan lengan realiti maya untuk pesakit pasca strok, tetapi reka bentuk tugas latihan lengan dengan mnguku aktiviti otot dahulu adalah kurang, dan kebanyakan urutan pergerakan rawak. Dalam kajian ini, 18 pergerakan tangan asas dianalisa menggunakan sistem perolehan EMG melibatkan, anterior deltoid, lateral deltoid, bisep, trisep, flesor dan extensor. Signal EMG diproses untuk menyingkirkan gangguan. Tiga ciri statistikal iaitu purata, sisihan piawai dan jumlah pergerakan (AOM) diekstrak dari signal EMG untuk menganalisa pergerakan tangan dan keaktifan otot. Berdasarkan keputusan, jumlah pergerakan dipilih sebagai ciri terbaik bagi mewakili aktiviti otot dan empat otot yang paling aktif iaitu lateral deltoid, anterior deltoid, bisep dan trisep telah dikenal pasti dengan masing-masing mempunyai AOM daripada 2.061, 1.113, 0.911 dan 0.394. Keputusan-keputusan ini kemudian digunakan untuk mereka bentuk aturan pergerakan di alam sebenar melibatkan satah koronal 2D. Jumlah pergerakan untuk semua aturan pergerakan diperoleh dan dibandingkan dengan kriteria ideal pemulihan (memanaskan badan, intensif dan menyejukkan badan). Keputusan menunjukkan pergerakan di alam maya mencetuskan AOM yang lebih tinggi berbanding alam sebenar tetapi dengan corak yang setanding. Eksperimen terakhir dijalankan untuk menilai konsistensi sistem berteraskan VR. SD daripada AOM untuk setiap pergerakan dihitung dengan nilai SD tertinggi 0.501 untuk pergerakan yang lebih intensif yang boleh diterima kerana gaya pergerakan yang tidak ditetapkan di antara subjek subjek. Umumnya, Keputusan eksperiment menunjukkan kemungkinan untuk mereka bentuk urutan pergerakan yang optimum untuk pemulihan tangan selepas strok. Sistem ini telah diuji menggunakan subjek yang sihat dan mendedahkan potensi sistem pemulihan untuk pesakit strok.

Design of Arm Movement Sequence for Upper Limb Management after Stroke Rehabilitation using Enhanced VR-based

ABSTRACT

Every year, 15 million people worldwide suffer from stroke attack. Nearly six million dead and another five million are left permanently disabled. According to National Stroke Association of Malaysia (NASAM), stroke is the third leading cause of death in Malaysia after cardiovascular disease and cancer. Stroke may lead to serious disability including loss of vision or speech, muscle disability and confusion. Muscle impairment can be treated by intense use and active movement of affected limbs to stimulate the weak muscle and slowly develop the motor function which enables sufferers to slowly regain the movement of the affected limbs. Conventional stroke therapy is costly at the same time less engaging, thus virtual reality (VR) system could be the main focus of enhancing stroke rehabilitation giving the stroke patient the possibility of action involvement sense at the same time offering many other benefits such as reducing therapy cost, providing more realistic assessment and adaptable to patient condition. Currently researchers are developing various virtual reality arm rehabilitation for post stroke patients, but less of the arm training task are design with measuring the muscle activity and most of the movement sequence are random. In this research, 18 fundamental arm movements are analyzed using EMG acquisition system involving deltoid anterior, deltoid lateral, biceps, triceps, flexor and extensor. The EMG signals were pre-processed to eliminate noise. Three statistical features which are mean, standard deviation and amount of movement (AOM) were then extracted from the EMG signals to analyze arm movements and muscle activation. Based on the results, AOM feature was chosen to represent muscle activity and four most activated muscles which are deltoid lateral, deltoid anterior, biceps and triceps were identified with each having AOM of 2.061, 1.113, 0.911 and 0.394 respectively. These results are then employed to design movement sequences in real (physical) environment involving 2D coronal plane, the amount of movement from all movement sequence were obtained and compared with the ideal criterion of rehabilitation (warming up, intensive and cooling down). The results were comparable to the proposed muscle activity pattern and the selected movement sequences were translated into virtual environment. Final experiment was conducted in virtual environments where subjects interacted with virtual objects using 5DT data glove and webcam, results show that movements made in VE trigger higher AOM compare to real environment but have comparable pattern. Final experiment to assess the consistency of the VR based system, SD of AOM for each movement are calculated with the highest SD of 0.501 for more intensive movements which is acceptable as movement style are not fixed between subjects. Generally, the experimental results show that it is possible to design optimum functional movements for arm rehabilitation after stroke. The system was tested using healthy subjects and revealed with potential rehabilitation system for stroke patient.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Stroke is the rapid loss of brain function due to interruption of blood supply to the brain whether due to blockage (thrombosis, arterial embolism) or hemorrhage as illustrated in Fig. 1.1. In Malaysia, stroke is the top five killer with 8.43/100000 rate in population (Siti Noorkhairina & Sakinah, 2014), it has been one of the major causes for long term disability. An estimated about 40,000 people in Malaysia suffer from stroke every year (NASAM, 2005).

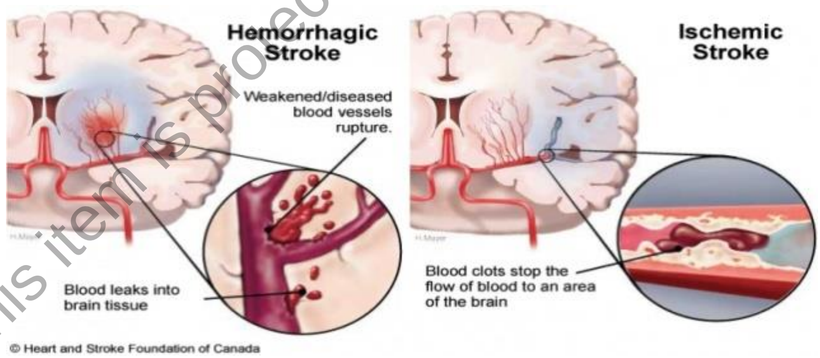

Figure 1.1: Two types of stroke (Leslie Ritter, 2015)

The complexity of the brain may affect the stroke patient in various forms including disability of muscle which impact arm, legs and face. Usually, the side effects of stroke are hemiplegia and hemiparesis. Hemiplegia is the condition which one side of the body becomes paralyzed, while hemiparesis is the condition of one sided weakness, hemiparesis attack roughly about 80 percent of stroke patient (FBIE, 2014). These muscle disabilities will affect daily activity such as eating, walking, dressing up and grabbing object in the same time will reduce the quality of life.

To regain the muscle strength loss, stroke patients will need to undergo suitable rehabilitation. Rehabilitation must starts as soon as 24 hours to 48 hours after stroke attack (Mayo Clinic Staff, 2014). Motor impairment could be improved or treated with well planned and organized treatment modules including intensive use of active movement in repetitive tasks and task-orientated activities which will result in improving motor skills and muscular strength by preventing muscle spasticity, muscle atrophy and osteoporosis (Dobkin, 2004; Riener, Frey, Bernhardt, Nef, & Colombo, 2005; Yeh et al., 2007). Carr and Shepherd (2003) illustrated that a discrete and efficient rehabilitative environment can prove to be advantageous in the recovery process.

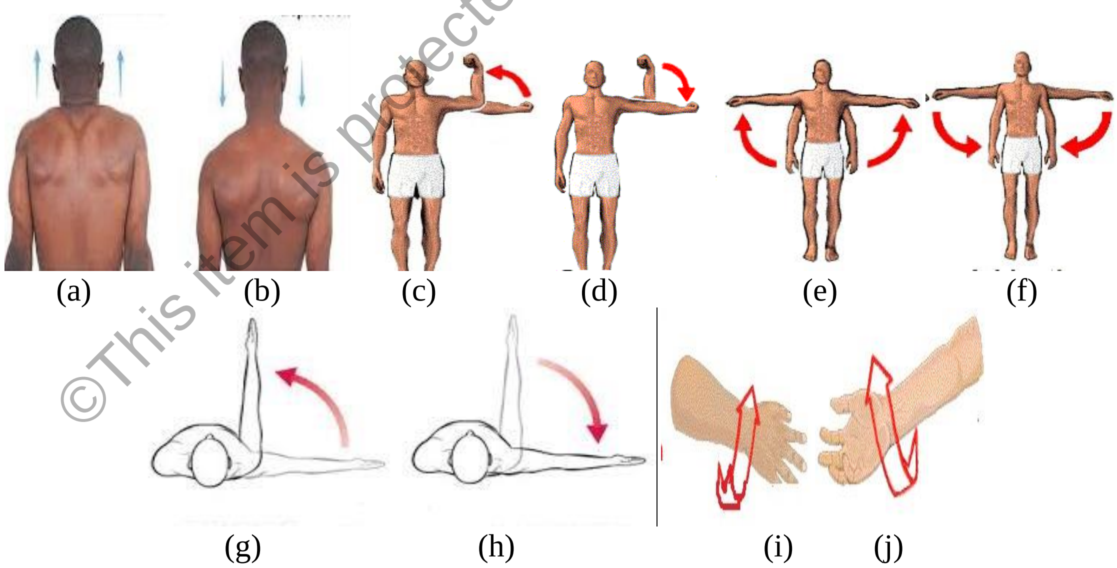

Figure 1.2: Fundamental arm movements; (a) shoulder elevation (b)shoulder depression (c) shoulder flexion (d) shoulder extension (e) shoulder abduction (f) shoulder adduction (g) shoulder horizontal abduction (h) shoulder horizontal adduction (i) wrist ulnar deviation (j) wrist radial deviation

Out of many rehabilitation for post stoke for example facial, arm, hand, leg and core, arm rehabilitation is usually put in focus over the other since many daily movements depend on the strength of the upper limb such as moving the arm and grasping objects (Saebo, 2017). Fundamental arm movement is one of the most popular conventional arm rehabilitation for post stroke, the movements consists of several general movements that involve the shoulder, elbow, wrist and fingers. The movements are classified by the direction of movement by the affected structures. The general movements include elevation, depression, flexion, extension, abduction, adduction, horizontal abduction, horizontal adduction, ulnar deviation and radial deviation as shown in Fig. 1.2 (Farfán, Politti, & Felice, 2010).

After patients able to gain control of movement through fundamental arm movement practice, the arm rehabilitation training will further with functional arm movement. This is a training of daily living activity movement such as grasping objects, combing hair and putting on clothes (Levin, Snir, Liebermann, Weingarden, & Weiss, 2012).

As alternatives platforms to the boring and repetitive conventional arm rehabilitation, various approaches were taken into consideration in research to develop technology assisted arm rehabilitation devices including robotic rehabilitation, virtual reality (VR) rehabilitation, electrical stimulation and brain stimulation.

VR is a computerised environment which can be completely controlled by the particular party. Patient who participates as the active user of VR is usually immerses in the artificial environment where he can interact in a dynamically changing scenario which the patient participated in as illustrated in Fig. 1.3. VR has its different capacity in today's improvement in restorative range which most have been utilized by the specialist for surgery re-enactment furthermore for mental treatment for the brain. As it stand VR has fill its need in the improvement of this task for restoration of the stroke tolerant. It is an effective way of establishing a variable and stimulating environment, allowing the patient to engage in meaningful and motivating therapeutic activities (Prashun, Hadley, Gatzidis, & Swain, 2010). Despite sometime being less accurate and slower, using virtual reality as a rehabilitation system for stroke patient is appropriate since results have proven its capacity to improve motor skills (De Mauro, 2011).

Figure 1.3: Patient interacts with VR (Larry Levanti, 2014)

This research proposes the methods to optimize the virtual reality arm rehabilitation after stroke with movement sequences which are based on the muscle activity of the arm. Surface EMG is used to measure movements of the upper limb. In the preliminary experiments, the signal processing approaches are proposed to find features and muscles representing muscles activity while performing fundamental arm movements which are provided by professional stroke therapists from Hospital Universiti Sains Malaysia (HUSM). The extracted movement feature is then will be used to design suitable movement sequence tasks involving real environment and virtual environment (VE), which the stroke patient needs to interacts in the process of rehabilitation therapy.

1.2 Problem Statement

Researches in post stroke patient prove that there are neural, muscle structure and function changes after stroke which may contribute to deficits of muscle strength. Deficits in muscle strength is one of the primary impairments which limit function after stroke, this is true for both upper and lower limb functions (J. J. Eng, 2004; Signal, 2014). This impairment can be treated by intense use of active movement involving repetitive tasks and task-orientated activities which will result in improvement of motor skills (movement skills) and muscular strength.

Conventional stroke rehabilitation is boring at the same time expensive. Thus, many researchers are developing VR rehabilitation which offers more engaging, motivating, repetitive, intensive and daily living oriented tasks for post stroke patients. But less are designed with measuring the muscle activity, even the existing arm rehabilitation studies on muscle did not emphasize on the most related muscles during the activities. This research will investigate the most activated muscles for arm movements and design arm rehabilitation module using the selected most activated muscles. Moreover, most of the rehabilitation modules developed by previous researchers are in random sequences, this research will optimize virtual reality arm rehabilitation with movement sequences based on muscle activity prior to standard rehabilitation criteria which follow the less intensive-intensive-less intensive movement sequence (Activity and Exercise Guide for Heart Patients, 2011).

1.3 Objectives

1) To determine the most suitable feature and the most activated muscles for muscle activity by analyzing the EMG signal of fundamental arm movement using signal processing techniques.
2) To investigate suitable movement sequence for post stroke arm rehabilitation.
3) To design the suitable movement sequence for arm rehabilitation in virtual environment.

1.4 Scope

1) EMG signal collection of arm muscles involving the main muscles that generate a particular movement of fundamental arm movement which are deltoid, biceps, triceps flexor and extensor.
2) EMG signal acquisition system used is 2 channels PowerLab 15T (AD Instrument).
3) EMG Signal Pre-Processing to remove unwanted noise.
4) Subjects recruited are healthy subjects' age between 25 to 29 years old.
5) Muscle features extraction using statistical features such as mean, standard deviation and amount of movement (AOM) as these are simple mathematical equation that able to quantify muscle activation.
6) Selection of the best feature which able to represent movement intensity to determine the particular movement should be put in a specific sequence.
7) Selection of the most activated muscle.

8) Suitable movement sequence development for post stroke (hemiparesis) arm rehabilitation consist of forward and return movement on two dimension frontal plane.

9) The movement sequence is based on the clinical relevance sequence which start with less intense movement, gradually increase to more intense movement and end with less intense movement.

10) Selected movement sequence pattern are developed in VE using Unity3D software which is easy and flexible for VR development.

11) The target objects in VE compared to real environment are similar in term of pattern arrangement.

1.5 Thesis Organization

There are 5 chapters in this thesis and it is organized in the following order. First chapter explains the introduction of this research followed by problem statement, objectives of the research and research scope.

Chapter 2 presents the literature review of the previous work from researchers. This chapter included the previous works type of arm movement in VR-based arm rehabilitation and EMG signal pre-processing techniques.

Chapter 3 elaborates the flow of the research and full description of process involves, the design of movement sequence is described clearly in this chapter.

Experiment setup and result were portrayed in chapter 4. Results obtained from signal pre-processing, feature extraction of various arm movements are presented in this chapter.

Final chapter which is chapter 5 expresses the overall conclusions over the current research and recommendation for future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Stroke

Most men aged 55 years and above with family history of stroke could be one of many vital factor risk of getting stroke. However other factors such as obesity, high blood pressure and others could be taken into considerations of early stroke (Kim et al., 2013). Strokes occurs when blood flow to the brain is stopped either due to blockage or ruptures of blood vessels which causing the brain tissue to die. The supply of blood to the brain that flows through the four arteries - the right and left carotid arteries, and the right and left vertebrobasilar arteries (Sanchez et al., 2004). When the particular area of the brain cells dies, the ability to control that area is lost, including function such as speech, movement and memory depending on the area of the affected brain and their severity. Suitable rehabilitation will help stroke patients to regain their lost skill, and must be carried out accordingly depends on stroke severity.

There are three bands to describe stroke severity which are mild stroke, moderate stroke and severe stroke. Mild stroke patients can be managed at home if outpatient resources are available and there are no specific issues to be addressed on an inpatient stroke unit. Moderate stroke patients are conscious and had a clinically significant hemiplegia or hemiparesis. These patients are best managed at both intensive rehabilitation unit or at home if outpatient resources are available. Moderate stroke patients make the most benefit from stroke rehabilitation and are the most common admissions to a stroke rehabilitation unit. Severe strokes patients are unconscious at the beginning with severe unilateral or bilateral paresis. These patients may have serious medical co-morbidity which adds to the stroke disability. It is quite hard for these patients to achieve functional independence, regardless of treatment, unless they are younger, and they will take the longest time to improve and recover. However, although they often unable to progress sufficiently to be discharged home, they do make significant gains. Severe stroke patients should be managed in a less intensive rehabilitation program (Teasell & Mcclure, 2008).

The most common stroke effect is hemiparesis and hemiplegia. Hemiparesis is the weakness of the one side of the body either left or right. While hemiplegia is a condition more severe than hemiparesis with paralysis of the entire right or left of the body. Thus, most of home based rehabilitation system focus on hemiparesis patient. Hemiparesis patients tend to have difficulty to move their arms and legs. Two types of hemiparesis are right sided hemiparesis and left sided hemiparesis which related to area of the brain that has been damaged. Right sided hemiparesis occurs when the left side of the brain injured and vice versa. Studies of post stroke recovery showed that only 50% of patient with hemiparesis recover useful function (Krakauer, 2005).

One of the factors that limit the functional performance of a hemiparesis is the inability of muscle to generate forces, two weeks of inactivity will leads to decreases of muscle mass and strength (Gray, Rice, & Garland, 2012). Thus, it is necessary to understand the most related muscle to rehabilitation movements prior performing any rehabilitation task.

2.2 Muscles of the Upper Limb

Muscle is the tissues that provide movement for human body structure. The upper limb muscles such as the muscles of the shoulder and upper arm muscles are the focus for arm rehabilitation of post stroke.

Shoulder's muscles that often being in interest of researchers is Deltoid since these muscles participate in generating various movements of the shoulders. Deltoid fibres include Deltoid Anterior (DA), Deltoid Lateral (DL) and Deltoid Posterior (DP). The DA band formed at the collarbones, DL fibres forming at the acromion and DP forming at the spine of the scapula. Contraction of the anterior fibres flexes and medially rotates the arm by pulling the humerus towards the collarbones, as in reaching forward or throwing a ball underhand. The DL abducts the arm by pulling the humerus toward the acromion. Abduction of the arm results in the arm moving away from the body, as in reaching out to the side. Contraction of the DP extends and laterally rotates the arm by pulling the humerus toward the spine of the scapula. Extension and lateral rotation moves the arm posteriorly, as in reaching backwards or winding up to throw a ball underhand. Deltoid muscles locations are as illustrated in Fig. 2.1 (a).

Muscles associates with elbow movement are biceps and triceps. As illustrated in Fig 2.1 (b), biceps Long head originates from the supraglenoid tubercle of the scapula, while the short head originates from the coracoid process of the scapula, and generates movement such as elbow flexion. While triceps Long head originates from the infraglenoid tubercle. Lateral head originates from the humerus, superior to the radial grove. Medial head originates from the humerus, inferior to the radial groove, triceps will generates movement such elbow extension.

As shown in Fig. 2.1 (c), Muscles of the forearm which are flexor and extensor generate flexion and extension of the wrist. Flexors located at the anterior compartment and extensors located at the posterior compartment.

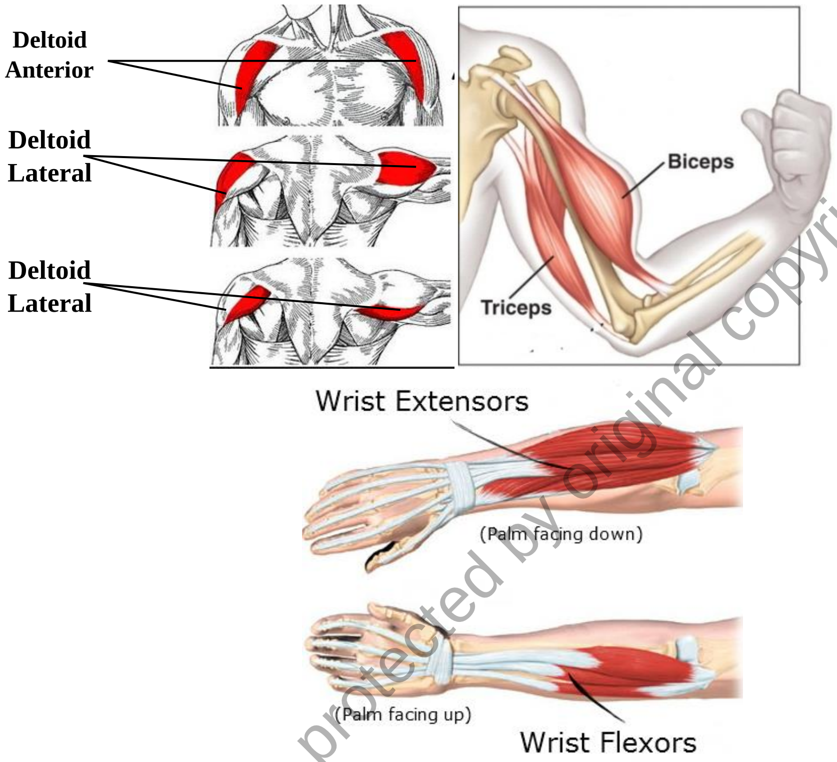

Figure 2.1: Muscle Location; (a) Deltoid (b) biceps and triceps (c) flexors and extensors

Muscles involved in EMG data collection will vary depends on the type of movement. Generally for EMG data collection, muscles involved in shoulder movements are deltoid, (Kibler, Sciascia, Uhl, Tambay, & Cunningham, 2008) since deltoid muscle are responsible to generate shoulder related movements. Biceps and triceps are the muscles that contract and relax while performing elbow related movements, while two muscles data collected in wrist movements are wrist flexors and wrist extensors.