ENHANCEMENT OF NON-MOTORIZED THREE DEGREE OF FREEDOM ASSESSMENT TOOL FOR STROKE PATIENTS

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For my beloved mother and father
Ruhana Binti Jaapar and Mazlan Bin Haron,
and my lovely family including my beloved wife
Norul Husna Binti Alias
Thank you for your support, guidance and love

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Bismillahirrahmanirrahim...

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ABSTRACT

The use of robotic devices for physical rehabilitation of the upper limb following brain injury can assist physiotherapists in rehabilitation program. The presence of robotic rehabilitator will help physiotherapists to assess the stroke patients effectively during their rehabilitation process. Although researchers in the field of robotic rehabilitation has designed the robotic assessment tools, it's still need improvement in term of design complexity. The goal of this project is to develop non-motorized device namely iRest 2.0 to enhance the previous iRest design that consist of reaching, forearm rotation and grasping movements. Moreover, The iRest 2.0 is developed more compact and portable compare to the iRest in term of weight and dimension. Besides, a study with 5 healthy subject who that has no injury history of upper limb was carried out to analyse the performance of iRest 2.0. This performance analysis was based on the three assessment module (Draw Capital I, Draw Diamond, and Draw Circle). Results shows the positive outcome where almost all the kinematic variables for the three assessment module had positively improved when using iRest 2.0 compared to iRest. The results of this project suggest that a nonmotorized system such as iRest 2.0 could be used to replace iRest in order to assess the hand function of stroke patients.

ABSTRAK

Penggunaan peranti robotik bagi pemulihan fizikal anggota badan atas akibat kecederaan otak boleh membantu ahli fisioterapi dalam program pemulihan. Kehadiran robot pemulihan akan membantu ahli fisioterapi menilai pesakit strok dengan berkesan semasa proses pemulihan mereka. Walaupun penyelidik dalam bidang robot ini telah merekabentuk alat penilaian robotik, ia masih memerlukan penambahbaikan dari segi reka bentuknya yang rumit. Matlamat projek ini adalah untuk membangunkan satu sistem mudah tanpa motor yang dinamakan iRest 2.0 untuk menambahbaik reka bentuk iRest sebelumnya yang mempunyai pergerakan mencapai, putaran lengan, dan membuka/tutup tangan. Selian itu, iRest 2.0 direka lebih kompak dan mudah alih berbanding dengan iRest dari segi berat dan dimensi. Di samping itu, satu kajian dengan 5 subjek sihat yang tidak mempunyai sejarah kecederaan anggota badan atas telah dijalankan untuk menganalisis prestasi iRest 2.0. Analisis prestasi ini adalah berdasarkan kepada tiga modul penilaian (*Draw Capital I, Draw Diamond,* dan *Draw Circle*). Keputusan menunjukkan hasil positif di mana hampir semua pemboleh ubah kinematic untuk tiga modul penilaian telah meningkat secara positif apabila menggunakan iRest 2.0 berbanding iRest. Hasil projek ini menunjukkan bahawa sistem mudah tanpa motor seperti iRest 2.0 boleh digunakan untuk menggantikan iRest untuk menilai fungsi tangan pesakit strok.

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LIST OF SYMBOLS AND ABBREVIATIONS

r	-	Correlation coefficient
r_l	-	Correlation coefficient in the training data set
r_v	-	Correlation coefficient in the validation data set
mm	-	Millimeter
V_l	-	Linear reaching velocity
V_r	-	Forearm rotation tangential velocity
$Lpos_{offset}$	-	Linear position at movement offset
$Lpos_{onset}$	-	Linear position at movement onset
θ	-	Angle
θ_{offset}	-	The angle at movement offset
θ_{onset}	-	Angle at movement onset
$time_{offset}$	-	Time at movement offset
$time_{onset}$	-	Time at movement onset
^{0}	-	Degree of angle
CMAS	-	Chedoke-McMaster Assessment
FMA	-	Fugl-Mayer Assessment
MAS	-	Motor Assessment Scale
ARAT	-	Action Research Arm Test
PT	-	Physiotherapy
OT	-	Occupational therapy
DOM	-	Degree of Movement
HSA	-	Hospital Sultanah Aminah
ROM	-	Range of motion
NASAM	-	National Stroke Association of Malaysia
iRest	-	Interactive rehabilitation and assessment tool

FKEE	-	Faculty of Electrical and Electronic Engineering
UTHM	-	Universiti Tun Hussein Onn Malaysia
DOF	-	Degree of Freedom
ARM Guide	-	Assisted rehabilitation and measurement guide
MEMOS	-	Mechatronic system for motor recovery after stroke
HWARD	-	Hand-wrist assisting robotic device
MT	-	Movement time
RT	-	Reaction time
ST	-	Stability time
MV	-	Mean velocity
PV	-	Peak velocity
TPV	-	Time to peak velocity
HWS	-	Hit wall score
PR	-	Path ratio
TE	-	Trajectory Error
SDE	-	Starting distance error
NDE	-	Nearest distance error
Gr	-	Grasping
MP	-	Master Project
STD	-	Standard Deviation

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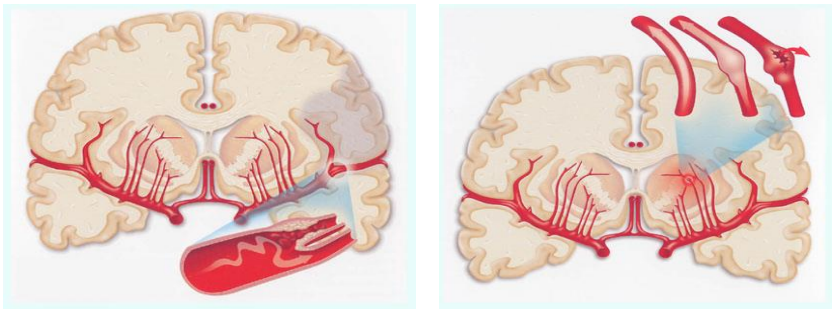
CHAPTER 1

INTRODUCTION

1.1 Stroke

Stroke is a disease that often leads to death. A stroke occurs when there is a blocked blood flow or broken arteries in the brain that will cause damage to the brain cells. The blockage of blood flow or arterial damage will cause sudden death of brain cells due to the lack of oxygen and glucose received by the brain. The types of stroke are divided into two categories which are Ischemic stroke and Haemorrhagic stroke [1]. Ischemic stroke is a type of stroke that most commonly faced by stroke patients. It occurs in the brain blood vessels caused by cholesterol obstruction that interferes or disrupting the blood flow to brain cells. Haemorrhagic stroke is the type of stroke caused due to the occurrence of damage to the blood vessels around the brain causes bleeding [2]. Figure 1.1 shows the overview of Ischemic stroke and Haemorrhagic stroke.



(a) (b)

Figure 1.1: Types of stroke. (a) Ischemic stroke, (b) Haemorrhagic stroke (adopted from www.nasam.org)

Stroke is classified as a circulatory system disease. This circulatory system diseases ranked first of the ten major causes of death in government hospitals of Malaysia. From that category, stroke score second higher disease after ischemic heart. In Malaysia, it is estimated that about 40,000 people suffer from stroke [3]. Stroke disease can be faced by all ages including children, but mostly are faced by adults. Normally stroke will remain for the long term and to recover from a stroke, patients need motivation and a strong mentality. In order to support the recovery process, suitable rehabilitation facility is required.

1.2 Rehabilitation Program

Clinical Practice Guidelines for the Management of Stroke [4] of Malaysia state that the stroke patients are prompted to enter the emergency unit and will be treated as an emergency medical condition. General hospital in Malaysia has its protocol of health care service. Figure 1.2 shows the protocol for patient with suspected stroke [5]. The suspended stroke patients which referred to the hospital that follow this guideline will be divided into critical or semi-critical or non-critical zones [5]. Patients with no neurological problems are normally entered the general medical ward and will be treated immediately after types of the patient's injury is identified.

Once the condition of the patient is stable, the patient will receive the first physical treatment which is mobilization. To avoid the neurology and general complications, it is recommended to start the treatment as early as possible [4]. At this sub-acute stage, the patient will stay in hospital for rehabilitation treatment for several weeks or months if necessary. In clinical settings, experienced physiotherapists assess impairment and disability by using established clinical scales such as Chedoke-McMaster Assessment (CMAS) [7], Fugl-Mayer Assessment (FMA) [8], Motor Assessment Scale (MAS) [9] and Action Research Arm Test (ARAT) [10] at the beginning and at the end of their stay in the hospital for the rehabilitation treatment.

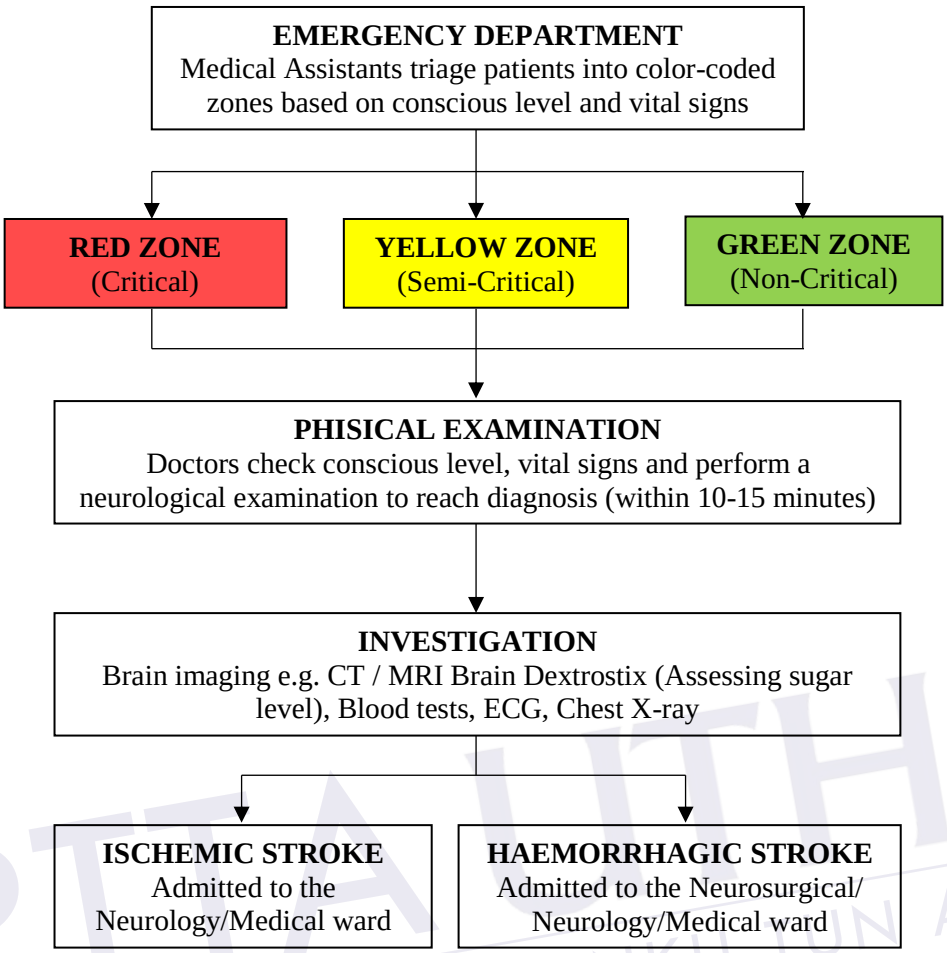


Figure 1.2: Flowchart for patient with suspected stroke (Adopted from Mohammed C. R. [5] and Abdul Rahman H. thesis [6])

1.2.1 Stroke Rehabilitation

In stroke rehabilitation process, the appropriate treatment will be given to the stroke patients according to their own capabilities. Generally, there are two types of stroke treatment which are Physiotherapy (PT) and Occupational therapy (OT). Physiotherapy is a method used for assist people with disabilities using physical approaches such as movements training to rehabilitate and maintain the physical movements of the patient [11]. Occupational therapy is a method used for helping people who have sensory, physical or cognitive disability to do daily work and help them to become more self-reliant as quickly as possible, such as dressing or eating

habits with just one hand [12]. Practically, the stroke treatment starts with a small degree of movement (DOM) for simple exercises. During exercise, higher levels of movement will be involved when the patient improves and builds their own strength.

Figure 1.3: Eating task for upper limb rehabilitation with intensive used of the affected limb

Physiotherapists in Hospital Sultanah Aminah (HSA), Johor Bahru, Malaysia uses physical rehabilitation technique, one of them is technique approach by Bobath [13]. This approach consists of the exercises with repetitive and stretching movements on the affected limb. In addition, physiotherapists also facilitate a proper use of the muscles while performing the functional tasks. Functional tasks used to encourage the voluntary movement of the patients such as for eating and drinking task. Range of motion (ROM) of the stroke patients should be considered not to affect the rehabilitation process. This is due to the ROM is restricted to the shoulders after the stroke [14]. Figure 1.3 shows the stroke patient performing eating task using affected limb during upper limb rehabilitation.

1.2.2 Stroke Assessment

Stroke assessment is the most important process before stroke rehabilitation. Physiotherapist was assigned to perform the functional assessment. However, the difficulties of the activities that need to be assigned to the patients is depends on their own level of stroke in term of difficulties level, suitable functionality, and environment [15]. This process needs to be carried out by experienced physiotherapists to evaluate disability or neurological disorders. Clinical assessment score is important for designing an effective rehabilitation program, with appropriate training protocols, tailored to the level of patient deterioration. The result from the assessment process will be used for tuning the rehabilitation parameter to ensure the maximum capabilities of the stroke patients is reached [16]. Furthermore, clinical assessment of motor function is commonly performed only in several phases during the rehabilitation program to monitor the progress of the stroke patient. However, the decline in motor function is difficult to assess and presently there is no "golden standard" for proper assessment [17]. Different clinical scales and results used by different rehabilitation centers is depending on the level of physiotherapy expert experience.

At National Stroke Association of Malaysia (NASAM) center, every three months, the physiotherapist assesses the stroke patient's progress. Before the patient arrive at the center during the assessment day, the physiotherapist will set up the assessment tools to ensure that the assessment day goes smoothly without any time delay [6]. Common assessment scales such as FMA, MAS, and ARAT are widely used to measure motor performance in stroke survivors. Although these common assessment scales have been widely used and well established, but the scoring systems are always subjective, lack reliability, highly dependent on the ability of the trained physiotherapist and provide only rough estimates on motor function [6]. Besides, it is difficult to objectively measure the impairment and disability [18].

1.3 Robotic Rehabilitation

Generally, robotic rehabilitation is divided into two types of rehabilitator tools which are training and assessment tools. Training rehabilitator tools focused on the motorized design while assessment rehabilitator tools focused on non-motorized design. In order

to improve rehabilitation methods in physiotherapy, different approach of robotic rehabilitation assessment has been designed and the innovation is needed for future improvement. The use of robotic devices or rehabilitators for physical rehabilitation of the upper limb following brain injury can assist physiotherapists in rehabilitation program. Other than that, the robotic devices can measure the patient's sensory motor performance precisely and objectively by integrating sensors [19]. Besides, robotic measure can also provide fast feedback on patient's progress and would reduce the subjectivity inherent in most of the conventional assessment scales [20]. The presence of robotic rehabilitator will help physiotherapists to assess the stroke patients effectively during their rehabilitation process. The details of the previous studies were discussed in Chapter 2.

1.4 Problem Statements

Although researchers in the field of robotic rehabilitation has designed the robotic assessment tools, it's still need improvement in term of design complexity. In previous assessment tool namely as iRest [6], the design can assess upper limb function of the fundamental movements i.e. hand rotation, hand gripping and hand reaching, but the design is complex and requires high supervision during the assessment process. Therefore, the design should be enhanced in term of hardware implementation. The issue of this lesson is how to utilise the iRest technologies?

Hand grasping is one of the three main fundamental movement for the assessment tools. The design become more effective, if the voluntary movements of patient's upper limb can be assessed. However, the existing iRest uses grasping mechanism that are less suitable to assess the voluntary movement of the patient's hand due to the gravity effect when the patient performs hand rotation (pronation and supination). In the other word, the rotation of patient's hand will affect the grasping mechanism of the iRest to assess the patient's voluntary grasping (opening and closing) movement. The design of grasping mechanism requires some enhancement.

Furthermore, in term of the structure design, platform must be compact which can be categorized as portable-type assessment tool. Ideally, the design of the assessment tools must be light in weight, smooth, and more practical in order to assess the hand voluntary movement. However, iRest design use two triple sliders mechanism

to perform the linear constraint movement which can be categorized as heavy material. In addition, the overall design is big to be said as compact and portable design. The structure design need to be upgraded in term of weight, smoothness, and design portability. At the same time, the assessment tool should reduce the workload of the physiotherapists.

1.5 Project Objectives

The main objective of this project is to develop an assessment tool for stroke patients for enhancement of the iRest. Its measurable objectives are as follows:

(i) To identify the suitable design to train and access hand grip function.

(ii) To enhance the design of non-motorized device (iRest) as a platform for hand assessment function namely as iRest 2.0.

(iii) To analyse the performance of proposed design compare to the iRest using kinematic data extracted from both devices.

1.6 Project Scopes

This project concentrates on monitoring stroke patient's performance. In order to achieve the objectives, knowledge of the following elements must be strengthened. The scopes of this project are:

(i) This project focus on the hardware development of iRest 2.0.

(ii) The design of the assessment platform uses the concept of belting and pulley.

(iii) The workspace area of this project is limited to 500mm x 150mm x 300cm portable type.

(iv) The kinematic data of 5 healthy subjects will be used for the score benchmark.

(v) The healthy subjects focused on the students from Faculty of Electrical and Electronic Engineering (FKEE) of Universiti Tun Hussein Onn Malaysia (UTHM).

(vi) The inclusion criteria for the healthy subjects allowed to who that has no injury history of upper limb.

1.7 Expected Results

The main expected result is this assessment tool will help stroke patient for their rehabilitation process. The expected result that related with objectives are:

(i) The hand grasping mechanism design is suitable to assess the hand grip function of the user's hand.

(ii) The enhancement of non-motorized device namely as iRest 2.0 can be functioned as a platform for hand assessment devices for stroke rehabilitation process.

(iii) The analysis of the performance using kinematic data extracted from the iRest 2.0 compared to the and iRest will resulting positive improvement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter begins with an overview of information related to the upper limb rehabilitation robot in sub-chapter 2.2, covering the types of existing robots and the mechanical features about the robot for manipulation, robot for reaching, and robot for reaching and manipulation. This is then followed by the discussion on the main issues with the proposed solution in sub-chapter 2.3, describing the issues and proposed design in term of hand grip, reaching, and rotation movement. The summary of the chapter is presented in sub-chapter 2.4.

2.2 Upper Limb Rehabilitation Robot

Robotic system has been developed consistently with present technology to ease physiotherapists assisting stroke patients in their rehabilitation process. Commonly, upper limb rehabilitation robot has been developed using exoskeleton-based systems or end-effector-based systems [21]. Robot with exoskeleton-based system has large number of Degree of Freedom (DOF) thus, allowing this robot to make a lot of motion as it has a more point of axis connection. The construction of an exoskeleton robot is design to look like the anatomy of human upper limb and it's also combined to some points of the human's arm. Large range of motion (ROM) of upper limb can be trained using exoskeleton rehabilitation robots such as Armeo Spring robot [22], ARMin [23,

24], upper limb power exoskeleton [25] and T-WREX [26]. However, the weakness of the exoskeleton robot is its complex design when works along with human's hand due to the presence of inertia and friction of the hand movements. In addition, the limited output torque or force and the flexibility to the size of the patient's upper limb become the extra concern [27]. Figure 2.1 shows the examples of the exoskeleton rehabilitation robots.

(a) (b) (c)

Figure 2.1: Exoskeleton rehabilitation robots. (a) Armeo Spring [22], (b) ARMin [24], and (c) upper limb power exoskeleton robot [25]

End-effector based system robot can be categorized as a simple operating robot used for the stroke rehabilitation process. This robot has interaction between the upper limb of the stroke patients and the robot design that are just one point joined together to perform the movement of the hands. In addition, the end-effector rehabilitation robot is easy to handle compared to exoskeleton rehabilitation robot. Even though this end-effector based robot does not provide overall control of patient's upper limb, it does support the patient's wrist which better to help the patients to do their daily routine such as manipulating objects. Figure 2.2 shows the illustration of exoskeleton and end-effector based robot concept. In general, the end-effector rehabilitation robot can be divided into three categories which are robot for manipulation, robot for reaching, and robot for manipulating and reaching.

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