Faculty of Engineering

DEVELOPMENT OF INTENTION DRIVEN REHABILITATION AND ASSISTIVE HAND EXOSKELETON CONTROL SYSTEM

LING TIEW CHEON

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Grade: ____________

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Final Year Project Report	√
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(Supervisor)

DEVELOPMENT OF INTENTION DRIVEN REHABILITATION AND ASSISTIVE HAND EXOSKELETON CONTROL SYSTEM

LING TIEW CHEON

A dissertation submitted in partial fulfilment

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Dedicated to my beloved family, friends, seniors and lecturers who supported me in the process of completing this project

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ABSTRACT

Stroke is the third largest cause of death in Malaysia. Hand motor impairment is common disability among stroke survivors and severely affects their ability in activities of daily living (ADLs), reducing their independence and quality of life. Through rehabilitation process, stroke patients can regain partial hand motor function. However, conventional rehabilitation process is limited by insufficient number of therapists, labour-intensive, costly, has low patient's compliance and provides inconsistent results. Some of the stroke patients still require assistance in ADLs even after year-long rehabilitation process. In overcome those limitations, several exoskeletons had been developed for rehabilitation and assistive purposes. One of them was Flexible Linkage Hand Exoskeleton Rehabilitation Robot (FLEXOR), a 3D-printed prototype hand exoskeleton actuated by linear actuators. FLEXOR required a control system that could recognize user's motion intention so that stroke patients could perform exercises on their own and assist them in ADLs. FLEXOR can make rehabilitation more accessible and affordable, and improving post stroke quality of life. In response to such requirement, an Arduino based control system that was driven by electromyography (EMG) signal was developed. The new control system protected the hand against over-flexing and excessive application of force with flex sensors and force sensing resistors. The control system was programmed into three different operating modes which enable FLEXOR to provide passive exercises to wearer's fingers, assist wearer in ADLs with minimal efforts, and provide active exercises while assisting wearer in ADLs. Programming of control system was refined through repeated session of pilot testing until a functional control system was developed. By using the developed control system, motion of FLEXOR was observed and recorded for analysis and comparison against program flowcharts and program codes.

ABSTRAK

Strok adalah punca ketiga kematian di Malaysia. Kehilangan fungsi motor tangan adalah kecacatan yang biasa dialami oleh pesakit-pesakit strok dan telah mengurangkan keupayaan mereka dalam aktiviti kehidupan harian. Hal ini telah menjejaskan kebebasan dan kualiti hidup mereka. Pesakit-pesakit strok boleh mendapatkan semula sebahagian fungsi motor tangan melalui proses pemulihan untuk strok. Walau bagaimanapun, proses pemulihan konvensional terhad oleh bilangan ahli terapi yang tidak mencukupi, mahal, mempunyai pematuhan pesakit yang rendah dan tidak konsisten. Sesetengah pesakit strok masih memerlukan bantuan dalam aktiviti kehidupan harian walaupun selepas menjalani proses pemulihan selama setahun. Beberapa exoskeleton tangan telah dcipta untuk tujuan pemulihan dan bantuan dalam kehidupan harian. Satu daripada exoskeleton tangan yang dicipta adalah FLEXOR, exoskeleton tangan prototaip bercetak 3D yang digerakkan oleh penggerak linear. FLEXOR memerlukan sistem kawalan yang boleh mengesan niat pergerakan pengguna supaya pesakit-pesakit strok boleh melakukan latihan pemulihan sendiri dan membantu mereka dalam kehidupan harian. Sistem kawalan ini dapat menjadikan pemulihan lebih mudah diakses, dan meningkatkan kualiti hidup pesakit strok. Sistem kawalan berasaskan Arduino yang digerakkan oleh isyarat elektromilogi (EMG) telah dibangunkan di dalam penyelidikan ini. Sistem tersebut melindungi tangan daripada pergerakan melebihi julat dan penggunaan tenaga yang berlebihan dengan sensor flex dan pengesan daya. Sistem kawalan tersebut telah diprogramkan kepada tiga mod operasi yang membolehkan FLEXOR untuk menyediakan latihan pasif kepada jari pemakai, membantu pemakai dalam kehidupan harian dengan usaha yang minimum, dan menyediakan latihan aktif semasa membantu pemakai dalam kehidupan harian. Program sistem kawalan telah diperbaiki berulang kali melalui sesi ujian perintis sehingga sistem kawalan yang berfungsi dibangunkan. Gerakan FLEXOR telah diperhatikan dan direkodkan untuk analisis dan perbandingan dengan carta aliran program dan kod program.

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DALY	-	Disability-adjusted Life-year
ADLs	-	Activities of daily living
QOL	-	Quality of life
ROM	-	Range of motion
DOF	-	Degree of freedom
IP	-	Interphalangeal
DIP	-	Distal interphalangeal
PIP	-	Proximal interphalangeal
PIP	-	Proximal interphalangeal
MCP	-	Metacarpophalangeal
HE	-	Hand exoskeleton
EMG	-	Electromyography
sEMG	-	Surface electromyography
EDC	-	Extensor Digitorum Communis
FDS	-	Flexor Digitorum Superficialis
APB	-	Abductor pollicis brevis
ED	-	Extensor digitorum
MAV	-	Mean absolute value
RMS	-	Root mean square
FSR	-	Force sensing resistor
MVC	-	Maximum voluntary contraction
PM	-	Passive Mode
AAM	-	Active Assisted Mode
AUM	-	Active Unassisted Mode

CHAPTER 1

INTRODUCTION

1.1 General Background

In Malaysia, stroke is the third largest cause of death after heart diseases and pneumonia in 2016 (Department of Statistics Malaysia, 2017). In the same year, stroke is estimated to be the third burdening diseases, responsible for 4.88% or 355.5 out of 7273.6 of total disability-adjusted life-year (DALY) (World Health Organization, 2018). According to World Health Organization, DALY is used to indicate overall burden of disease (Stevens et al., 2018). By 2020, stroke is expected to be the second cause of death and disability in worldwide (Murray & Lopez, 1997). According to Malaysian Society of Neurosciences (2012), stroke is defined as “clinical syndrome characterized by rapidly developing clinical symptoms or signs of focal, and at times global, loss of cerebral function, with symptoms lasting more than 24 hours or leading to death, with no apparent cause other than that of vascular origin” (Basri et al., 2012).

Association of Malaysia (NASAM) (n. d.), stroke is a brain attack that interrupts the vital supplies of oxygen rich blood to brain and deprives brain tissues of oxygen, damaging them in the process. Strokes are categorized into ischemic strokes and hemorrhagic strokes. Ischemic strokes are caused by blockage such as blood clots or progressive build-up of plaque and other fatty deposit in the arteries, cutting off the blood supply to brain. If the blockage is temporary, transient ischemic attack occurs, imitating stroke-like symptoms for less than 24 hours before disappearing. On the other hand, hemorrhagic strokes occur when a blood vessel in the brain bursts and spills blood into the brain. Swelling created by accumulation of blood pressures and damages the brain cells and tissues (Basri et al., 2012). According to Stroke Association, ischemic strokes comprise approximately 85% of all strokes while the remaining 15% are hemorrhagic strokes (*State of the nation Stroke statistics*, 2018). The advancement in medical field has helped prevented 80% of stroke cases. However, despite the advancement in medical field , 2/3 of stroke survivors still suffer from some type of disability instead of complete recovery (National Stroke Association, n.d.).

Our sensation, cognitive, and body motor functions are controlled by different specialized areas in the brain. Stroke affect either some or all the functions depending on the location of stroke in brain and severity of lesion. While every stroke is different, some effects are common, such as hemiparesis or hemiplegia, dysarthria, or dysphagia, fatigue, loss of emotional control and changes in mood, cognitive changes, behaviors changes and decreased field of or trouble with visual perception (American Heart Association, 2015). Hemiparesis is characterized as weakness of half of the body caused by mild to moderate lesion on the opposite side of brain, while hemiplegia is partial or total paralysis of half of the body due to moderate to severe lesion to opposite side of brain.

Hemiparesis and hemiplegia due to stroke often manifest at the face, arms and legs' muscles. This project deals with hand motor disability of stroke survivors rather than the wide scope of stroke effects. Hand motor functions refer to the coordination and control of muscles to control hands and fingers to achieve common activities such as reaching, picking up, grabbing and holding objects. Hemiparesis and hemiplegia are permanent conditions that cannot be reversed and often constrain normal hand motor function. These conditions left the stroke survivors with difficulty in accomplishing essential activities of daily living (ADLs) to maintain level of care like eating, bathing, dressing, toileting, transferring and continence.

Therefore, post stroke disability is often measured by assessing ADLs of patients. Reduced in independence in ADLs diminish quality of life (QOL) of stroke survivors, forcing them to depend on professional caregivers or family members. Additionally, stroke survivors tend to neglect paralyzed or weakened limbs, preferring the use of non-affected limbs (Uswatte, Mark, & Morris, 2006). Eventually, the brain unconsciously suppresses the use of affected limb altogether. This condition is called learned non-use condition and may further deteriorate the motor function. Figure 1.1 summarized the development of learned non-use condition in stroke survivors. However, while being irreversible, hand motor disability in hemiparesis and hemiplegia stroke survivors can be mitigated through rehabilitation.

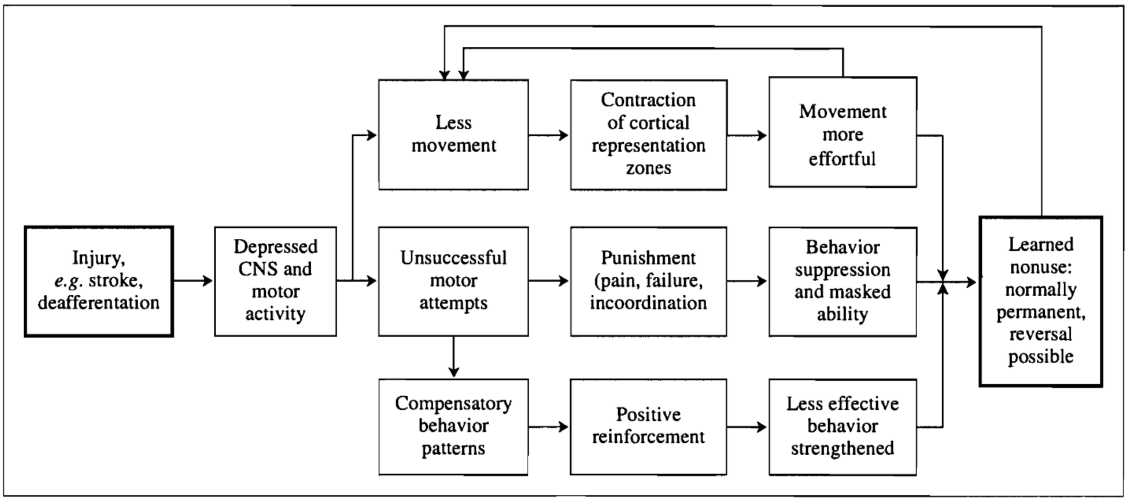

Figure 1.1: Development of Learned Non-use Condition (Uswatte et al., 2006)

Rehabilitation is the most effective method to reduce motor impairments of stroke survivors. Rehabilitation exploits the neuroplasticity, ability of brain to reorganize functions of damaged area to undamaged parts of the brain by forming new neural connection between intact neurons through repetition of certain activities. In all cases, the aim of rehabilitation is to regain physical functioning to regain independence in ADLs and improve post-stroke QOL of stroke survivors. Rehabilitation begins as soon as possible following a stroke after the patient is medically stable. Recovery of motor function is most effective with highest chance of success in the first few months after a stroke, following by slower pace over the years with patient’s continuous efforts.

Stroke rehabilitation involves multidisciplinary approaches, including physical and occupational therapy. Physical therapy focuses on improving muscle strength and coordination, mobility, and other physical function of patient. Physical therapy involves passive and active exercises. Passives exercises or passive range of motion (ROM) exercises involves moving affected muscles and joints through their full range of motion with the help of non-affected side or others. Passive exercises do not require effort from patient to move the affected muscles and joints, therefore it is suitable for hemiplegia stroke survivors that have no control over their muscles.

Active exercises are best suited for hemiparesis stroke survivors and hemiplegia stroke survivors that regained slight motor functions. Active exercises require physical effort by patient to produce muscular activity. Continuous repetitive passive or active exercises will eventually activate neuroplasticity. Alongside passive and active exercises, several other strategies such as mirror therapy and constraint-induced movement therapy are used in rehabilitation of hand motor functions. Mirror therapy involves the use of mirror between arms to reflect the movement of non-affected limb, providing the illusions of same normal movement in the affected limbs (Thieme, Mehrholz, Pohl, Behrens, & Dohle, 2012).

Constraint induced therapy deals with learned non-use condition (Kim, 2013), where the unaffected limbs are restrained to promote the use of affected limbs in exercises and ADLs. While hand motor functions are taking time to recover, occupational therapy focuses on improving involvement of patient in social setting with therapeutic use of everyday life activities (American Occupational Therapy Association, 2014) through environmental modification, use of adaptive and assistive equipment, and sensory integration. According to Legg et al. (2007), researches had shown that stroke patients that undergo occupational therapy were more independent in ADLs and capable or preserving those abilities.

There have been numerous researches that introduce robotics devices in the form of hand exoskeleton (HE) into the field of stroke rehabilitation. Robotics technology has advanced rapidly with the development of more powerful and efficient microprocessor, computational approaches, sensing and control technologies, enabling the robotic devices to accurately reflect user's intention. Robotic therapies that incorporates such technology show promising future for rehabilitation of stroke patient with physical disability.

1.2 Problem Statement

Stroke patients are guided by certified physiotherapists and occupational therapists in performing physical and occupational therapy in conventional stroke rehabilitation. Therapist are responsible for providing advice, support, supervision and rehabilitation exercises based on their professional knowledge. In Malaysia, only a total of 2446 therapists, comprising of 1073 occupational therapists and 1373 physiotherapists, worked in healthcare facilities under Ministry of Health Malaysia in 2016 (Ministry of Health Malaysia, 2016). On the other hand, 16612 patients survived from stroke and discharged from hospital under Ministry of Health Malaysia in the same year (Ministry of Health Malaysia, 2017). Since all these patients required some form of rehabilitations, the ratio of therapists to patients is approximately 1 : 7, meaning that a therapist has to tend to seven patients. The low number of therapists is worrying as a therapist may not be able to pay full attention to all his/her patient. Based on the projection given by (Murray & Lopez, 1997), together with improving medical technology and increasing unhealthy lifestyle, the number of people who experiences stroke and survives will keep on increasing faster than the increase in number of therapists, further worsen the situation.

Stroke rehabilitation involves high-intensity and task-specific training with specific goal setting in recovering hand motor function (Langhorne, Bernhardt, & Kwakkel, 2011). At the same time, conventional stroke rehabilitation involves manual one on one interaction between patients and therapists for a long period of time, making these methods labour-intensive and costly in conjunction with low number of therapists. The cost increases further if a patient consults private therapists due to the limited number of government therapists. These hands-on-therapies sessions often inflict strain injuries and fatigue for therapists. Furthermore, limited therapists together with overwhelming number of patient limits the available duration and frequency of conventional rehabilitation sessions, preventing high-intensity and high-frequency therapies to achieve optimal rehabilitation results.

Therapists customize rehabilitation strategies according to type of disability and severity of patient's conditions based on their past experiences and training. Consequently, there are variations in methods for each patient, resulting in inconsistent outcomes. Coupled with repetitive rehabilitation regime, patients may become less motivated in participating rehabilitations, slowing down their recovery. Besides, rehabilitations do not guarantee success in full recovery of hand motor function. According to (Hartman-Maeir, Soroker, Ring, Avni, & Katz, 2007), more than 25% of patients involved in the research still needed assistance in ADLs one year after onset of stroke.

In order to deal with the limitation of conventional rehabilitation, the implementation of robot in rehabilitation is imminent. A system that allow patients to perform exercises on their own and assist them in ADLs is needed to make rehabilitation more accessible and affordable, producing better outcomes and ultimately improve post stroke QOL of patient. Such requirements can be fulfilled by robotic hand exoskeleton with the capability to analyse, sense and monitor patient motion, allowing patient to control the robotic hand exoskeleton.

Robotic hand exoskeleton extends the rehabilitation session to home by delivering high-intensity and high-frequency training without requiring full-time monitoring by a therapist, increasing the pace of rehabilitation process. Rehabilitation training protocol that is adjusted by therapists can also be replicated accurately to ensure consistent outcomes. Moreover, robotic hand exoskeleton can compensate for patients' weakened strength to improve their independence in ADLs during their long process of recovery.

In response to above requirements, Flexible Linkage Hand Exoskeleton Rehabilitation Robot (FLEXOR), as shown in Figure 1.2, had been developed as rehabilitation and assistive device for stroke patients. FLEXOR is a 3D printed prototype hand exoskeleton that features five individual movable finger modules. Five electric linear actuators are used to actuate the finger modules and allow active flexion and extension at metacarpophalangeal joint. Such motions enable FLEXOR to simulate hand grasping and opening motion. FLEXOR utilizes elastic links in the linkage of finger modules, allowing the hand exoskeleton some flexibility in adapting to object's shape. To achieve rehabilitation and assistive function, FLEXOR requires a control system that recognizes hand grasping intention of the wearer and translate it into corresponding movement of the linear actuators. At the same time, the control system must detect onset of hazardous actions and provide automatic hazard mitigation, reducing risk of endangering wearer during usage.

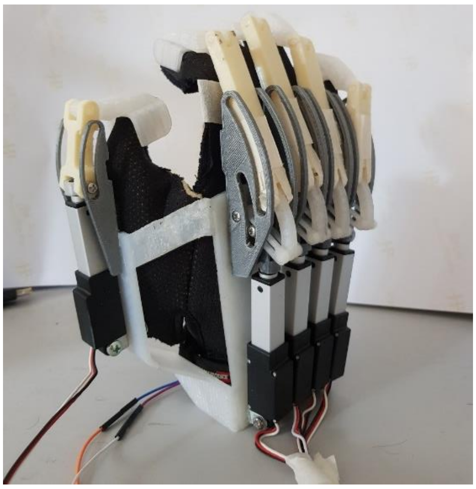

Figure 1.2: Flexible Linkage Hand Exoskeleton Rehabilitation Robot (FLEXOR)

1.3 Objectives

The objectives of this research are:

1. To develop a control system with effective intension sensing capability for FLEXOR as home finger rehabilitation exercises and motion assistance in activities of daily living (ADLs).
2. To develop safety mechanism for control system to protect the subject against excessive application of force and over-flexing.
3. To evaluate the validity of the control system programming and safety mechanism.

1.4 Scope of the Research

This research is conducted with the eventual goal of improving the pace of rehabilitation process and increasing independence in ADLs of stroke survivors suffering from hand motor disability due to hemiparesis or hemiplegia. This research will focus on controlling the movement of index, middle, ring and little finger to perform hand grasping and opening motion. Hence, a control system with effective intension sensing capability will be researched and implemented in FLEXOR to control the corresponding finger modules. Additionally, danger to wearer's fingers during FLEXOR operation is considered and mitigated by researching on appropriate safety mechanism, ensuring safety and comfortable of wearer. There are several limitations to this research. First