FORCE CONTROL FOR ONE DEGREE OF FREEDOM HAPTIC DEVICE USING PID CONTROLLER

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A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

JANUARY 2019

For my beloved mother and father,
Zaiton Binti Abdul Karim and Mohamad Husni Bin Ahmad,
Thank you for your love, inspiration and prayers; day and night
make me able to complete this project.
For my fellow friends especially Nurul Aqilah Binti Jainal Abidin,
Thank you for being there through thick and thin
while making the project.

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious, the Most Merciful.

Alhamdulillah, all praises to Allah for His blessing, grace and kindness, I am able to complete my Master's Project Report, Session 2018/2019.

First and foremost, I offer my sincere gratitude to my supervisor, Dr. Hisyam Bin Abdul Rahman who has given me a lot of guidance in finishing this project. His advice and ideas from the beginning until the end of the project really helps in order to make this project more organized. Besides, not to forget to the other lecturer who has helped to ease my problem in carrying out this project.

My profound gratitude goes to my beloved parents, Zaiton Binti Abdul Karim and Mohamad Husni Bin Ahmad who has inspired me to continue my study in Universiti Tun Hussein Onn Malaysia and pursue my Master. Without love and support from them, it is impossible for me to be where I am right now. Their encouragements have made it possible for me to complete another part of my education journey.

Last but not least, I give my appreciation to my colleagues and for those who supported me in any way especially while completing the project.

ABSTRACT

Haptics has been used as an additional feedback to increase human experience to the environment over years and its application has been expanded into education, manufacturing and medical. The most developed haptic devices are for rehabilitation purpose. The rehabilitation process usually depends on the physiotherapist. But, it requires repetitive movements for long-term rehabilitation, thus haptic devices are needed. Most of the rehabilitation devices are included with haptic feedback to enhance therapy exercise during the rehabilitation process. However, the devices come with multiple degrees of freedom (DOF), complex design and costly. Rehabilitation for hand movement such as grasping, squeezing, holding and pinching usually does not need an expensive and complex device. Therefore, the goal of this project is to make an enhancement to One DOF Haptic Device for grasping rehabilitation exercise. It is improved to perform a force control mechanism with few types of conventional controller which are Proportional (P) controller, Proportional-Integral (PI) controller, Proportional-Derivative (PD) controller and Proportional-Integral-Derivative (PID) controller. The performance of the haptic device is tested with different conventional controller to obtain the best proposed controller based on the lowest value of the Mean Square Error (MSE). The results show that PID Controller is the most suitable for the proposed device with Proportional gain (Kp), Integral gain (Ki), Derivative gain (Kd) are 1.3, 0.01 and 0.2 respectively. The force control mechanism can imitate the training motion of grasping movement for the patient.

ABSTRAK

Sejak bertahun lalu, haptik telah digunakan sebagai mekanisme maklum balas tambahan untuk meningkatkan tindak balas manusia terhadap persekitan sekeliling dan aplikasinya telah semakin meluas dalam bidang pendidikan, pembuatan dan perubatan. Peranti haptik sering dibangunkan bertujuan untuk proses pemulihan. Proses pemulihan lazimnya bergantung pada ahli fisioterapi. Namun begitu, pesakit perlu melakukan satu pergerakan yang berulang untuk jangka masa panjang. Justeru itu, peranti haptik diperlukan untuk memudahkan tugas ahli fisioterapi. Kebanyakan alat pemulihan mempunyai maklum balas haptik untuk meningkatkan latihan terapi. Walau bagaimanapun, kebanyakan peranti yang sedia ada mempunyai pelbagai darjah kebebasan, reka bentuk yang rumit dan harga yang tinggi. Pemulihan untuk pergerakan tangan seperti menggengam, memerah, memegang dan mencubit tidak memerlukan peranti haptik yang kompleks dan mahal. Oleh itu, objektif utama projek ini adalah untuk membuat penambahbaikan kepada Peranti Haptik dengan Satu Darjah Kebebasan untuk latihan pemulihan genggaman. Ia ditambah baik untuk melaksanakan mekanisme kawalan daya dengan beberapa jenis pengawal konvensional yang dicadangkan iaitu pengawal P, PI, PD dan PID. Prestasi peranti haptik diuji pengawal konvensional yang berbeza untuk mendapatkan cadangan jenis pengawal yang terbaik berdasarkan nilai terendah Ralat Min Kuasa Dua. Keputusan menunjukkan bahawa Pengawal PID adalah yang paling sesuai digunakan untuk peranti yang dicadangkan dengan nilai Kp, nilai Ki dan nilai Kd masing-masing ialah 1.3, 0.01 dan 0.2. Mekanisme kawalan daya boleh meniru gerakan latihan menggenggam pergerakan untuk pesakit.

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LIST OF SYMBOL AND ABBREVIATIONS

N	- Newton
MHz	- Mega-Hertz
A	- Ampere
V	- Voltage
mm	- Millimeter
g	- Gram
Kg	- Kilogram
ms	- Milliseconds
DOF	- Degree of freedom
P	- Proportional
PI	- Proportional-Integral
PD	- Proportional-Derivative
PID	- Proportion-Integral-Derivative
MSE	- Mean Square Error
WHO	- World Health Organization
ICIDH	- International Classification of Impairments, Disabilities, and Handicaps
NINDS	- National Institute of Neurological Disorders and Stroke
CVA	- Cerebrovascular accident
TIA	- Transient ischemic attack
Kp	- Proportional gain
Ki	- Integral gain
Kd	- Derivative gain
AFX	- Actuated Finger Exoskeleton
ROM	- Range of Motion

MIME	- Mirror Image Movement Enabler
RUPERT	- Robotic Upper-Extremity Repetitive Trainer
PMA	- Pneumatic muscle action
FES	- Functional electrical simulation
CAD	- Computer-aided design
GUI	- Graphical user interface
PWM	- Pulse Width Modulation
UART	- Universal Asynchronous Receiver/Transmitter
USB	- Universal Serial Bus
ICSP	- In-Circuit Serial Programming
PC	- Personal Computer
DC	- Direct Current
VCC	- Voltage At The Common Collector

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CHAPTER 1

INTRODUCTION

1.1 Finger Impairment

Most of the people often misuse the words “impairment”, “disability” and “handicap” as it seems to have the same meaning. However, in medical field, each word has different definition where it is very significant in order to understand the effects of neurological injury. As stated in the International Classification of Impairments, Disabilities and Handicaps (ICIDH) by the World Health Organization (WHO), an impairment defines any loss or abnormality of a psychological, physiological or anatomical structure or function [1]. While disability means any limitation or lack of ability to perform an activity in the manner or within range considered normal for a person [1]. Handicap is a disadvantage for a person that limits or prevents the fulfillment of a role that is normal to that person [1].

Finger impairment indicate a problem with the structure of finger where the hand functionality to perform basic activity is limited due to injury. A finger is one of human body limb where the bones are called phalanges. Normally, a human born with five fingers on each hand, named thumb, index finger, middle finger, ring finger and small finger [2]. The thumb only has two phalanges while the other fingers have three. The thumb allowed freedom of movement, ability to touch the other four fingers and grasping objects. The function of hand incorporates several components, including strength, range of motion, and dexterity. The structure of human hand is shown in Figure 1.1.

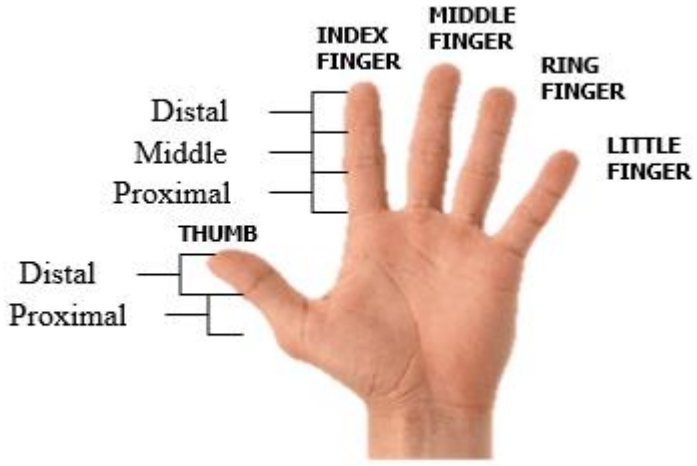

Figure 1.1: The structure of human hand.

Normal hand function is important in order to independently engage in daily activities and occupations [3]. Damage to one or more of these components can lead to dysfunction of the hand and limit participation in everyday life [4]. Peripheral nerve injury, arthritis and stroke are one of the causes of hand function loss which due to injuries, illnesses or defects. Among those causes, stroke ranked third as the highest cause of death rate and being in top ten cause for hospitalization in Malaysia [5]. The severity of stroke depends on where it happens and how much is the brain affected. Minor problems such as weakness in arm or leg caused by minor stroke. While a major stroke may lead to paralysis or death. This disease can be faced by all ages including children, but frequently happens to middle ages and above. Based on research conducted by the National Institute of Neurological Disorders and Stroke (NINDS), United States has approximately 700,000 patients with stroke. [6].

1.2 Stroke

In medical term a stroke is called as cerebrovascular accident (CVA). When the blood supply to the brain is interrupted due to injury to the brain, the stroke occurs. This reduces the supply of oxygen and nutrients and damages the cells of the brain. When this happens, part of the body controlled by the damage brain cells stops working. Ischemic stroke, hemorrhagic stroke and transient ischemic attack (TIA) are three main types of strokes.

About 87 percent of stroke cases are ischemic stroke. It occurred when the blood flow to a part of brain was stopped by a blockage due to a narrowed artery or a

blood clot that has broken off from another place [7]. Another 15 percent comes from hemorrhagic stroke. This type of stroke take place when there is bleeding in the brain due to ruptured weakened blood vessel [8]. While symptoms of TIA are like ischemic stroke but do not last long. It happens suddenly and only last for a few minutes. It is also known as mini-stroke [9]. It happens when blood supplies to part of the brain are blocked or reduced briefly. The patient who has experienced mini-stroke must be aware as it can be a sign of risk having a stroke in the future [10]. Figure 1.2 shows the diagram of ischemic stroke and hemorrhagic stroke. While Figure 1.3 shows how transient ischemic attack occurs. A major or minor stroke will affect the patient mobility due to the motor function deficits. This limits their daily activities, participation in society and the likelihood of returning to their work. All these will also lead to a low quality of life.

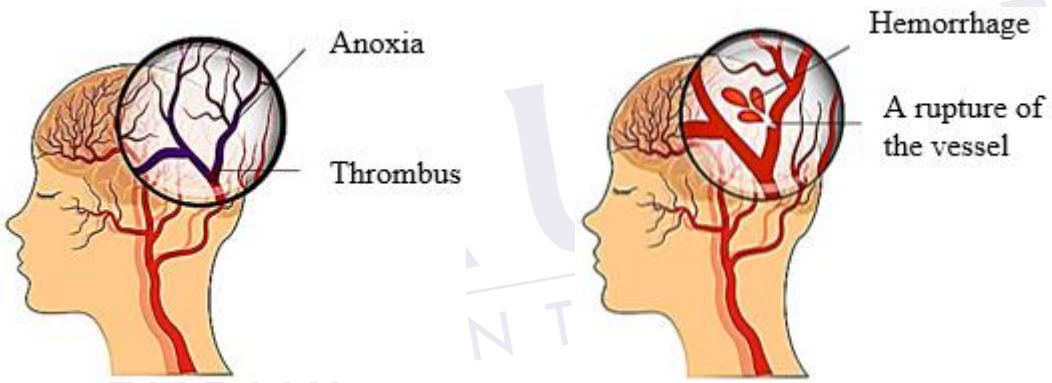

Figure 1.2: (a) Ischemic stroke and (b) Hemorrhagic stroke.

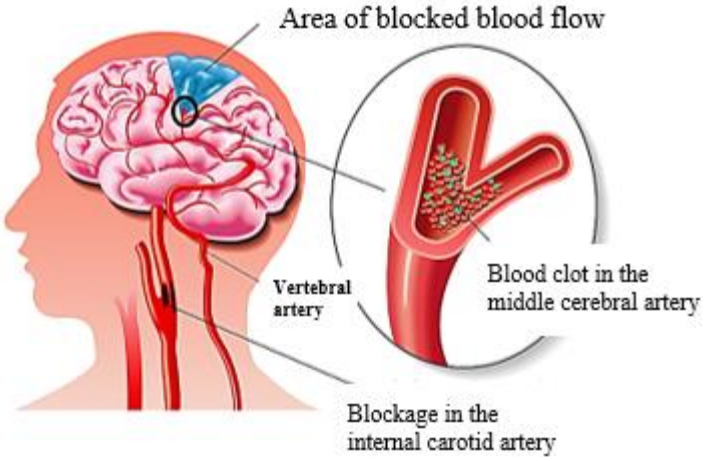

Figure 1.3: Transient ischemic attack.

1.3 Finger Rehabilitation

The stroke patients can enhance the relearn skill of brain by undergoing a rehabilitation program. Rehabilitation can be defined as an action to restore someone to health or normal life after an addiction or illness through training and therapy [11]. The motor impairment of the stroke patients can be reduced by undergoing a rehabilitation training. The physiotherapist will monitor the progress of the patients according to the rehabilitation cycle shown in Figure 1.4 for a certain period of time based on their condition. Rehabilitation does not cure the but help patient with best possible long term outcome.

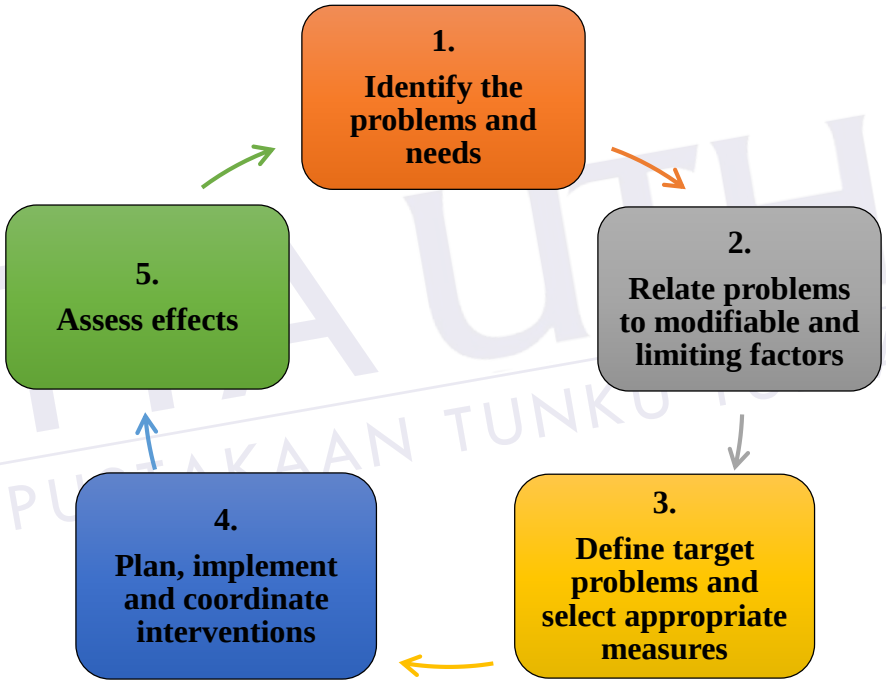

Figure 1.4: Modified version of the Rehabilitation Cycle. (Source: Physical Therapy, 2002)

The finger rehabilitation concentrate on how the motor skill operates at the finger. Motor skill is can be defined as a combination of series movements to produce a smooth and efficient action. The motor skill can be categorised into two types which are fine motor skill and gross motor skill [12]. Fine motor skill is focused more to dexterity in the movement of small muscle in contact with movement of eye to control the fingers, thumb and hand. The fine motor is suitable for drawing, writing and

coloring as children refine their motor skills during child age. On the other hand, gross motor skill is more on grasping the large object.

Rehabilitation should be done two days after the patient had been diagnosed. The patient will be given an intensive care for several weeks. Some of the patient will undergo further intensive care either at home or hospital. There are several types of rehabilitation that helps to enhance the motor disabilities of post-stroke patient. There are physical, occupational and home-based rehabilitation. Home-based rehabilitation provided the best care since it has more privacy and the patient has their ample time to perform the therapy. The long waiting time for a single session at the hospital will make the patients tired, thus they tend to choose home-based rehabilitation.

However, there are some disadvantages doing the therapy exercise at home such as lack of device and specialized equipment even though reduce the transportation travelling back and forth for daily therapy. The combination of rehabilitation and specialized equipment or device would help the stroke patient to improve their daily life plus the motor ability of hand and fingers. The stroke patient can develop the motor skill functions and the rehabilitation exercise will help more on brain relearn skill thus enhance the movement of disabilities part.

1.4 Robotic Rehabilitation

An injury to the finger can lead to a severe problem as it plays an important role in daily life. An appropriate and persistent rehabilitation is needed by the patients to regain their missing abilities and get back into their usual daily lives [13]. Eventhough there is a rehabilitation training but the number of physiotherapists is relatively short. Thus, a longer training session with physiotherapists is not always available for patients. This problem can be overcome with robotic rehabilitation system for hand fingers used by the patients.

Robotic rehabilitation is generally classified into two types of rehabilitator tools named as training and assessment tools. Each of rehabilitator tools has their own focused design. The training rehabilitator tools basically focusing on the motorized design and the assessment rehabilitator tools focused on non-motorized design. The rehabilitation methods in physiotherapy can be improved by assigning different approach of robotic rehabilitation assessment. The physical rehabilitation for hand due to brain injury can be assist by physiotherapist with the help of robotic rehabilitators.

Besides, the performance evaluation of the patients can be make more precisely and effectively. Hence, its presence helps physiotherapists to assess the stroke patients during their rehabilitation process [14]. In addition, the robotic rehabilitators also provide quick feedback on the progress of the patient and reduce the subjectivity of most conventional evaluation scales [15].

The developed robotic rehabilitators are controlled by certain type of controller for an easy control and give high performance. The aim of using a controller is to provide the device with good control and to perform various tasks. Various examples of conventional and numerical controllers can be used. Few examples are P Controller, PI Controller, PD Controller, PID Controller, Fuzzy Logic Controller, Genetic Algorithm Technique and etc. The details of the previous studies related to robotic rehabilitation and the controller used will be discussed in Chapter 2.

1.5 Problem Statement

There is various equipment provided in the hospitals for rehabilitation training but most of them are in spring-shaped. Thus, the force applied to each equipment cannot be changed according to the needs of the patients throughout the training. Having equipment that suit the patient's needs help the therapist to evaluate the progress continuously. In previous haptic device named One Degree of Freedom Haptic Device for Hand Therapy Exercise [5], it is designed in consideration of a compact, simple and low-cost rehabilitation device. However, it still needs improvement in term of the hardware implementation for better performance.

The existing motor torque device is not strong, so using a motor with gear can provide a high torque supply, but the problem is there needs to be a controller for the motor in order to ensure the desired force according to the patient’s needs is obtained. Different types of controller are available to be used. The issue is what type of control can be used to imitate the grasping movement?

The haptic device design must be improved to imitate the training of grasping movement for patient to exercise independently and reduce the workload of the physiotherapists. The haptic device is intended to be used for grasping rehabilitation movements perform with a single DOF. Hence, a suitable controller is required to have a good system response and better performance.

1.6 Objectives

The objectives of this project are as follows:

i) To develop a force control mechanism by improving the grasp handle design of one DOF haptic device with load cell and geared DC motor.

ii) To analyse the performance of One DOF Haptic Device with P, PI, PD and PID Controller.

iii) To proposed a suitable controller of one DOF haptic device for grasping rehabilitation.

1.7 Project Scope

Generally, every project has their own scope or limitation as a guideline. This project scope aspires from the problem arise from the previous design. There are some added feature to enhance its value. The scopes of this project are:

i. The project focus on the mechanical part of the haptic device and its controller.
ii. The new grasp handle is designed with 5kg attached load cell which used as force measurement input.
iii. The 12V Micro Metal Gear Motor-RPM20 motor is used to maximize the virtual reality tactile sensation felt by the patient.
iv. The proportional gain (Kp) is set from 1.0 to 2.0 scale to get the best tune.
v. The integral gain (Ki) is set from 0.01 to 0.10 scale to get the best tune.
vi. The derivative gain (Kd) is set from 0.1 to 1.0 scale to get the best tune.
vii. The P, PI, PD and PID Controller performance is compared base on the lowest value of Mean Square Error (MSE).

1.8 Outline of Thesis

The outline gives an overview of the main points of the thesis. It explains the structure of the thesis and helps in focusing the work to obtained the objectives. The thesis is divided into five chapters. The first chapter is for the introduction of the project, including finger impairment, stroke, finger rehabilitation, robotic rehabilitation and controller types. This chapter also describes the reality of the problem, objectives, scope and limitations of the project.

The second chapter discusses the literature research done while the project is carried out. Literature research is important as it provide ideas and direction regarding the projects to be developed. Overview of information related to finger rehabilitation robot and its controller is discussed. The main issues with proposed solution for this project is identified.

Meanwhile, chapter three outlines the method used to develop the project. All techniques and concepts related to the project are also described. There are five phases involved in this project, which are system design, projects supplies, software development, hardware development and performance analysis. Each phases have specific task to be accomplished in order to ensure the project functions properly.

In chapter four, it discusses the result and analysis on haptic device. The result focuses on the controller part of the haptic device. Each controller which are P, PI, PD and PID will be discussed in detail to find the best proposed controller for the haptic device.

The final chapter summarizes the project as a whole and few recommendations suggested for improvements in the future. This chapter can be consulted by other individuals interested in pursuing this project in the long term.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter starts with the details about physical rehabilitation therapy in Sub-chapter 2.2, followed by example of exercise for finger rehabilitation in Sub-chapter 2.3. Next, robotic in rehabilitation systems in Sub-chapter 2.4, which explain the types of hand rehabilitation devices that has been developed and their features. This is then continued by the discussion on the robot for hand manipulation in Sub-chapter 2.5. The types of the conventional controller used were presented in Sub-chapter 2.6. In the last sub-chapter described the characteristics of proportional, integral and derivative gain.

2.2 Physical Rehabilitation Therapy

Medical professional that involved in post-stroke rehabilitation are physical, occupational and physiotherapist. There are three types of physical rehabilitation which are physical therapy, occupational therapy and home based therapy [16].

2.2.1 Physical therapy

Physical therapy normally concentrates on the treatment of motor functional disabilities and sensory impairments of patients with a stroke. The physical therapist will assess the patient disabilities, find a way to reduce the impact of remaining deficits and set up few continuous exercise to help patients develop their newly learned skills. The continuous and repetitive program helps to reduce the impaired limbs' disabilities,

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