GRASPING MOTION CONTROL OF A ROBOTIC HAND MECHANISM

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DECLARATION

I declare that this thesis entitled "GRASPING MOTION CONTROL OF A ROBOTIC HAND MECHANISM" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name :

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APPROVAL

I hereby declare that I have checked this report entitled "Grasping Motion Control of a Robotic Hand Mechanism" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature :

Supervisor Name :

Date :

DEDICATIONS

To my beloved mother and father

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ABSTRACT

Robotic hand is a type of mechanical hand with similar function to human hands which utilizing an actuator to obtain the force for providing motion, action and position. The robotic hand is needed due to the working environment, the task or dangerous application which the executor in the edge of death. In additionally the robot are faster more precise and their speed is steady as well. This paper presents a survey on the previous and current research on controlling the motion for grasping manipulation by robotic hand. There are difficult task to design the controller for grasping motion control in order to obtain high precision control in term of its performance. Furthermore without the controller, the robotic hand will not be able to grasping with desired performance. Therefore, the objective of the project is to design the controller for grasping motion control of robotic hand and compare the controller performance between simulation and experiment method. The experiment will be conducted by using Micro-Box 2000/2000C that will act as interface between MATLAB Simulink and Robotic Hand. The open loop test with load will be the initial test in order to provide the suitable plant for the finger of the robotic hand with System Identification Tools which the transfer function will be determined. Then uncompensated closed loop system was developed using a plant transfer function to provide a feedback to the input for improving the system performance. After that a Proportional-Integral-Derivative (PID) controller was designed based on the uncompensated closed loop system designed to further improve the overall system performance of the robotic hand. Lastly, the comparison between the performance of real time simulation and real time experiments from the Micro-Box was done. The result shows that the performance of the grasping motion control depend on the tuning controller.

ABSTRAK

Robot tangan merupakan sejenis tangan mekanikal dengan fungsi yang hampir sama dengan tangan manusia dan menggunakan penggerak untuk mendapatkan daya bagi memberikan gerakan, tindakan dan kedudukan. Robot tangan diperlukan kerana persekitaran kerja, tugas atau aplikasi berbahaya dimana pelaksana di jurang kematian. Tambahan, robot lebih cepat, tepat dan kelajuannya stabil. Kertas ini membentangkan kajian lepas dan semasa untuk mengawal gerakan genggaman oleh tangan robot. Terdapat kesukaran untuk mereka bentuk pengawal dalam mengawal gerakan genggaman bagi mendapatkan kawalan ketepatan yang tinggi dari segi prestasinya. Selain itu tanpa pengawal, tangan robot tidak akan dapat menggenggam dengan prestasi yang diingini. Oleh itu, matlamat projek ini adalah untuk merekabentuk pengawal untuk mengawal kawalan gerakan tangan robot dan membandingkan prestasi pengawal melalui kaedah simulasi dan eksperimen. Eksperimen ini akan dijalankan dengan menggunakan Micro-Box 2000/2000C bertindak sebagai perantara diantara MATLAB Simulink dan robot tangan. Ujian gelung terbuka dengan beban dimulakan untuk menyediakan plant yang sesuai untuk jari robot tangan dengan sistem alat pengenalpastian dimana fungsi pemindahan akan ditentukan. Kemudian sistem gelung tertutup tanpa kompensasi telah dibangunkan menggunakan fungsi pemindahan plant untuk memberi maklum balas kepada input bagi meningkatkan prestasi sistem. Selepas itu, pengawal-turunan-terbitan (PID) direka berdasarkan sistem gelung tertutup yang tidak dikompres yang direka untuk meningkatkan lagi prestasi sistem robot tangan. Akhir sekali, perbandingan antara prestasi simulasi masa nyata dan eksperimen masa sebenar dari Micro-Box telah dilakukan. Akhirnya, prestasi kawalan gerakan pada genggaman bergantung kepada pengawal penalaan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

V	:	Voltage
°	:	Degree
θ	:	Angle
T	:	Torque
DOF	:	Degree of Freedom
SISO	:	Single-Input-Single-Output
PID	:	Proportional-Integral-Derivative
DC	:	Direct Current
FLC	:	Fuzzy Logic Controller
GUI	:	Graphical User Interface
ANN	:	Artificial Neutral Network Controller
3D	:	Three Dimensional
LHP	:	Left Hand Pole
RHP	:	Right Hand Pole

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Human hands playing a key role in implementing many important tasks in public life and also for special purposes. There are many applications that can only be done by human hands such as surgical operation because of their opportunity and capacity to grasping and twist fingers at various edge. However, in dangerous application, the life of executor is always at the edge of death. There are situation like bomb detection/diffusion, cutting industry with high speed cutting machines possess danger for the operator and many others where now human beings perform task and victims sometimes occurred. To save these life, robotic hand needed, which can operate same way as human hands.

The robotic hand is a type of mechanical hand that had a comparative capacities as a human hands which utilizing an actuator to obtain the force for provide motion, action and position. Today the robotic design mostly uses an automatic control system to control and monitor the operation of the robots. The using of automatic control system on the robotic hand will reduce the human outstanding burden due to their repeatability, high accuracy and ready to operate continuously without human control. Furthermore, in some cases the robotic hands are a necessary due to the workplace environment or task such as cutting industry, the human operator is in danger as the high speed cutting machine possess danger to the operator.

Generally, simplest design of robotic hands having two degree of freedom (2-DOF) and the most complex robotic hands can be more than 30-DOF when high accuracy and precision of position are needed. As all know, humans being among one of the special specie which created by God that have been gifted this kind of dexterous hands that can doing so many task in their routine and also many applications that only human hands can perform much more efficiently compared to a machine shaft because of their degrees of freedom and ability to bend fingers at different angle. Therefore to design the perfect robotic hand, the shape and it size should similar to actual human hand with five finger and three degree of freedom (3-DOF) for each finger except the thumb that only have two degree of freedom (2-DOF). So that the finger of robotic hand had the ability and motion to function as human hands. Then the angle and position of the finger will be change by increasing or decreasing the voltage to the actuator.

The single-input-single-output (SISO) system have been used in this project as a control system to control three degree of freedom (3-DOF) robotic hands. A Proportional-Integral-Derivative (PID) controller will be used to stabilize the system and then the system will be improve by tuned the PID controller to a better system such as intelligent PID. All the system performance on the finger of robotic hands are analyzed and compare the system performance of the robotic hands.

1.2 Motivation

In recent year, the number of robots and robotic hands is being observed to be increasing gradually throughout the industry. Robots are replacing erroneous human operators in the modern procedures at a fast speed as more computerization is being connected in the industry. The robots working in industry not make an error that can be anticipated from humans, they are faster more precise and their speed is steady as well. In some cases, the robots are needed, due to the workplace, the tasks or in dangerous applications, the life of the executor is dependably on the edge of death. (For case within the cutting industry, a human operator is in peril as the high speed cutters have risk for the operator, or in the high temperature environment, similar to the elastic plants, humans are presented to consume wounds).

So, the obvious solution in order to reducing the occurrence accidents to operators is to replacing the human works by using robot hand which have skills and can operate like actual human hands. High accuracy with dexterous robotic hand can work and function better than human hand. Moreover, the use of the actuator that had spring or wire connected to the robotic finger which are function as tendon allow the robotic finger to have the motion like human hand with lesser actuator. Furthermore, the under actuated robotic hand able to grasp and adapt to the shape of object which make it an advantage in grasping motion control of the robotic hand.

1.3 Problem Statement

Robotic hand exceptionally helpful in risky work situation or fine work that can be utilized by robot hands as opposed to utilizing human hands. Therefore, robotic hand monitor turned out to be a piece of the major issues he did not advance to structure a controller that would make detailed motion plans for grips and manipulations provided task and furthermore mirror development as human hands. The control of robotic hands is not a big problem but to improve the precise of the robots finger gestures, a good controller becomes necessary to demonstrate high accuracy and fast response.

However, the difficulty in developing a controller for the robot hands appears due to non-linear characteristics of the system. Therefore, to provide and maintain a robotic finger with high precision and good motion in grasping by minimize the effect of non-linear characteristics to the minimum, a good controller is needed in the system.

Other than that, the robot hand with 3-DOF of each finger makes the control system for the robotic hands to be more complicated as the controller will be used for each joint. Therefore, to reduce complexity of a robot hands at the same time to perform the performance as well, the actuators are embedded outside the hand and by using wire to connect it with robot finger. So that, the robotic hand with require a controller can adapt to the object shape for grasping motion. A suitable controller design for robotic hands is importance in order to obtain high adaptability and accuracy control in term of its performance.

Since designing a controller to achieve high accuracy of robotic hand is an extremely difficult task, the robotic hands which the robotic finger is actuated by a wire will be used in order to reduce the complexity of multi-device robotic controller. Then, the Proportional-Integral-Derivative (PID) controller will be used to control the movements of the actuator due to simplicity and good performance of controller. Then, the robotic hand can be designed and tested it performance with difference type of controller such as Artificial Neutral Network Controller (ANN) and Fuzzy Logic controller (FLC) for obtaining the most suitable controller in order to developing the grasping motion control of a robotic hand mechanism.

1.4 Objective

The aim of this project is to design a controller for grasping motion control of a robotic hand mechanism. Therefore, the good controller must be good enough in providing the best output position for robotic fingers and can minimize the effect of the input fault on the position control system. Then the designed controller will be added to the current robotic hand of 3-DOF MATLAB and Simulink model to analyze system performance.

The objective of the project are:

i. To perform the performance of the robotic hand by open-loop control system.
ii. To design the controller for grasping motion control of robotic hand mechanism.
iii. To analyze and compare the controller performance of robotic hand by simulation and experimental method.

1.5 Scope of Project

In this research, the scope are:

i. The controller of the robotic hand is develop using MATLAB-Simulink.
ii. The robotic hand will be design for grasping motion.
iii. The position control of the finger for the robotic hand is control by giving the direct input signal to the controller of robotic hand.
iv. The position for the finger of the robotic hand is actuated by wire mechanism.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Robotic Hand

Human hands play an important role in the implementation of many important tasks in public life as well as for specific purposes. There are many applications that can only be done by human hands with more efficiently than machine shafts due to the degree of freedom and their ability to bend the fingers at different angles. However, the executor life always on the edge of death when doing a dangerous application such as bomb detection, high temperature environment like rubber factory and so on where injury occurs occasionally. To prevent accidents from continuing to human beings, there is an urgent need of robot hand that can operate in the same way as human hands [1] [2]. The focus on the research project will be on grasping motion control of robotic hand mechanism. The grasping motion of the robotic hand will be same as human hands because it have shape and size similar to the actual human hand but the way in this project it will only grasp by using three fingers due to the actuator that only have three where each actuator will control one finger of robotic hand.

2.2 History of Robotic Hand

The exploration on robot hands is being conducted for a long time ago. Looking back to the history of robotic hands, Heinrich Ernst became the first to be developed in the year of 1961, MH-1 a computer control mechanical hand at MIT. The design gripper of robotic hand start from two fingers to pick and hold some blocks using an electric motor as an actuator and touch sensor for object identification. Then the development of technology from day to day make robotic hand with multiple function and multiple finger according to user suitability [2] [3].

2.3 The Design of Robotic Hand

The robotic hand is a mechanical hand which has similar function as human hand [1], [2]. The physical design of robot hand is comparable to actual human hand, therefore it is an anthropomorphic hand. The design consider the hand of the robot with four fingers which is the index finger, middle finger, ring finger and pink finger with three joint on each finger and another one finger is thumb with two effective joints and wrists, manipulating rigid objects. Each joint represents one degree of freedom (DOF), so each finger has three DOF and thumbs have two DOF. The combination off all joints allows the robotic hand to move and grip like the human hands. [3]. Figure 2.1 presents the kinematic model of the specified hand.

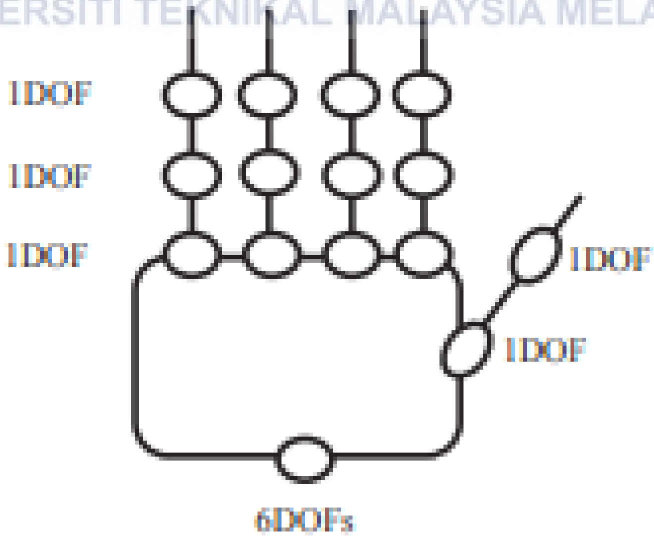

Figure 2.1: Kinematic model of the specified hand [3]

Mostly application of specific robots are using grippers and they do not copy complete characteristic of actual human hand. The finger of robotic hand count to grippers ranges from two to five fingers. A lot of research had been done on grippers [3], [4], [5], [6], [7], [8], [9] and many of companies start producing method of grippers for robotic hands. In years 1980s, the concentrated research work for gripper was done and it was established early in the decade of 1990. There are several type of research which had been done on robotic hand and was developed such as MIT/UTAH hand, iHY Hand, NASA's Robonaut Hand, anthropomorphic NTU hand, SARAH Hand, Compact fluidic hand, Stanford/JPL hand [2], [10].

The iRobot-Harvard-Yale (iHY) Hand is a robotic hand which shows a good performance in term of grasping ability. The iHY Hand as shown in Figure 2.2 is a three finger hand with six degree of freedom (6-DOF) and was actuated by five actuated. Each finger of iHY Hand is able to rotate and connected to the spring that returns the finger to fully open configuration when unactuated. However, to manipulate and stabilize the grasping object, it enable the dexterous in manipulation without any feedback of control system [11], [12].

Figure 2.2: The iRobot-Harvard-Yale (iHY) Hand

Other than that, various type of robotic hands was been design nowadays. Robotic hand also can be design and print out by using 3D Printer. The Baxter Easyhand is underactuated had which was produced by using 3D Printer. Since it was made from 3D Printer, the Baxter Easyhand is light weight, small size and the price to make it is certainly cheap. The advantage of the design is it can grasp any object large than 4 cm with two finger parallel jaw gripper and also shows the flexibility and robust performances. However, the Baxter Easyhand with two finger is driven by single motor without any feedback in the system [13]. Figure 2.3 shows the prototype of the Baxter Easyhand.

Figure 2.3: The prototype of The Baxter Easyhand

For the motion of finger segment, the actuator is required that allows the robots hand to perform the desired motion while spring is also required for extension motion. Spring force needed in finger of robot to make sure that the finger segment return to the default position. Spring force can be considered as a constant force [2]. The ultimate goal of human size robot hand with enough functionality, a stronger and heavier actuator are needed to develop them. Then the important thing need to be emphasized is to make detailed motion plans for a given grasp and manipulation tasks [14].

The concept of wire-driven robotics is where only the actuator needed for every robots finger. All the joint of the finger are tendons with wire-drive. With this connection of wire-drive from actuator to an active DOF, which can controls the motion across three joints [15].

2.4 Motion Control of Robotic Hand

The main function of the robotic hand is to function like a human hand which is can bent the finger up and down and gripper the object. Specifically, each finger of robotic hand can be bend up until the maximum angle which is 90˚ from the rest position. DC geared motor is used in the robotic hand to generated force for pulling the robotic finger by using wire mechanism. Since there is only three DC geared motor is used in the robotic hand, so only three finger will have the motion which are index, pinky and thumb finger.

Introducing this type of robotic hand is also called as underactuated hands. This is an alternative method to approaching manipulation of the robot with less actuators compare to degree of freedom (DOF) [11], [16]. Moreover, each joint of the finger of robotic hand is connected by using wire mechanism. The iHY Hand is one of the robotic hand where it using the wire/string that function as a tendon to pull and caused the robotic finger to bend [12]. The iHY Hand finger design was shown in Figure 2.4.

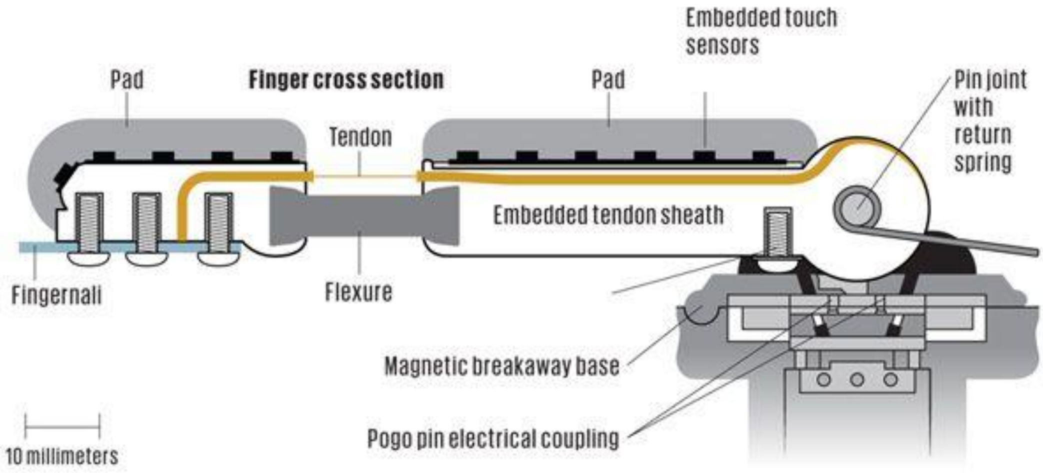

Figure 2.4: iHY Hand Finger Design

The motion occurred on the robotic finger due to the attraction from the DC geared motor where the coupling will pull the robotic finger using the wire. The DC geared motor will generate the force from the rotation and pull the wire to make the robotic finger to bend. The motion of robotic finger bent will reach at the limit angle if the DC geared motor produces a large number of turns. The rotation of DC geared motor will be controlled by controlling the input voltage to the motor. Once the robotic finger reaches the desire position, it will remain in position until the next position is given. Although there are several type of methods that can be used to control the position of the robotic finger but the robotic hand with wire mechanism is suitable for grasping motion control and adaptability to the shape for the grasping object [12].

2.5 Robotic Hand Control Technique

The research for controlling method of robotic hand mechanism has gained a great attraction over the past half-decade, this is because the robotic hand can be function like human hand is and can replace the human work especially in dangerous environment. There are numerous type of control technique are applied by the previous researchers to control the grasping motion of the robotic hand. The controller is needed in the robotic hand to provide a high accuracy and precision besides to maintain the smooth motion grasping motion control system of the robotic hand.

There are several type of controller that can be used to control the robotic hand such as Proportional-Integral-Derivative (PID) controller, Fuzzy logic controller or intelligent PID controller. Other than that, there is also a new control technique still under research due to high precision of the system which is Nominal Characteristic Trajectory Following (NCTF) controller [17]. A PID controller is mostly used by previous research due to simple design and straightforward manner [18]. However, once the PID controller had been designed, another controller such as fuzzy logic, intelligent PID controller also can be design in the robotic hand in order to obtain the good performance in term of low steady state error, fast response and high precision.

2.5.1 Propotional-Integral-Derivative (PID) Controller

An alternative technique to control the grasping motion of robotic hand is by applying the traditional controller which is PID controller. PID stands for Proportional-Integral-Derivative. The PID controller is easy to implement [18] compare to other non-traditional controller such as fuzzy logic controller and intelligent controller which is more complicated [19], [20]. Furthermore the advantage of using PID controller is the principle to conduct the experiment was easily to understand. Then the PID controller is used to reduce the ripple in the system and suitable for system with linear system [18]. Other than that, the

PID controller will be able to use for removing overshoot in the system and increase the speed of the motor [21].

The PID controllers tuning technique consist of consist of three basic coefficients which is proportional, integral and derivative which are varied to obtain the optimal response of the grasping motion. The optimal response in the system including the time rise, settling time, overshoot of the system and also steady state error that occurred in the system [22], [23]. So, to improving the control system by using PID controller to the good performance, the PID need to be adjusted by change the parameter of P, I, and D of the controller [22].

The PID controller tuning method is a trial and error tuning which need to change the gain parameter between P, I, and D until the gain achieve the desired output for motor position. While conduct the PID tuning method, the Proportional (P) controller will be tuned first, then followed by the Integral (I) and the last is Derivative (D) until the desired output obtained. During the tuning process, the effect from Proportional (P) controller is the system increasing the overshoot of the system and at the same time decrease the rise time. It provide stable operation in the system but always maintains the steady state error. The effect from tuning the Integral (I) is it will reduce the percentage of overshoot and eliminate the steady state error in the system. On the other hand, the Derivative (D) adjustment will decrease the overshoot and settling time. Table 2.1 shows the effect of PID controller parameter to the system performance.

Table 2.1: The Effect of PID Controller Parameter to the System Performance.

Response	Rise Time	Overshoot	Settling Time	Steady State Error
Proportional Gain, Kp	Decrease	Increase	No Change	Decrease
Integral Gain, Ki	Decrease	Increase	Increase	Eliminate
Derivative Gain, Kd	No Change	Decrease	Decrease	No Change

Since the effect of the noise and disturbances in the system can be reduced to the minimum so that a higher precision on the grasping motion can be achieve. The PID controller is a good controller which will reduced the error that occurred in the system in order to provide a good performance with high accuracy and precision on the grasping motion control of robotic hand [24]. However, without tuning the PID controller, the system will not give the desire performance and sometimes will leads to instability and slow control performance. The different type of tuning method are developed in order to obtain the best value of proportional, integral and derivative gains. The most fundamental tuning method for PID controller was Ziegler-Nichols Tuning Method and Trial and Error tuning Method.

2.5.1.1 Ziegler-Nichols Tuning Method

The Ziegler-Nichols Tuning Method was the famous method for tuning the PID controller. It proposed closed loop method tuning method for tune the PID controller which will improve the performance of the system [25]. Based on the Ziegler-Nichols rule, the Proportional (P) gain will be the initial to adjust while the Integral (I) gain and Derivative (D) gain will set to the zero. The proportional (P) gain will be set from zero and increasing the value until the system oscillate at constant amplitude. Then the tuning method will be continue with adjusted the Integral (I) and Derivative (D) gain while the Proportional gain was used the desire value. The Proportional (P) gain, time Integral (Ti) and time Derivative (Td) will be determined based on the system response of a given plant [25].

2.5.1.2 Trial and Error Tuning Method

The trial and error tuning method is the method that only relevant to closed loop control system. The adjusted value for Proportional (P) gain, integral (I) gain and Derivative (D) gain only trial with any value until the system achieve the desired performance. Since the tuning just trial and error the value of Proportional (P) gain, Integral (I) gain and Derivative (D) gain until the better performance will be achieved, it take a long time to finishing the tuning and obtain the PID parameter because the parameter in tune one after another. However, the trial and error tuning method also can achieve a good performance if the tuning of PID parameter is correctly.

2.5.2 Artificial Intelligent Controller

Recently, the intelligent control technique such as Fuzzy logic controller, Neural Network controller and Genetic Algorithms controller have been used to solve the problem occurred on the robotic hand due to PID controller cannot provide satisfactory position in the highly nonlinear system. The effect that occurred from nonlinear characteristic such as friction between degree of freedom of robotic finger and saturation of the motor cannot be eliminated while using the PID controller. The previous research shows that by using artificial intelligent on the robotic hand, it was providing more effective compare to PID controller in term of high accuracy and precision to the grasping motion of robotic hand.

A fuzzy logic controller is a control system based on fuzzy logic. The fuzzy logic controller is a logical system that really closer to human thinking and natural language than traditional system. The fuzzy logic controller are operate under non-linear characteristic [19] which will effected the imprecision of the system [26], [27], [28]. Figure 2.5 shows the block diagram of fuzzy logic controller.

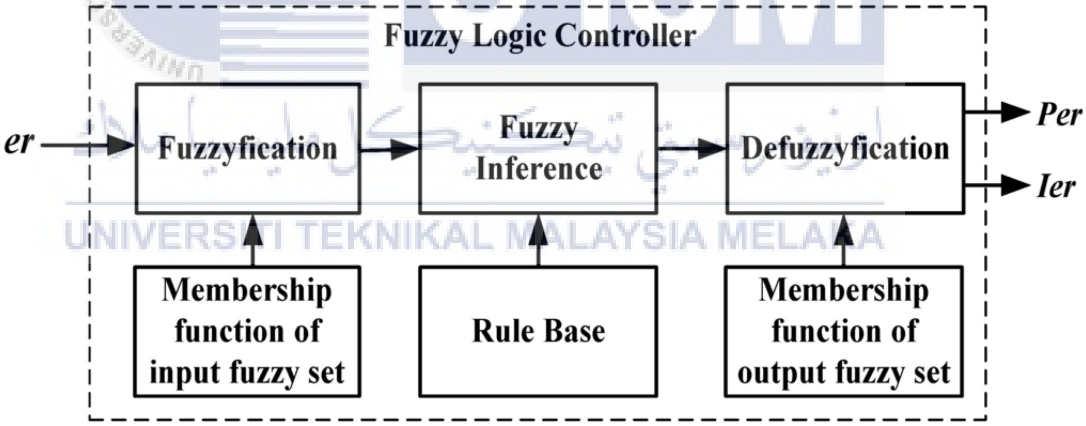

Figure 2.5: The Block Diagram of Fuzzy Logic Controller

The artificial intelligent controller such as Fuzzy Logic Controller (FLC) have more advantage compare with traditional controller. The artificial controllers are more powerful than PID controller because it can operate under non-linear characteristic. Furthermore, artificial intelligent controller can learn and produce the output based on the knowledge base.

However, the design of the artificial intelligent controller is more complicated compare to PID controller.

2.6 Micro-Box

Micro-Box 2000/2000C is act as a microcontroller with high performance, less fan and low power consumption which is attached to the computer. The computer can work with MathWorks tools such as MATLAB and Simulink which make it a top choice for PID controller to work with [28], [29]. The others name of Micro-Box is XPC target machine [30]. Micro-Box can be used to conduct the prototyping, testing experiment and develop the real time analysis of the control system. Micro-Box is chosen to be a microcontroller for a robotic hand because it consume low power consumption and provide high performance for robotic hands processing. Furthermore, Micro-Box can supports all standard computer peripherals such as video, mouse and keyboard. Other than that, it was interfaces with analog to digital and digital to analog converter. The Micro-Box interface with MATLAB Simulink Software and the robotic hand hardware that will be communicate by using LAN cable. The Micro-Box 2000/2000C controller was shown in the Figure 2.6.

Figure 2.6: The Micro-Box 2000/2000C Controller

2.7 Summary

The robotic hand model was used a SISO system which is single input and single output where the motion of the robotic hand will be controlled by input given. The PID controller was chosen for the robotic hand due to it suitable for the model with linear system and able to reducing the error occurred in the system in shortest time while the design is so simplicity will be the reason for used it. Other than that, the most importance part is where the Micro-Box 2000/2000C will be used to interface between computer MATLAB Simulink and robotic hand where it allow the robotic hand to describe real time analysis, real time modelling and real time control system simulation. Furthermore, the artificial intelligent controller such as fuzzy logic will be conduct latter due to it provide a good performance compare to PID controller. Finally, the PID controller and artificial intelligent will be compare in term of it performance and the best controller will be chose to the robotic hand.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this section, the detail designing of a grasping motion control of robotic hand mechanism by using the Proportional-Integral-Derivative (PID) controller for three degree of freedom (3-DOF) robotic finger are included. The robotic hand with size and shape similar to actual human which had 5 finger with three joints for each finger except the thumb which had two joint only.

In the current research project, the Micro-Box 2000/2000C will be used which act as a microcontroller to control the grasping motion of the robotic hand. Micro-Box module acts as the interface between robotic hand and MATLAB-Simulink in order to fully operation and functioning in the system. Since most of the robotic hand are using the controller such as Arduino Mega 2650, Motion Controller and PIC microcontroller while Micro-Box is still new and has not been used by other researchers in the robotic hand, current research projects will be developed to test the proposed control method by using Micro-Box allowing experiment to be done and analyzed in term of "real-time". Real-time analysis and control system of robotic hand can be performed since the Micro-Box is controls the robotic hand in real-time without any delay. This will reduce the development time of robotic hand.

In addition, mostly actuator which is often used by previous research to produce their motion in robotic hand is DC brushless and micro motor. Due to this reason, another DC motor with gear will be proposed and used in this current research due to excellent performance in term of accuracy and precision and low voltage consumption where it can easily to control for desire position of the finger of robotic hand. Furthermore, no previous research project was conducted using DC geared motor, the current research project would be carried out using DC geared motor in order to analyze the performance of the DC geared motor on robotic hand.

The PID controller was developed to control input voltage of the motor based on the reference angle so that any changes in the motor for rotation angles, the reaction and error occur will have a minimum effect on the grasping motion control system. The designed PID controller will then be added to the finger of the robotic hand model. Then, the system performance on time response with respect to input voltage, angle of rotation and error occurred was analyzed. However, the PID controller parameters will be tuned to develop the better performance in the system by using two methods which were Ziegler-Nichols Tuning Method and Trial and Error Tuning Method. The Ziegler-Nichols Tuning Method will be used to obtain the Proportional gain while the Trial and Error Tuning Method will use for obtaining the Integral gain and Derivative gain.

The PID controller was designed using MATLAB Simulink Block diagram. A Simulink is a graphical user interface (GUI) used to design the grasping motion control model by using the block. A PID algorithm was used to develop the controller to control the output of the system to the desired output. The PID used in the Simulink block diagram was the conventional PID due to its simplicity in controller design. Then, the controller was then implemented on the robotic hand to improve the system performance. Finally, the system performance for the open loop system, uncompensated closed loop system and PID controller closed loop system were used for analysis and compared.

3.2 Project Development

The overall project design for this research could he summarized as shown in the Figure 3.1. The modeling of robotic finger with three degree of freedom (3-DOF) of the robotic hand was understood before the open loop test without load and open loop test with load were developed to determine the characteristic of the robotic finger by using the MATLAB Simulink software. Since the use of the Micro-Box as the controller is fresh for robotic hand development, the operation and function of the Micro-Box 2000/2000C was studied and understood so that the next experiment can be proceed. The open loop test with load was developed to obtain the suitable plant for the finger of the robotic hand with System Identification Tools. The System Identification was developed to obtain the transfer function for three DC geared motor. In this section, the real time simulation and real time modeling are done with a Micro-Box interface. However, the verification of the robotic hand modeling need to be verified based on the data measured. The uncompensated closed loop system was developed using a plant transfer function to provide a feedback to the input for improving the system performance of the robotic hand. Then, a Proportional-Integral-Derivative (PID) controller was designed based on the uncompensated closed loop system designed to further improve the overall system performance of the robotic hand. Then, the performance of the robotic hand was analyzed. Lastly, the comparison between the performance of real time simulation and real time experiments from the Micro-Box was done.

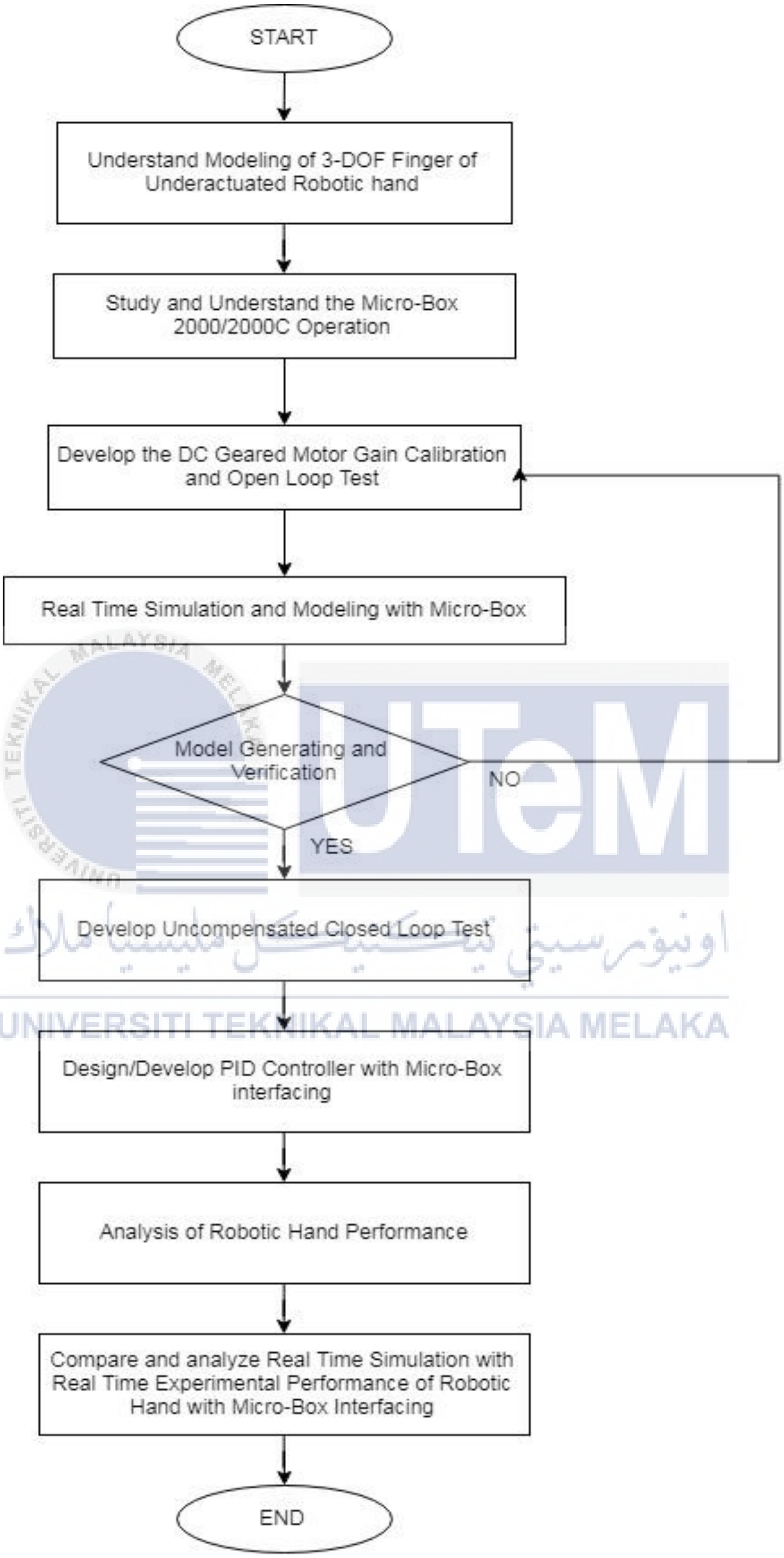

Figure 3.1: Flowchart for Grasping Motion Control of a Robotic Hand Mechanism

3.3 System Overview of Robotic Hand System

The Micro-Box connected to the computer that had been install MATLAB Simulink software on it. Then, the power supply was supply 15V to the Micro-Box. The Micro-Box will received the commands from the block diagram that was drawn in the Simulink and then Micro-Box will control the rotation and speed of the motor and convert the encoder count into angle value. Then the motor rotation will directly controlling the position of the finger of the robotic hand. The system overview of the robotic hand by using Micro-Box was shown in Figure 3.2.

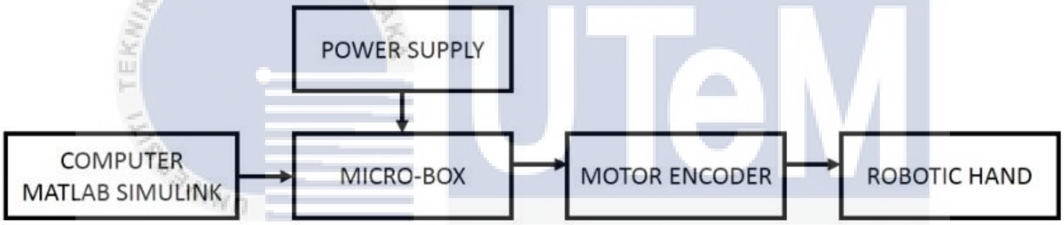

Figure 3.2: The System Overview of Robotic Hand by Using Micro-Box

3.4 Micro-Box Connection and Wiring Layout

The DC geared motor of robotic hand and the Micro-Box can interact by connecting it using two major importance wiring which is the power cable and the encoder cable. The integration between the DC geared motor and the Micro-Box was shown in the Figure 3.3.

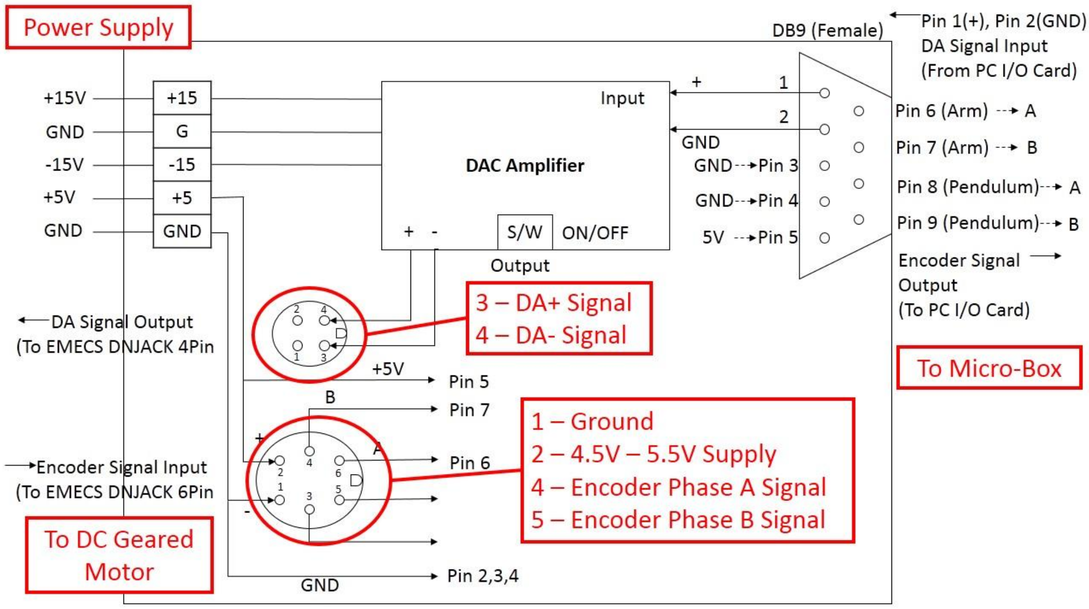

Figure 3.3: The driver Board Connection

3.5 Robotic Hand Experiment Setup

The DC geared motor (SPG 30-60K) of robotic hand at the base is connected to the Micro-Box 2000/2000C by TC/PIP crossover connection by using the LAN cable and will string. This connection will make the robotic hand able to interface with Micro-Box and MATLAB Simulink. Nylon covered stranded stainless steel wire will pull and bend the finger of robotic hand according to the angle of rotation of DC geared motor. The thickness of the string is 0.65mm and manage to support the load up to 50 lbs or 22.7kg. Figure 3.4 shows the top view of the robotic hand while Figure 3.5 shows the side view of robotic hand that assembled with actuator and cable connection.

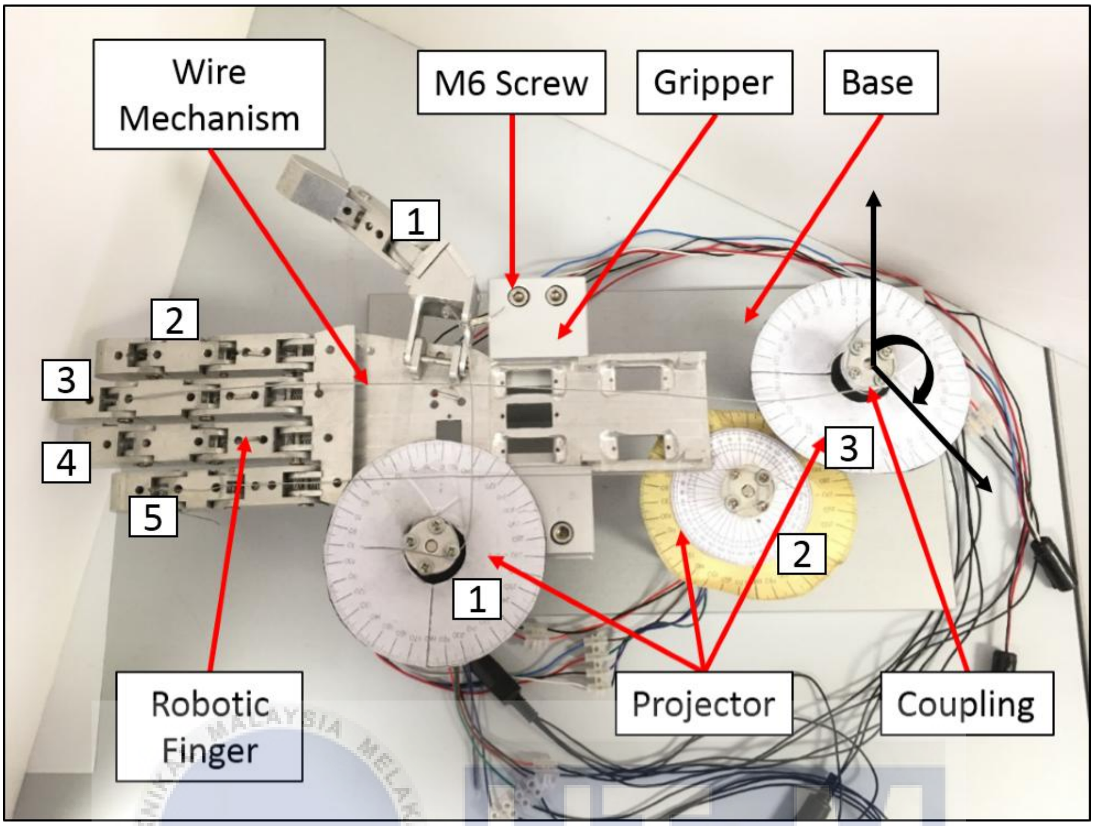

Figure 3.4: Top view of Robotic Hand

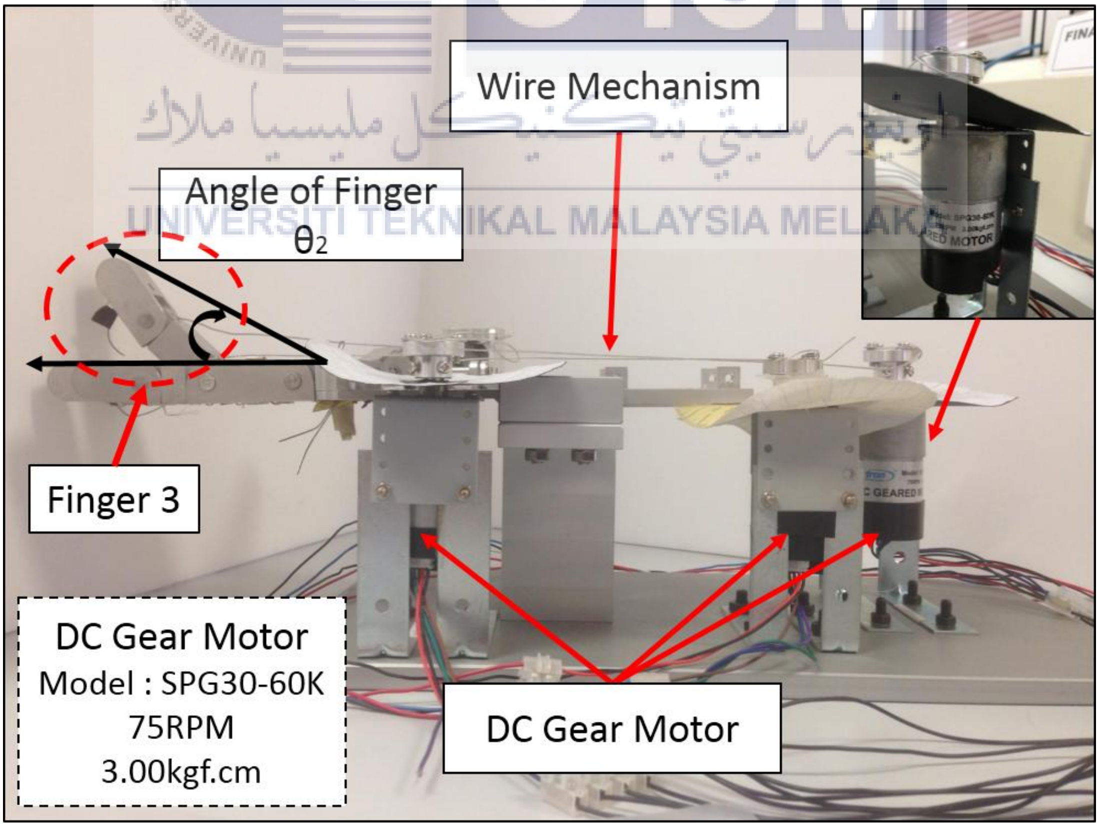

Figure 3.5: Side view of Robotic Hand

In this project, there are three finger of robotic hand will be evaluated for grasping motion control which is finger 1, 2 and finger 3. The angle of each finger will be measure by using protractor that are place at the encoder of DC geared motor and then the angle data will be collected for analysis. The Figure 3.6 below shows the angle of rotation of DC geared motor of robotic hand measured by protractor.

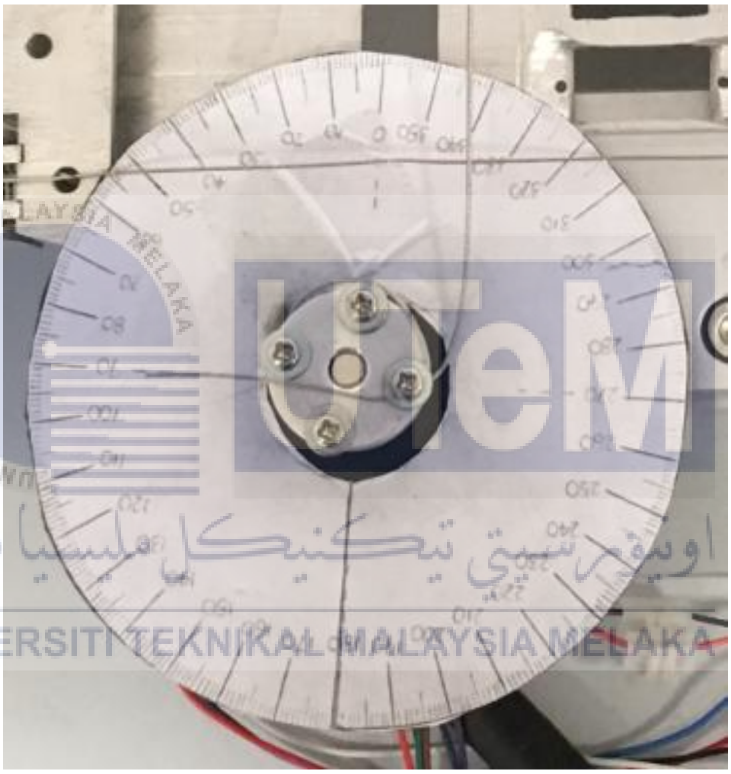

Figure 3.6: Angle of Rotation of DC Geared Motor 3 with Protractor 3

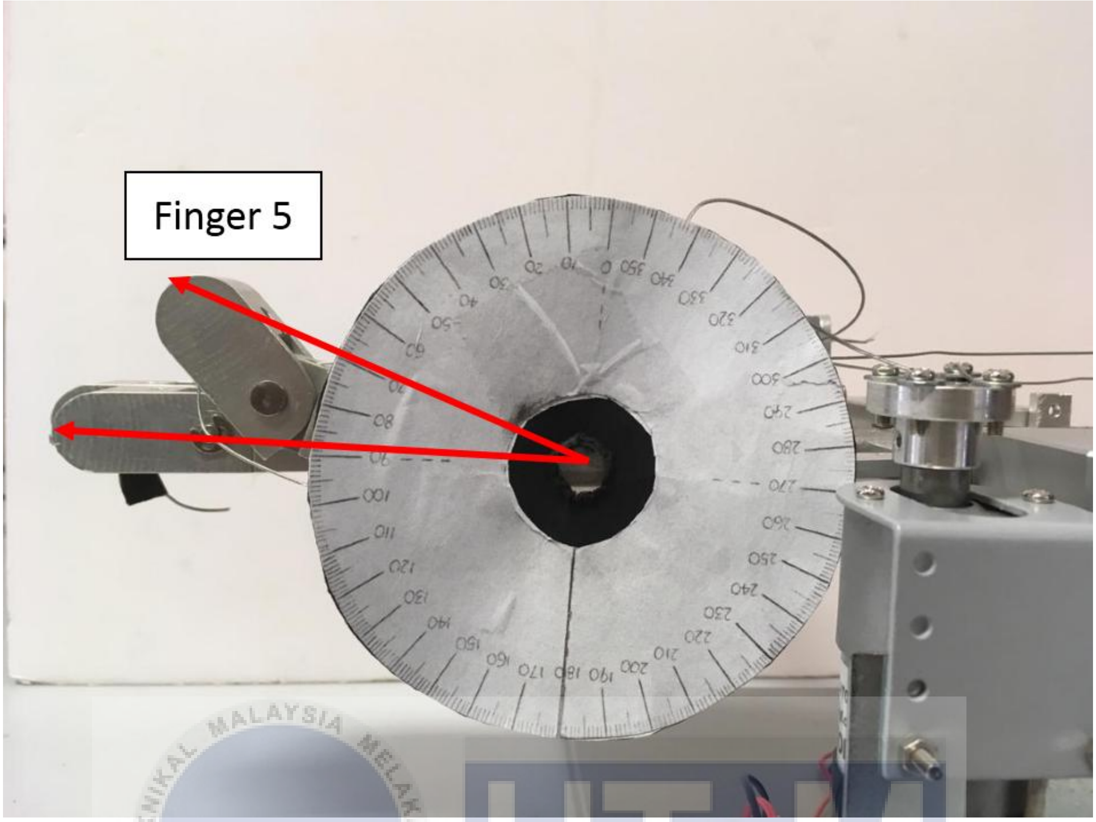

Figure 3.7: Angle Between Finger 5 and Palm of Robotic hand with Protractor

Since the wire mechanism will be used to pull and bent the finger, the coupling will use to pull the wire around its body according to the angle of rotation of DC geared motor. Figure 3.7 shows the wire is connect to the body of coupling that will pull up the finger of robotic hand.

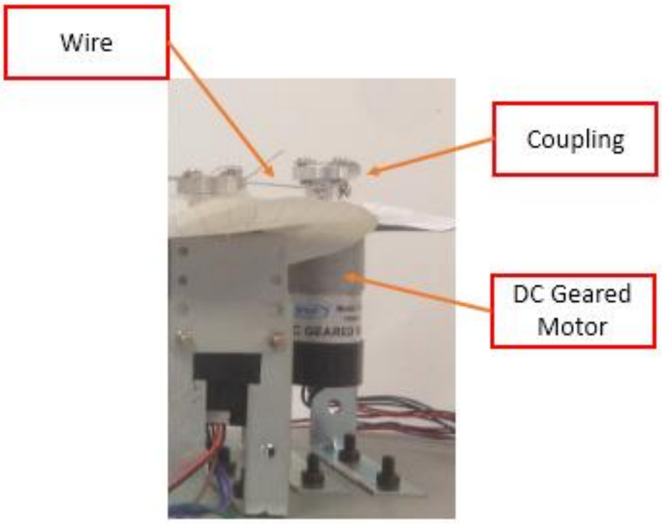

Figure 3.8: The Wire Connect to the Coupling

3.6 Calibration of Encoder for DC Geared Motor

To produce a better performance in term of accuracy and precision in the experiment result, the calibration for the encoder of DC geared motor is needed so that the encoder can collected the reading as the desire value. The encoder of DC geared motor should be done calibrate before open loop test was conducted. The encoder resolution with DC geared motor should be found where the conversion of the input voltage supply to the angle of rotation together with the encoder reading is necessary. To determine the reliability and validity of the conversion, the value read by the encoder should be same as the protractor reading as shown in Figure 3.4 and Figure 3.6. Then a gain was added into the Simulink to in order to convert the encoder value to the angle value and the experiment was run to observe the encoder reading and protractor reading which it will determine the reliability of the gain conversion.

3.7 Development of Open Loop System

An open loop system is a type of system where the output of the system is not used as a variable to control the system because there is no feedback in the whole system. An open loop system was conducted due to it quickly response on the system where an input reference is directly given to the plant and then an output is produce without any feedback to improve the error. Since there is no feedback in the system, the error occurred in the system will be accumulate in the system design. The simple block diagram of the open loop system of the robotic hand as shown in the Figure 3.8.

Figure 3.9: The Block Diagram of the Open Loop System for Robotic Hand

In this experiment setup, the experiment was conducted by drawing the block diagram of the open loop system model in MATLAB Simulink as shown in Figure 3.9. The input of the model was signal builder input which able to rotate the motor in forward and backward within the sampling time. The saturation was added in the block diagram for the safety purpose where it will saturate the input voltage when the input voltage exceed to the set value .Then, ten sample were tested with input supply of 1V to 10V with repetition of at least three time for data collection.

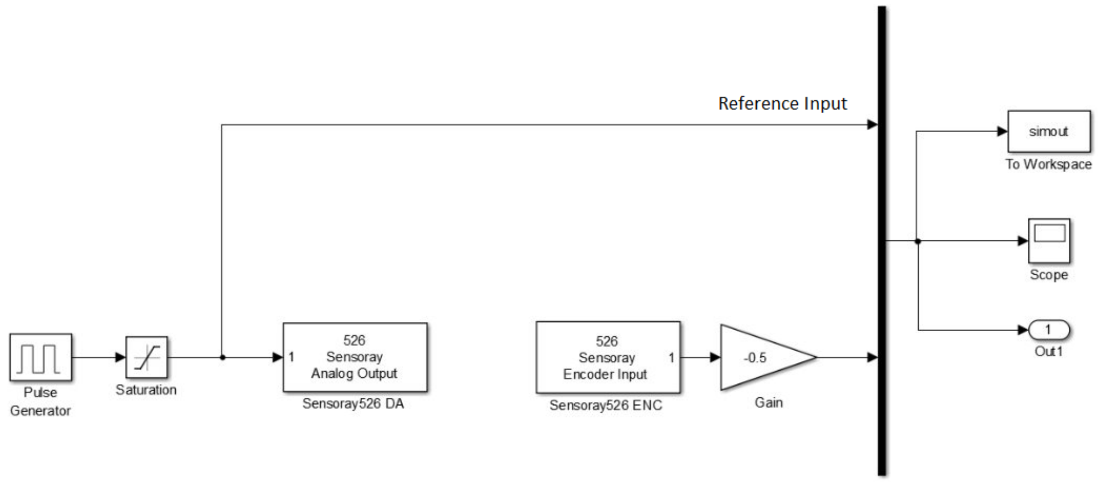

Figure 3.10: The Open Loop System Model Block Diagram

There are two experiments that will be conducted during the construction of an open loop system which is an open loop system with load and open loop system without load. The first experiment was open loop system without load where the wire was not connected to the encoder of robotic hand. The characteristic of the motor and encoder can be determined while an open loop system without load is conducted. The open loop system with load was conducted where the wire was connected between encoder of DC geared motor and robotic hand. The output characteristic that provided from an open loop system with load will be collected then be used to generate the transfer function of robotic hand using System Identification Tools which will then be used to design the controller.

Since ten sample of input were tested from 1V until 10V, there might be ten transfer function were generated. Then to determine the performance characteristic of transfer function, each of the transfer function from tested will be used to run the real time simulation with experiment output and the Simulink result which is similar to experiment result will be used in closed loop system analysis. Figure 3.10 shows the block diagram to obtain the real time simulation and experimental performance characteristic of robotic hand.

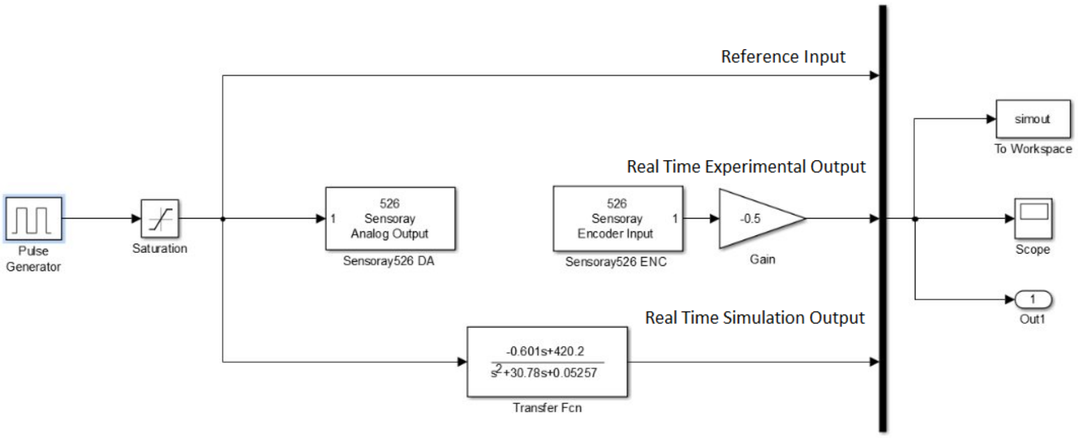

Figure 3.11: Real time Simulation and Experimental Block Diagram

3.8 System Identification

System Identification Tools is a MATLAB toolbox which will used to obtain the mathematical model from the input and output data measured. The mathematical model obtained through the system identification is an approximate based on the input and output data collected. The System Identification Tools also will convert the information from state space model to transfer function model. Figure 3.10 shows the System Identification Tools from MATLAB. The output of open loop system that was successfully conducted will then save in data file. Then the transfer function related to the model will be generated by imported the data file into the System Identification Tools.

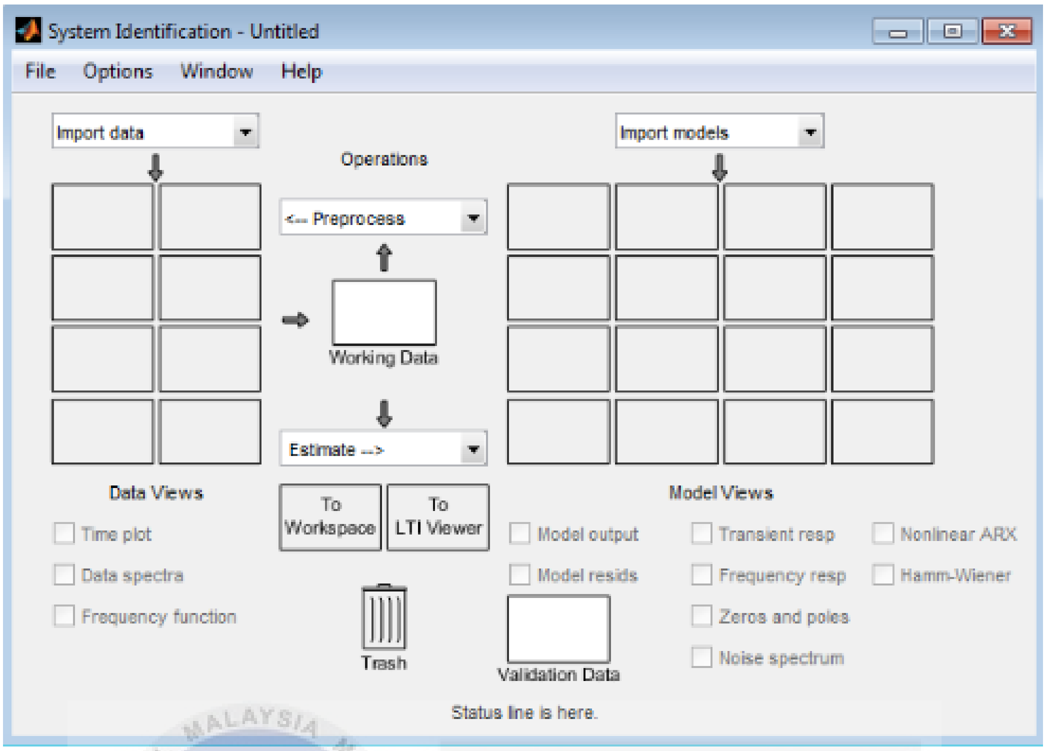

Figure 3.10: System Identification Toolbox

3.9 Development of Closed Loop System

A closed loop system was designed with feedback loop to automatically achieve and maintain the desired output condition by comparing it with the input reference. The feedback loop on the system will improve the system performance by reducing an errors signal when there was difference between input and output. The development of closed loop system will be divided into two part which is uncompensated closed loop system and compensated closed loop system with PID controller.

3.9.1 Uncompensated Closed Loop System

An uncompensated closed loop system has a feedback system where a portion of the output signal is feedback to the input to reduce errors and improve stability. However there will no controller in the system. The block diagram of the uncompensated closed loop system for the robotic hand mechanism was shown in Figure 3.11.

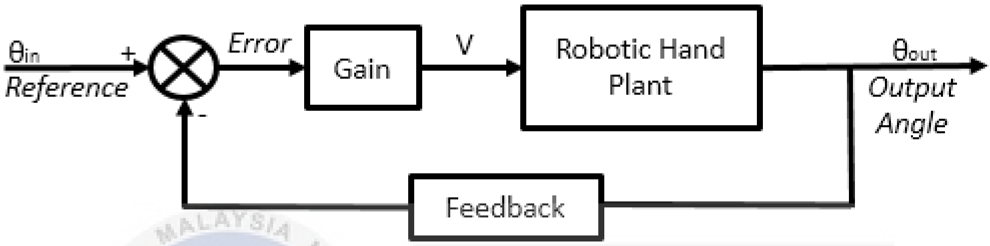

Figure 3.11: The Block Diagram of the Uncompensated Closed Loop System for the Robotic Hand

An uncompensated closed loop system was develop without any controller. The feedback loop was provide from output angle and directly feed back to the input reference in order to compare the difference between output and input. The difference between output and input reference is the error occurred and the feedback loop will reduce the error in the system. In this experiment, the simulation was conducted by drawing the block diagram of the uncompensated closed loop system model in MATLAB Simulink as shown in Figure 3.12.

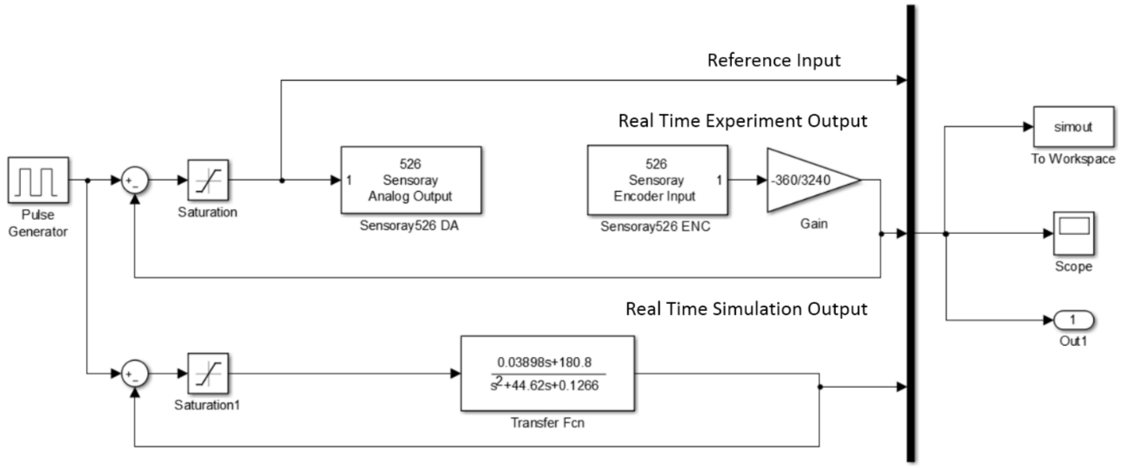

Figure 3.12: Uncompensated Closed Loop System of Robotic Hand

3.9.2 Compensated Closed Loop System with PID controller

A compensated closed loop system is quite similar with uncompensated closed loop system which also have feedback in the system. However, compensated closed loop system has controller in the system where it will be further used for improving the system performance in term of accuracy, precision and stability due to the error is being reduce and the system performance can be controlled. The block diagram of the compensated closed loop system with PID controller for robotic hand as shown in Figure 3.13.

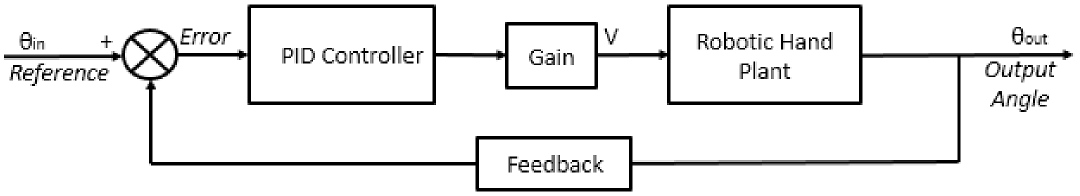

Figure 3.13: The Block Diagram of the Compensated Closed Loop System with PID Controller for Robotic Hand

A compensated closed loop system was develop wth controller in the system. For this research, a PID controller will be used and was added for further improving the system performance of the robotic hand. The negative feedback from the output will passing through a PID controller which can eliminate the error occurred to zero and able to improve the transient response to the desired output. Figure 3.14 shows the design of the compensated closed loop system with PID controller for simulation part by using MATLAB Simulink.

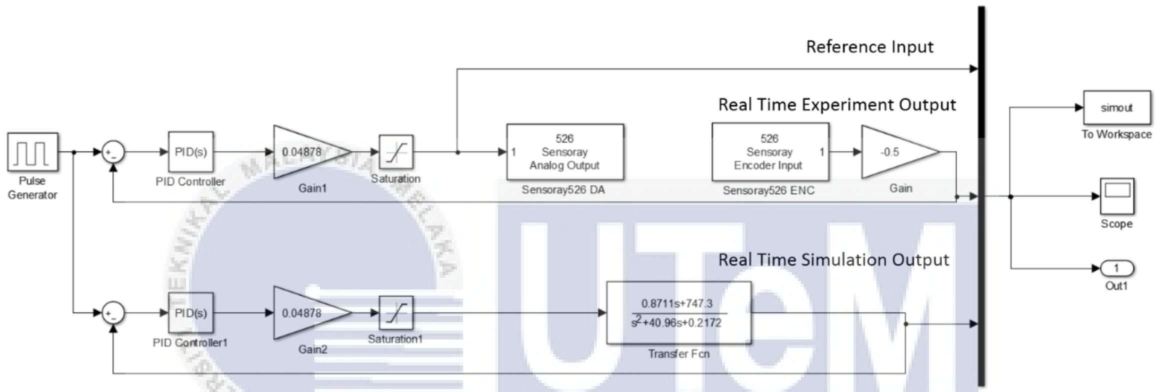

Figure 3.14: Compensated Closed Loop System with PID Controller Using MATLAB Simulink

The design of compensated closed loop system with PID controller in order to obtain a better performance in the system, there were three parameter need to be adjust which were proportional parameter (P), integral parameter (I) and derivative parameter (D). The proportional parameter was the first parameter need to be adjusted while integral and derivative parameter will be set to zero. The proportional parameter was adjusted from zero and increasing the value until the system start to oscillate with constant oscillation. From the tuning, the rise time were reach the desire value and the proportional was known. Then the integral parameter will be adjusted while allowing the proportional parameter with desire value and derivative parameter remain as zero. The integral parameter adjustment was adjusted until the error in the system was eliminated. Lastly, the derivative parameter will be adjusted until the transient response provide the best system performance and all the three parameter found will improve the grasping motion control of the robotic hand mechanism. The concept of design PID controller was summarized as shown in Figure 3.15.

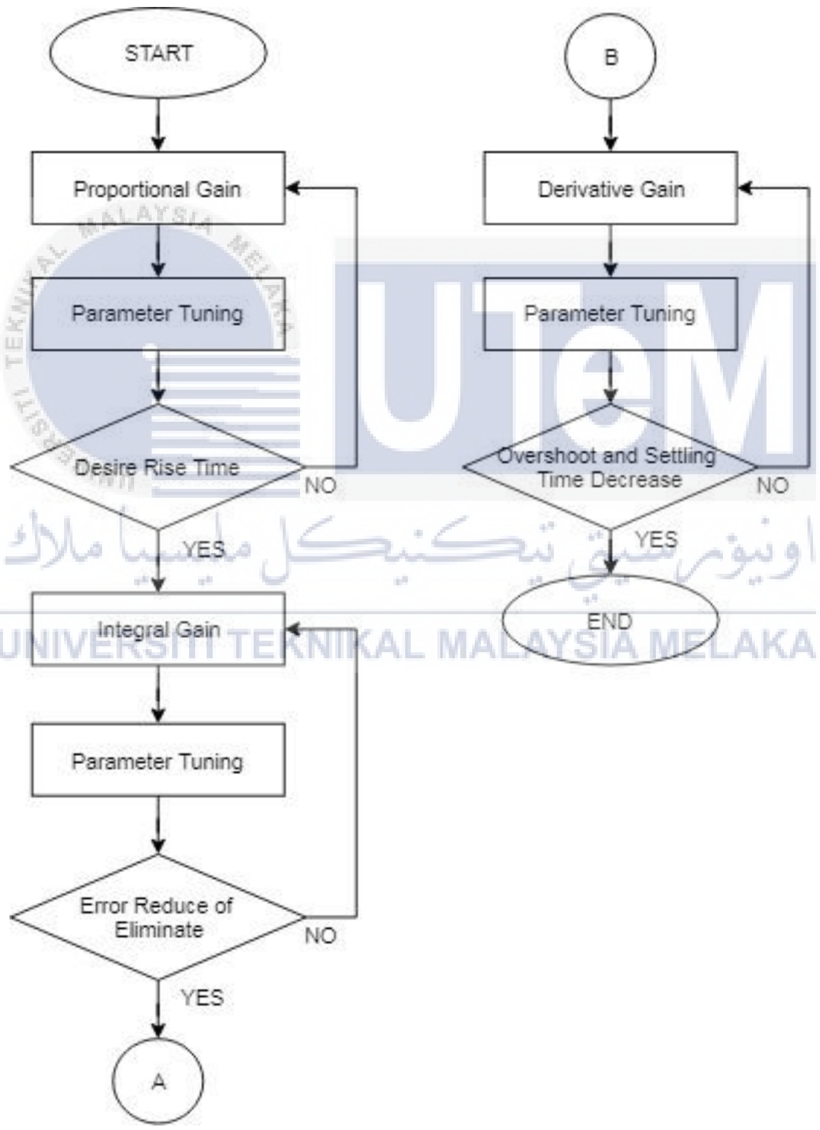

Figure 3.15: The Flow Chart for Designing the Proportional-Integral-Derivative Controller

However in this project, two tuning method will be used which is Ziegler-Nichols tuning method and trial and error tuning method. The Ziegler-Nichols tuning method was conducted until the constant oscillation occurred to obtain the Proportional gain while trial and error tuning method was conducted to adjust the Integral gain and Derivative gain parameter until the robotic finger shows better performance in grasping motion control. However to obtain the proportional, integral and derivative gain, a gain was added into the robotic hand and the gain of the controller will be increase until the robotic hand has produce a better performance.

3.10 Summary

In this project, the system used is single input and single output (SISO) as a model. The Proportional-Integral-Derivative controller (PID) will be designed to perform the task of grasping motion control. Since the grasping motion control require a fast response and precision in the system, so the system requirement were be set for percentage of overshoot less than 5%, rise time and settling time with less than 1s and the important things is the steady state error that occur in the system will be eliminate. In order to design the PID controller, two tuning method will be used to tuning the PID parameter which is Ziegler-Nichols tuning method and trial and error tuning method. The Ziegler-Nichols tuning method was conducted until the constant oscillation occurred to obtain the Proportional gain while trial and error tuning method was conducted to adjust the Integral gain and Derivative gain parameter until the robotic finger shows better performance in grasping motion control. The performance of the system will be compare between uncompensated closed-loop and compensated closed loop with PID controller. Then the relationship between base reference angle and angle of finger to palm of robotic hand will be analyze.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Calibration DC Geared Motor Encoder

The experiment was started by calibrate the DC geared motor of encoder before open loop experiment test. A calibration on the encoder finger 5 was evaluated without attaching the load which is finger 5 to the DC geared motor. The experiment using 1 seconds of time interval with sampling time 0.001 seconds where the results for every 0.001 seconds was collected. Then the voltage from 1V until 10V were tested to obtain the output angle. The reliability and validity of the voltage to angle conversion gain will be determined by comparing the encoder reading and protractor reading. From the results as shown in Figure 4.1 and Figure 4.2, when 1V of input reference was supplied to the DC geared motor 2, the angle of encoder reading was 15.4˚ while the protractor is 16.4˚. Then when 10V was supplied to DC geared motor 2, the angle of encoder reading 132.22˚ while the protractor 131.4˚. During the calibration of encoder from 1V until 10V, the rotation of angle of encoder were increasing linearly approximate 20˚ for every 1V until 7V. Then after 7V and above, the rotation of encoder was almost similar which 131.5˚. The output angle of encoder was similar same for input reference 7V and above because the DC geared motor 2 has reached its saturation point. Table 4.1 and Table 4.2 shows that the summarized of relationship between input voltage with encoder reading and protractor reading while Figure 4.3 shows that the comparison between angle of encoder and protractor reading with error.

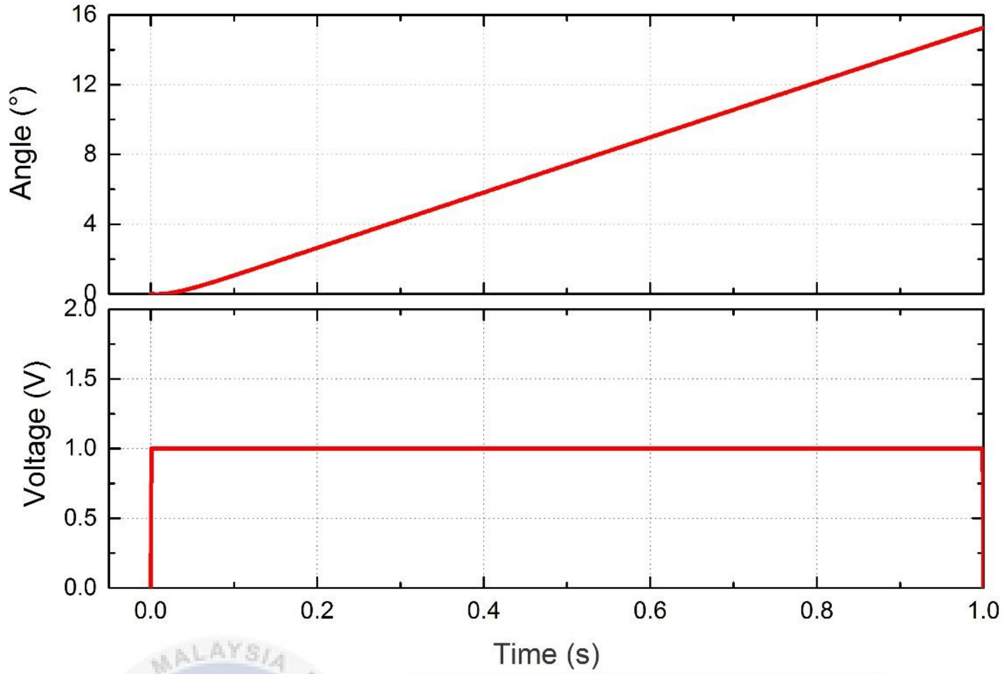

Figure 4.1: Output Angle of Encoder with input 1V

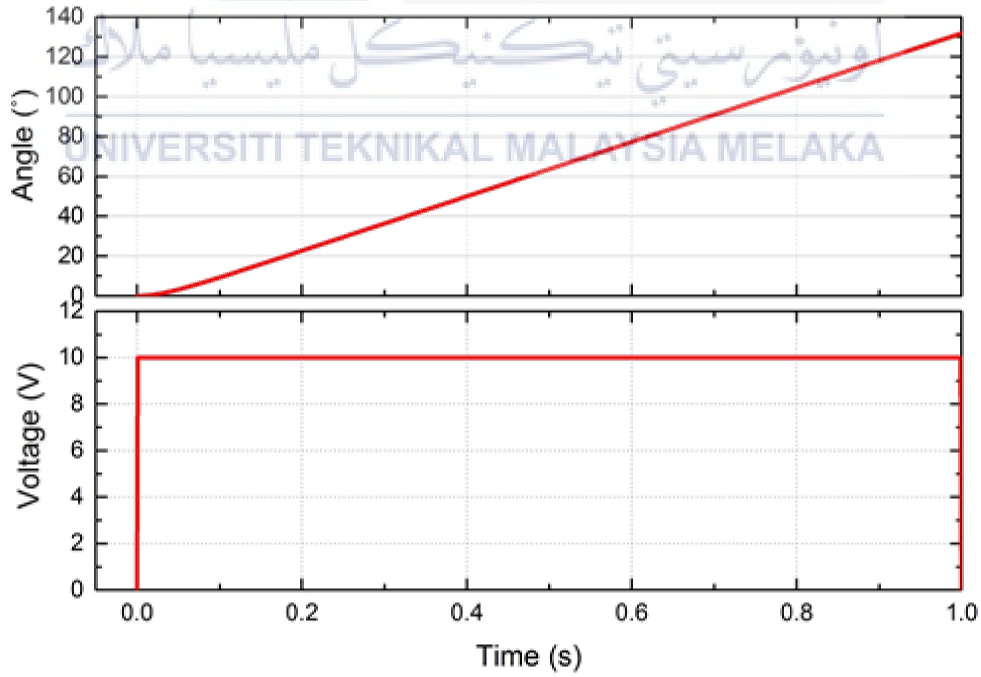

Figure 4.2: Output Angle of Encoder with input 10V

The final rotation of angle DC geared motor 2 for open loop system without load for 1 seconds was shown in Table 4.1. The average and standard deviation was calculated from data collected of five time repeatability. From observation of standard deviation, the results obtain were less than 0.5, but the error value is consider quite small and rotation of angle were close to average angle.

Table 4.1: Angle of Encoder for DC Geared Motor 2

Angle (˚) / **Input Voltage (V)**	**Repeatability**						
	1	**2**	**3**	**4**	**5**	**Average**	**Standard Deviation**
1	14.8	15.3	15.7	15.5	15.7	15.4	0.374166
2	34.8	35.2	35.7	36	35.5	35.44	0.461519
3	56.4	56.5	56	56	56.5	56.28	0.258844
4	75.6	76.7	76.4	76.5	76.8	76.4	0.474342
5	97.2	97	97.3	96.8	97.8	97.22	0.376829
6	117.6	118.3	118	118.2	117.9	118	0.273861
7	132.5	132.7	133.2	132.5	133.1	132.8	0.331662
8	131.6	132.2	132	132.5	132.2	132.1	0.331662
9	135	133.5	131.8	131.6	132.5	132.88	1.398928
10	132.5	132.2	131.9	132	132.5	132.22	0.277489

Table 4.2: Angle of Protractor for DC Geared Motor 2

Angle (˚) / Input Voltage (V)	Repeatability						
	1	**2**	**3**	**4**	**5**	**Average**	**Standard Deviation**
1	18	17	16	16	15	16.4	1.1401754
2	33	36	34	35	35	34.6	1.1401754
3	55	56	57	56	56	56	0.7071068
4	76	77	77	76	80	77.2	1.6431677
5	99	98	98	97.5	98	98.1	0.5477226
6	118	118	118	119	118	118.2	0.4472136
7	131	132	131	130	132	131.2	0.83666
8	132	132	130	130	132	131.2	1.0954451
9	131	128	131	130	132	130.4	1.5165751
10	132	132	132	131	130	131.4	0.8944272

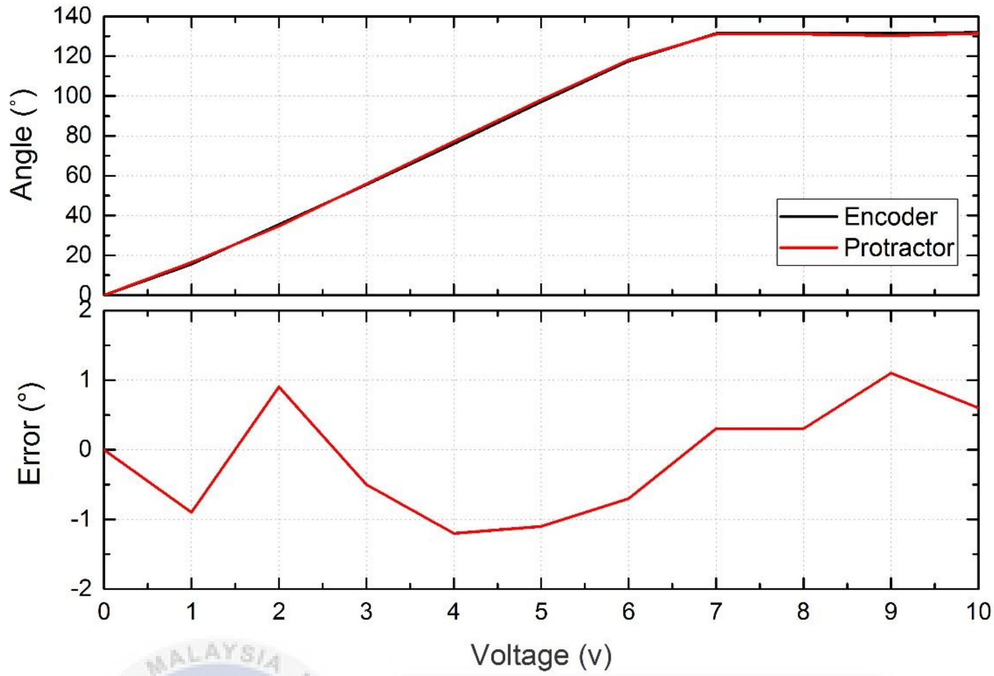

Figure 4.3: Comparison between Encoder and Protractor Reading with Error

Figure 4.3 shows that the value of encoder and protractor reading quite similar. But the error occurred between encoder and protractor reading might be due to parallax error during collected measurement on protractor. Based on these data, the conversion gain that be used in the open loop experiment to convert voltage to angle is -0.5 which is resolution of encoder. Therefore, this gain will be used to convert the rotation of DC geared motor value to angle of encoder.

4.2 Open Loop Characteristic

An open loop system was conducted by connecting robotic finger 5 to DC geared motor 2 by using string or wire. The experiment was running by using Simulink block diagram as shown in Figure 3.10. Since finger 5 was connected to DC geared motor 2, the performance of the finger 5 was analyzed. The experiment was used 1s time interval and 0.001s of sampling time. Other than that, the accuracy and precision results of the motor was obtained by repeatability five time test in order to provided performance characteristic equation. Then the characteristic equation will be choose to represent the characteristic equation of robotic hand. Lastly the effect of the open loop system on robotic hand will be determined.

4.2.1 Open Loop Experimental Test

An open loop experimental test was conducted in MATLAB Simulink software to compare the result between simulation block diagrams. The Simulink block diagram was shown in Figure 3.10. From the results obtained, when 1V of input voltage was supplied to the DC geared motor 2, the angle of encoder reading was 15.5˚ Then when input voltage increasing from 1V until 6V, the angle of encoder reading was 118˚ with approximate 20˚ for every 1V increasing. After 6V and above, the angle of rotation will be similar same which is 132.5˚ due to saturation reach its point. Then from the data as shown in Table 4.3, the standard deviation was calculated and shows the results obtain less than 0.3 which mean it has very small and consider the output of robotic hand is very consistency. Table 4.3 shows angle of DC geared motor 2 with different input voltage and Figure 4.4 Output angle of DC geared motor 2 and Standard Deviation with Respect to Input Voltage.

Table 4.3: Angle of DC Geared Motor 2 with Different Input Voltage

Angle (˚) / Input Voltage (V)	Repeatability						
	1	**2**	**3**	**4**	**5**	**Average**	**Standard Deviation**
1	15.5	15	15	15	15	15.1	0.2236068
2	35.5	35.5	35.5	36	35.5	35.6	0.2236068
3	56	56	56	56	56	56	0
4	76.5	76.5	76.5	76.5	76.5	76.5	0
5	97.5	97.5	97.5	97.5	97.5	97.5	0
6	118	118	118	118	118	118	0
7	132.5	132	132	132	132	132.1	0.2236068
8	132.5	132	132.5	132.5	132	132.3	0.2738613
9	132	132	132	132	132.5	132.1	0.2236068
10	132.5	132	132	132	132	132.1	0.2236068

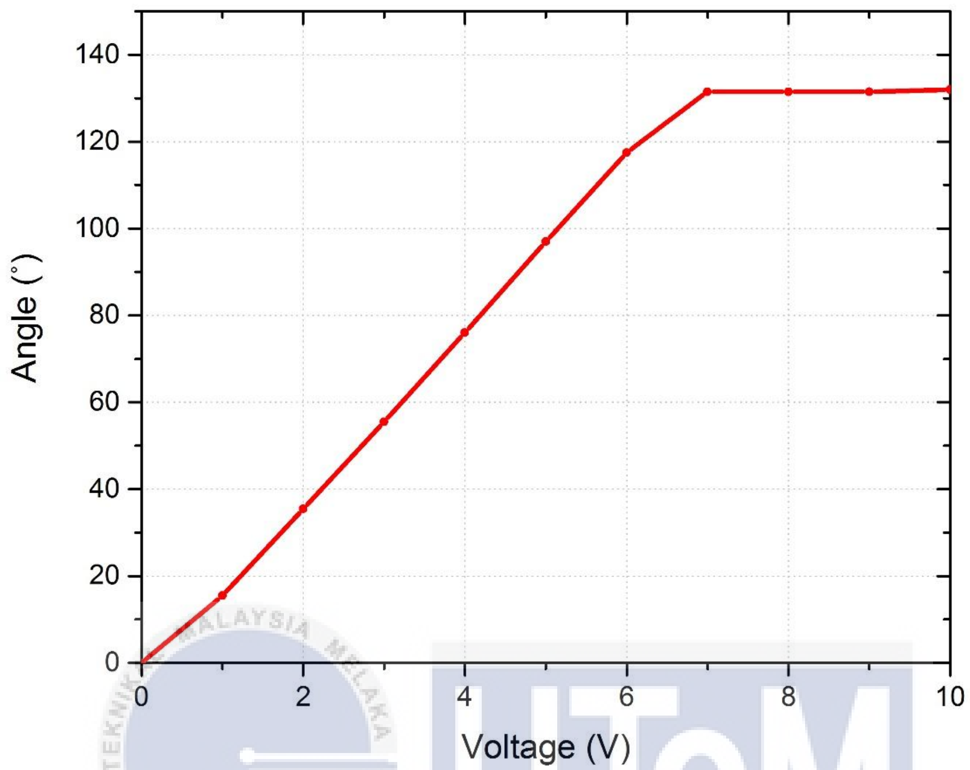

Figure 4.4: Output angle of DC Geared Motor 2 and Standard Deviation with Respect to Input Voltage

The rotation angle of DC geared motor 2 for open loop system was control directly by manipulate the input voltage. The angle of rotation DC geared motor 2 cannot be control precisely because the system not have a controller. The value obtain initially from the encoder was the amount that the encoder detected. In order to convert the value of encoder into angle of rotation, the gain was added in the Simulink block diagram. The gain that been used to convert encoder value is 720 which is resolution of DC geared motor.

By using Micro-Box as a controller in this system, it provide real time simulation and analysis for experimental. However, the output angle of rotation not obtained as a desired results which is quite different even the input voltage was same. This is because there are some small voltage still in the motor while the power supplied was stop supplying. This situation will affect the small amount of angle of rotation. Even though, there were some quite difference, but the standard deviation was proved that the error in the system was consider small and output of the system was consistency. Nevertheless, the system shows a linear system which it increasing approximate 20˚ for every 1V when the input voltage was supply to motor until 6V. Due to this reason, PID controller will be design in the close-loop system. Moreover, the saturation point for DC geared motor 2 started reach the voltage at 7V and above, considering that after input voltage 7V, it will remain at same angle of rotation.

4.2.2 Characteristic Equation

The characteristic equation was obtained through the open loop test. Since, the reference input voltage used from 1V until 10V, so there will be ten transfer function that might be generated by using System Identification Tools in MATLAB. Furthermore, the robotic hand characteristic was fulfill the requirement of System Identification Tool which have linear system that the system only provide the requirement. Table 4.4 shows the transfer function that have been generated by using system identification. Other than that, the performance for each transfer function was been compared with experiment results as shown in Figure 4.5 until Figure 4.14. Additionally, the comparison between errors for all transfer function was shown in Figure 4.15 until Figure 4.17 and then be used as characteristic of robotic hand. The general equation for characteristic of robotic hand mechanism can be summarized as below;

$$G(s) = \frac{As + B}{Cs^2 + Ds + E} \tag{4.1}$$

Table 4.4: Characteristic Equation of Robotic Hand Mechanism

Transfer Function	A	B	C	D	E
1	-4.904	603.4	1	37.78	0.7995
2	0.8711	747.3	1	40.96	0.2172
3	-6.437	963.3	1	50.15	0.3099
4	-5.023	947.3	1	48.08	0.2561
5	0.05086	876.2	1	43.76	0.217
6	-4.038	925.1	1	45.72	0.1788
7	1.209	588	1	30.2	0.04149
8	1.052	515.9	1	30.26	0.01192
9	-0.7264	471.5	1	31.16	0.01133
10	-0.601	420.2	1	30.78	0.05257

Table 4.4 shows that ten transfer function have been generated by using system identification tools in MATLAB. Transfer function 1 indicates transfer function that was generated from input voltage 1V and same to other transfer function. Each transfer function was done repeatability for five times and transfer function that is nearest to average value was chose as shown in Table 4.4.

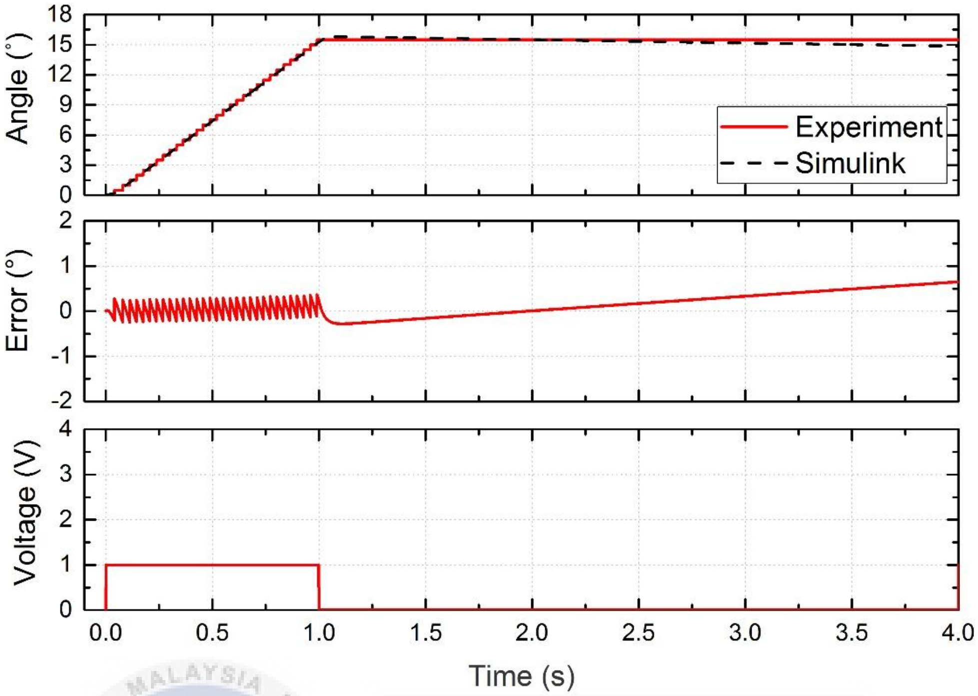

Figure 4.5: Experiment and Simulation output for Transfer Function 1

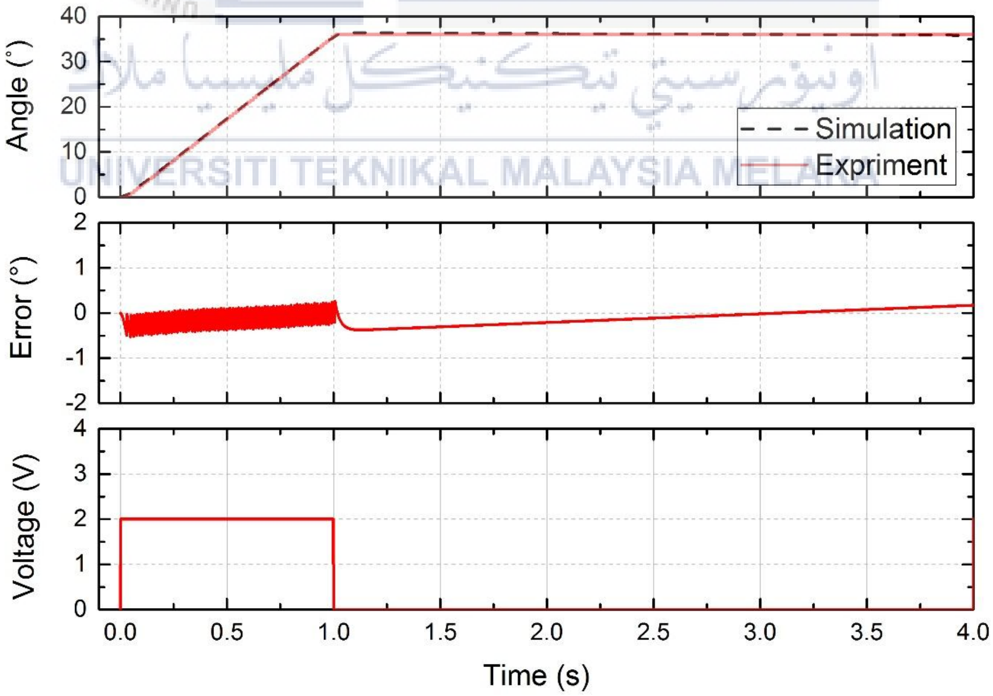

Figure 4.6: Experiment and Simulation output for Transfer Function 2

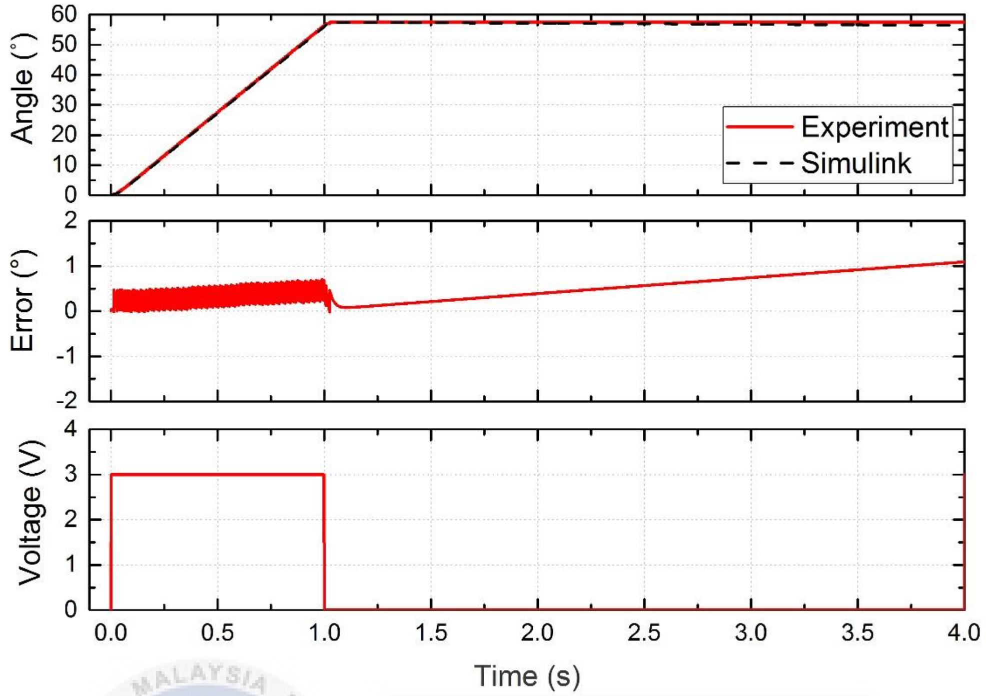

Figure 4.7: Experiment and Simulation output for Transfer Function 3

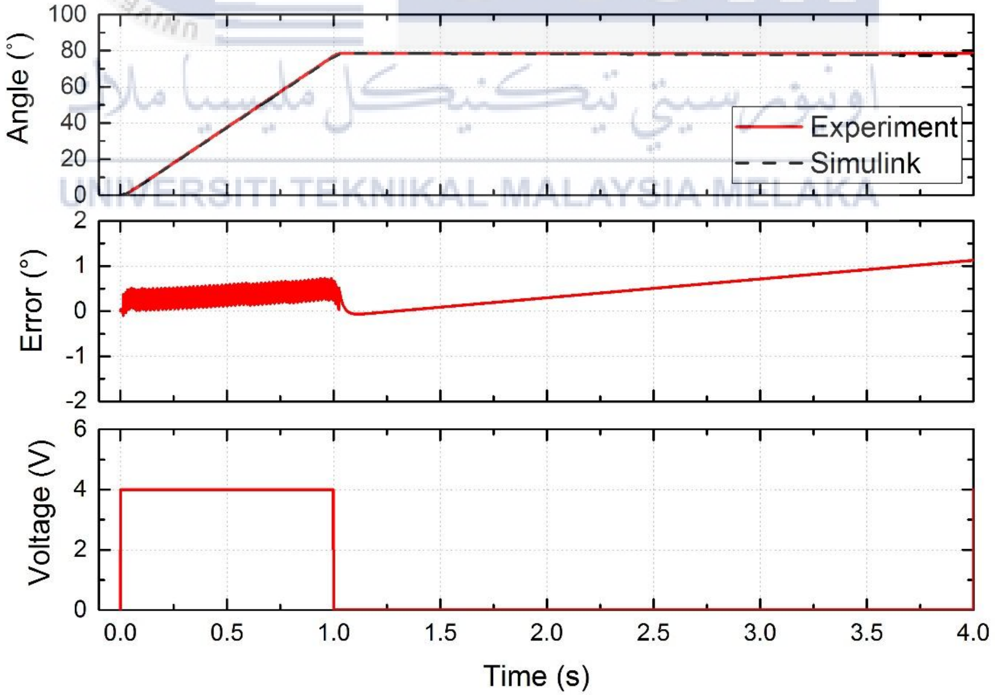

Figure 4.8: Experiment and Simulation output for Transfer Function 4

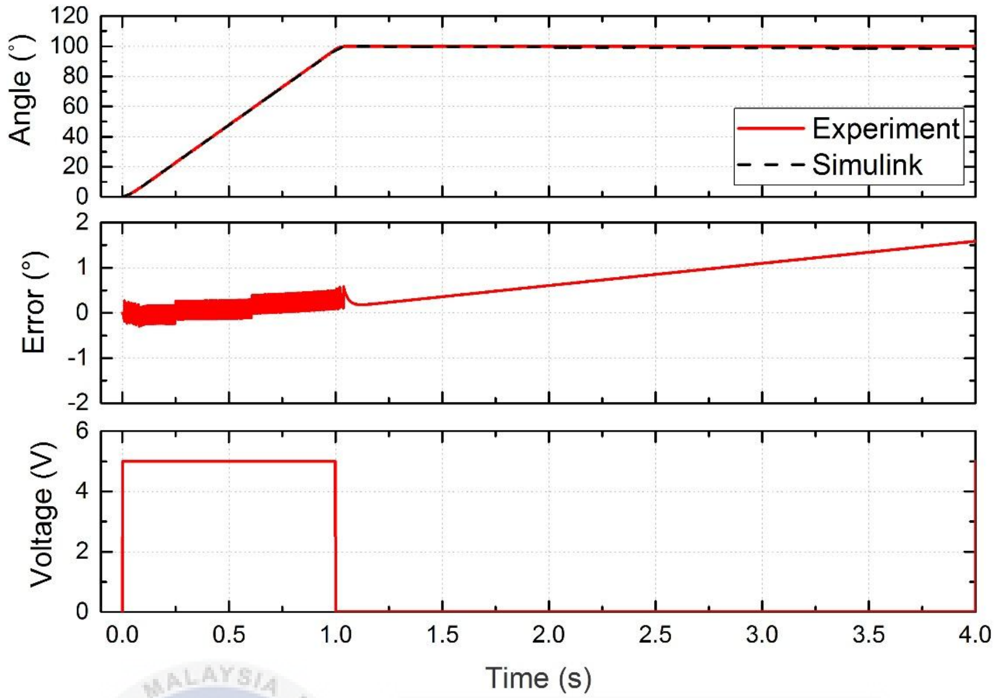

Figure 4.9: Experiment and Simulation output for Transfer Function 5

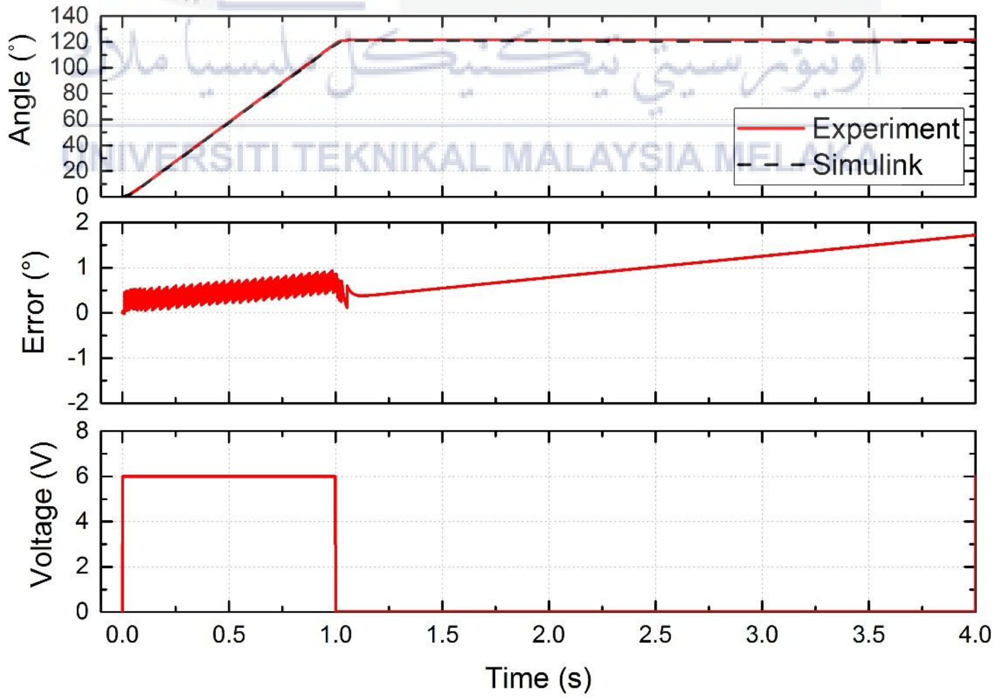

Figure 4.10: Experiment and Simulation output for Transfer Function 6

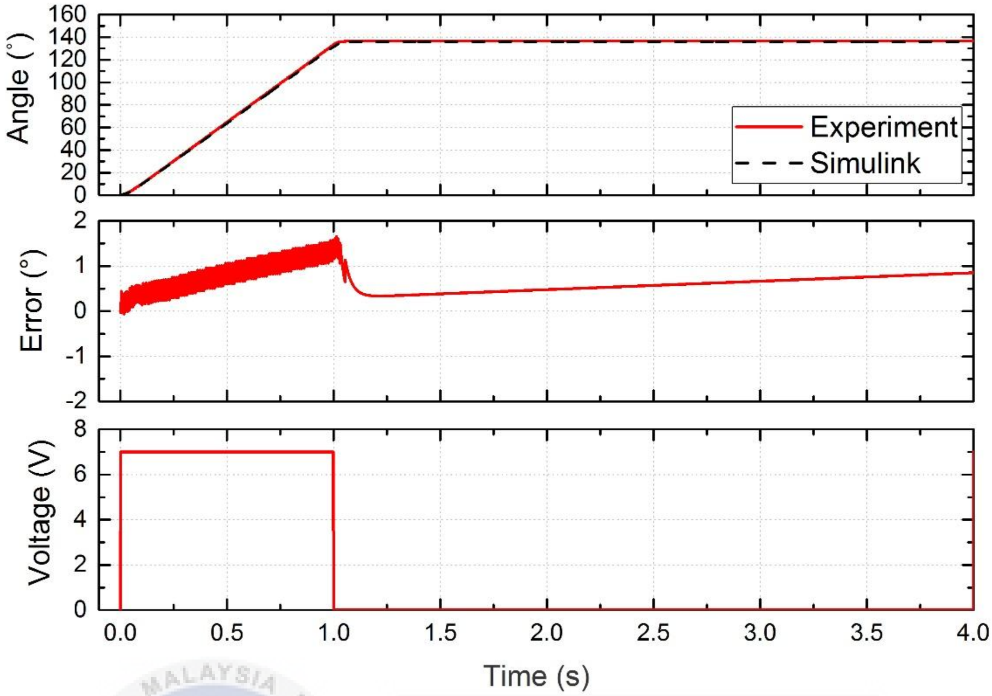

Figure 4.11: Experiment and Simulation output for Transfer Function 7

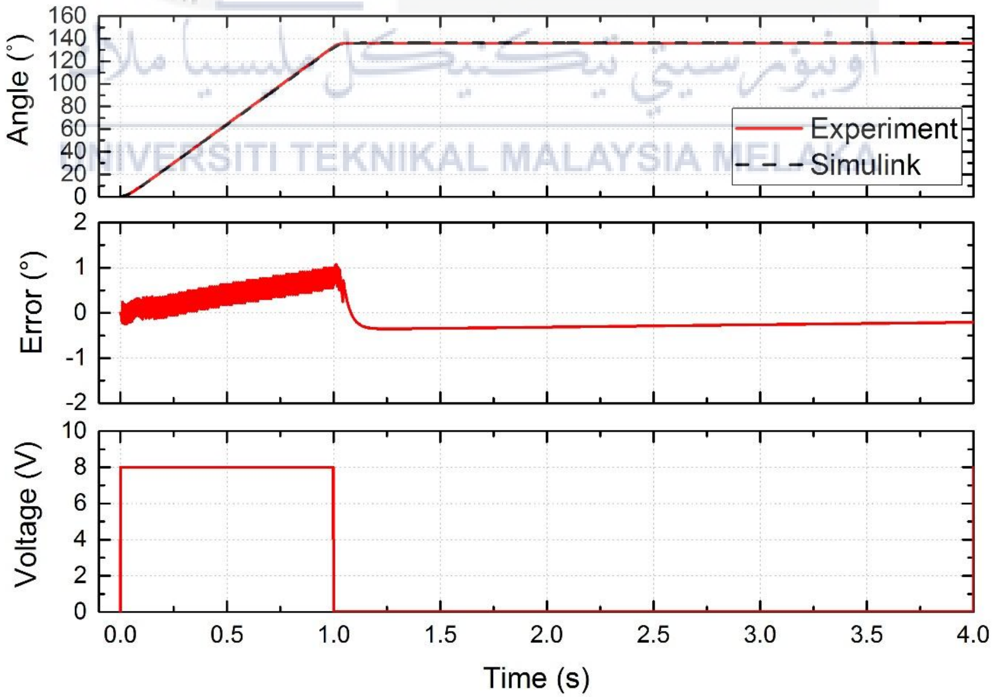

Figure 4.12: Experiment and Simulation output for Transfer Function 8

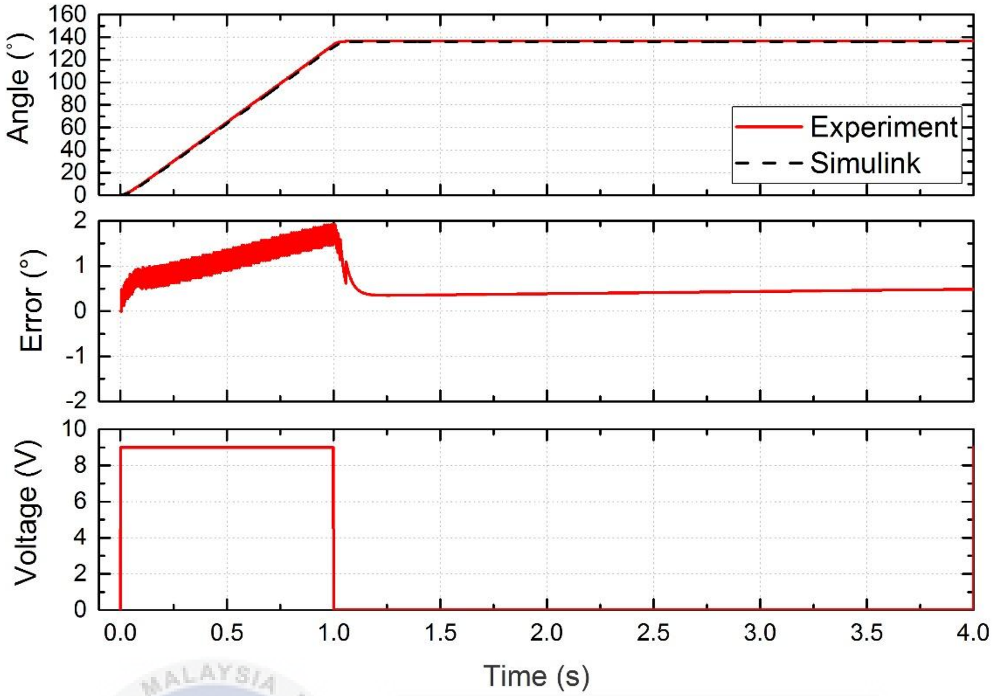

Figure 4.13: Experiment and Simulation output for Transfer Function 9

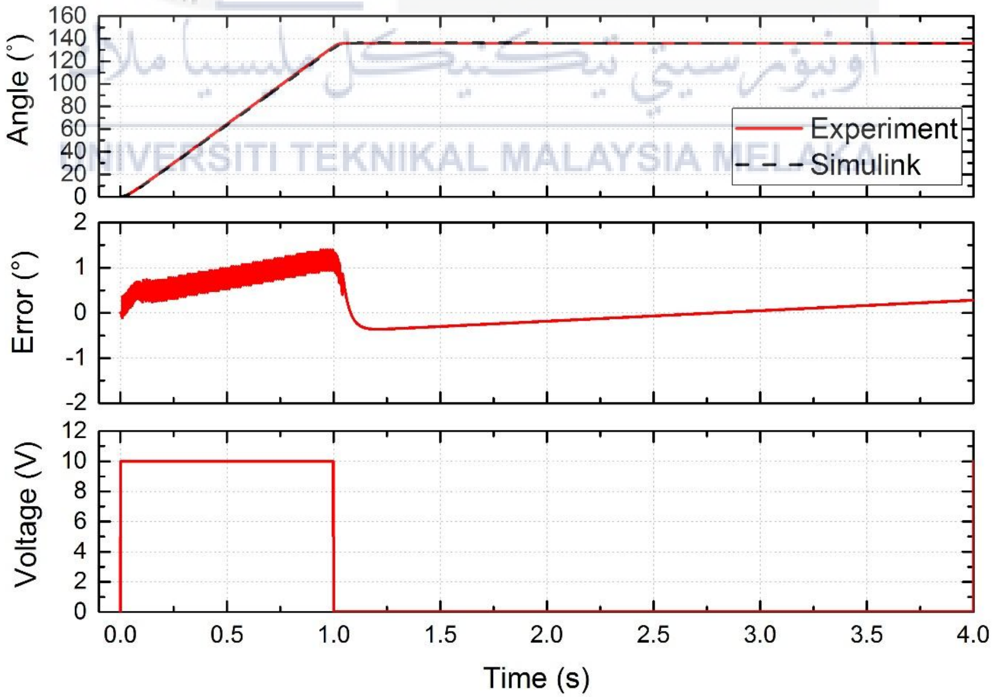

Figure 4.14: Experiment and Simulation output for Transfer Function 10

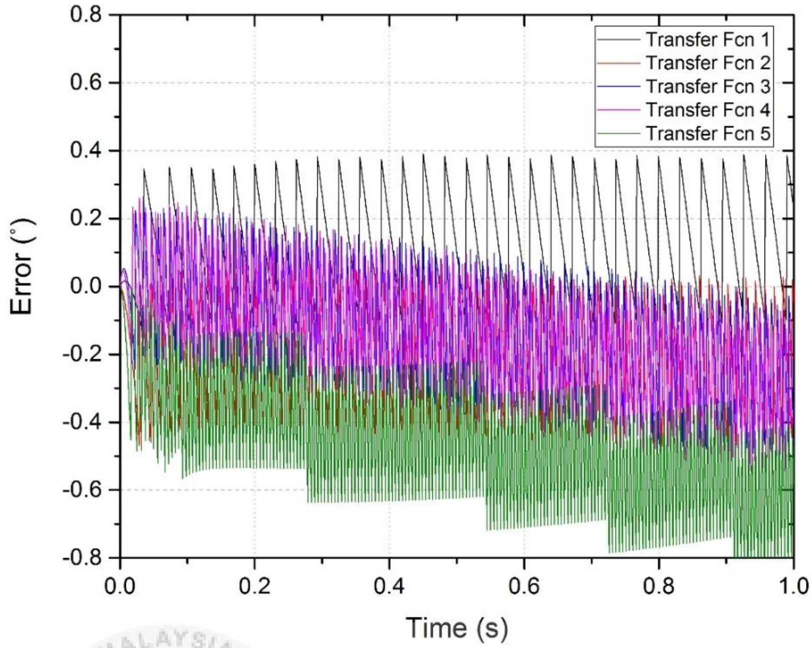

Figure 4.15: Graph of Error Occured on Transfer Function 1 to Transfer Function 5

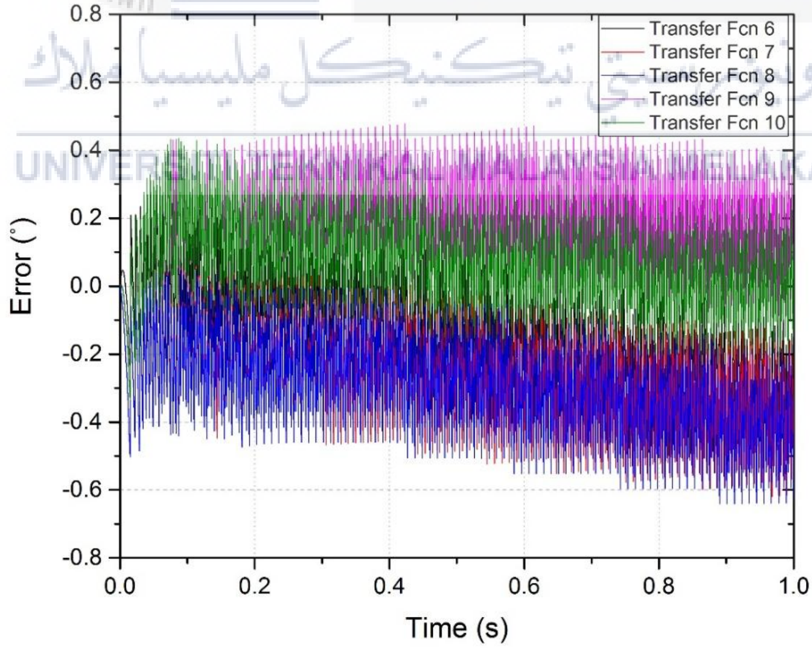

Figure 4.16: Graph of Error Occurred on Transfer Function 6 to Transfer Function 10

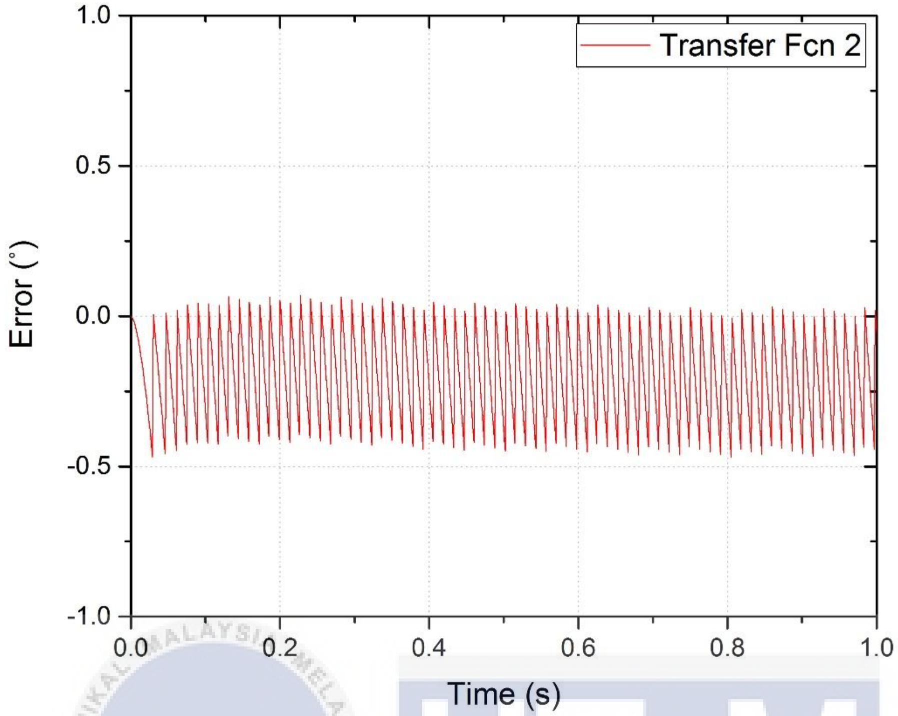

Figure 4.17: Graph of Error occur on Transfer Function 2

All ten transfer function was generated by using system identification tools in MATLAB system software. The performance of each transfer function have been tested by compared the results between experiment and simulation. Then, the lowest error from ten transfer function will be choose as a characteristic equation for robotic finger. The error is where the difference angle of encoder between experiment and simulation. Figure 4.15 and Figure 4.16 shows that the error occurred between experiment and simulation on the output angle of encoder. And Figure 4.17 shows the error that occurred on the output angle of transfer function 2 is smallest error along the period. Based on the Figure 4.15 and Figure 4.16, transfer function 2 is most suitable transfer function and will be used in the Simulink model due to it obtain lowest error compare to other transfer function. So the transfer function 2 that was represent as characteristic equation for finger 5 was as below;

$$G(s) = \frac{0.8711s + 747.3}{s^2 + 40.96s + 0.2172} \tag{4.2}$$

4.2.3 Effects of Open Loop System to Robotic Hand

The finger of robotic hand is connected directly to the DC geared motor by using string. Therefore, when the DC geared motor is rotated, the robotic finger also be raised to a certain angle as well. The result for open loop test to determine the angle of rotation of robotic finger as shown in Figure 4.18 shows that the angle of robotic finger increasing linearly along with the angle of DC geared motor. In other to ensure the releability for encoder reading of DC geared motor, the protractor was paired to DC geared motor to comply with the change and compare the angle of encoder. In addition, other protractor also was paired to robotic finger in order to compare the angle of ratation between DC geared motor with the angle that raised on robotic finger as shown in Figure 3.6 and Figure 3.7. Figure 4.18 below shows the performance of angle of encoder DC geared motor 2 with angle of robotic finger 5 and Table 4.5 shows the summarization of the output angle.

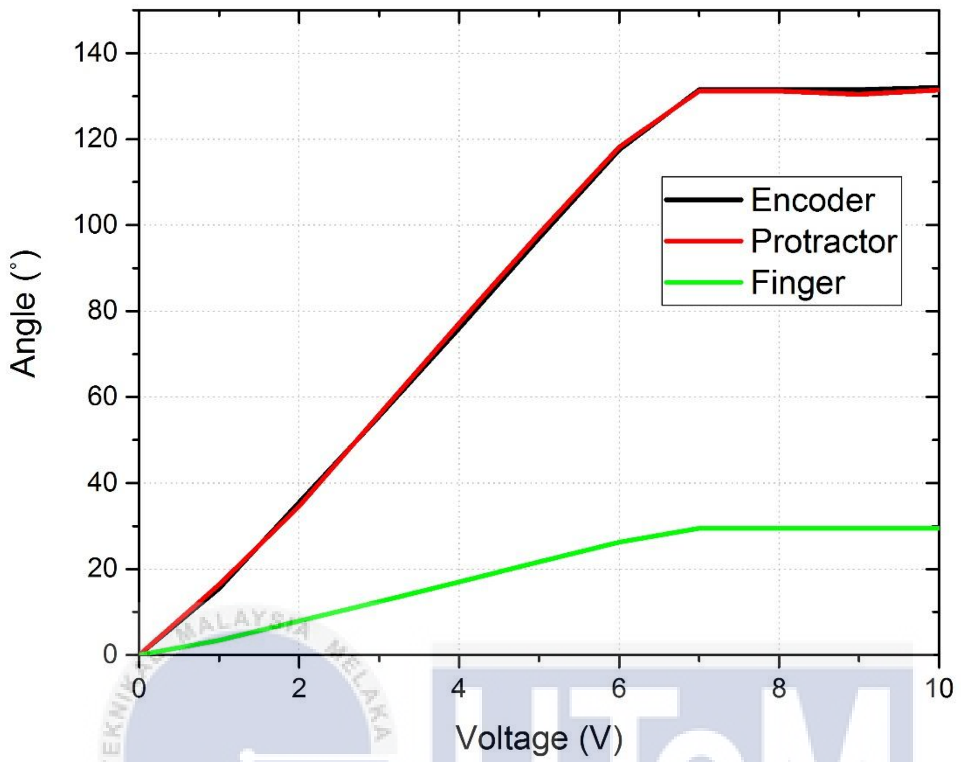

Figure 4.18: Relationship Between Angle Of Encoder And Protractor With Angle Raised By Robotic Finger 5

Table 4.5: Average Angle Of Encoder And Protractor at DC Geared Motor 2 and Angle Raised By Robotic Finger 5

Angle (˚) / Voltage (V)	**DC Geared Motor**		**Finger**
	Encoder	**Protractor**	
0	0	0	0
1	15.1	16.4	3.42
2	35.6	34.6	7.89

3	56	56	12.47
4	76.5	77.2	16.98
5	97.5	98.1	21.62
6	118	118.2	26.22
7	132.1	131.2	29.42
8	132.3	131.2	29.36
9	132.1	130.4	29.37
10	132.1	131.4	29.42

From the Figure 4.18, the ouput angle for both DC geared motor 2 encoder and angle raised by robotic finger 5 shows the angle with the input voltage from 1V until 6V was linearly output. However, the saturation was reach it point when the input voltage is 7V and above. Then the relationship relationship between angle of encoder and protractor with angle raised by robotic finger 5 can be summarized as below;

$$Angle\ of\ Finger, F = 0.22665\ x\ (\ Angle\ of\ Encoder, E) \tag{4.3}$$

Figure 4.18 shows that when 1V input was supply to DC geared motor 2, the output angle of encoder obtained was 15.5˚ while the robotic finger 5 raised at angle 3.42˚. Then when input voltage is 6V, the output angle of encoder obtained was 188˚ while the robotic finger 5 raised at angle 26.22˚.The change of the angle DC geared motor 2 was approximate 4.5004 time the angle of robotic finger which was shown in equation 4.3. Table 4.5 above shows the average value for angle of encoder reading and protractor reading of DC geared motor 2 with angle of robotic finger 5.

4.3 Uncompensated Closed Loop

An uncompensated closed loop system is a system which is similar to open loop system. However a negetive feedback was added into the system where a portion of the output signal is feedback to the input. The negative feedback was required into the system in order to reduce errors and improve the stability of the system. In this system, the reference angle was used as the input and DC geared motor will produce the output as a reference angle. The Simulink block diagram for uncompensated closed loo system was shown in Figure 3.12. Then an additional gain was added into the system in order to convert the input reference angle to reference voltage which will supply to DC geared motor. The value of additional gain has been calculate from the data produced on open loop test as shown in Figure 4.4. Where the formula as shown in equation 4.4 below which is the result are linear system. Choose two point on the graph as shown in Figure 4.4.

$$Gain = \frac{4-3}{76.5-56} \tag{4.4}$$

$$Gain = 0.04878$$

The gain used to convert the angle to the voltage gain value was 0.04878 which will be used in the closed loop system block diagram. Due to the open loop system output shows a linear system, PID will be used in the closed loop system. Figure 4.19 to Figure 4.24 shows the performance of uncompensated closed loop system on robotic finger 5 while Table 4.6

to Table 4.11 shows the step response for the robotic finger 5 for both experiment and simulation.

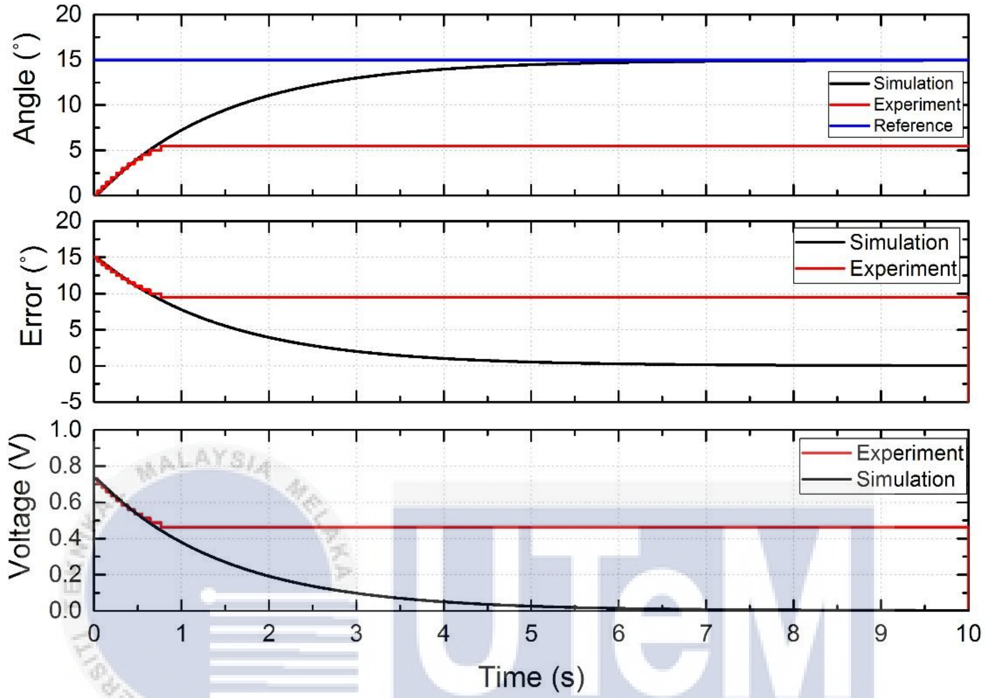

Figure 4.19: The Performance of Robotic Finger 5 for 15˚ of Input Angle

Table 4.6: The Step Response of Robotic Finger 5 for 15˚

System Response	**Experiment**	**Simulation**
Rise Time, Tr (s)	0.5200	2.4010
Settling Time, Ts (s)	0.6608	4.2928
Overshoot, OS (%)	0	0
Steady State Error, Ess (˚)	9.5	0.05504

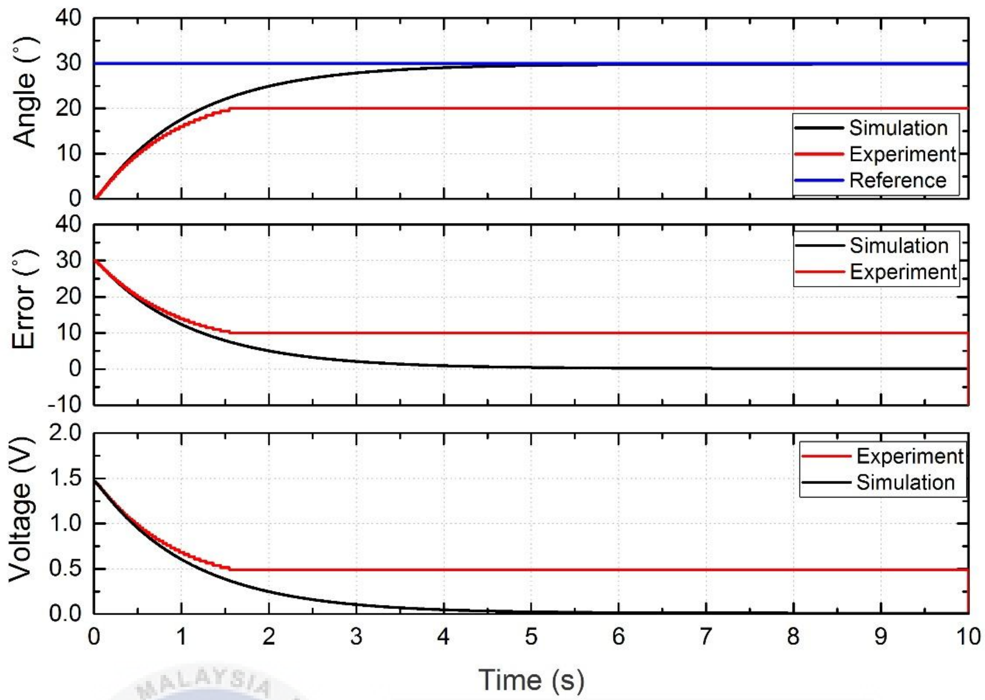

Figure 4.20: The Performance of Robotic Finger 5 for 30˚ of Input Angle

Table 4.7: The Step Response of Robotic Finger 5 for 30˚

System Response	**Experiment**	**Simulation**
Rise Time, Tr (s)	1.1230	2.4010
Settling Time, Ts (s)	1.5712	4.2928
Overshoot, OS (%)	0	0
Steady State Error, Ess (˚)	10	0.181

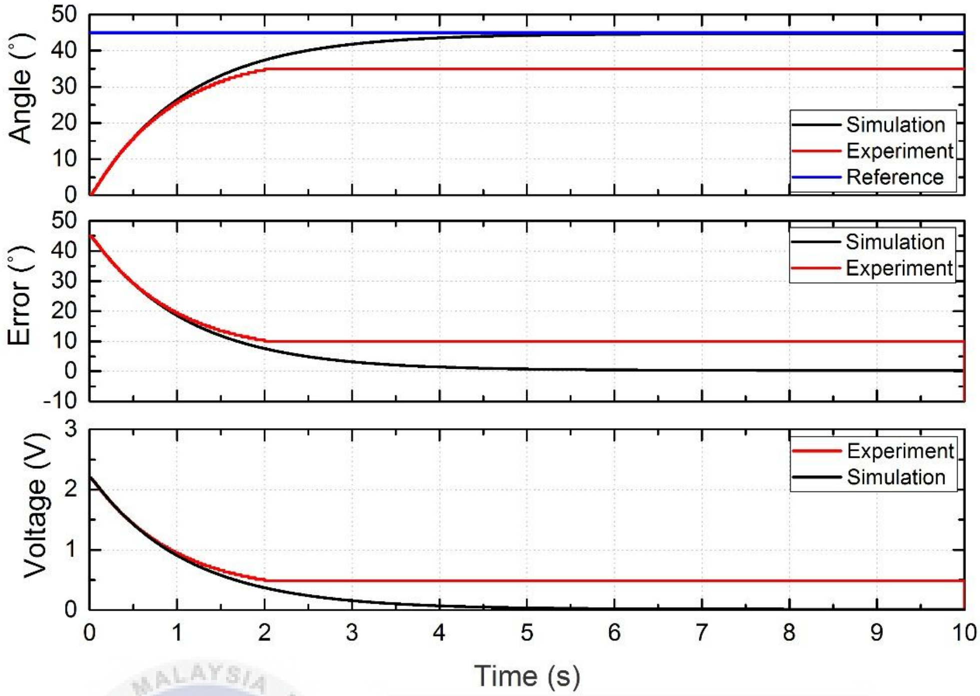

Figure 4.21: The Performance of Robotic Finger 5 for 45˚ of Input Angle

Table 4.8: The Step Response of Robotic Finger 5 for 45˚

System Response	Experiment	Simulation
Rise Time, Tr (s)	1.3840	2.4010
Settling Time, Ts (s)	1.9206	4.2928
Overshoot, OS (%)	0	0
Steady State Error, Ess (˚)	10	0.27145

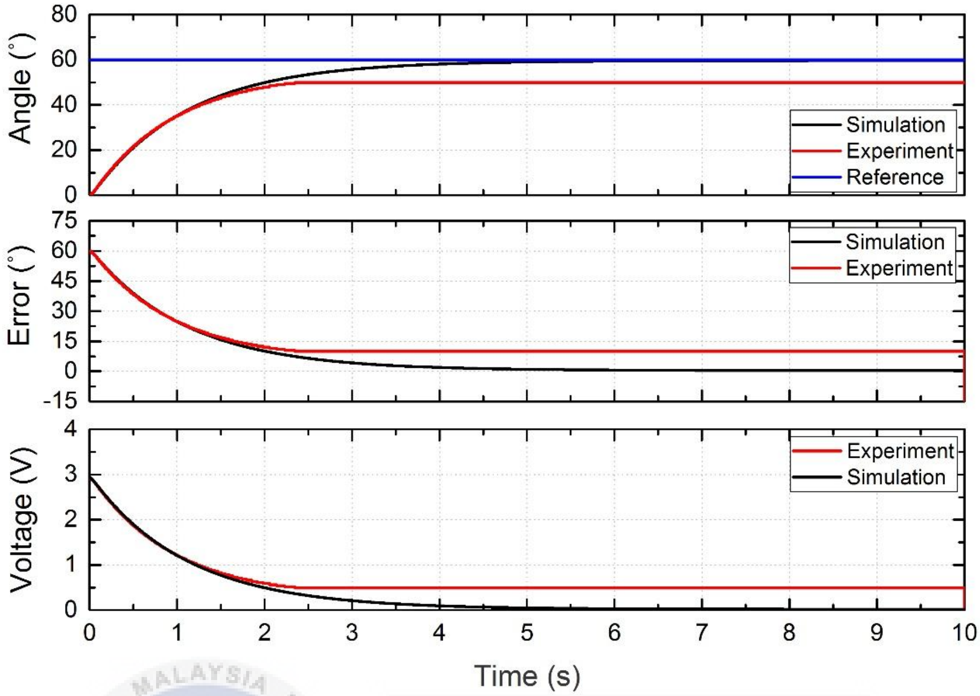

Figure 4.22: The Performance of Robotic Finger 5 for 60˚ of Input Angle

Table 4.9: The Step Response of Robotic Finger 5 for 60˚

System Response	Experiment	Simulation
Rise Time, Tr (s)	1.5472	2.4010
Settling Time, Ts (s)	2.1830	4.2928
Overshoot, OS (%)	0	0
Steady State Error, Ess (˚)	10	0.3619

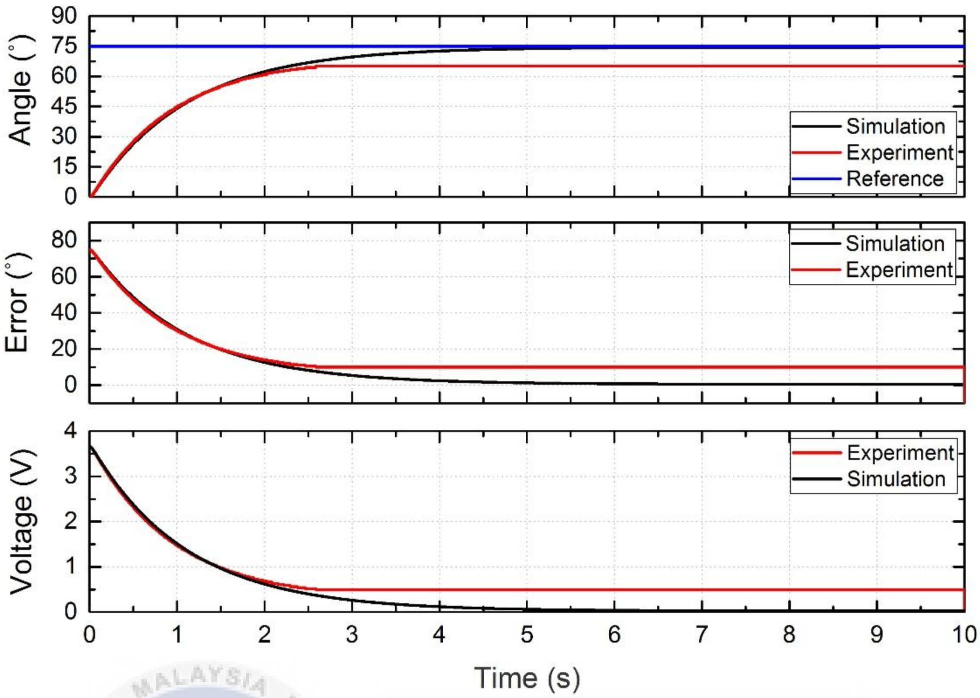

Figure 4.23: The Performance of Robotic Finger for 75˚ of Input Angle

Table 4.10: The Step Response of Robotic Finger for 75˚

System Response	Experiment	Simulation
Rise Time, Tr (s)	1.6432	2.4010
Settling Time, Ts (s)	2.3314	4.2928
Overshoot, OS (%)	0	0
Steady State Error, Ess (˚)	10	0.4524

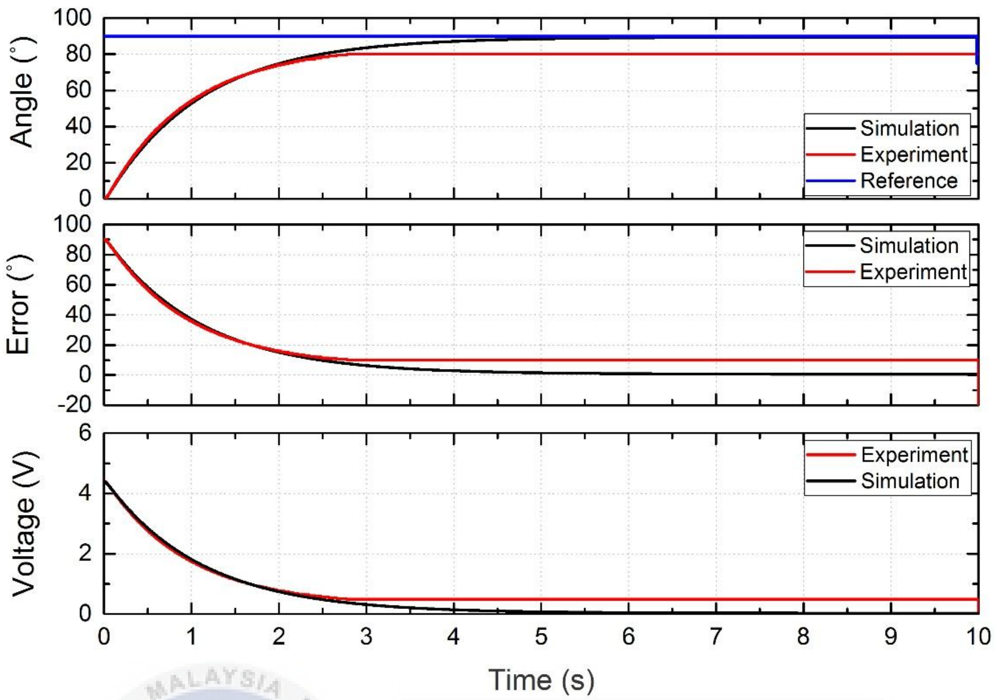

Figure 4.24: The Performance of Robotic Finger for 90˚ of Input Angle

Table 4.11: The Step Response of Robotic Finger for 90˚

System Response	Experiment	Simulation
Rise Time, Tr (s)	1.7072	2.4010
Settling Time, Ts (s)	2.4338	4.2928
Overshoot, OS (%)	0	0
Steady State Error, Ess (˚)	10	0.5429

From the observation on uncompensated closed loop system, the input voltage supply to DC geared motor was based on the input reference angle. This shows that when 1˚ of input angle was supply to motor, 0.4878 V was required by the motor to reach its desired angle. But if the voltage was less than 0.4V, the DC geared motor 2 was not getting enough torque to drived for experiment results.

The input reference angle that was used in this experiment were 15˚, 30˚, 45˚, 60˚, 75˚ and 90˚. Then, step response was carried out for each experiment in order to compare the result between experiment and simulation of the uncompensated closed loop system. However, from the results for input reference 15˚ until 90˚, there was no overshoot in the system. The rise time for experiment results was 0.5200s while simulation results was 2.4010s for 15˚ of input angle. Then, the rise time became 1.7072s while simulation results was 2.4010s when the input reference angle increased to 90˚.

In addition, the settling time for experiment results for 15˚ was 0.6608s while 4.2928s for simulation resuts. Then, when the input reference was increased to 90˚, the experiment results was 2.4338s and the simulation results was 4.2928s. Another step response that was summarized from Table 4.6 to Table 4.11 is steady state error. The error that occurred in the system was approximate 10˚ for experiment results while for simulation it was less than 0.55˚. The error for experiment results were large compare to simulation results due to the input voltage that was supply to DC geared motor was not get enough torque to pull the finger of robotic hand.

Based on performance of uncompensated closed loop system on robotic hand, the results was long rise time, long settling time and large steady state error for both experiment and simulation. Hence, a controller is needed in this system in order to reduce the rise time and settling time to less than 1s, eliminate the steady state error and reduce the percentage of overshoot to less than 1% of the robotic hand in order to achieve the grasping motion control of robotic hand mechanism.

4.4 Compensator Closed loop (PID Controller)

Compensated closed loop system is designed with PID controller to improve the transient response of the system which is rise time, settling time, percentage of overshoot and steady state error. Then a PID controller block diagram was added into the system. The Simulink block diagram for compensated closed loop with PID controller was shown in Figure 3.14. There are two method were used to tuning the PID controller. First method will be Ziegler Nichols tuning method and the second one is Trial and Error tuning method. Ziegler Nichols tuning method is a heuristic method to tuning a PID controller. It is functionally to calculate the Proportional gain when the ultimate gain and ultimate period were successfully obtained. Then Trial and Error tuning method will be used in order to obtain the Integral gain and Derivative gain. Integral and Derivative gain will be set as zero, then the Integral gain will be tune until the system eliminate its error and follow by Derivative gain until the system achieved it desired performance.

4.4.1 Ziegler Nichols Tuning Method

Based on the Ziegler Nichols tuning method, the tuning method will be started by removing the Integral gain and Derivative gain or set both of the gain to zero. Then increase the Proportional gain from zero until the output was produce an constant oscillation. The constant oscillation of the gain along with the time is namely as ultimate gain which is the minimum gain that can cause the system to be unstable or marginally stable. Forthermore, the period for a cycle of oscillation is namely as ultimate period. Figure 4.25 to Figure 4.35 shows the results for Ziegler Nichols tuning method.

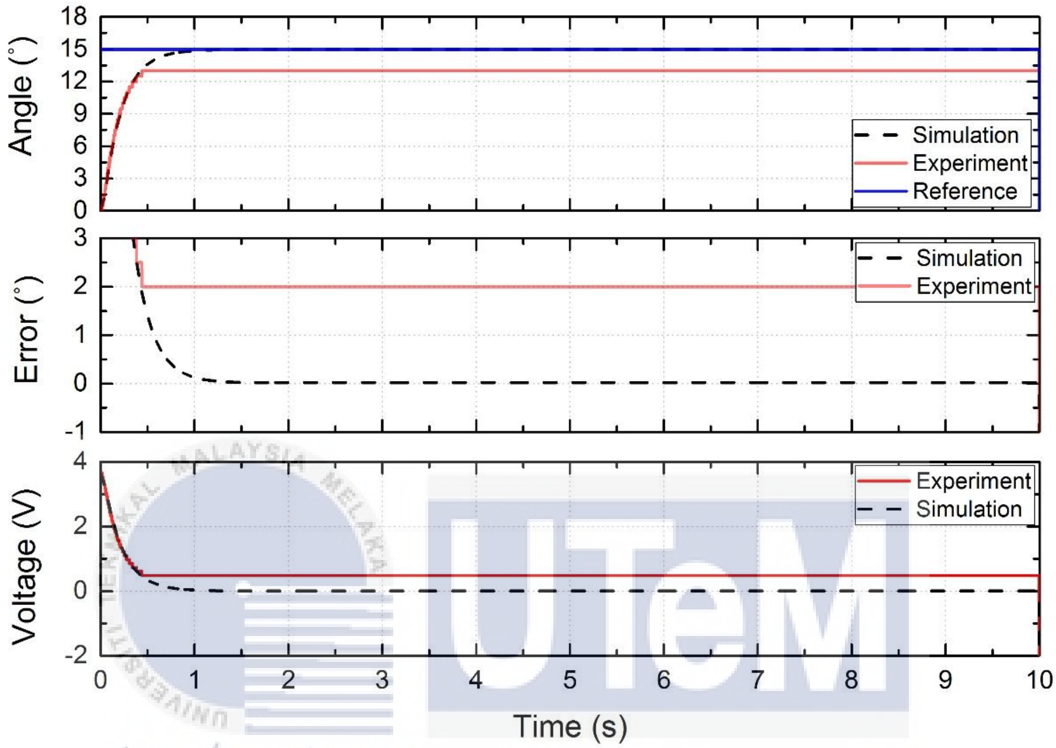

Figure 4.25: Ziegler Nichols Tuning Method with input angle 15˚ and Kp value of 5

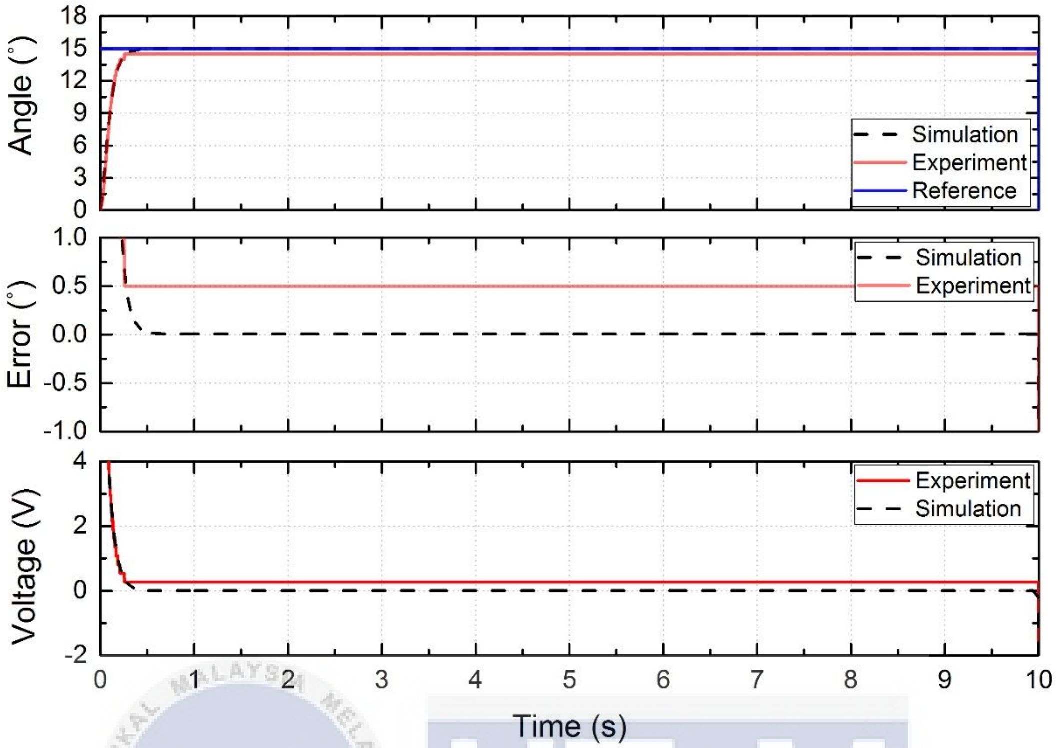

Figure 4.26: Ziegler Nichols Tuning Method with input angle 15˚ and Kp value of 11

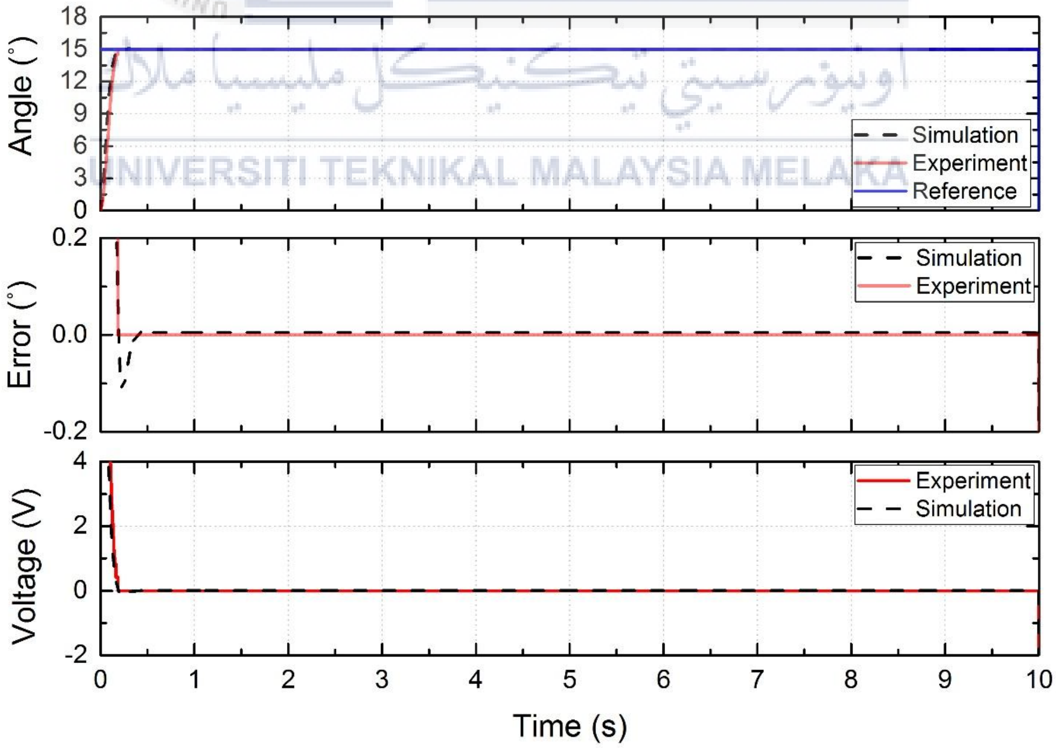

Figure 4.27: Ziegler Nichols Tuning Method with input angle 15˚ and Kp value of 17

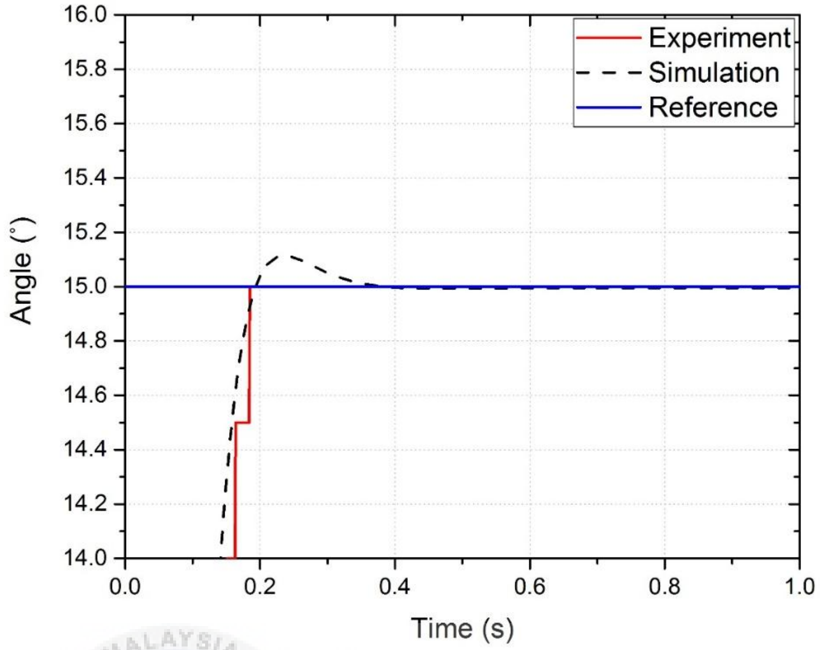

Figure 4.28: Zoom View of Angle for Kp value of 17

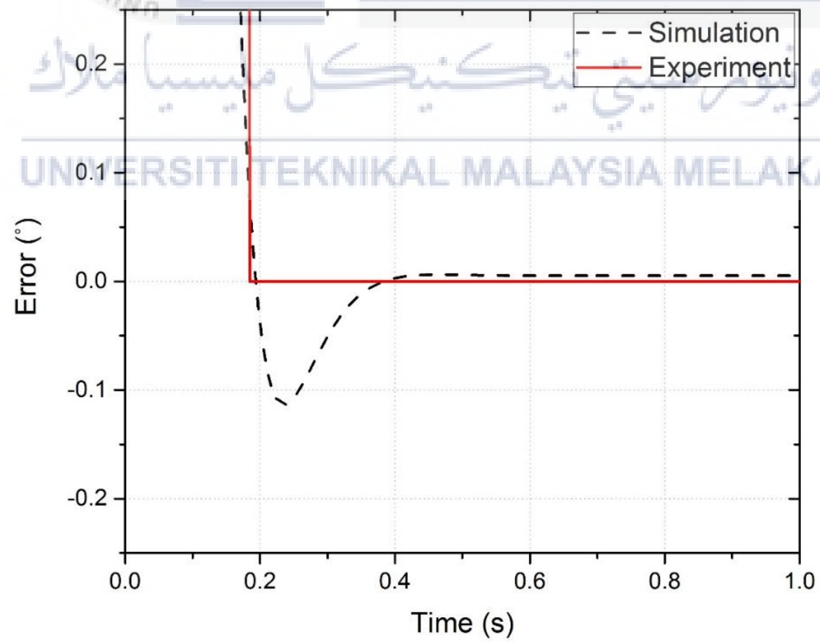

Figure 4.29: Zoom View of Error for Kp value of 17

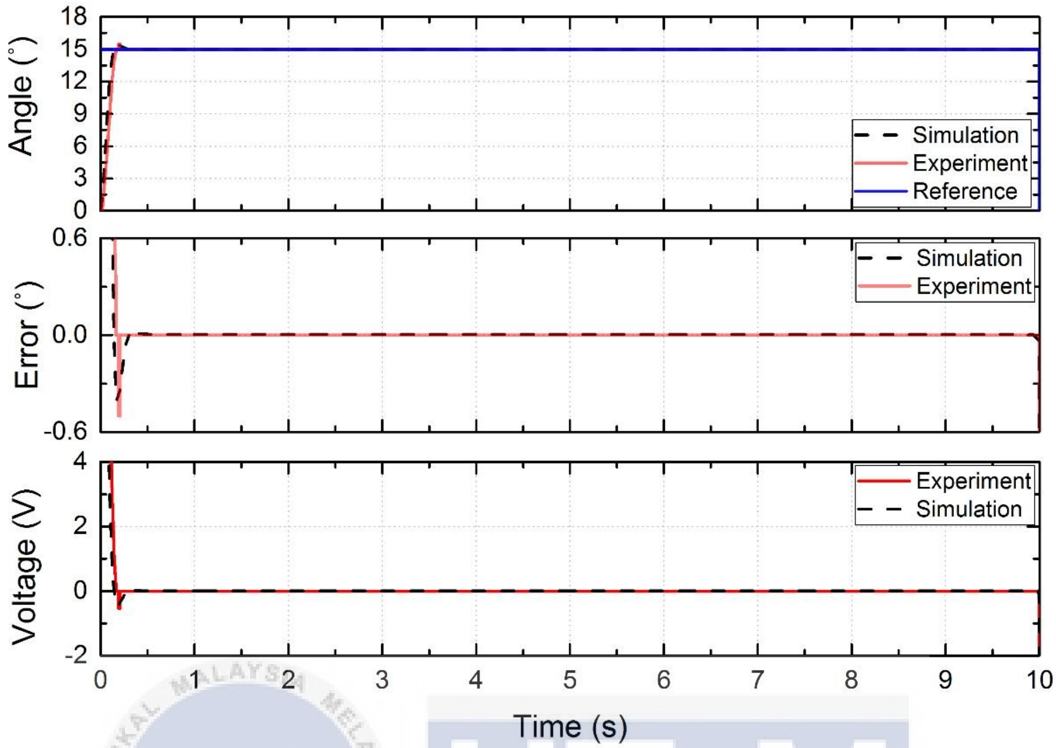

Figure 4.30: Ziegler Nichols Tuning Method with input angle 15˚ and Kp value of 23

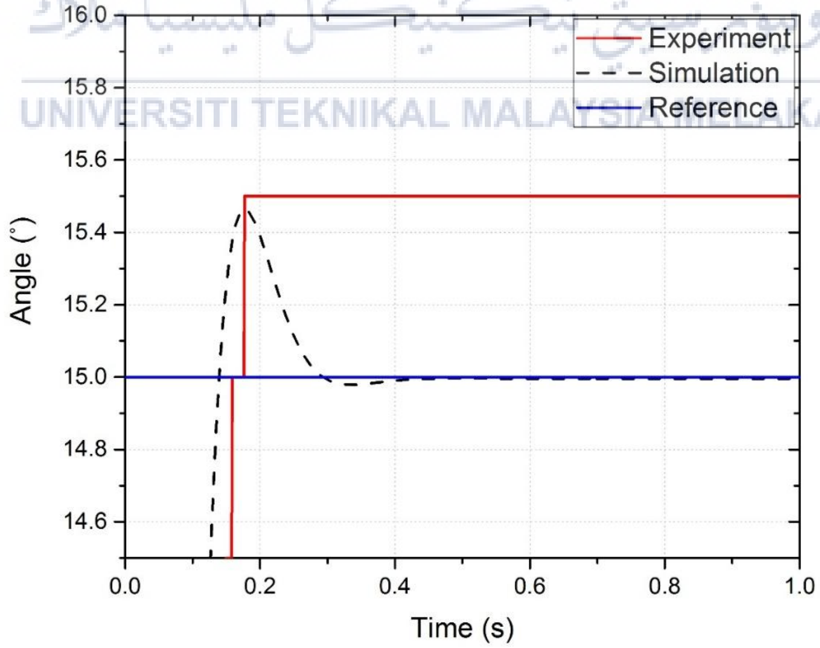

Figure 4.31: Zoom View of Angle for Kp value of 23

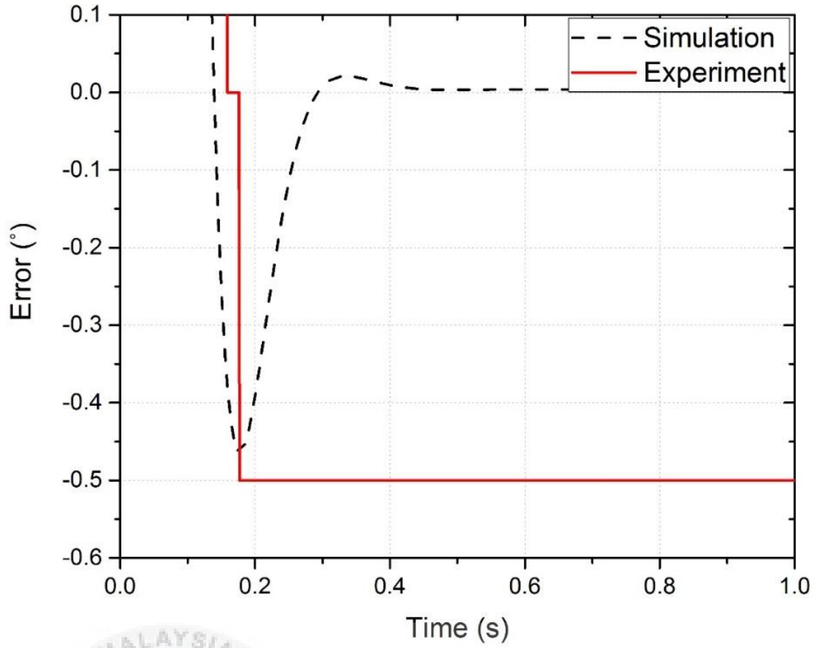

Figure 4.32: Zoom View of Error for Kp value of 17

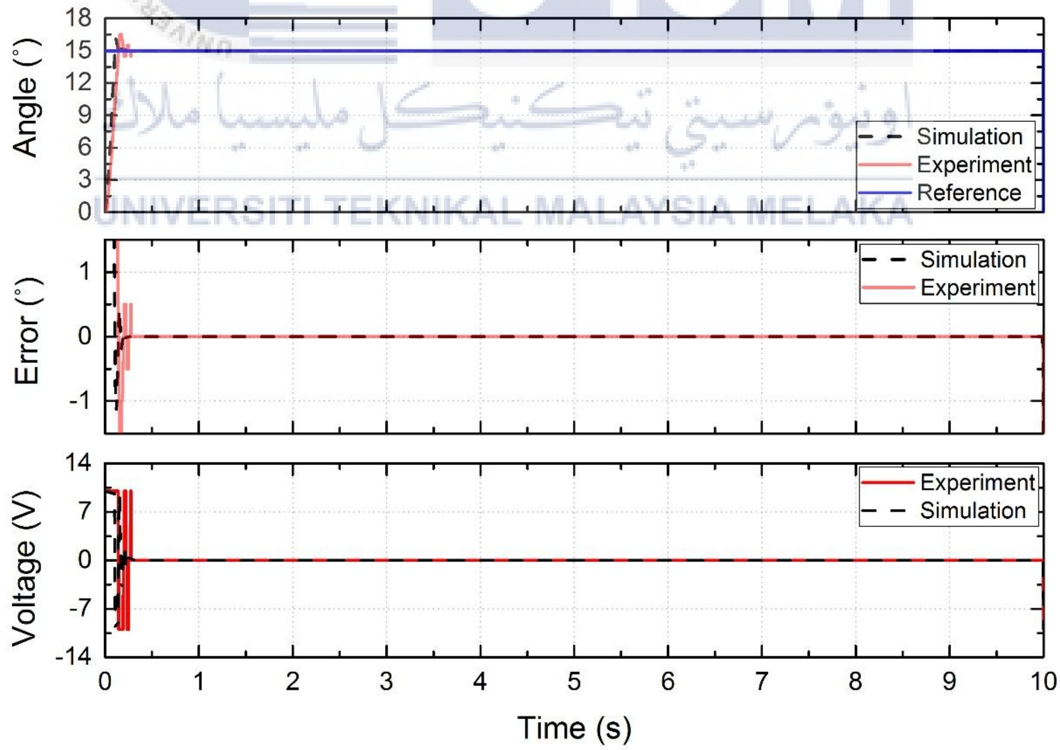

Figure 4.33: Ziegler Nichols Tuning Method with input angle 15˚ and Kp value of 90,000

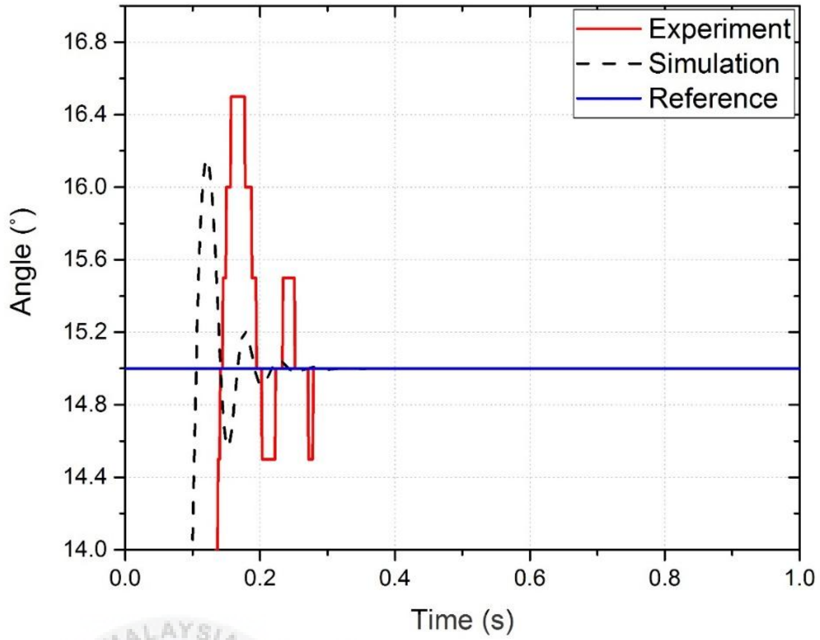

Figure 4.34: Zoom View of Angle for Kp value of 90,000

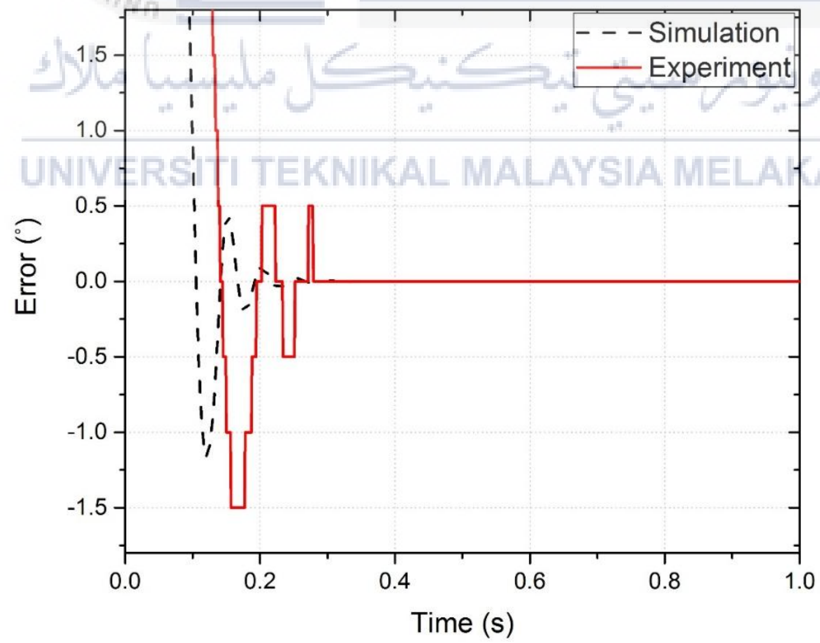

Figure 4.35: Zoom View of Error for Kp value of 90,000

Based on the results from Figure 4.25 to Figure 4.35, the system of robotic finger 5 with DC geared motor 2 shows that, the constant oscillation cannot be occured while the gain K was increased until 90,000. This situation occured due to the system is already stable with any input. The stability of the system has been proven by plotting the root locus graph as shown in Figure 4.36.

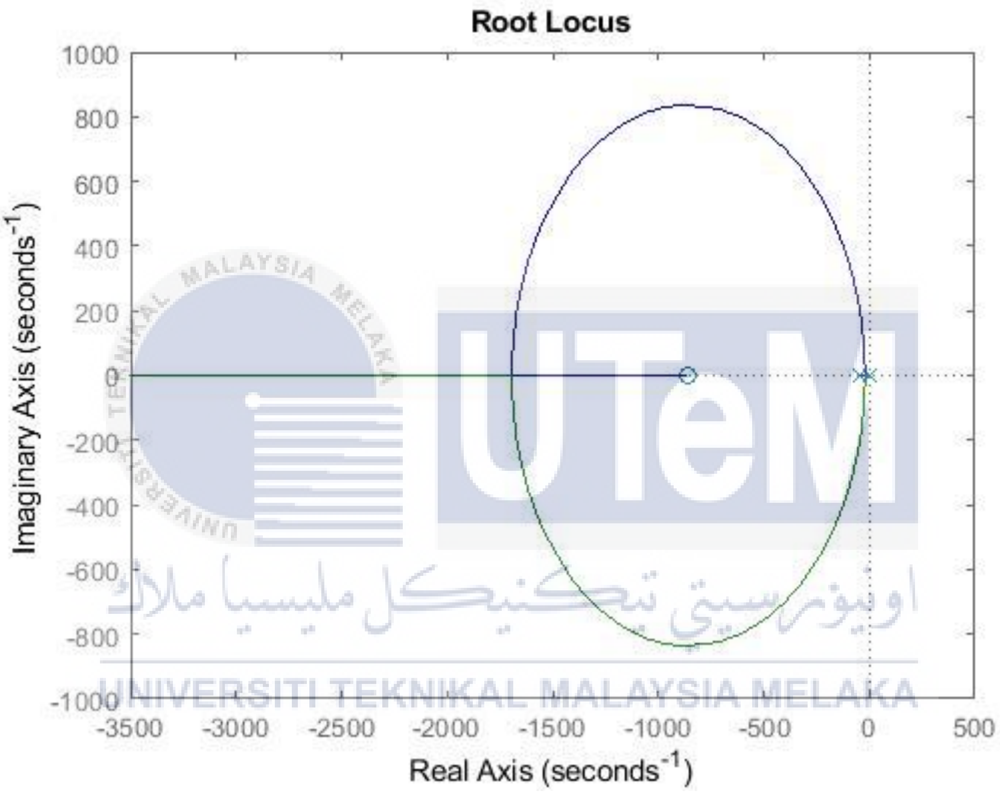

Figure 4.36: Stability of the System of Robotic Finger 5

Based on the root locus as shown in Figure 4.36, all the closed loop system poles strictly lie on the left hand pole (LHP). Since, the stability of the closed loop system where the closed loop pole must strictly lie in the LHP, the controller of robotic finger 5 with DC geared motor 2 stabilises the system by relocated the poles only on LHP. Therefore, Ziegler Nichols tuning method is not suitable to tune the PID controller for this system. Although, Trial and Error tuning method will be used in this system to tune the controller of the robotic finger 5 in order to achieve the performance of the system.

4.4.2 Trial an Error Tuning Method

The Proportional gain, Kp value for the robotic finger 5 had be increased until the output angle are proportional with the input angles. The gain is increased slowly then the results had been observed where the input angle is constant with 15˚. Figure 4.25 shows that when the Kp value increase from 0 to 5, the system was improved it performance with increasing the overshoot of the system from 5˚ to 13˚ while the error of the system had been reduced from 10˚ to 2˚. These observation had been compare with uncompensated results with input angle 15˚ as shown in Figure 4.19. Then the gain were be continue increase until the output angle are parallel with input angle. Figure 4.37 to Figure 4.44 shows the performance of the P Controller of the system.

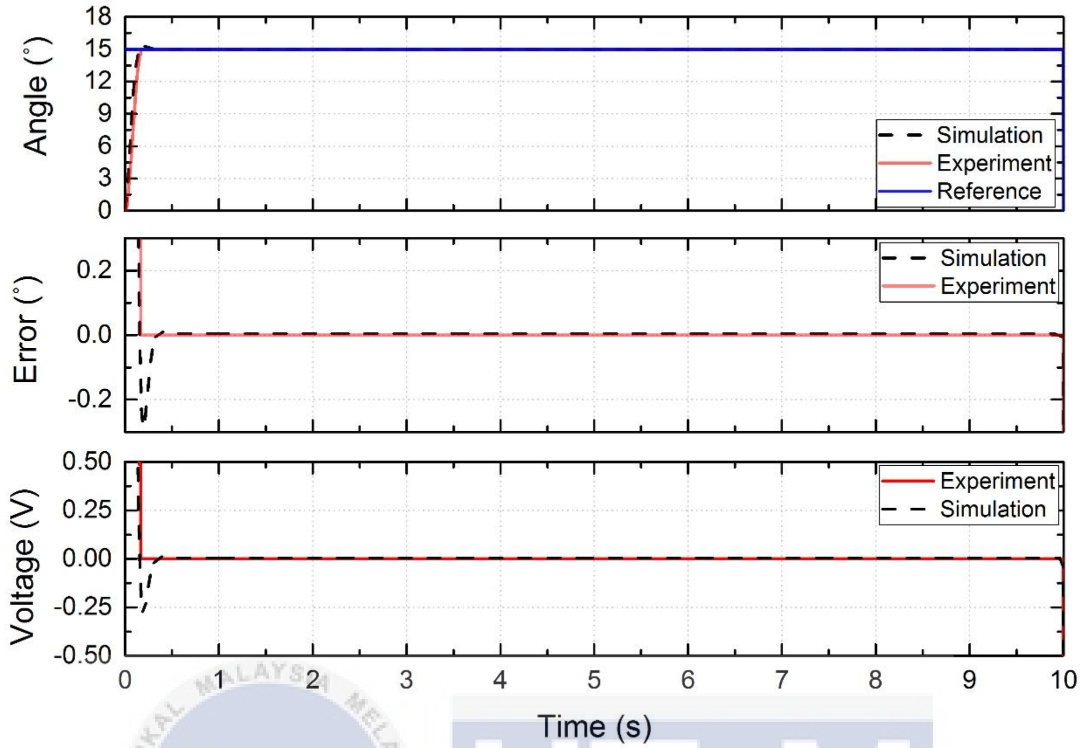

Figure 4.37: Robotic Finger 5 Performance with P Controller value of 20

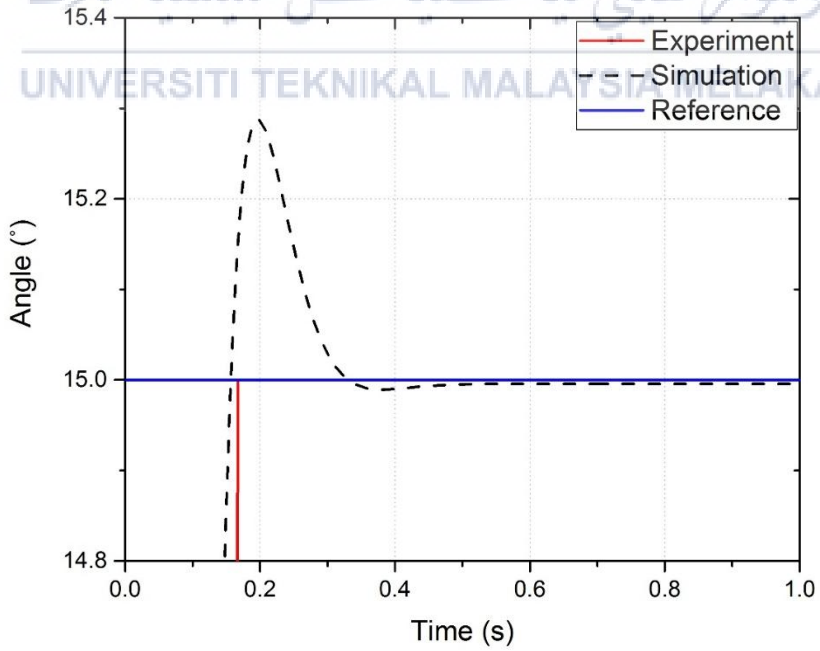

Figure 4.38: Zoom View of Angle for Kp value of 20

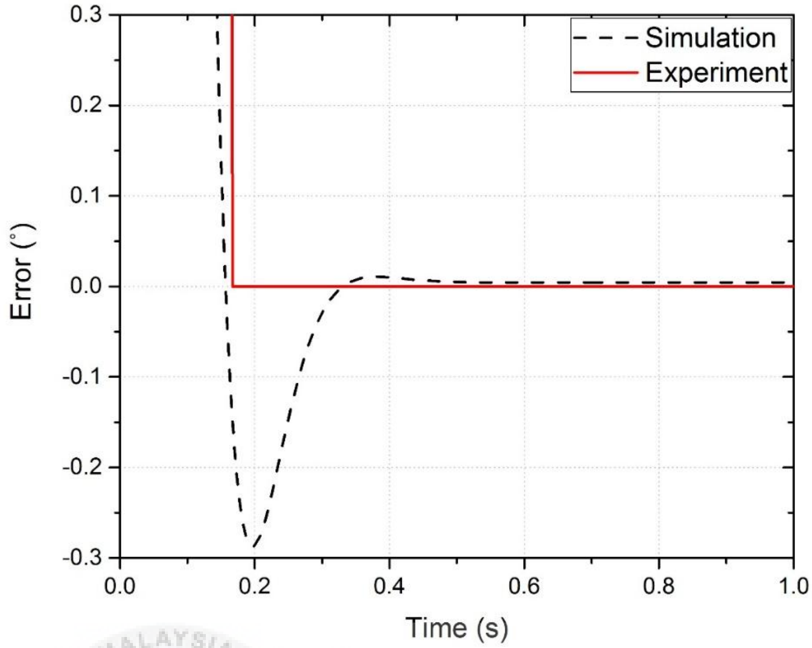

Figure 4.39: Zoom View of Error for Kp value of 20

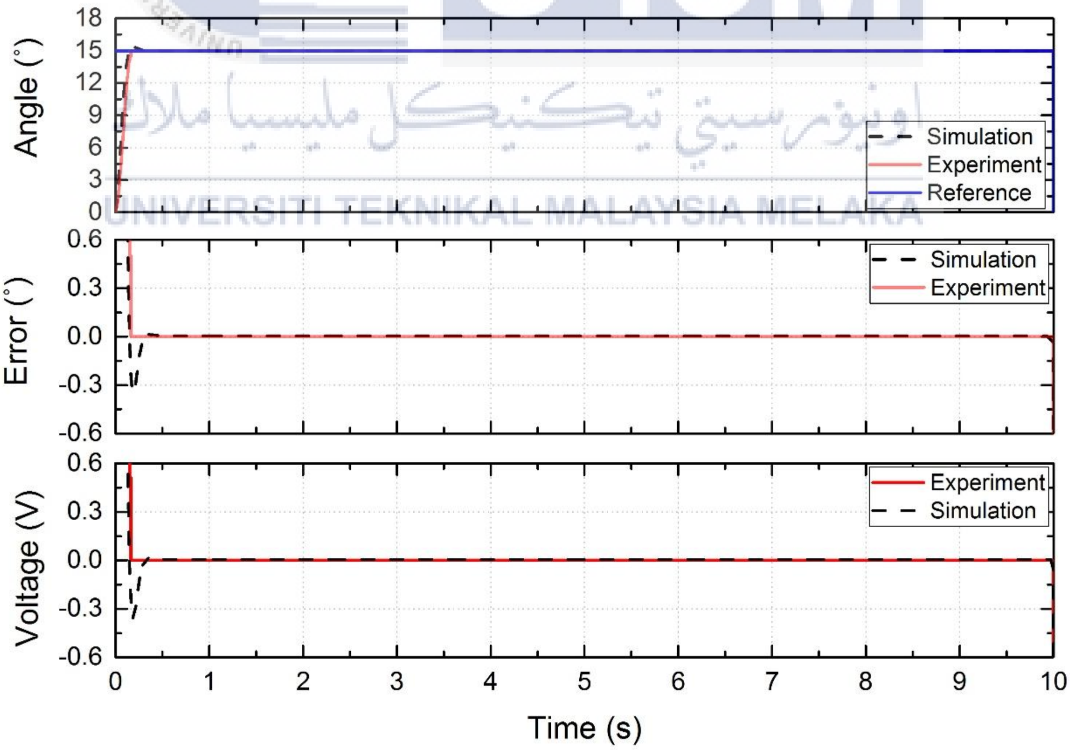

Figure 4.40: Robotic Finger 5 Performance with P Controller value of 21

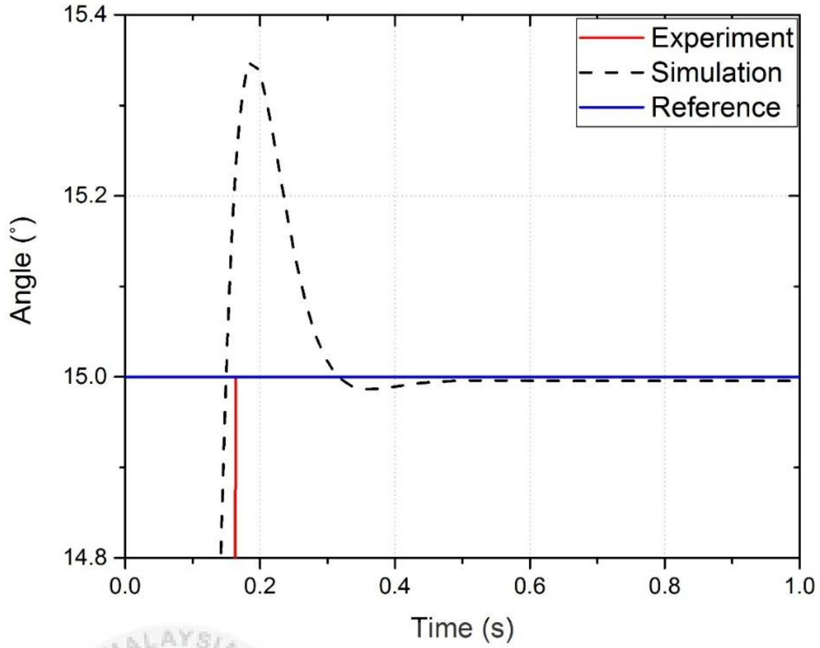

Figure 4.41: Zoom View of Angle for Kp value of 21

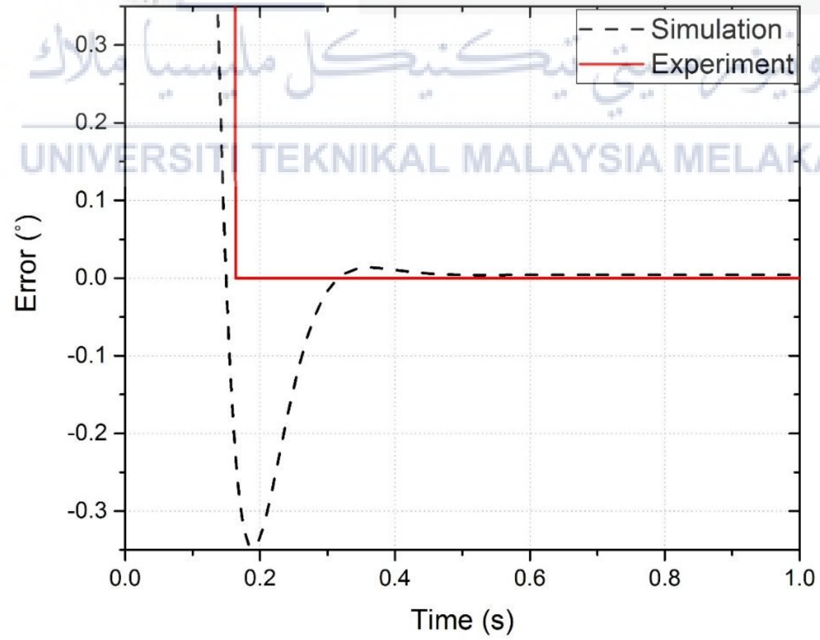

Figure 4.42: Zoom View of Error for Kp value of 21

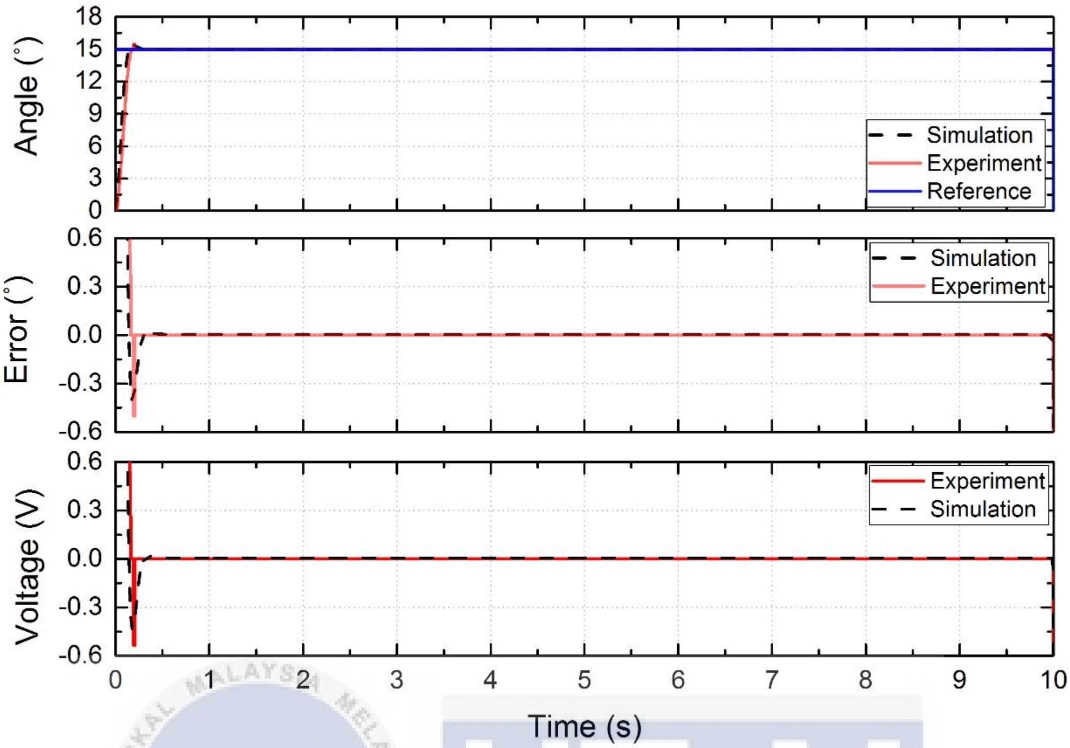

Figure 4.43: Robotic Finger 5 Performance with P Controller value of 22

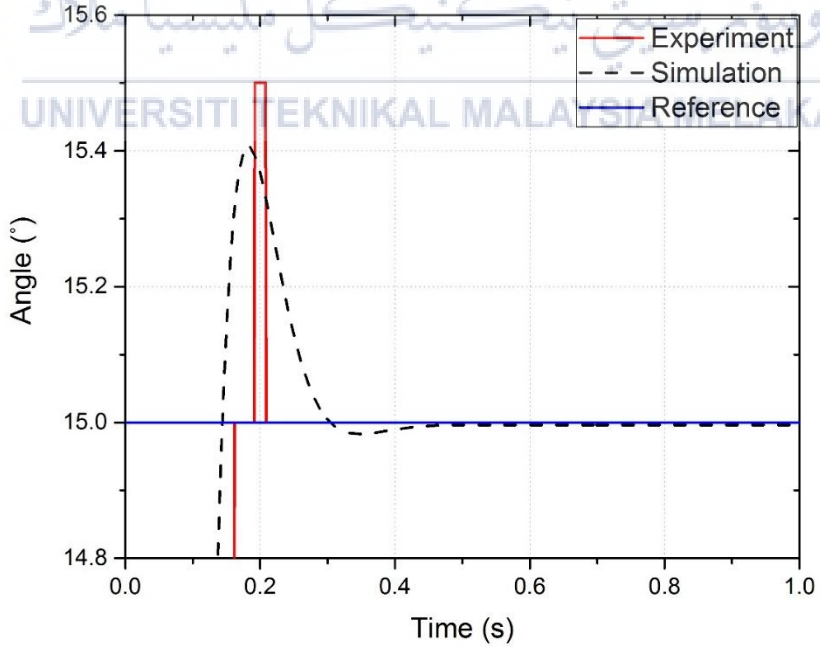

Figure 4.44: Zoom View of Angle for Kp value of 22

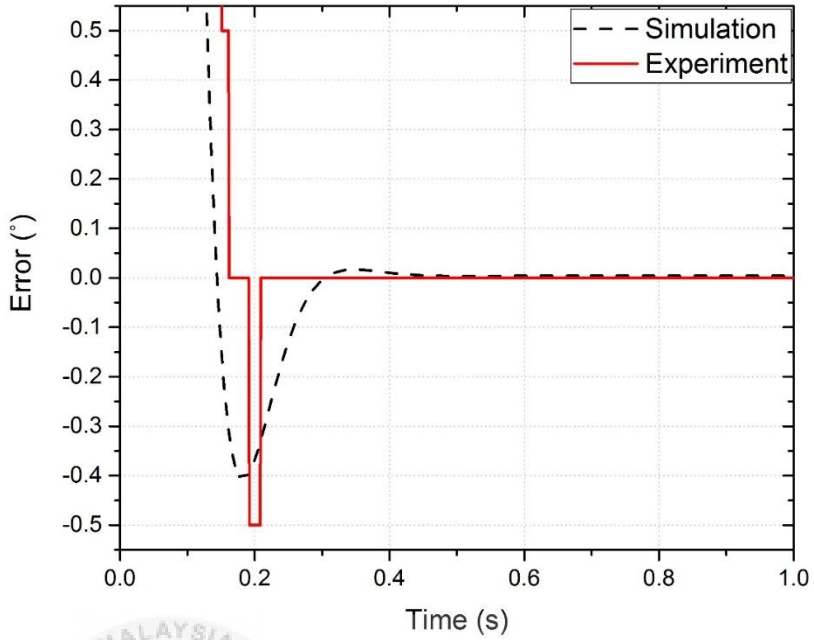

Figure 4.45: Zoom View of Error for Kp value of 22

From the results as shown in Figure 4.37 to Figure 4.45, gain Kp =20 shows better performance in term of low steady state error and low percentage of overshoot compare to gain 21 and 22. When gain, K is 21, the output angle produced a high percentage overshoot and biggest error on the system then the unstability of the system increased when then gain is increased. Due to this situation, Proportional gain of 20 will be used in the robotic finger 5 and the process tuning of the controller will be continue with Integral gain and then follow by Derivative gain.

Figure 4.46 and Table 4.12 show the performance of the robotic finger 5 with Proportional gain of 20. Meanwhile, the performance of tuning Proportional gain of 20 and Integral gain of 1 will be shown in Figure 4.47 and Table 4.13 while the Proportional gain of 20 and Derivative gain of 1 is show in Figure 4.48 and Table 4.14.

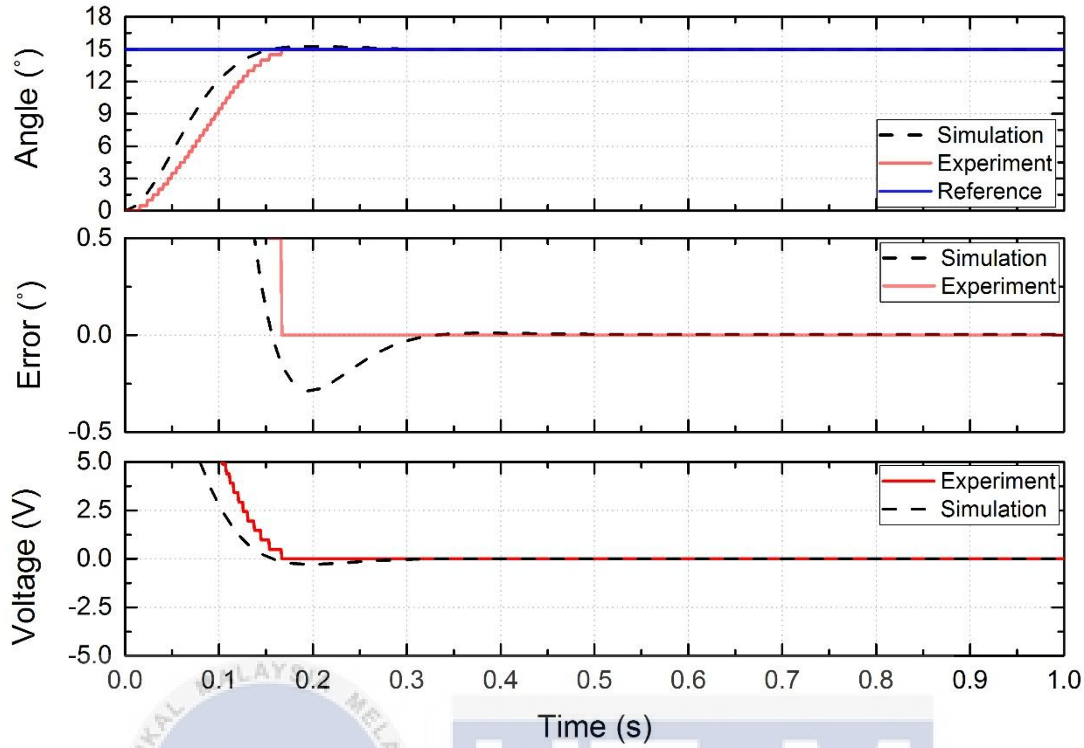

Figure 4.46: Robotic Finger 5 with P Controller

Table 4.12: Performance of Robotic Finger 5 with Kp = 20

System Response	**Experiment**	**Simulation**
Rise Time, Tr (s)	0.113	0.092
Settling Time, Ts (s)	0.167	0.225
Overshoot, OS (%)	0	1.896
Steady State Error, Ess (˚)	0	0.004467

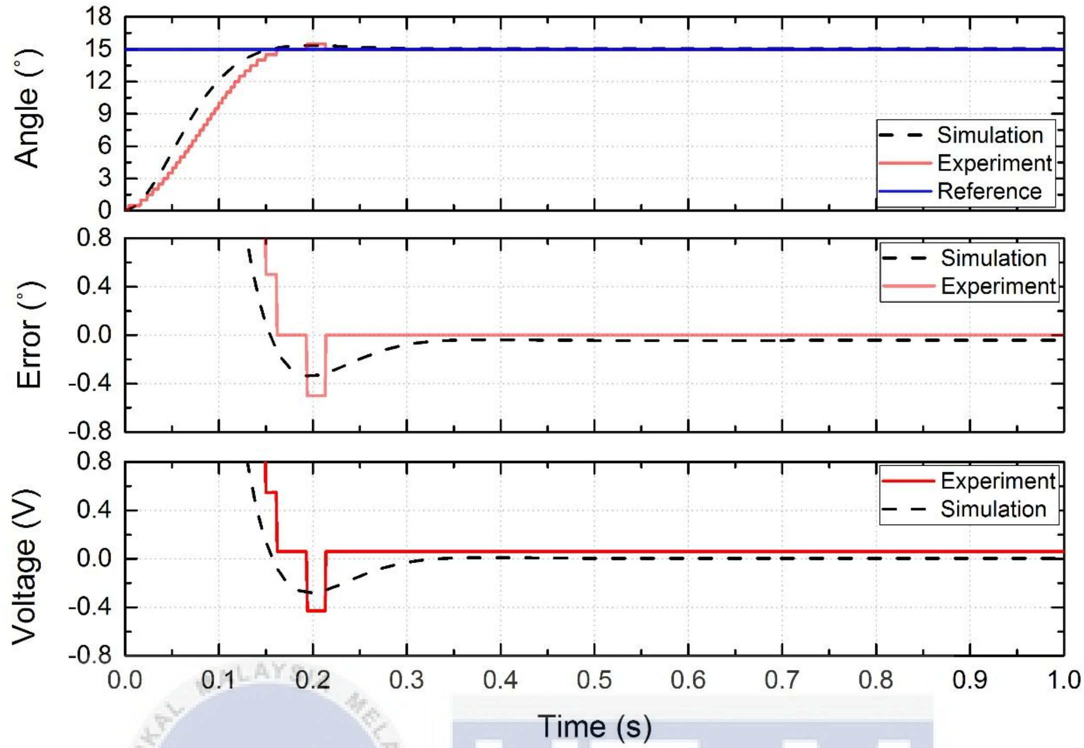

Figure 4.47: Robotic Finger 5 with PI Controller

Table 4.13: Performance of Robotic Finger 5 with Kp = 20 and Ki = 1

System Response	Experiment	Simulation
Rise Time, Tr (s)	0.1223	0.095
Settling Time, Ts (s)	0.162	0.250
Overshoot, OS (%)	3.223	2.2164
Steady State Error, Ess (°)	0	0.02712

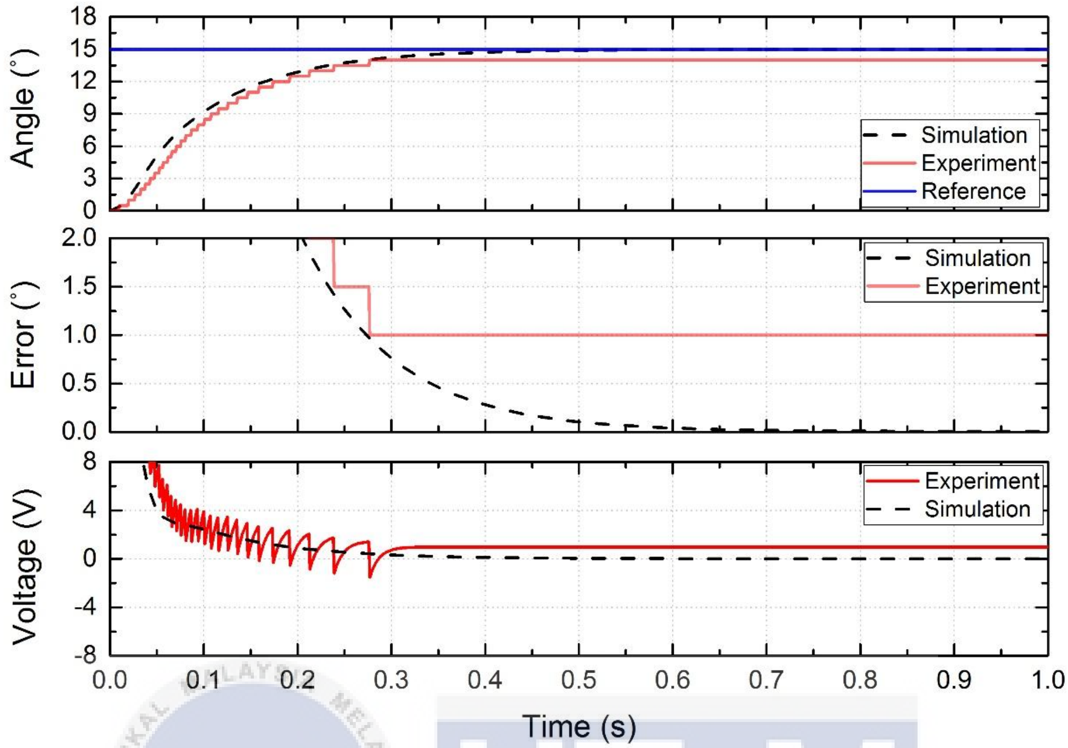

Figure 4.48: Robotic Finger 5 with PD Controller

Table 4.14: Performance of Robotic Finger 5 with Kp = 20 and Kd = 1

System Response	**Experiment**	**Simulation**
Rise Time, Tr (s)	0.1571	0.135
Settling Time, Ts (s)	0.272	0.432
Overshoot, OS (%)	0	1.896
Steady State Error, Ess (˚)	1	0.004467

Based on the Figure 4.46, Figure 4.47 and Figure 4.48, the Integral gain and Derivative not make any improvement to the system. So the Integral gain and Derivative gain will be neglected in the controller system. While only Proportional gain of 20 will be used in the robotic finger 5 and the transient response of the system with various Proportional gain are summarized as in Table 4.15.

Table 4.15: Comparison between Experiment Result of Robotic Finger 5 Performance with Proportional Gain Tuned

Proportional Gain, Kp	**Rise Time (s)**	**Settling Time (s)**	**Steady State Error (°)**	**Percentage Overshoot (%)**
2	0.354	0.573	3	0
5	0.274	0.437	2	0
8	0.184	0.322	1	0
11	0.146	0.241	0.5	0
14	0.125	0.198	0	0
17	0.115	0.175	0	0
20	0.113	0.167	0	0
21	0.114	0.163	0	0
22	0.114	0.152	0	3.225
23	0.114	0.153	0.5	3.226

Based on Table 4.15, the Proportional gain with Kp=20 shows better performance compare with others in term of fast rise time. Even though, the settling time is slower about 0.014s compare to Proportional gain from 21 to 23, but the 0.014s will not effect much performance of the robotic finger 5. So the P controller will be used in the robotic finger 5 with proportional gain of 20. The P controller has improve the performance of the system to fast rise time of 0.113s and settling time of 0.167. There was no percentage of overshoot and steady state error in the experiment results.

4.4.3 Performance of PID Controller on Robotic Finger 5

The PID controller is design in the system to improve the performance of the robotic finger in term of grasping motion control. The PID controller is design to reduce the rise time, settling time, percentage of overshoot and error that occur in the system will be eliminated. So the parameter for the PID controller consists of Proportional gain, Kp=20. Figure 4.49 until Figure 4.56 shows the Performance of the robotic finger 5 with PID controller for 15˚, 30˚, 45˚, 60˚, 70˚ and 90˚. Meanwhile the performance of the robotic finger 5 for experiment is summarize as in Table 4.16 while the simulation was shown in Table 4.17.

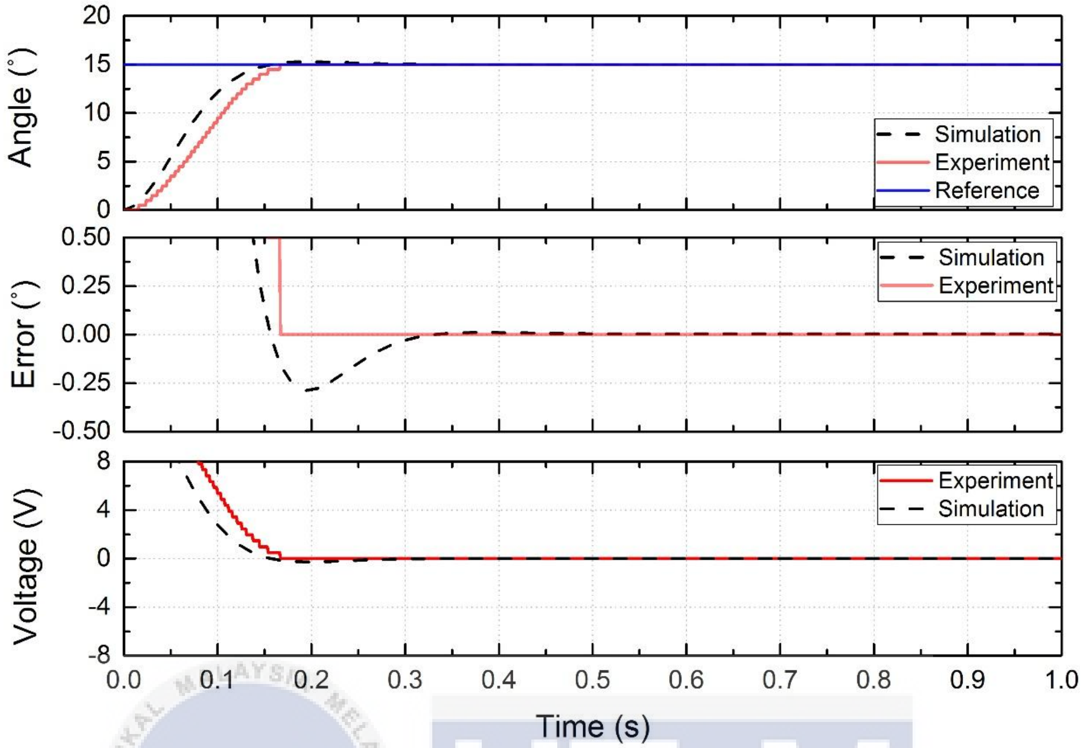

Figure 4.49: Performance of Robotic Finger 5 with PID Controller for 15˚ of Input Angle

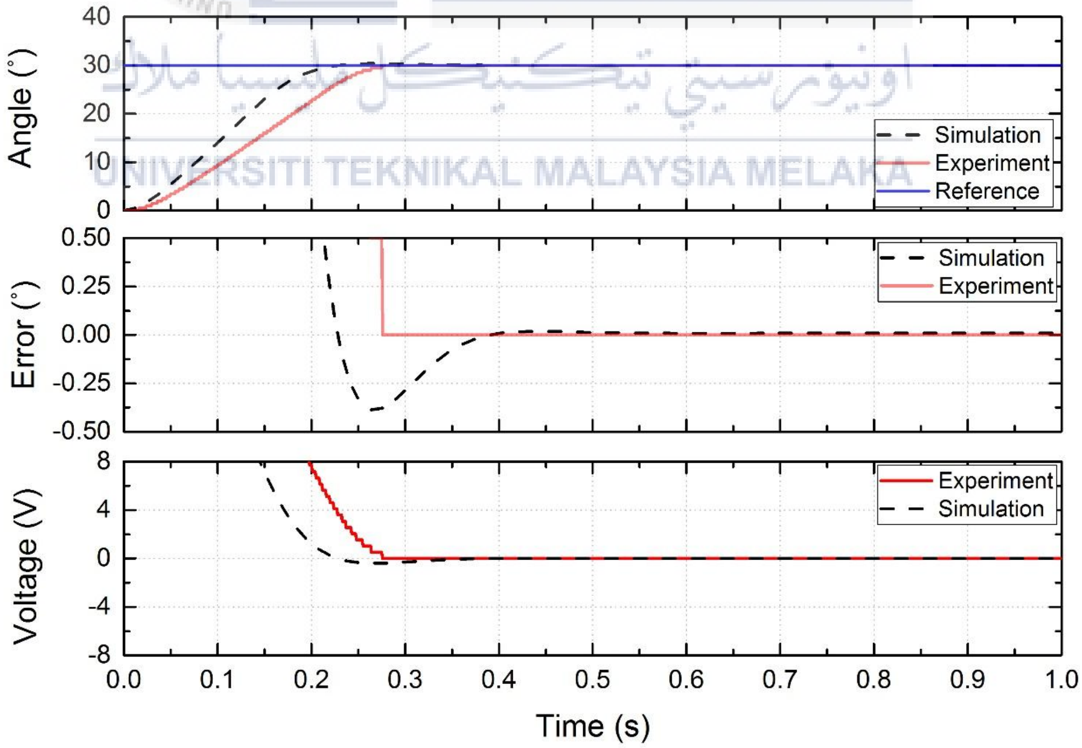

Figure 4.50: Performance of Robotic Finger 5 with PID Controller for 30˚ of Input Angle

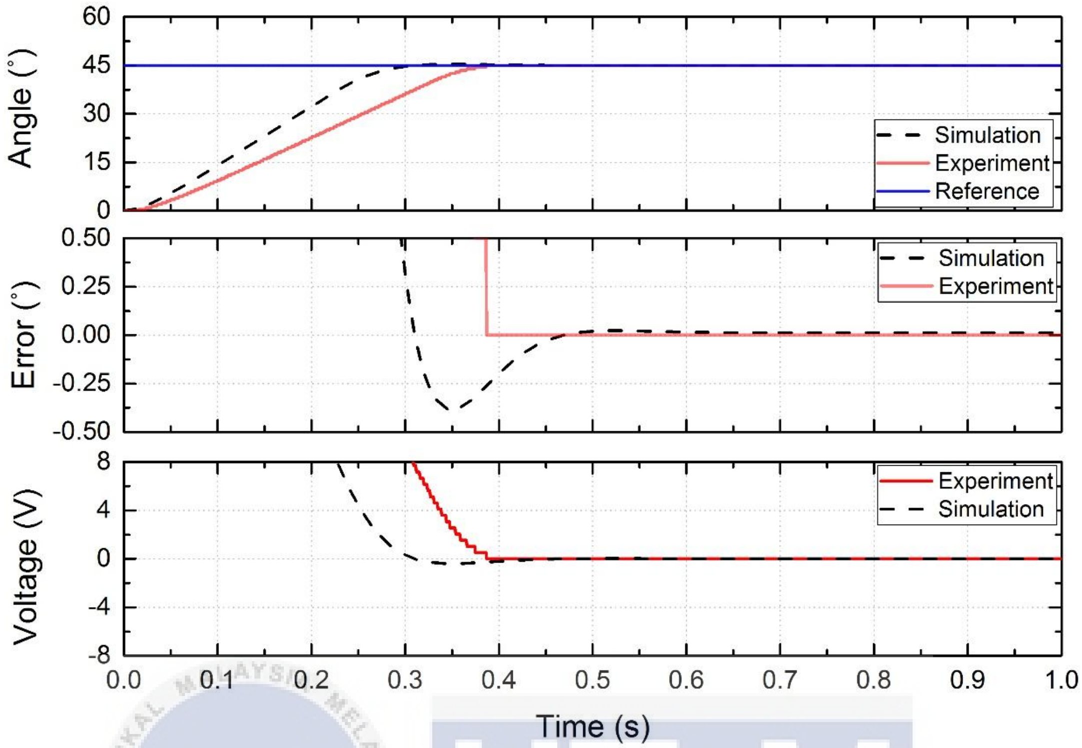

Figure 4.51: Performance of Robotic Finger 5 with PID Controller for 45˚ of Input Angle

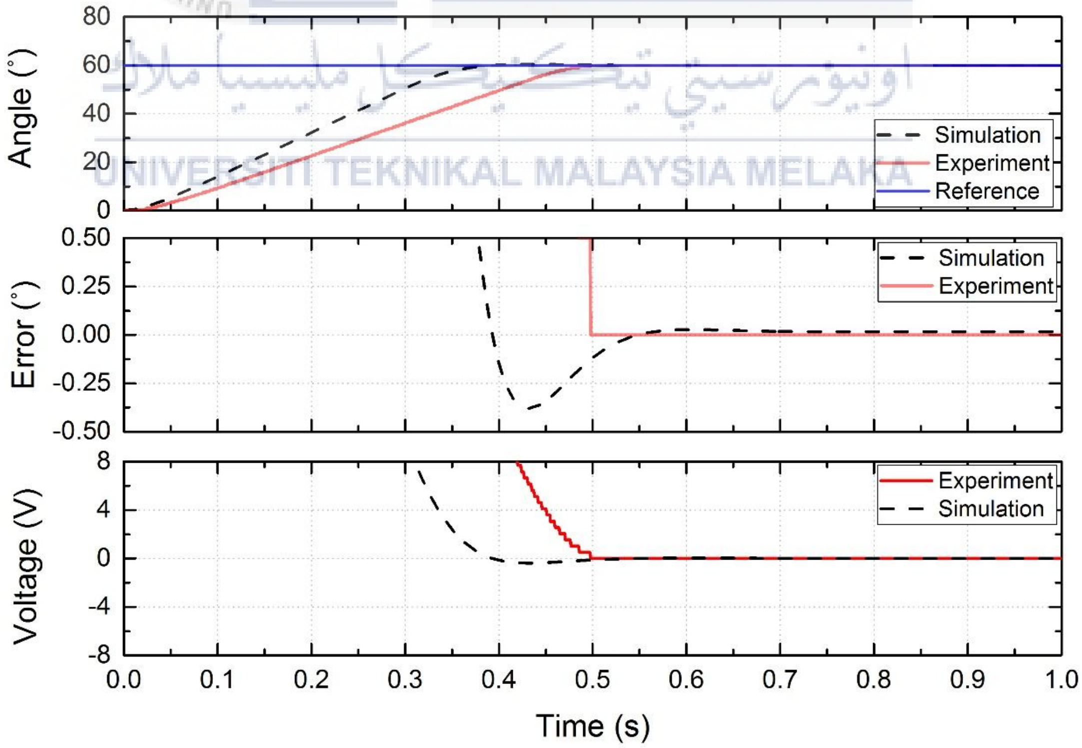

Figure 4.52: Performance of Robotic Finger 5 with PID Controller for 60˚ of Input Angle

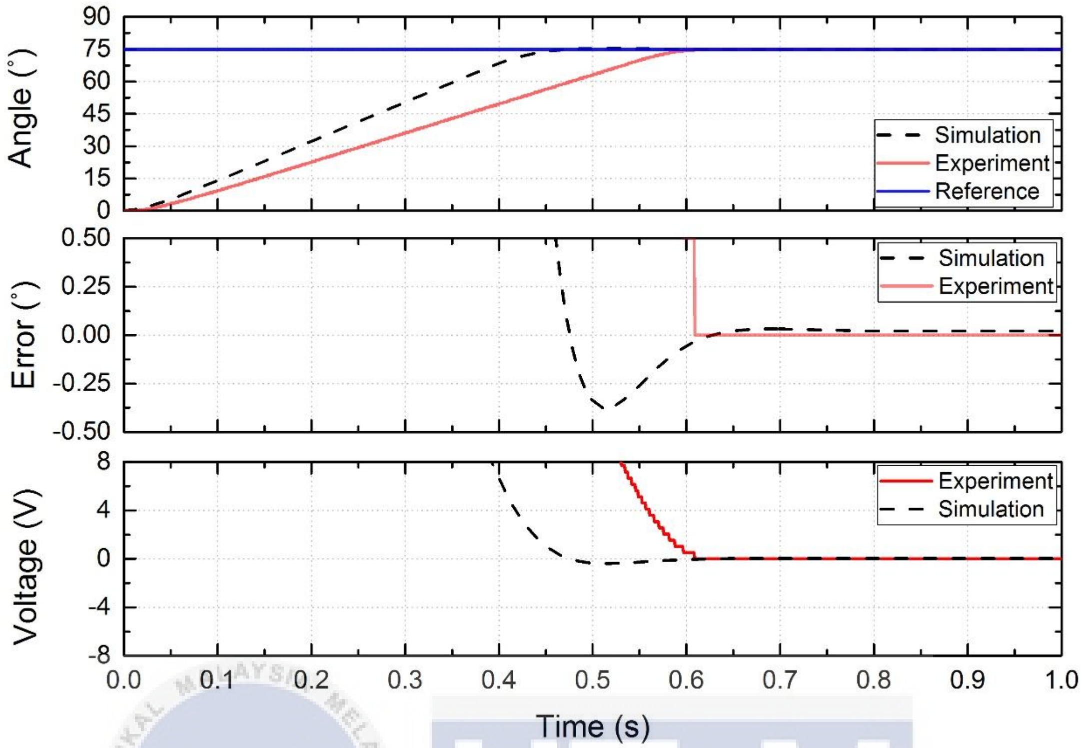

Figure 4.53: Performance of Robotic Finger 5 with PID Controller for 75˚ of Input Angle

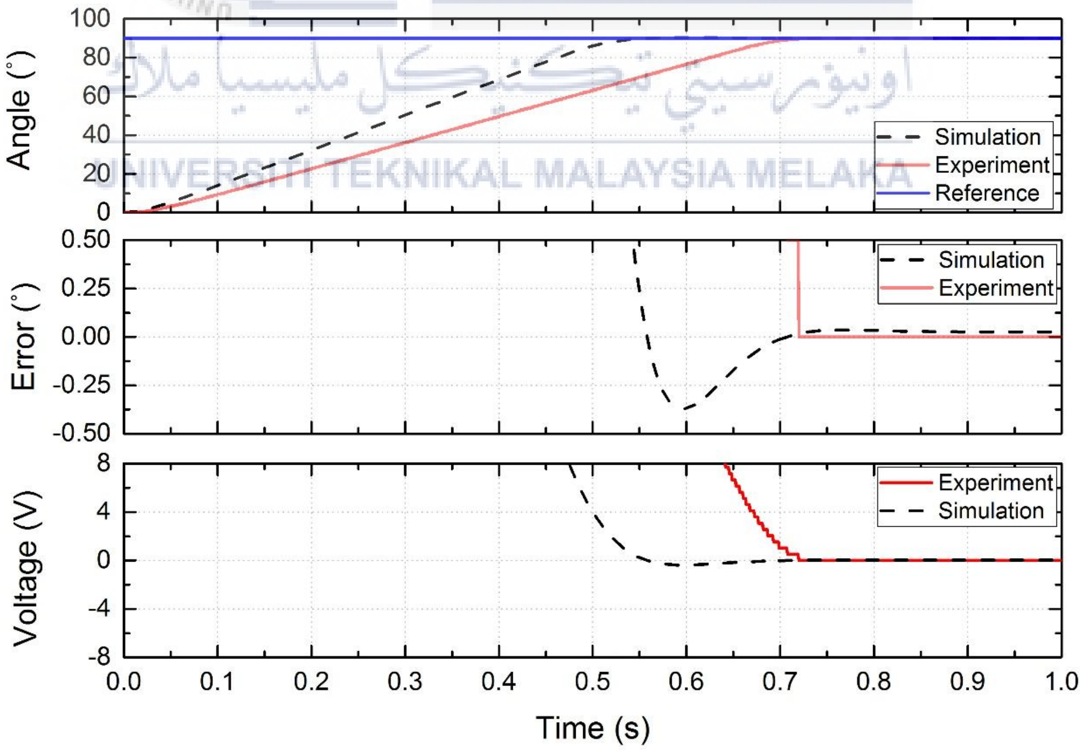

Figure 4.54: Performance of Robotic Finger 5 with PID Controller for 90˚ of Input Angle

Table 4.16: Performance of Robotic Finger 5 with PID Controller for Experiment

Angle (˚) / Step Response	Experiment					
	15	**30**	**45**	**60**	**75**	**90**
Rise Time (s)	0.113	0.221	0.331	0.445	0.556	0.665
Settling Time (s)	0.167	0.273	0.385	0.498	0.613	0.713
Percetage Overshoot (%)	0	0	0	0	0	0
Steady State Error (˚)	0	0	0	0	0	0

Table 4.17: Performance of Robotic Finger 5 with PID Controller for Simulation

Angle (˚) / Step Response	Simulation					
	15	**30**	**45**	**60**	**75**	**90**
Rise Time (s)	0.092	0.175	0.243	0.331	0.415	0.495
Settling Time (s)	0.225	0.282	0.362	0.478	0.539	0.633
Percetage Overshoot (%)	1.896	1.316	0.881	0.662	0.504	0.442
Steady State Error (˚)	0.0045	0.0085	0.0128	0.0170	0.0213	0.0225

Since there are various input angle used to analyze the robotic finger 5 with PID controller, the performance of experiment between uncompensated closed loop system and compensated closed loop system with PID controller for robotic finger 5 with input angle 15˚, 30˚ and 45˚ will be compare as in Table 4.18.

Table 4.18: Comparison Between Performance of Uncompensated and Compensated Closed Loop System for Robotic Finger 5

Angle (˚) / **Step Response**	**Uncompensated**			**PID**		
	15	**30**	**45**	**15**	**30**	**45**
Rise Time (s)	0.5200	1.1230	1.3840	0.113	0.221	0.331
Settling Time (s)	0.6608	1.5712	1.9206	0.167	0.273	0.385
Percetage Overshoot (%)	0	0	0	0	0	0
Steady State Error (˚)	9.5	10	10	0	0	0

Based on Table 4.18, the designed of closed loop system with PID controller has improve the performance of the robotic finger 5 with different input angle compare to uncompensated closed loop system without any controller. The comparison between uncompensated closed loop and compensated closed loop as shown in Figure 4.18, with input angle 15˚, the PID controller has inprove the rise time of the system from 0.5200s to

0.113s and the settling time from 0.6608s to 0.167s while the percentage of overshoot maintain the performance with 0 percentage overshoot. Lastly the designed of PID controller in the robotic finger 5 system has successfully eliminate the steady state error of 9.5˚ from uncompensated close loop system.

In general, the designed of PID controller has improve the performance of robotic finger 5 in term of reducing the rise time and settling time with less than 1s, percentage of overshoot with less than 1% and most importanlty in the system is the PID controller should eliminate the steady state error that occured in the system in order to achieve the grasping motion control of robotic hand mechanism. On the other hand, the relationship between angle of base reference of DC geared motor 2 and angle from robotic finger 5 to robotic hand palm will be shown in Figure 4.55 and Table 4.19.

Table 4.19: Relationship Between Angle of Base Reference And Angle of Finger 5 To Robotic Hand Palm

Angle of Base Reference (˚)	**Angle Finger 5 to Robotic Hand Palm (˚)**						
	Repeatability					**Average**	**Standard Deviation**
0	0	0	0	0	0	0	0
15	3.4	3.4	3.4	3.4	3.4	3.4	0
30	6.8	6.8	6.8	6.8	6.8	6.8	0
45	10.2	10.2	10.2	10.2	10.2	10.2	0

60	13.6	13.6	13.6	13.6	13.6	13.6	0
75	17.0	17.0	17.0	17.0	17.0	17.0	0
90	20.0	20.0	20.0	20.0	20.0	20.0	0

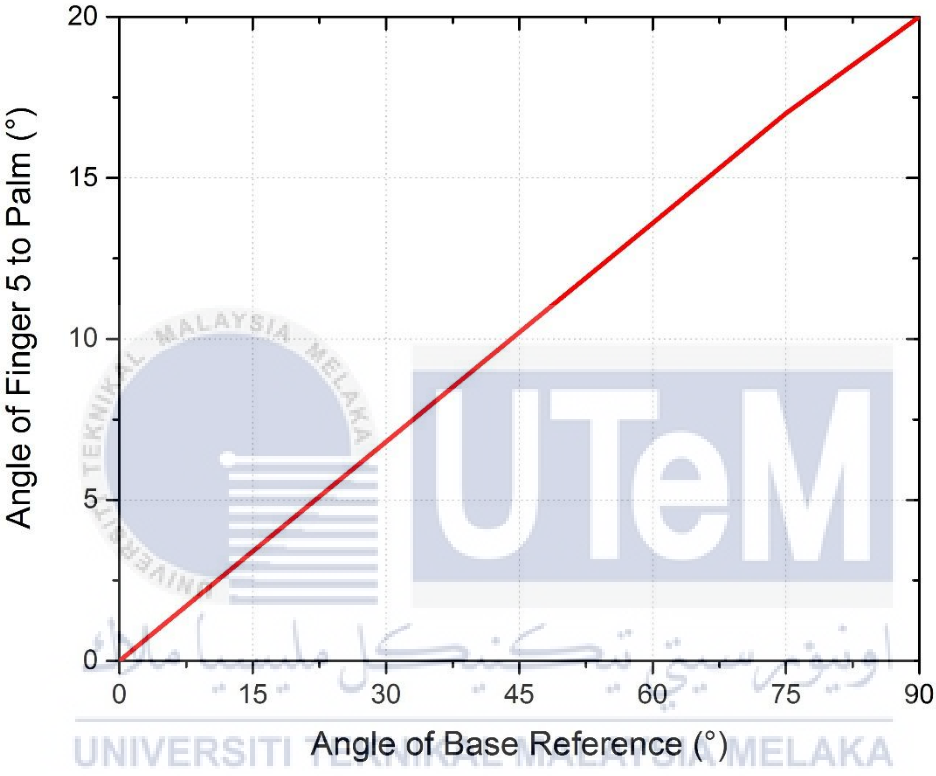

Figure 4.55: Relationship Between Angle of Base Reference And Angle of Finger 5 to Robotic Hand Palm

From Table 4.19 and Figure 4.55, the relationship between angle of base reference with DC geared motor and angle of finger 5 to robotic hand show linear characteristic system in which it can be summarized as equation 4.3.

The relationship between angle of base reference with DC geared motor and angle of finger 5 to robotic hand is with ratio 0.22665 where when 1˚ of input angle was supply to

DC geared motor 2, the finger 5 will require angle of 0.22665˚. Since the finger 5 is a linear characteristic system, the rotation of DC geared motor will cause the Finger 5 move linearly to the position as well.

4.5 Summary

In this project, the performance of robotic finger 5 with PID controller has been observed with various type of experiment. During the experiment of uncompensated closed loop system without controller, the Robotic Finger 5 show slower rise time, settling time and large steady state error. However, when the PID controller was added into the system with Proportional gain of 20, Integral gain of 0 and Derivative gain of 0, the system was successfully improve the transient response in term of fast rise time, settling time and steady state error was eliminated which the system was fulfill the characteristic of a grasping motion control. The results of comparison between experiment and simulation for uncompensated and compensated closed loop with PID controller are summarized into Table 4.20.

Table 4.20: Summary of Uncompensated and PID Controller

Angle (°) / Step Response	Uncompensated					
	15	**30**	**45**	**60**	**75**	**90**
Rise Time (s)	0.5200	1.1230	1.3840	1.5472	1.6432	1.7072
Settling Time (s)	0.6608	1.5712	1.9206	2.1830	2.3314	2.4338
Percetage Overshoot (%)	0	0	0	0	0	0
Steady State Error (°)	9.5	10	10	10	10	10
Angle (°) / Step Response	**PID Controller**					
	15	**30**	**45**	**60**	**75**	**90**
Rise Time (s)	0.092	0.175	0.243	0.331	0.415	0.495
Settling Time (s)	0.225	0.282	0.362	0.478	0.539	0.633
Percetage Overshoot (%)	1.896	1.316	0.881	0.662	0.504	0.442
Steady State Error (°)	0.0045	0.0085	0.0128	0.0170	0.0213	0.0225

However, the design of controller for grasping motion control of robotic hand mechanism only successfully done on robotic finger 5 with DC geared motor 2. The other finger which are finger 1 with DC geared motor 1 and finger 3 with DC geared motor 3 as shown in Figure 3.4 will be done in future works. This is because, this experiment project spend a long time to design the controller for robotic finger 5 with various repeatability on the experiment in order to make sure the system achieved the performance as desire results.

Other than that, the problem occured while tuning the PID controller with ziegler nichols tuning method, the system not produce constant oscillation on the output while the gain Kp was increased until 90,000. This problem causes the experiment to be repeated again in order to make sure that the output on the system will produce contant oscillation when proportional gain is increase. Then the problem can be conclude that, the ziegler nichols tuning method is not suitable method that can be use in this system due to the system is already stable by plotting the root locus graph.

Finally, the other finger which is finger 1 and finger 3 will be done design the controller in future work and will be combine together in MATLAB Simulink block diagram in order to perform the grasping motion control of robotic hand mechanism.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

As a conclusion, all objectives for Final Year Project with title Grasping Motion Control of a Robotic Hand Mechanism has been achieved on Finger 5 only where the performance of open loop control system was evaluated. Then, the design of PID controller was also successfully improve the performance of Robotic Finger 5. In addition, the performance of the PID controller for Robotic Finger 5 was analyzed and compared the results between experiment and simulation method.

The important things before starting the experiment are to calibrate the gain for DC geared motor in order to ensure the encoder provide the correct value base on the resolution of DC geared motor. From the calibration on DC geared motor 2, the gain obtained was -0.5 where negative sign indicate that the rotation of DC geared motor was in clockwise direction. Then, the open loop test was done on Robotic Finger 5 with 5 time repeatability in order to obtain the characteristic equation of the Robotic Finger 5. The characteristic equation of the mathematical model obtained through the System Identification Tools in MATLAB where ten transfer function might be generated for each input voltage supply. Then, the smallest error from the transfer function will be selected to represent the characteristic equation of Robotic Finger 5. So the transfer function 2 with characteristic equation of $G(s) = \frac{0.8711s+747.3}{s^2+40.96s+0.2172}$ was choose as to represent the robotic finger 5.

Then uncompensated closed loop system was developed using a plant transfer function to provide a feedback to the input for improving the system performance. However, the uncompensated closed loop system do not perform its performance as well in grasping motion control where the finger 5 has slow rise time and long settling time while the system provided large steady state error. In order to improve the performance of the system in term of rise time, settling time and eliminate steady state error, PID controller was designed into the system.

The Proportional-Integral-Derivative (PID) controller was designed based on the uncompensated closed loop system designed to further improve the overall system performance of the robotic hand. There are two method to tuning the PID controller which is Ziegler Nichols tuning method and Trial and Error tuning method. However, the robotic finger 5 only using Trial and Error tuning method to improve the performance of the system due to the system was already stable with any input. The Trial and Error tuning method was done where only Proportional gain was adjusted until the robotic finger 5 shows better performance in grasping motion control. So the parameter of PID controller were Proportional gain of 20, Integral gain of 0 and Derivative gain of 0. The design of PID controller was successfully improve the performance of the system where the robotic finger 5 has fast rise time, short settling time and steady state error was eliminated compare to uncompensated closed loop system. Moreover, the relationship between angle of DC geared motor and angle of finger 5 was analyze and generated a general equation which was, $Angle\ of\ Finger, F = 0.22665\ x\ (\ Angle\ of\ Encoder, E)$.

Lastly, the comparison between the performance of real time simulation and real time experiments from the Micro-Box was done. The result shows that the performance of the grasping motion control depend on the tuning controller.

5.2 Recommendation

The PID controller has successfully designed for robotic finger 5 to perform the grasping motion control. However, the grasping were not perform only for 1 finger. So, the suggested for future works are list below.

i. Design the controller for other finger for grasping motion control on robotic hand

The project only successfully done on the performance of robotic finger 5 with DC geared motor 2. Whereas the other finger which are finger 1 and 3 will be done in future work. Then all the controller which is controller for finger 1, 3 and 5 will be combine together in MATLAB Simulink block diagram in order to perform the grasping motion control of a robotic hand mechanism.

ii. Design Artificial Intelligent Controller

The artificial intelligent is a controller technique such as Fuzzy logic controller, Neural Network controller and Genetic Algorithms controller have been used to solve the problem occurred on the robotic hand due to PID controller cannot provide satisfactory position in the highly nonlinear system. The nonlinear system produce a better performance for grasping motion control of the robotic hand compare to linear system. The previous research shows that by using artificial intelligent on the robotic hand, it was providing more effective compare to PID controller in term of high accuracy and precision to the grasping motion of robotic hand. The artificial controllers are more powerful than PID controller because it can operate under non-linear characteristic. Furthermore, artificial intelligent controller can learn and produce the output based on the knowledge base. Then, the results for the performance of Artificial Intelligent controller and PID controller will be compared.

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APPENDICES

APPENDIX A GANTT CHART

DURATION / ACTIVITIES	FYP I													FYP II														
	SEP			OCT				NOV				DIS		FEB		MAR				APR				MAY				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Literature Review i. Search & Review journal	■	■	■	■	■	■																						
ii. Journal Summarize		■	■	■	■	■	■																					
Introduction i. Background				■	■	■	■																					
ii. Motivation				■	■	■	■																					
iii. Problem Statement				■	■	■	■																					
iv. Objective and Scope				■	■	■	■																					
Learning i. Micro-box									■	■	■	■																
Research Methodology i. Robotic Hand & Equipment Setup														■	■	■	■	■										
ii. Open-Loop System														■	■	■	■	■										
iii. System Modelling														■	■	■	■	■										
iv. Uncompensated Close - Loop System														■	■	■	■	■										
v. Compensated Closed-Loop System														■	■	■	■	■										
Experiment and Simulation Process																			■	■	■	■	■					
Result and Discussion i. Open-Loop Result & Analysis																			■	■	■	■	■					
ii. Closed-Loop Result & Analysis																			■	■	■	■	■					
Preparation Final Report												■	■											■	■	■	■	
Presentation FYP I											■																	
Presentation FYP II																												■