"I hereby declare that I have read through this report entitle "Arm Rehabilitation Device Controller Based on Fuzzy Logic Techniques" and found out that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)"

Signature :…………………………………………

Supervisor's Name :…………………………………………

Date :…………………………………………

ARM REHABILITATION DEVICE CONTROLLER BASED ON FUZZY LOGIC TECHNIQUES

NA EISYAH SARAH BINTI MUSTAFA

A report submitted in partial fulfillment of the requirements for the degree of

Bachelor of Electrical Engineering (Control, Instrumentation and Automation)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

I declare that this report entitle "*Arm Rehabilitation Device Controller based on Fuzzy Logic Techniques*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………………………………

Name : ……………………………………………

Date : ……………………………………………

To my beloved mother and father

ACKNOWLEDGEMENT

Alhamdulillah. This final year report is basically for student in final year to complete the undergraduate program that leads to the Bachelor of Electrical Engineering. I would like to extend my appreciation especially to the following.

Firstly, I would like to express my highest appreciation and gratitude to my supervisor, Mr. Mohd Hafiz bin Jali who has guided me during conducting this project and for the continuous support on my final year project research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and completing this project.

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ABSTRACT

In this thesis, the arm rehabilitation device controller based on fuzzy logic techniques is presented. Patients who has post-stroke may lose control of their upper limb. If they are treated with functional rehabilitation training, the patients can rehabilitate their motion functions and working abilities. These rehabilitation devices are used to recover the movement of arm after stroke. Many controllers had been used for the rehabilitation device and one of them is ANFIS-PID controller where Adaptive Neuro-Fuzzy Inference System (ANFIS) technique is the combination of fuzzy logic and neural network system. The objectives of this project are to develop arm rehabilitation device based on fuzzy logic techniques for rehabilitation. This paper presents the development mathematical modeling of the arm rehabilitation device by using System Identification and to design ANFIS-PID controller. Several transfer function is evaluated in order to represent the best performances for the system. The derived model is validated via simulation and experimental for stability analysis. Whereas the developed ANFIS is purposely as an inverse model to the system and there is a proportional-integral-derivative (PID) controller as a feedback control. EMG model also is integrated to the control system where Artificial Neural Network (ANN) is used to model the EMG. Simulation is conducted using MATLAB to validate the system performance that is integrated with EMG model via simulation. Then the performance is compared between ANFIS-PID controller and PID alone controller. ANFIS–PID controller reduced more tracking error compared to PID controller and demonstrates better results when applied to control system via simulation.

ABSTRAK

Dalam kertas ini, alat kawalan rehabilitasi lengan berdasarkan teknik *fuzzy logic* dibentangkan. Pesakit awal strok akan menghadapi masalah pergerakan anggota badan bahagian atas kebiasaanya pada lengan, pergelangan tangan, dan bahu. Untungnya, kebanyakan pesakit boleh dipulihkan fungsi motif dan juga kebolehan pergerakan jika mereka dirawat dengan latihan rehabilitasi yang efektif. Alat robotic digunakan untuk memulihkan pergerakan lengan selepas strok. Banyak jenis kawalan yang telah digunakan untuk penggunaan alat rehabilitasi dan salah satunya ialah *ANFIS-PID Controller* dimana teknik *Adaptive Neuro-Fuzzy Inference System (ANFIS)* yang juga kombinasi dari pada system *fuzzy logic* dan *neural network.* Tujuan projek ini adalah untuk memajukan alat kawalan rehabilitasi lengan berdasarkan teknik *fuzzy logic*. Kertas kerja ini membentangkan model matematikal menggunakan Sistem Identifikasi untuk alat rehabilitasi lengan dan kemudian *ANFIS-PID Controller* direka bentukkan. Beberapa *transfer function* akan dinilai dan dianalisis untuk memberikan hasil respon yg terbaik untuk system ini. Model tersebut akan disahkan melalui simulasi dan experimentasi untuk analisis kestabilan. Manakala perkembangan ANFIS adalah bertujuan sebagai *inverse model* kepada sistem dan terdapat *PID controller* sebagai kawalan tindak balas. Model EMG juga diaplikasikan ke sistem kawalan dimana *Artificial Neural Network (ANN)* digunakan untuk memodelkan EMG. Simulasi dijalankan menggunakan MATLAB untuk mengesahkan respon sistem apabila EMG diaplikasikan melalui simulasi. Kemudian, respon tersebut akan dibandingkan antara *ANFIS-PID controller* dan *PID controller*. *ANFIS-PID controller* mengurangkan lebih banyak *tracking error* berbanding *PID controller* dan mendemonstrasikan keputusan yang bagus apabila diaplikasikan dalam sistem kawalan melalui simulasi.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Stroke is the third largest cause of death in Malaysia [1]. Ever year estimated about 40,000 people in Malaysia suffer from stroke and it is examined to be the single typical cause of severe disability. In 2010, American Heart Association identified the robot assisted therapy as a method of rehabilitation which can provide resistance or assistance of movement, accurate feedback, and also as a method to provide rehabilitation to the patient with less assistance from the therapist. Furthermore, it also mentions that “Current robots tend to exercise only the proximal arm, and then improve motor skills at the shoulder and elbow but not those of wrist and hand; consequently, robots that only train the shoulder and elbow are limited in their ability to improve completion of Activities of Daily Living (ADL)[2]”. Besides, various control techniques have been proposed and researched to solve the motion control problems, but the neural network and fuzzy logic are most reported design that relies on control techniques[3]. Artificial neural network and fuzzy logic is used by the researchers to control many types of human movements such as walking, cycling, free swing legs, swimming and some others movement. To compare with conventional, these techniques are a bit different and have unique abilities in identifying the relationship of mathematical in a complex system and operating of nonlinear system [4]. Furthermore, for the fuzzy modeling method, the neuro-adaptive learning technique gives a procedure to get information about the data set and hence the fuzzy logic able to evaluate the membership function parameters that enable the associated fuzzy inference system to follow the input and output data given [5]. ANFIS control algorithm is better performance due to its robustness in nonlinear systems [5]. ANFIS also generate intelligent self-learning by combining the fuzzy logic with the neural networks which led to many applications in the past time. Established on Sugeno type of inference system ANFIS has special architecture which able the use of hybrid learning algorithm [6]. This present paper purposes to develop an adaptive controller that gives a good performance compared to PID controller even when integrated with EMG model via simulation.

1.2 Motivation

i. To help stroke patients in activities they do in real life and decrease long term healthcare costs on stroke patient.

ii. The arm rehabilitation devices can achieve long term results compare to the therapist training.

iii. Modelling a plant along with a controller to gain a better performance in controller design.

iv. Overcome the limitation from previously control techniques.

1.3 Problem Statement

Nowadays, there are many researchers have carried out a lot of solution and design to improve the arm rehabilitation devices. However, most of the researchers only focused on kinematics models of rehabilitation devices. The arm rehabilitation devices must be more functional for example, in case of the controller used must be effective and robust to the desired system. Therefore, this project will be start by developing a mathematical modeling of the arm rehabilitation devices and designing ANFIS-PID controller. An accurate system modeling is crucially important to represent the system well. Inaccurate model will jeopardize the overall control system later on. Furthermore, the performance of the controller is validate by integrate EMG model via simulation. The proposed control system needs to become adaptive to the nonlinearity of the EMG model. MATLAB software will be used to analyze this project where the proposed controller design which is ANFIS-PID controller is compared with PID controller and validate via simulation in order to improves the functionality of the controller.

1.4 Objectives

The objectives of this project are

i. To develop mathematical modeling of the arm rehabilitation device using System Identification technique.

ii. To design ANFIS-PID controller for the system in term of position tracking using MATLAB/Simulink software.

iii. To validate the system performance that is integrated with EMG model via simulation.

1.5 Scope of project

In this study, the rehabilitation device only focuses on one arm/ upper limb muscle of the right hand while the wrist joint is neglected. To ensure project objectives are achieved, some scopes are identified which is;

i. Using System Identification to find transfer function from experimental data and evaluate the stability analysis.

ii. Modeling EMG position relationship using ANN.

iii. Fuzzy logic technique will be developed to design the ANFIS-PID controller for position tracking.

iv. The chosen software is MATLAB which is used in designing the controller and applied to the control system via simulation.

v. Integrate EMG model as references to the control system.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Literature review is a process reviewing written and published knowledge that related on this project and which is included in research through the journal, book, articles, magazines, website, conference proceeding, thesis and other sources that can be applied. The reviews are includes the arm rehabilitation devices controller and the fuzzy logic techniques which is ANFIS-PID controller that applied ANFIS Inverse model and PID controller at the feedback of the control system. This chapter also discussed about the devices that has been used which are related to this rehabilitation device controller.

2.2 Arm Rehabilitation Devices

Robotic exercises devices are extensively used in rehabilitation training for the improvement of the patient's upper-limb [7]. To automate therapy for the arm, wrist and hand following stroke, the rehabilitation robotic devices and system are being developed. As shown in Figure 2.1 the upper limb has several DOFs and it is very difficult to doing the rehabilitation as it really is [7]. The parameters that needed to control from Figure 2.1 are angle position.

Figure 2.1: Human arm structure

In recent years, a number of devices have been developed expressly for arm rehabilitation. Robotic devices designed for arm rehabilitation of stroke patients are such as the MIT-Manus (Massachusetts Institute of Technology Manus) [8] (Figure 2.2.a) and Assisted Rehabilitation and Measurement (ARM) Guide [8] (Figure 2.2.b).

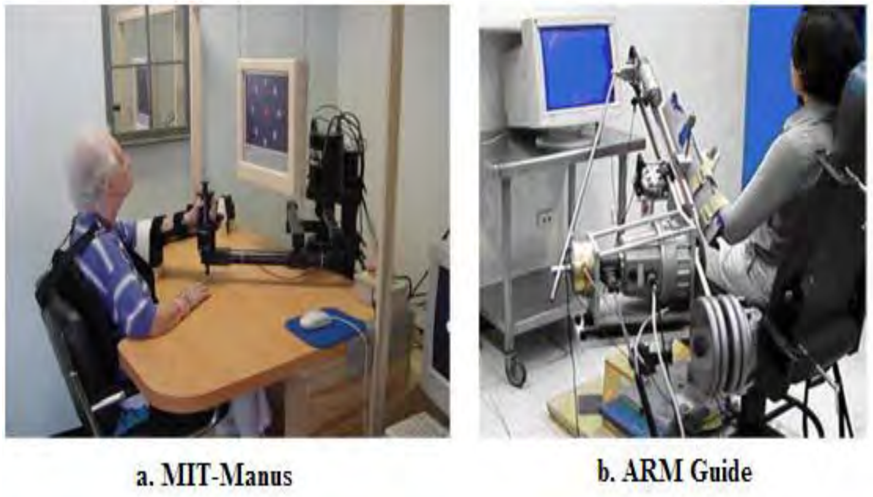

Figure 2.2: Robotic Devices for Arm Rehabilitation

2.3 Previous Research

2.3.1 Comparison of Existing Model

Much works have been done in the area of robotic rehabilitation for the upper limbs. Many previous devices have also proved the interest of robot-assisted therapy in helping dependent people with disabilities. There are many type of controller that can be chooses to design in creating arm rehabilitation devices. Robot assisted therapy systems need three elements which are algorithms, robot hardware and computer system [9]. Moreover, the design of the control system is a one of the main difficulties especially when intending to realize predefined complex movement and recovering at the same time motion and force human capabilities/ force [10].

In this paper, [7] fuzzy logic incorporating with the hybrid controller was developed to restriction the motion in the desired direction and to maintain a constant force along the moving direction. The planned movements of circular or linear trajectories were considered. The controller was stable in the implementation range of forces and movements. To quantitatively assess the progress of rehabilitation, offline analyses of data were used. The upper limb of subjects can be conducted by the robot in linear and circular movements under predefined external force levels and a desired force is applied along the tangential direction of the movements [11].

On the other hand, [12] in a new control architecture which is development of high-level controller design is presented that work in combination with the low-level controllers where it can dynamically determine the task updates based on patient's performance. The safety related events is monitored in an automated manner and generate an accommodating plan of action such as, MIT Manus uses impedance controller while MIME uses PID controller for movement assistance. However, each low-controller and high-controller may require different types of inputs and outputs so they cannot communicate directly [12]

Meanwhile, for the fuzzy logic controller used in stability analysis where the main advantages of this technique seem to be the possibility of applying "rule of the thumb" experience and it does not need a model of the process. Whereas, the disadvantages of this method seem to be lack of appropriate tools for analysis of the controller performance such as stability, optimality, etc [13].

Fuzzy logic in control system is examined as an alternate for conventional control theory where definite mathematical modeling is impossible or harder in the control of nonlinear system. it also requires less multiplex mathematical operations compared to classical controllers such as PID controller [14]. Between the proportional control and fuzzy control, it shown that the fuzzy control particularly decrease the overshoot percentage and essentially eliminated limit cycling. Applying fuzzy algorithm in a controller gives a faster and more accurate response compared to the other industrial controller [15].

On the other hand, many control application is extensively used such as PID controller because of its potency and implicitly. PID controller has been used a long time in the field of engineering and commonly the three controller gain parameter is fixed. But the PID controller limitation is it is terrible in dealing with system uncertainty which is parameter variations and external disturbance [15].

Based on paper [4], the composed method is used which is the evolved ANFIS works as an inverse model to the system and PID controller at the feedback of the system. The ANFIS-PID is designated to control knee joint during sit to stand movement to quadriceps muscles through electrical stimuli. Referred to the simulation results, the ANFIS-PID successes improving sit to stand execution compared to the PID controllers. The results of this study give better performance compared to the other studies which use Fuzzy Logic or Neural Network intelligent techniques concerning to minimizing errors during tracking desired motion. In conclusion of this study, ANFIS-PID controller indicates a slightly better performance rather than the ANFIS alone controller and PID controller.

2.3.2 Adaptive Neuro –Fuzzy Inference System (ANFIS)

From the gain research, ANFIS is the executions of fuzzy inference system (FIS) to adaptive networks for generate fuzzy rules with ideal membership function to get the required inputs and outputs. Fuzzy theory is used where fuzzy-if-then rules and fuzzy reasoning produce bases conduct mapping from a given input knowledge to desired output [16]. A feed-forward multi layer Artificial Neural Network (ANN) is an adaptive network with relatively or fully, adaptive nodes in which parameter of adaptive nodes predicted the output and the learning rules described the adjustment of parameters due to error term. Learning type in adaptive ANFIS is hybrid learning and the configuration of ANFIS is shown in Figure 2.3 below [16].

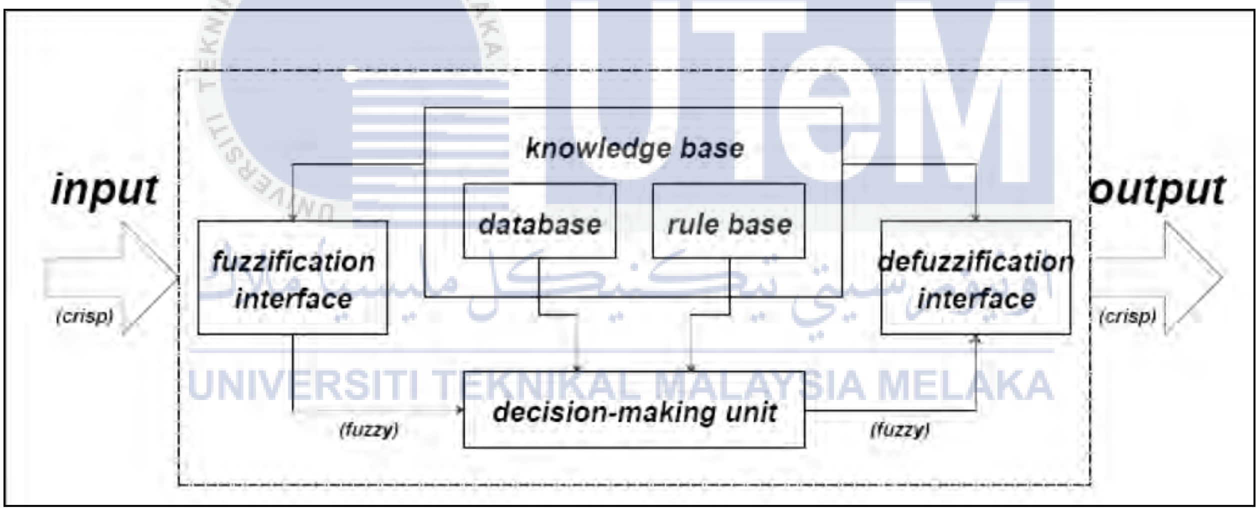

Figure 2.3: Configuration of ANFIS

2.4 DC Geared Motor with Encoder (MO-SPG-30E-300K)

This DC Geared Motor with Encoder is formed by a quadrature Hall Effect encoder board which is designed to fit on the rear shaft of Cytron's SPG-30 Geared Motor series. Two hall effect sensor are placed 90 degree apart to sense and two output A and B are produce which is 90 degree out of phase and the direction of rotation allowing to be determined. This encoder present 3 counts per revolution of the rear shaft. The encoder is mounted at the rear shaft, the minimum resolution is depends on the motor's gear ratio.

Figure 2.4: DC Geared Motor with Encoder

Features:

- Voltage of operating: 4.5V to 5.5V
- Two digital outputs (Quadrature waveform)
- The size is small and weight is light
- Resolution: 3 pulses per rear shaft revolution, single channel output.
- 900 count per main shaft revolution for 1:300 geared motor

2.5 Cytron 4 Channel Motor Driver (FD04A)

4 Channel Motor Driver, FD04A is designed to manage four DC brush motors and it also can be used to handle more than two motors. It is easy to use and provides low cost DC motor driver that able to operating up 4 DC brush motor, and the current can reach up to 3A. As its interface is minimums the board is ready to drive motor with stop, start, direction, and speed control.

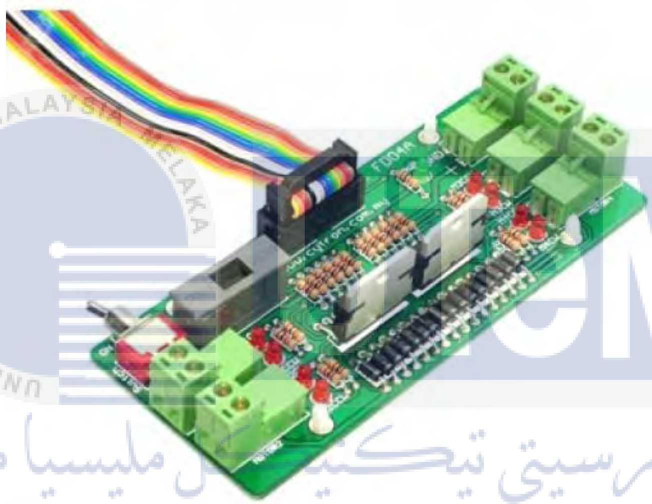

Figure 2.5: 4 Channel Motor Driver (FD04A)

Features:

- Capable to operates 4 DC motor at 1.5A continuosly and 2.5A (peak).
- Motor voltage from 7 to 25VDC
- 4 DC motor with Bi-directional control.
- Compatible with Cytron DIY project, Flexibot.
- The PCB is industrial grade.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter is about the process of work to fulfill the aim that was prepare in order to make sure that this project is finished and done systematically. The methodology will give a details explanation of procedure that will be accomplish in this research. The methods begin with the research from previous works on how the previous works has been done to achieve the goal.

3.2 Process Flowchart

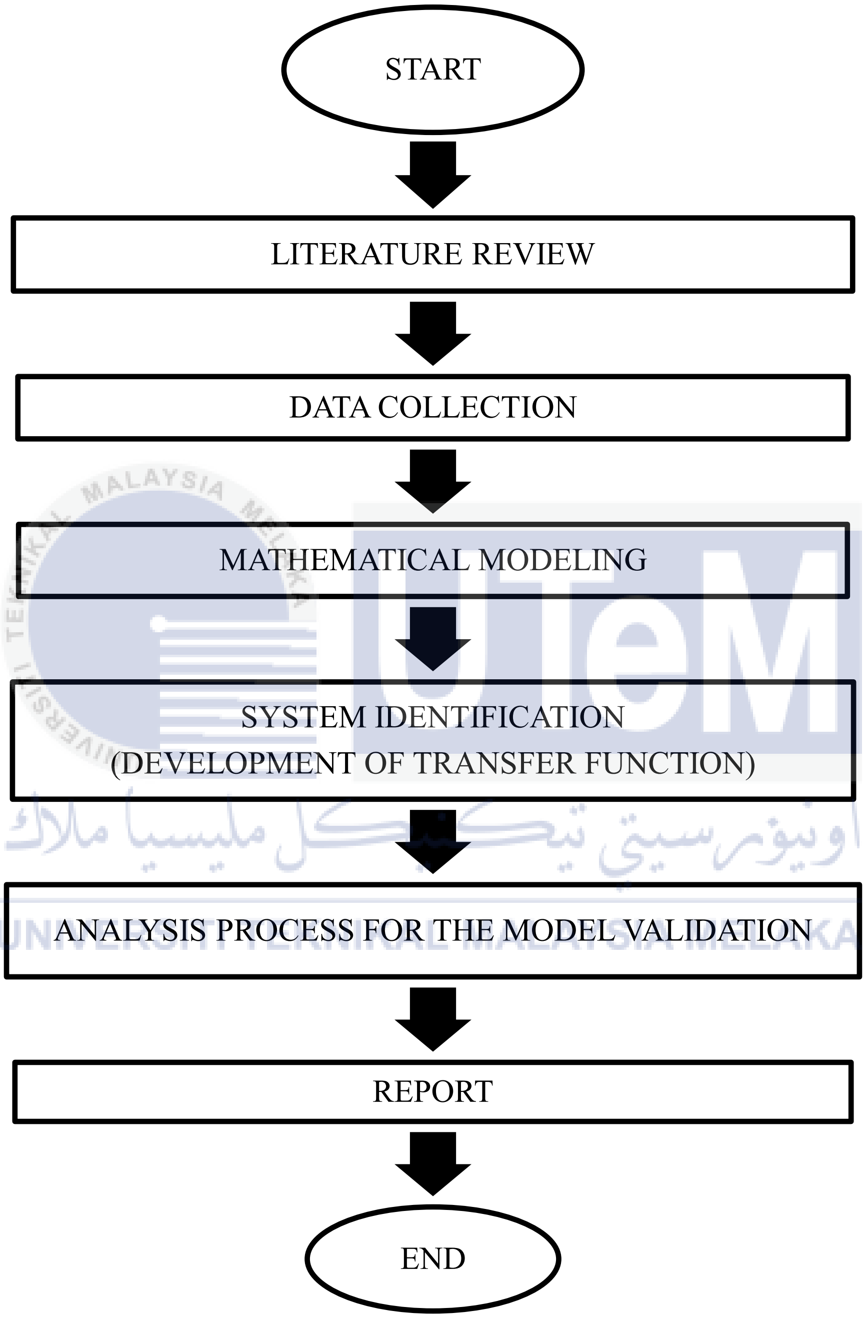

Figure 3.1: Flowchart of Project 1

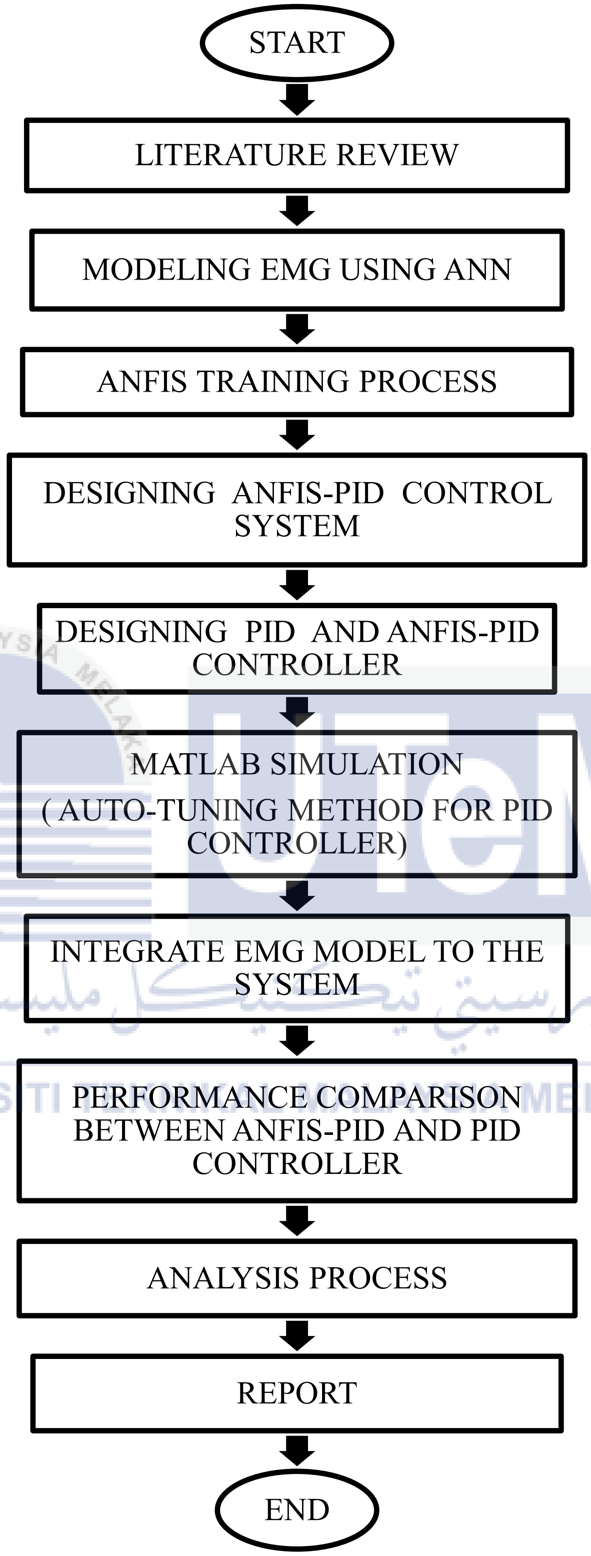

Figure 3.2: Flowchart of Project 2

3.3 Experimental Setup

3.3.1 Data Collection

Firstly, a portable reconfigurable I/O (RIO) device which is The National Instruments myRIO-1900 is used to design control system. Before that, the NI myRIO-1900 is connected to the host computer by using USB and also to the adapter that supplies voltage, the NI myRIO-1900 led will blinking. After the NI myRIO-1900 successfully connected to the computer port as in Figure 3.3, the connecting wire is used to connect to the 4 Channel Motor Driver and NI myRIO-1900's user manual is referred for info regarding the connector pin outs.

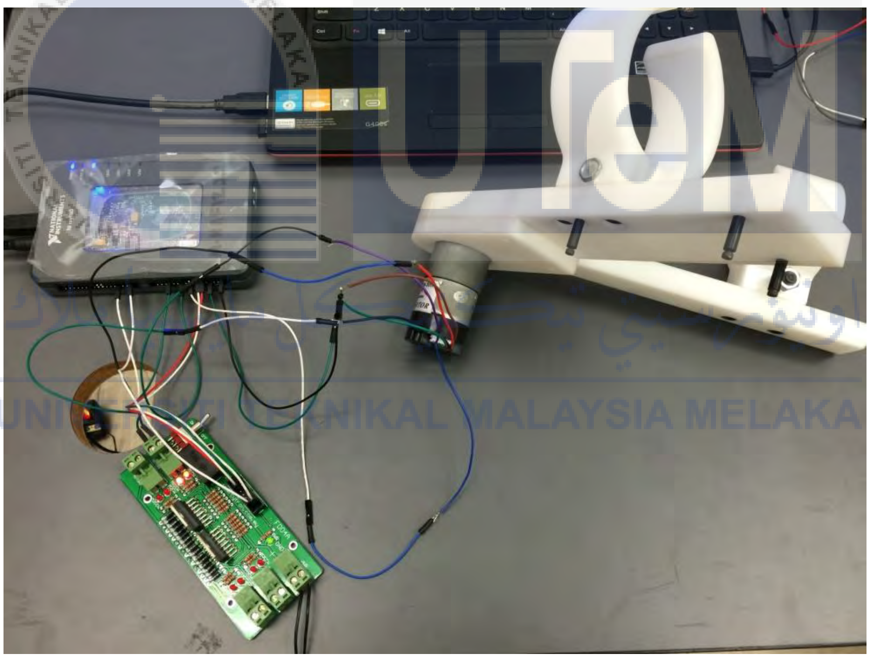

Figure 3.3: Connection between the NI myRIO-1900 with computer and 4 Channel Motor Driver

Then, the DC Motor that applied to the arm prosthesis model is connected towards the 4 Channel Motor Driver as shown in Figure 3.4 below. The block diagram is designed as Figure 3.5 where there are three input of sine wave signal to the system and the data is collected as the encoder moves clockwise and anticlockwise for several times. While collecting the position data, EMG data is also collected at the muscle of the arm. During the data collection, the sampling time is set to 0.001.

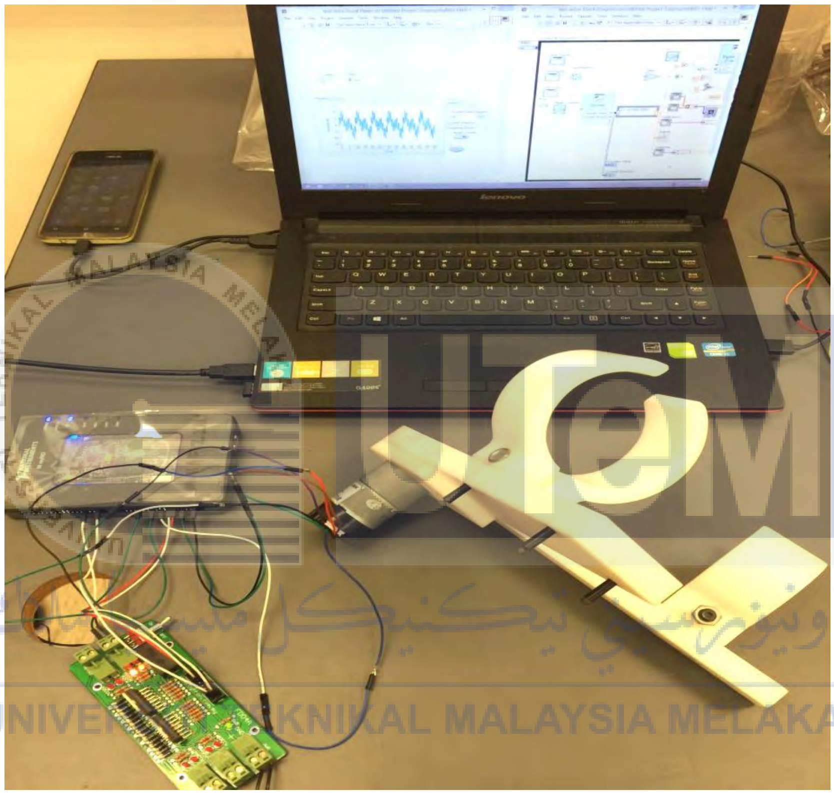

Figure 3.4: The experimental setup

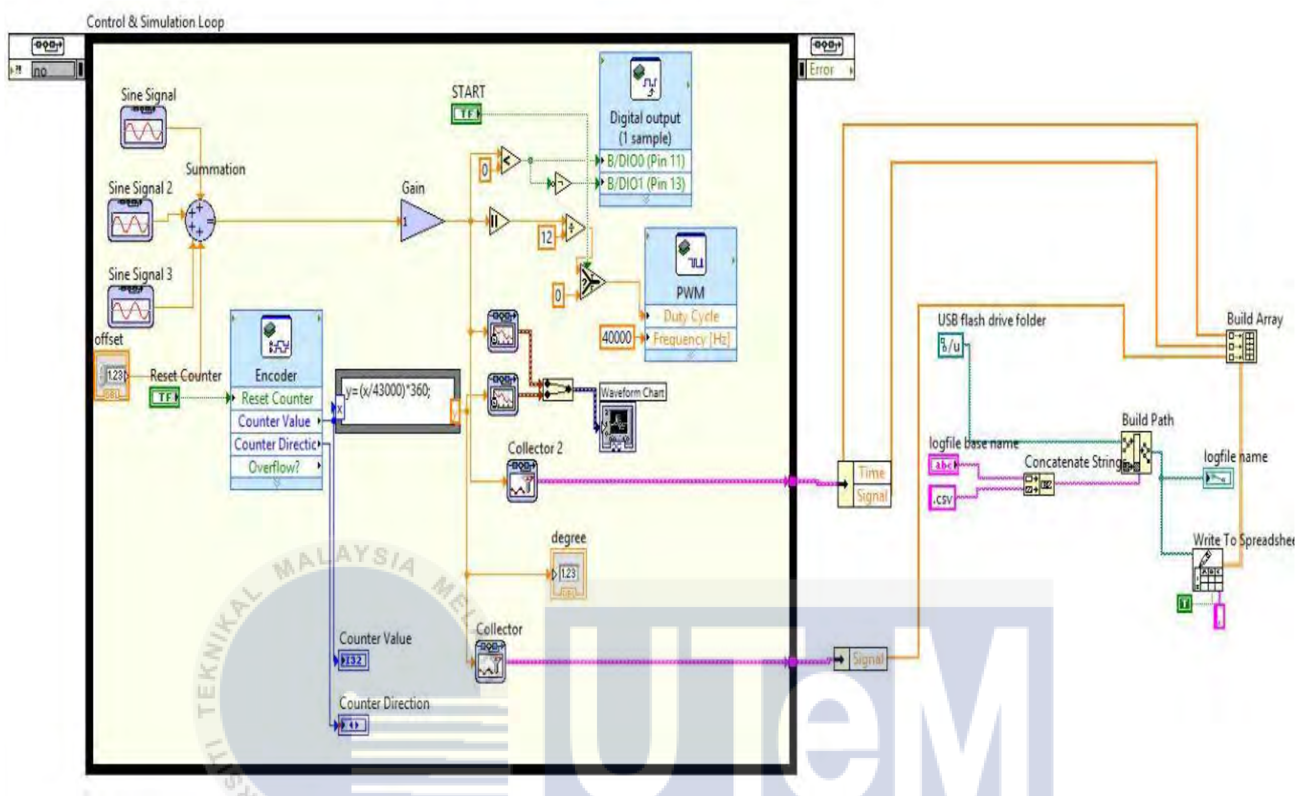

Figure 3.5: Block diagram for the data collecting system

3.4 MATLAB Simulink

MathWorks developed MATLAB which is a numerical computing environment and fourth-generation programming language. It enables plotting of functions and data, matrix manipulations, execution of algorithms and others. Furthermore, one of the programming tools in MATLAB is Simulink. It is uses for modeling, analyzing multi domain dynamic systems and simulating. It is also present with a customizable set of block libraries and the graphical block diagramming tool.

3.4.1 System Identification

The steps of developing or improving the mathematical description of a physical system using experimental data are called System Identification. To discover a mathematical model of a dynamic or physical system from observed data is the main purposes of System Identification. Step function, ARMA sequences, sum of sinusoids and pseudo random binary sequence (PRBS) are the standard input signals in system identification. It is mathematically randomized bit stream so that it will become neutralized and balanced data.

By using MATLAB, “ident” is the coding to open the system identification toolbox. To compare three types of data and build a transfer function, this tool can be used. Figure 3.6 shows the model system of system identification.

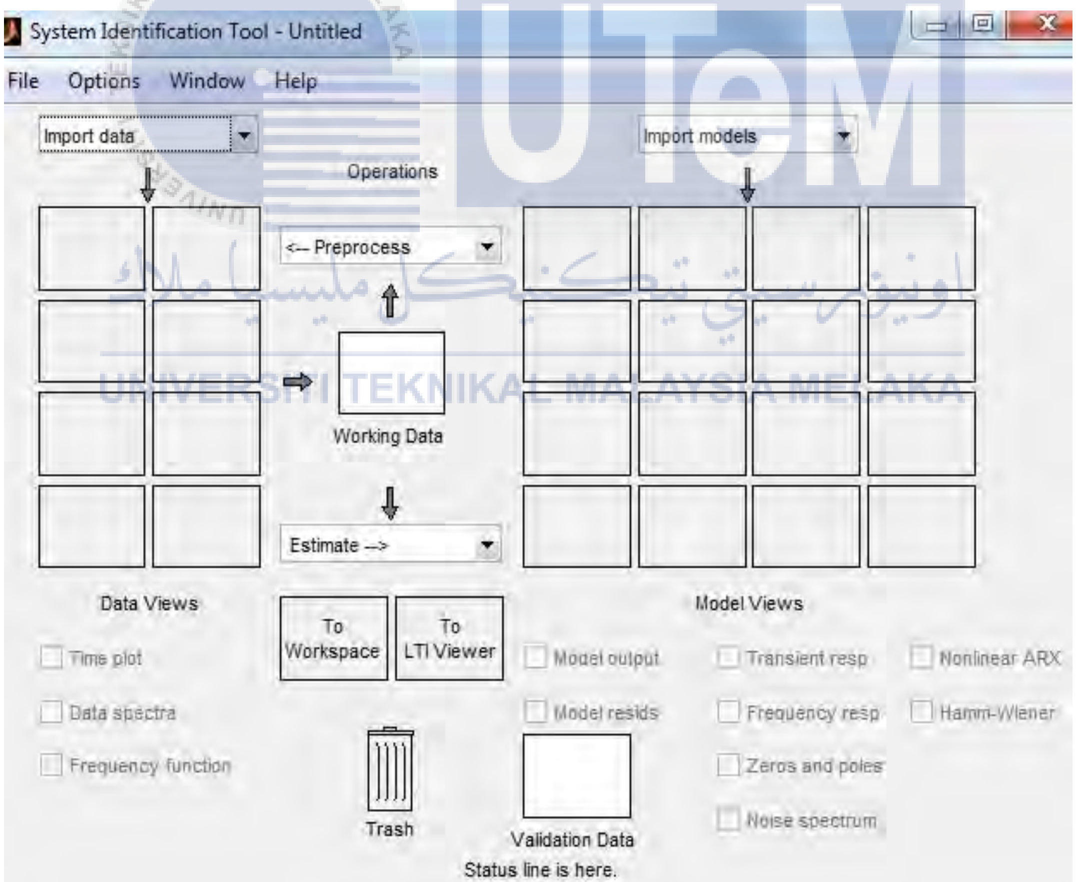

Figure 3.6: Layout of system identification tool

Figure 3.7 shows the type of data of input and output used in this system. The data to model this system is *mydata* which is selected as the input and starting time is set to 0 while the sampling time or interval for the data is 0.001.

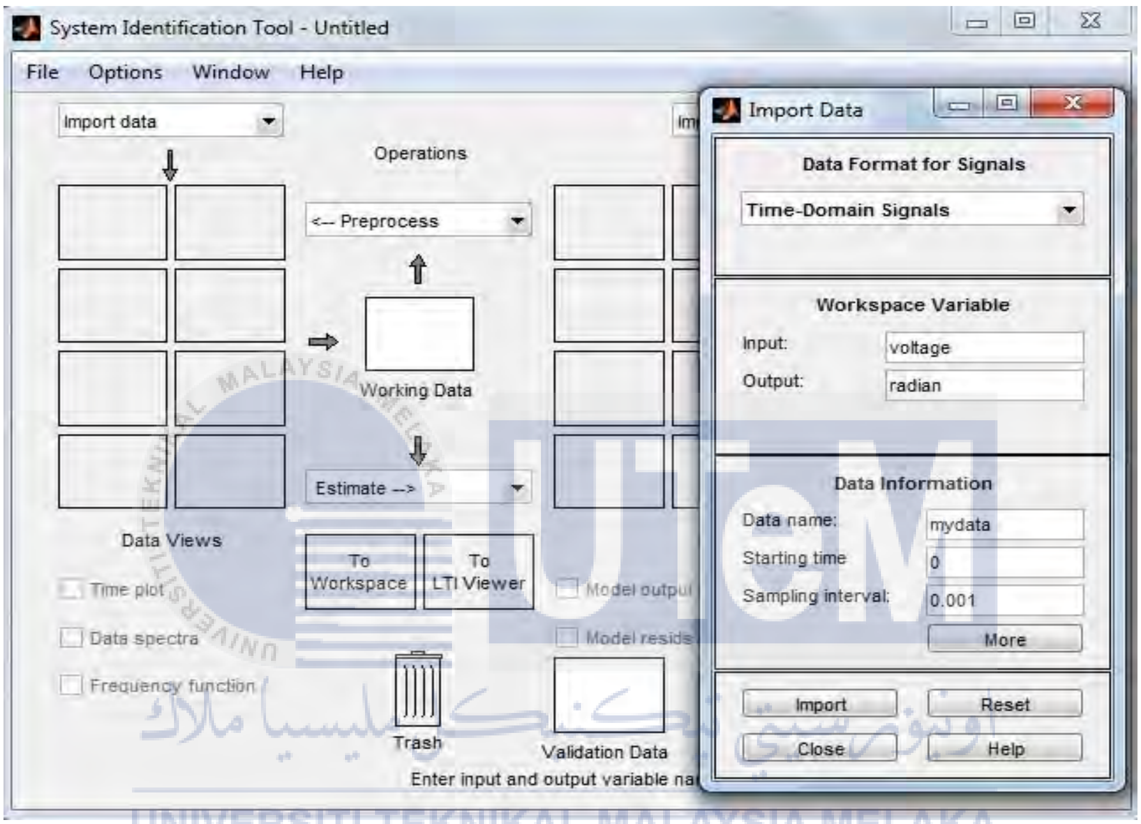

Figure 3.7: Data of model used in this system

Figure 3.8 shows the validation data which is *mydata* as the input. This tool compared the data between validation data and working data based on the model selected for this system which is *transfer function model* as shown in Figure 3.9.

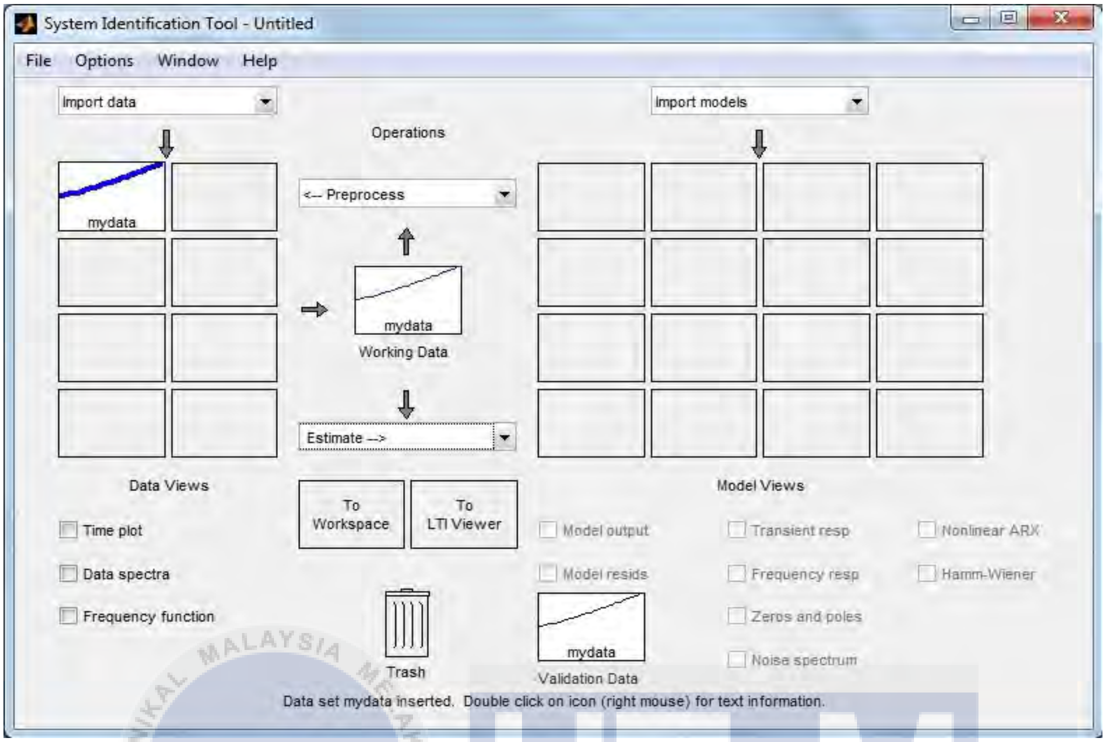

Figure 3.8: Data selection in validation data and working data in system identification

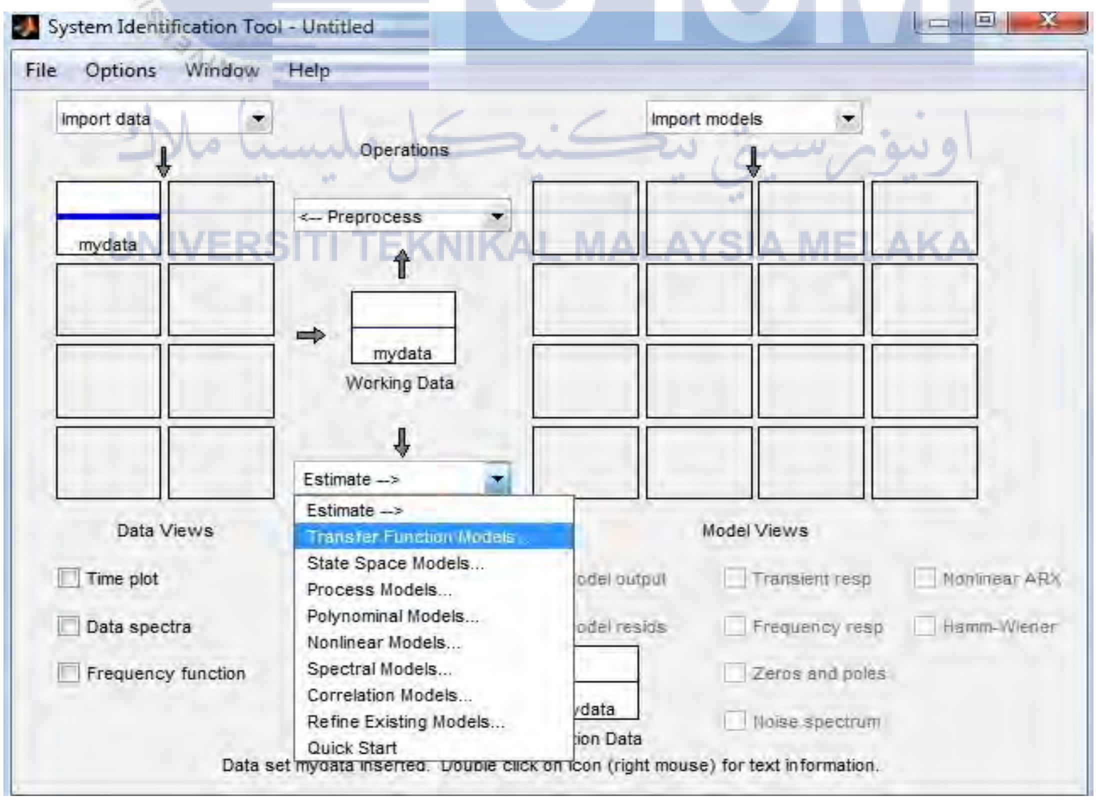

Figure 3.9: Selection of model in the system identification

There were parameters to be filled-in what number of poles and number of zeros that are used according to the characteristics of the system. After that, the transfer function for the system will be estimated. The number of poles and zeros is adjusted as shown in Figure 3.10.

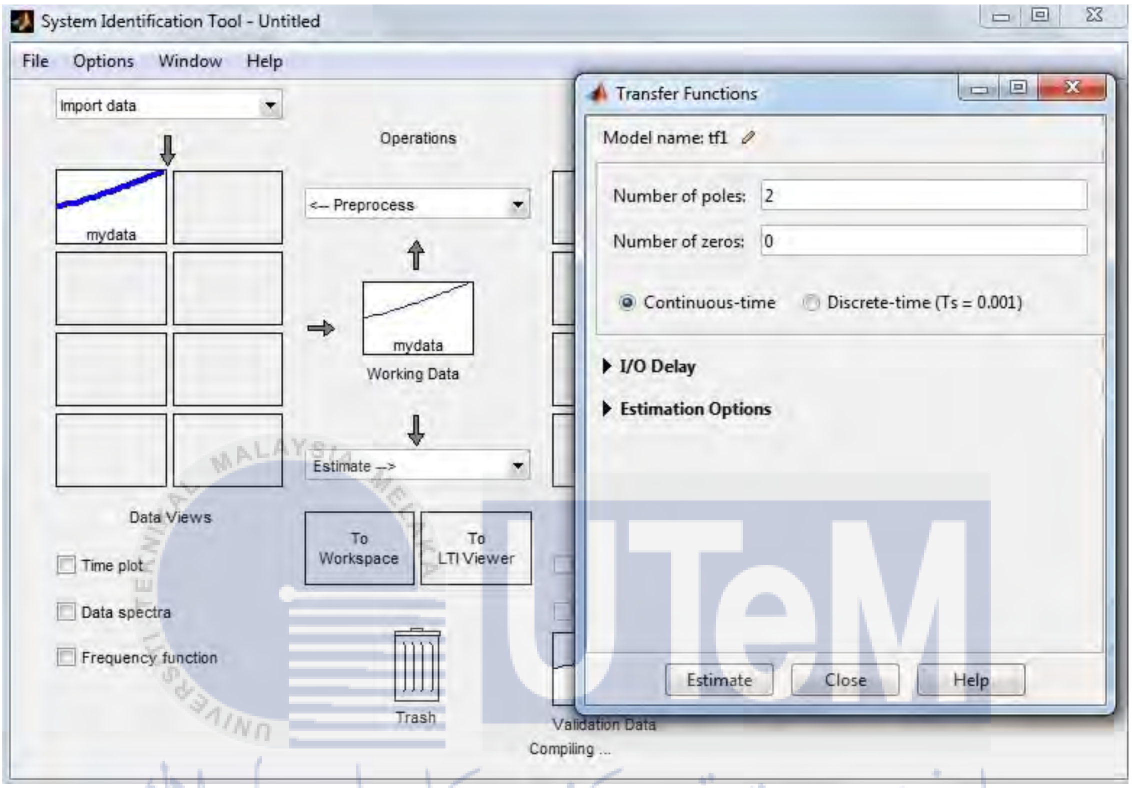

Figure 3.10: Selection of characteristics in the system identification

The value of poles and zeros is changed to estimate the difference type of transfer function, Figure 3.11 show that variety of transfer function that will compared the data. Furthermore, Figure 3.12 shows system of model information based on system identification.

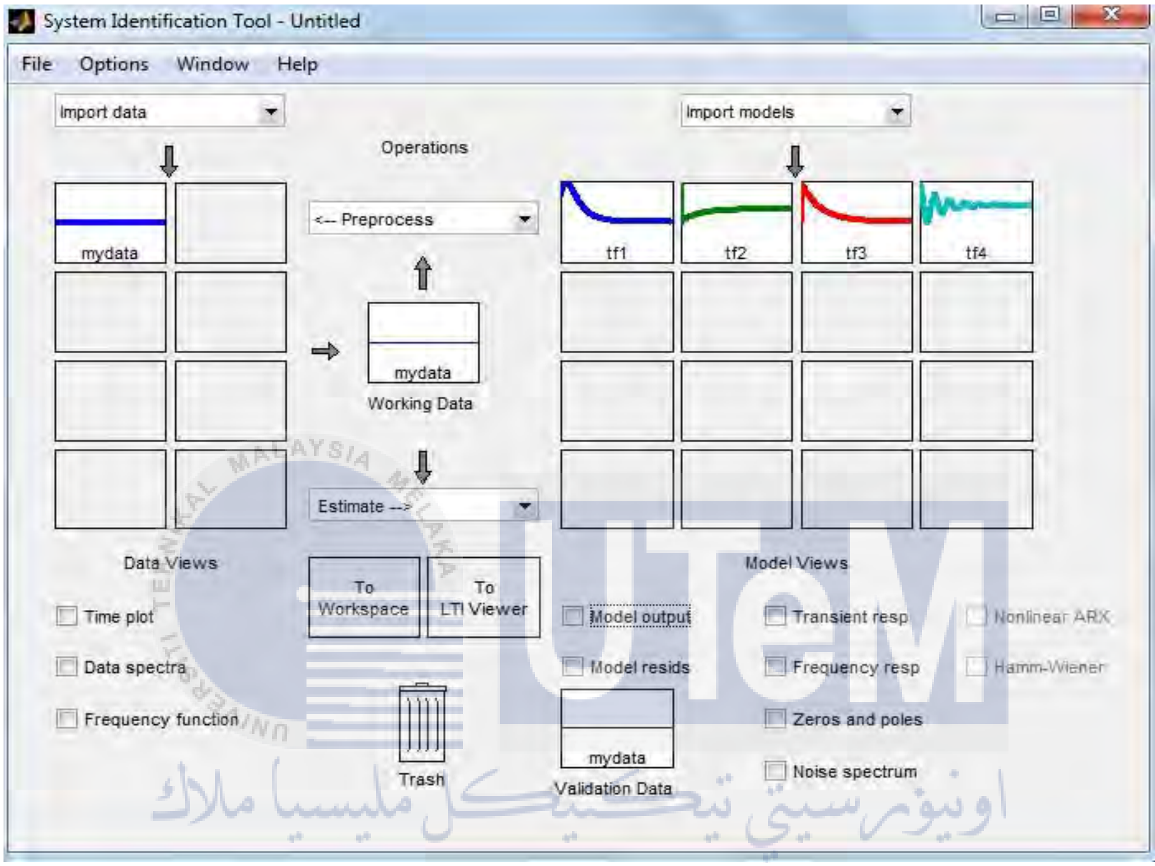

Figure 3.11: Comparison of transfer function data

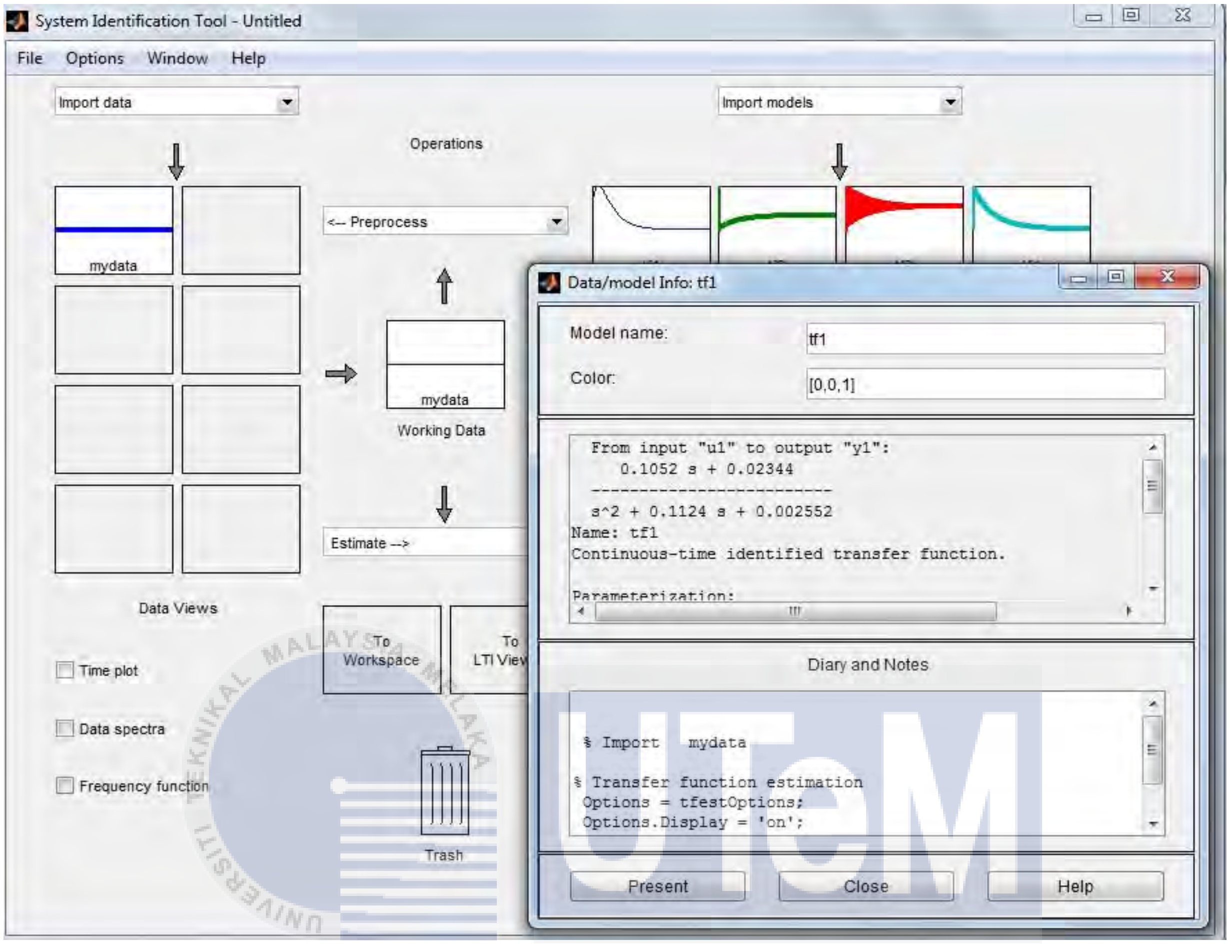

Figure 3.12: Model output information in the system identification

3.5 Artificial Neural Network (ANN)

ANN is capable for modeling a nonlinear data for example EMG data, and it can cover variance among different conditions. ANN is designed for a given exertion that required the number of hidden units and numbers of units in input and output layers. Figure 3.13 shows the Neural Fitting tool where the data for the inputs and targets data is selected based on the fitting problems. A Lavenberg-Marquardt training back propagation algorithm is used for this project to model the EMG. Then the number of hidden neuron is adjusted until the training process minimized the error and network performance gives a good result [17]. Based on Figure 3.14 the network performance is referred on Mean Squared Error (MSE), Regression (R) and the characteristics of the training and validation performance as well.

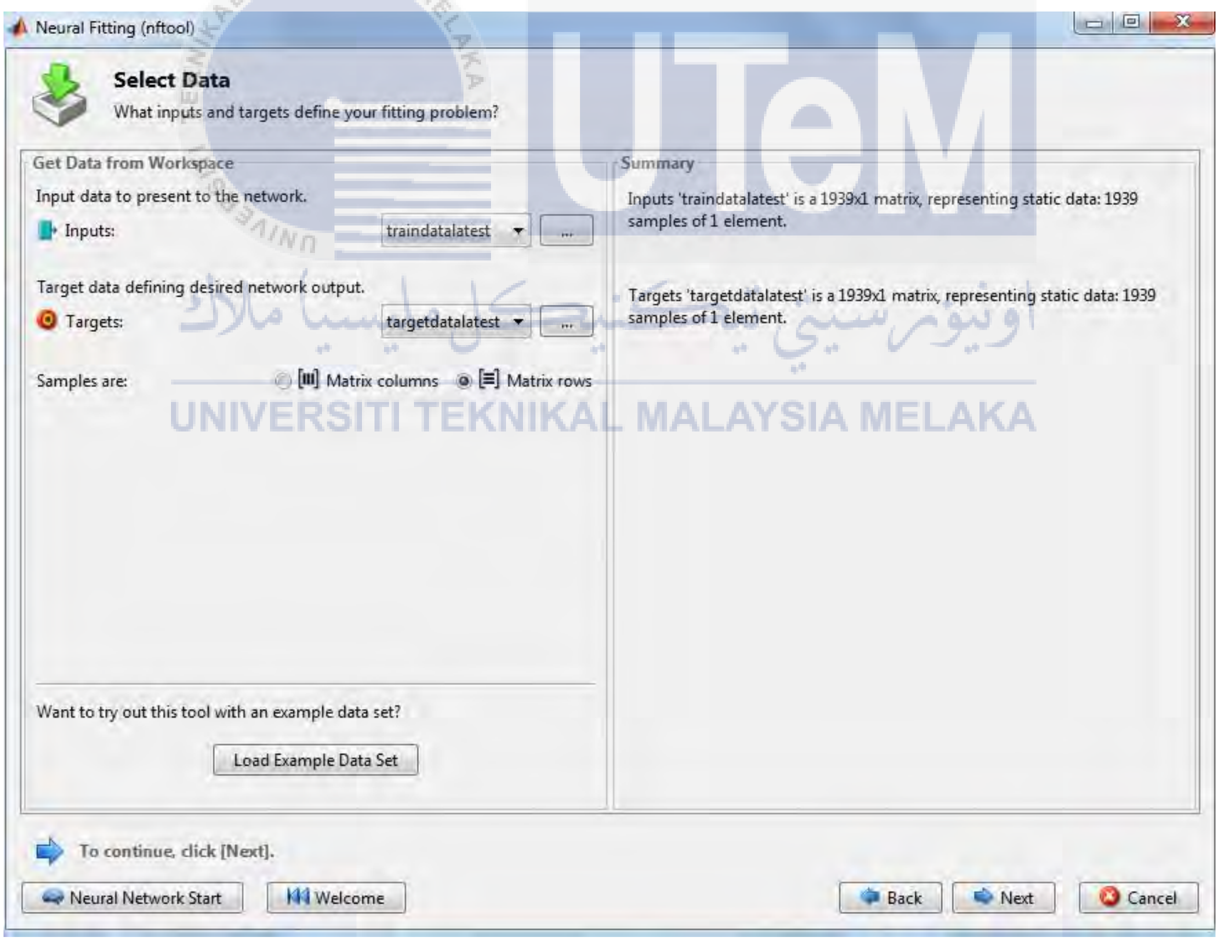

Figure 3.13: Data selected for the Neural Network Training

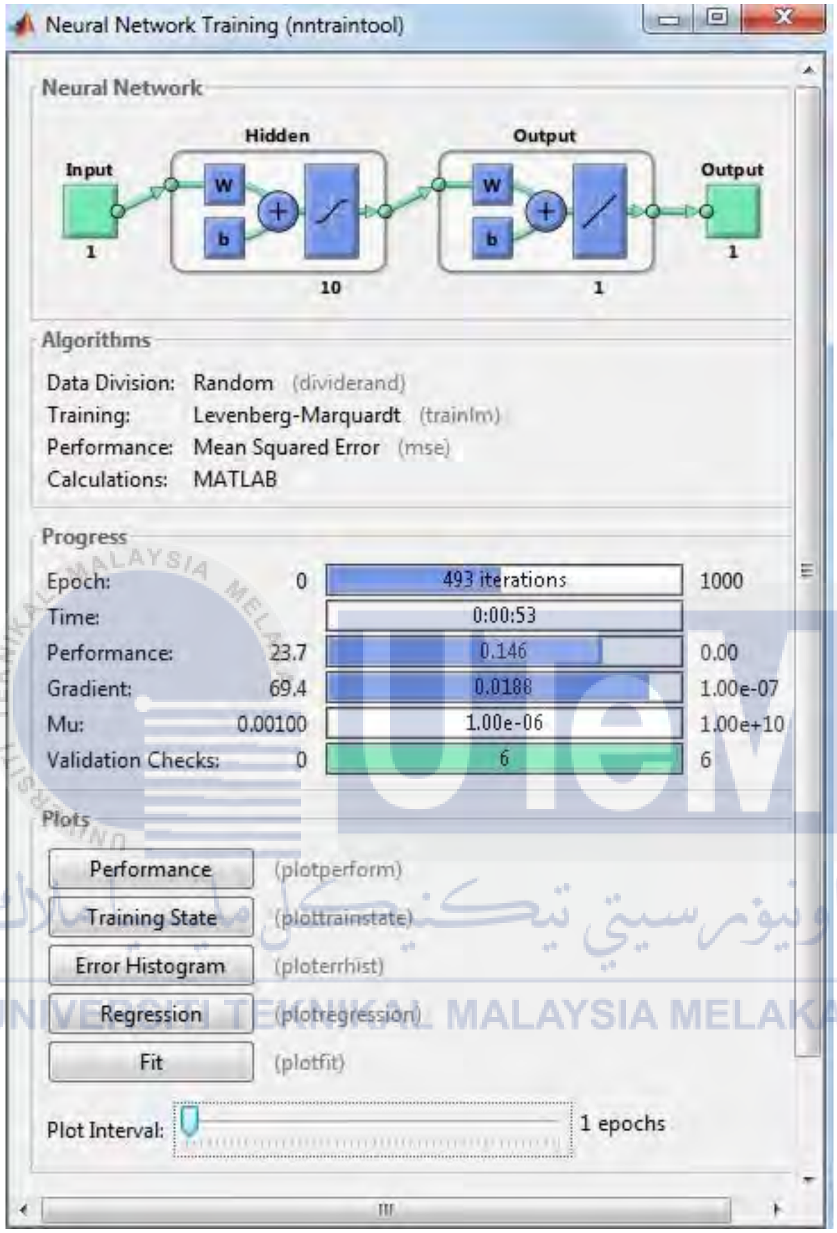

Figure 3.14: Performance of the Neural Network Training

3.6 Block Diagram of ANFIS-PID Control System

ANFIS-PID controller is designated that incorporate with two elements; ANFIS controller and PID controller with a fixed parameter. The plant indicates the arm position model. The ANFIS inputs and outputs are trained successfully to imitate the inverse dynamics of the plant [4]. The ANFIS controller provides some Fuzzy rules and memberships functions with inverse input and output [16]. Moreover, a PID feedback controller is combined in parallel to the ANFIS control system to compensate for the residual tracking errors that caused by the disturbances and modeling errors. The configuration of the block diagram of ANFIS-PID control system is as Figure 3.15 below;

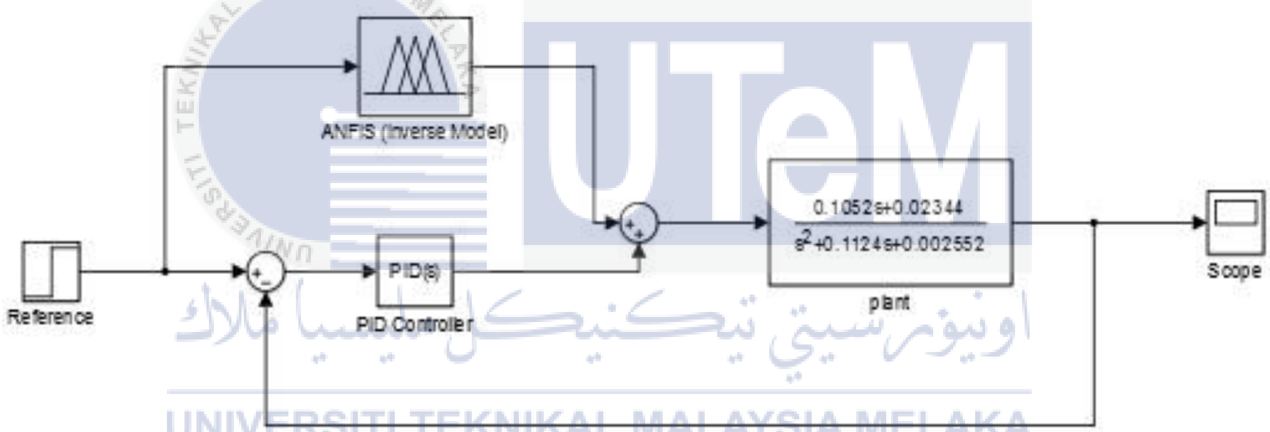

Figure 3.15: Configuration of the block diagram of ANFIS-PID control system

CHAPTER 4

RESULT AND DISCUSSION

4.1 Modeling EMG-Position using ANN

To achieve the satisfactory results, the network performance is optimized for several times and Lavemberg-Marquadt algorithm is used to train the network where Mean Squared Error (MSE) and Regresssion (R) are measured to see the performance of the network.

Based on Figure 4.1, the best validation performance of the network is 0.15242 at epoch 487. As the validation set error and test set error shown a similar behavior, it is an acceptable result. Along the epoch during the training, the MSE decrease quickly as shown in the Figure 4.1 below.

Since most error approaching zero values, the error sizes are well distributed and hence make the trained model perform better as shown in Figure 4.2 below.

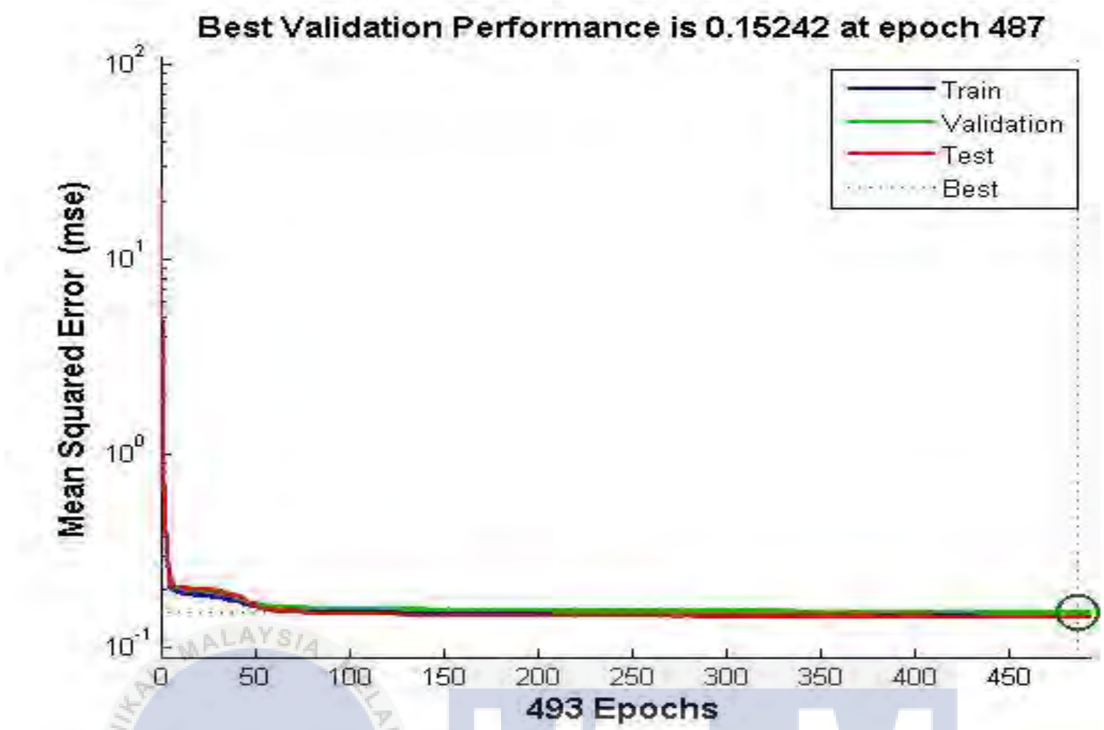

Figure 4.1: Validation Performance

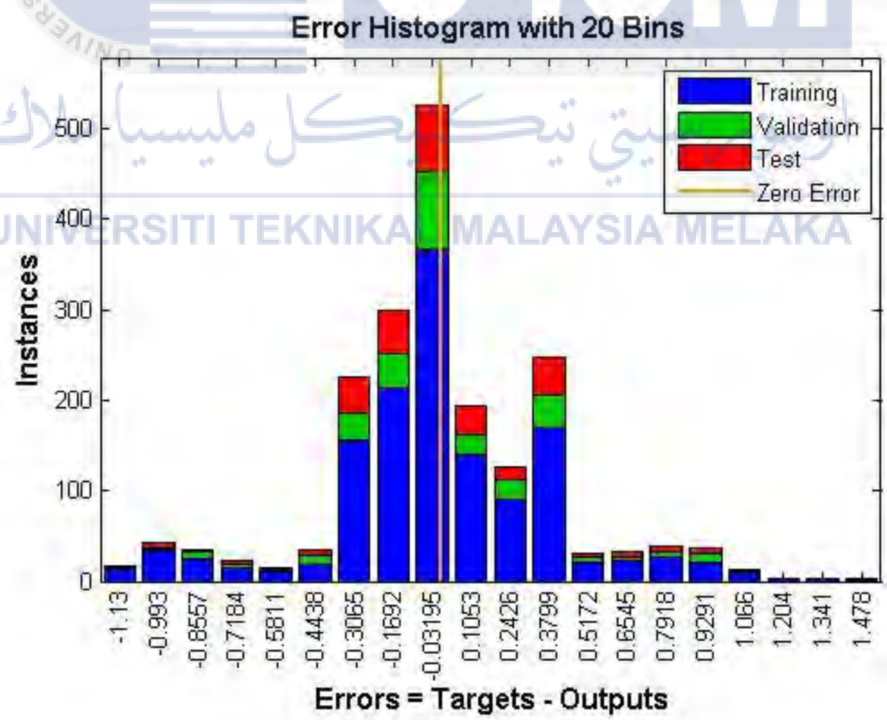

Figure 4.2: Error Histogram

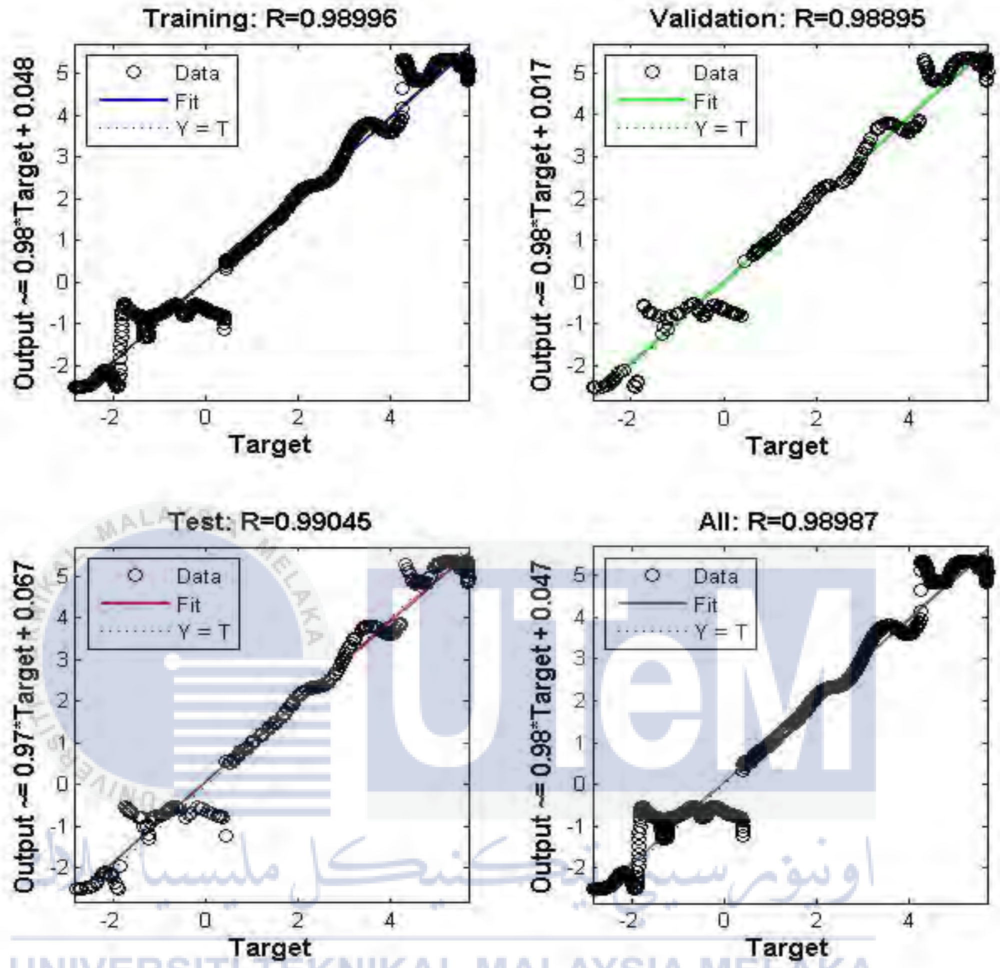

Figure 4.3: Regression Test

From Figure 4.3, it shown that the regression for the training, test and validation produces quite well curve fitness where all the regressions value is near to 1.000 and give an optimal value for the model.

This neural network model can represent the relationship between the EMG signal and arm position as it produces a good performance result as shown in figure above. This model can be use for motor position of the arm rehabilitation devices.

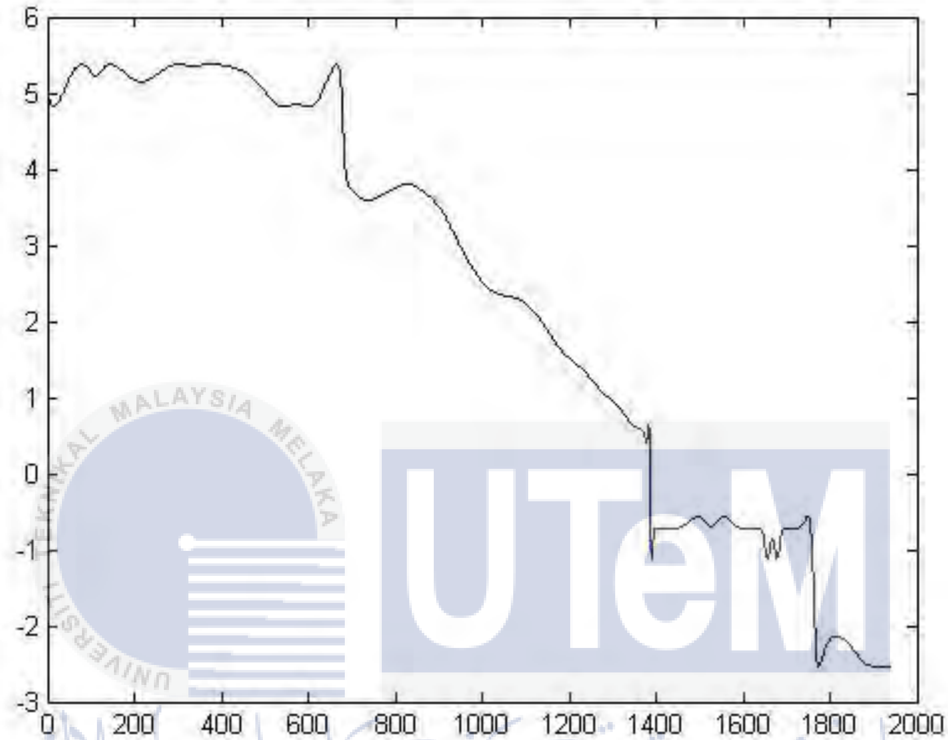

Figure 4.4: The output of the neural network model

4.2 Modeling using System Identification

The data obtained from experiment is used to build transfer function that suitable for the system. By using system identification the transfer function is build by estimating the number of poles and zeros and then it is verified by comparing the model output, transient response, frequency response and stability of the zero and pole. The voltage is the input and motor position (radian) as the output as in Figure 4.5.

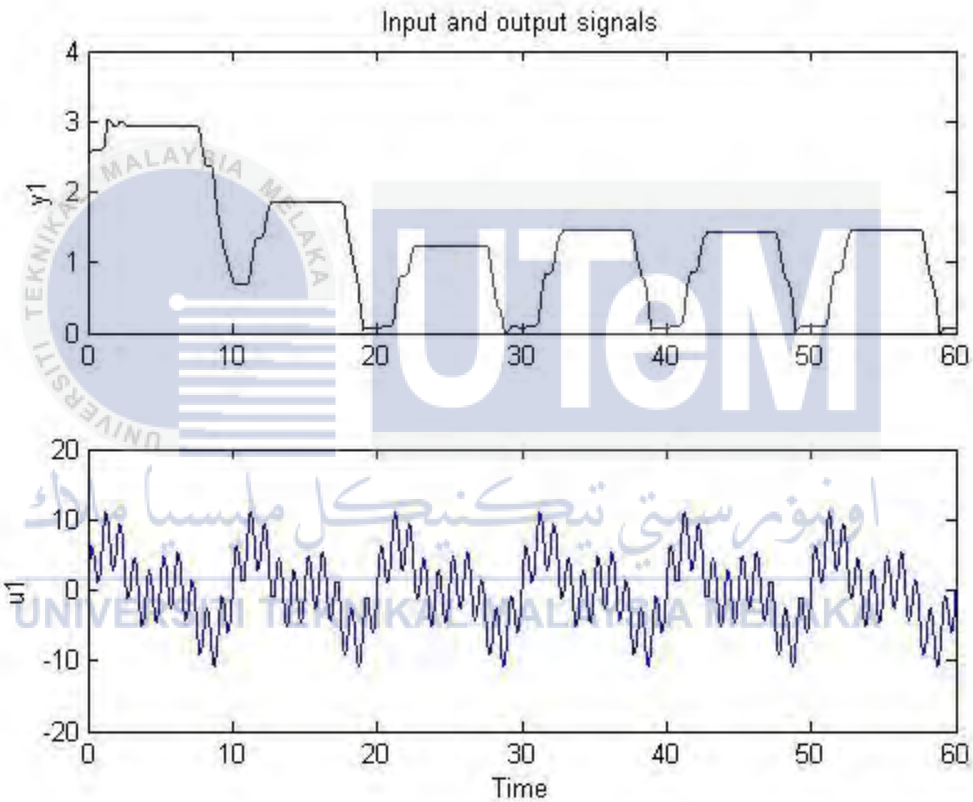

Figure 4.5: Signal of input is voltage (u1) and output is position (y1)

4.2.1 Model Output Percentage

For the first transfer function, the pole is 2 and zeros is 1. The model output for the measured and simulated is compared as shown in Figure 4.6 and this transfer function got its best fits percentage which is 79.75%. Whereas for the second transfer function, the pole is 2 and zeros 2 and the best fits percentage is 56.92%. While the third transfer function has pole 3 and zeros 0 and the percentage is 38.59% and lastly the pole is 3 and zero is 1 with its best percentage 48.04%. The equation for each transfer function is in the Table 4.1 below;

Table 4.1: Transfer Function Block Parameter

Label	Transfer Function
TF 1 (blue)	$\frac{0.1052s + 0.02344}{s^2 + 0.1124s + 0.002552}$
TF 2 (green)	$\frac{-0.016s^2 + 0.08733s - 0.001832}{s^2 + 0.04416s + 1.27e - 19}$
TF 3 (red)	$\frac{-0.003343}{s^3 + 0.03264s^2 + 0.396s + 0.01291}$
TF 4 (light blue)	$\frac{2.465s + 0.1089}{s^3 + 24.6\ {}^{2} + 2.659s + 0.06956}$

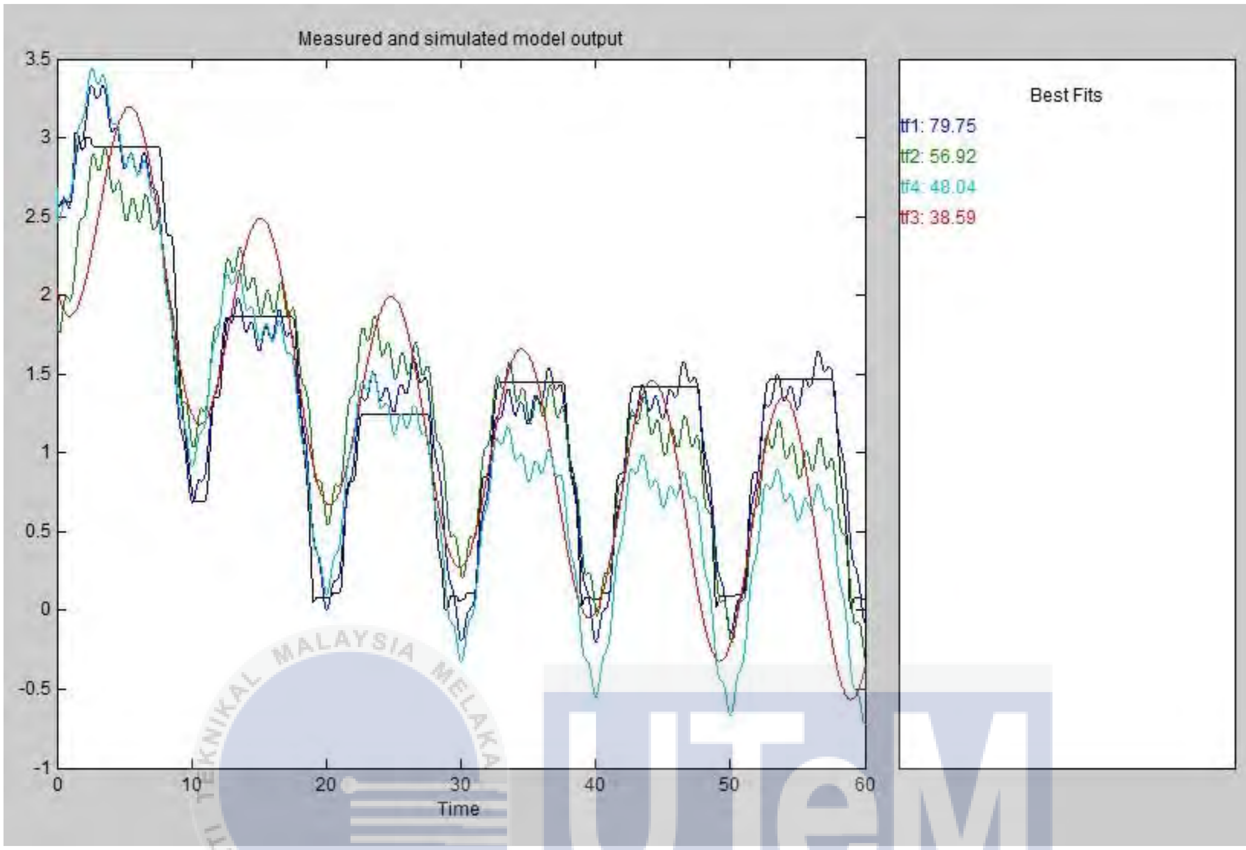

Figure 4.6: Best Fit Percentage Validation

From Figure 4.6 it shows that between all the transfer function, transfer function 1 has the best fits percentage which is 79.75% (rounding to 80%) based on modeling rule of thumb at least 80% best fits percentage considered model acceptable. Therefore it can be conclude that the transfer function of the arm rehabilitation device is the 2nd order system similar to the DC motor system. The linkage and bearing of the device does not affect much the motor characteristic.

4.2.2 Stability of Poles and Zeros

Stability can be determined directly from its transfer function where the poles should be in the negative real parts (left side) to be stable. The system becomes less stable when the poles get closer to the boundary. Whereas for the unstable pole, it lying in the right hand side of the s-plane. When added poles to the transfer function, it makes the root locus pulled to the right hence the system becomes less stable while addition of zeros makes the root locus pulled to the left and thus the system becomes more stable. The location of poles and zeros are as below in Figure 4.7.

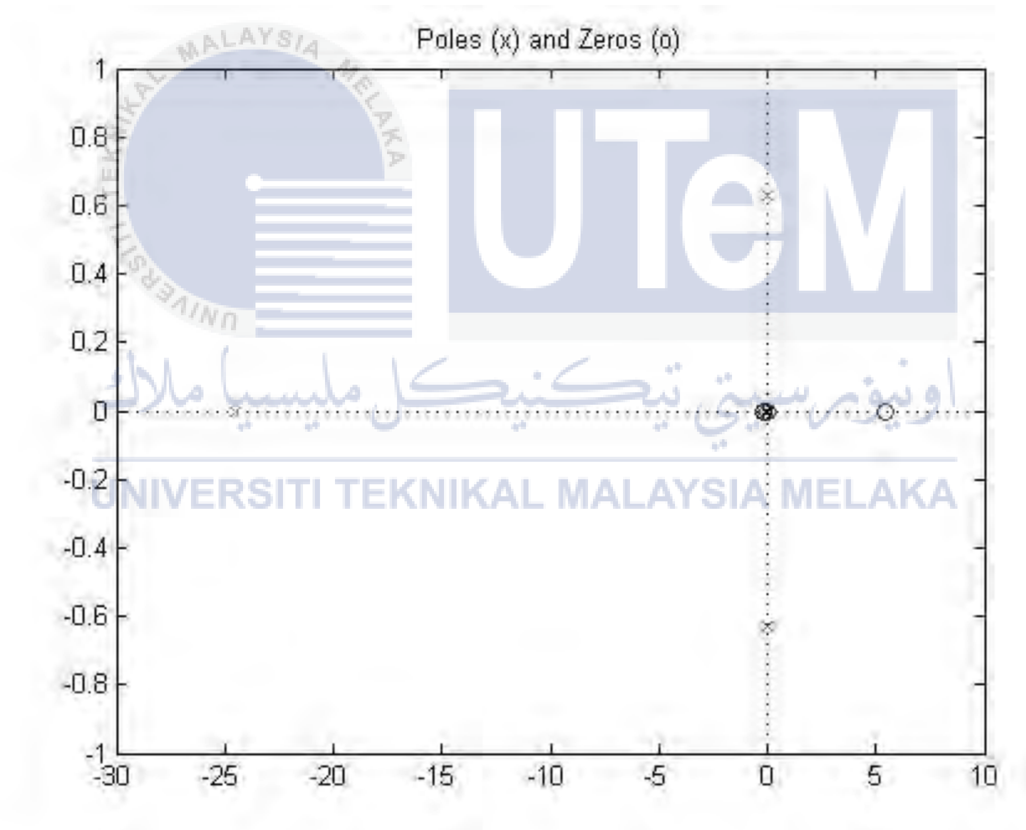

Figure 4.7: Poles and zeros of transfer function

For the transfer function 1, the poles both on the left sides and zeros too. While, transfer function 2, the poles are nearly to the origin and there is one zero at the right half-plane indicating that the response starts off at negative direction thus the increase in the magnitude of the derivative leads an increase in the magnitude of the undershoot. Transfer function 3 is marginally stable because it has 2 distinct poles at the imaginary axis and the remaining one pole at negative real part and it has no zero. The forth transfer function, all three poles and one zero are at the left side. So, from the observation, transfer function 1 is more stable compared to the other three because the poles is both on negative sides and there is a 1 zeros added which can increase the stability of the system.

4.2.3 Frequency Response from the Bode Plot Diagram

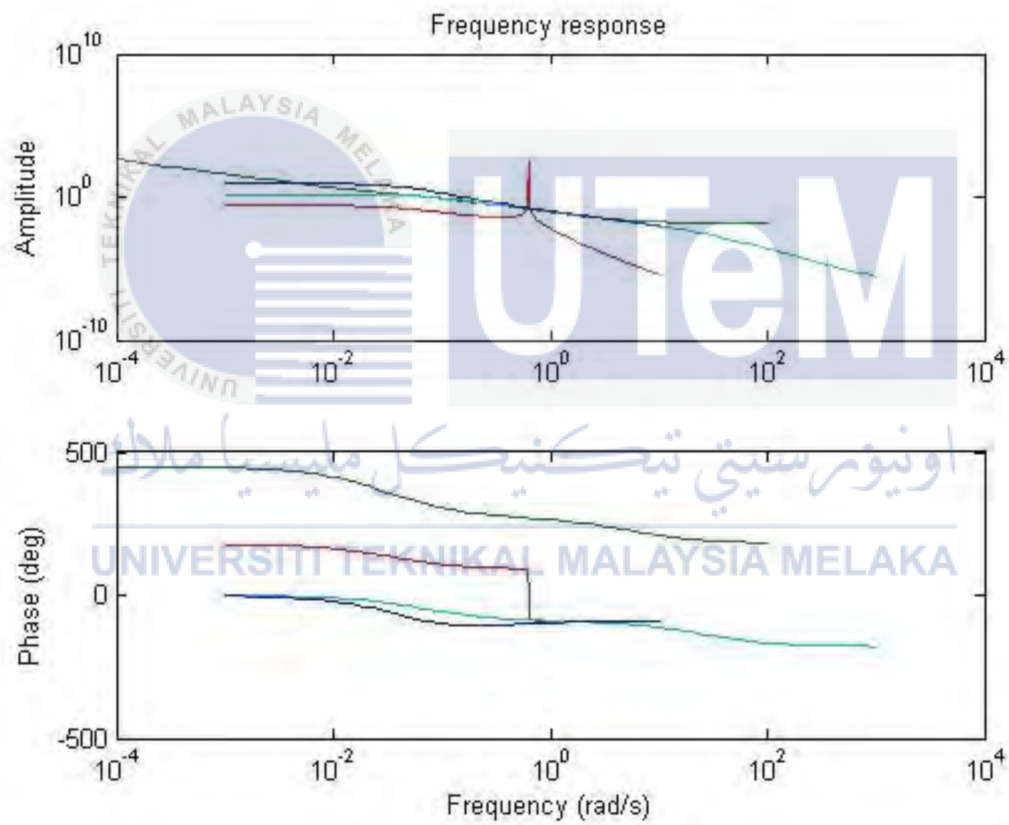

Figure 4.8: Frequency Response of the transfer functions

Based on Figure 4.8, the frequency response of transfer function 1 at frequency less than 100 rad/s is close to 0dB which means the output of the motor will look like the motor's input. If 0.01 Hz input position command, the motor with this control system can go along with close to identical amplitude. The output will not lag behind the input as observed in the same frequency range; it shows that the phase is at 0 degrees. Between the input and output of the system, 0dB at 0 degrees indicates perfect agreement. Figure 4.8 shows that the transfer function 1 gives a better frequency response compared to the other transfer function where the system move too far from identical amplitude.

4.3 Designing ANFIS-PID Controller

From Figure 4.9, it shows the block diagram of the control system. It consists of two controllers which are ANFIS controller and fixed parameter proportional-integral-derivative (PID) controller and thus designates the ANFIS-PID controller. By using the step input set point, ANFIS could calculate the required stimulus activation of the plant after it trained to mimic the inverse dynamics of the plant successfully. PID feedback controller is applied in parallel to the ANFIS controller to make up for the residual tracking errors that caused by the modeling errors and disturbances. Two different control system configurations is used which are ANFIS-PID controller and PID controller, their control performances is compare then.

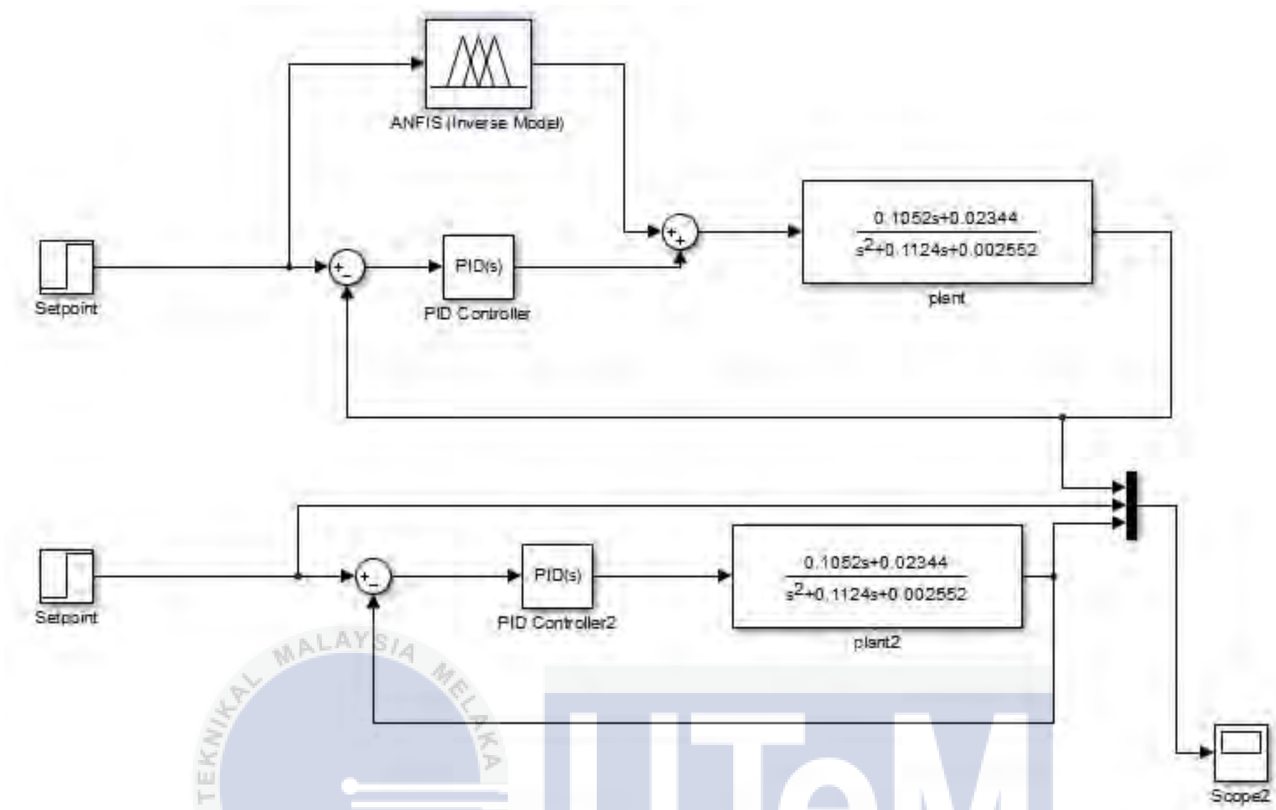

Figure 4.9: Configuration of ANFIS-PID and PID control system

The PID controller in the control system is tuned using Auto-tuning method where the controller parameters are as Table 4.2 while for the curve response in Table 4.3 below and the step response for the PID is shown in Figure 4.10;

Table 4.2: Controller Parameters

Proportional (P)	0.878302512706282
Integral (I)	0.100881436931177
Derivative (D)	-2.68374281601281

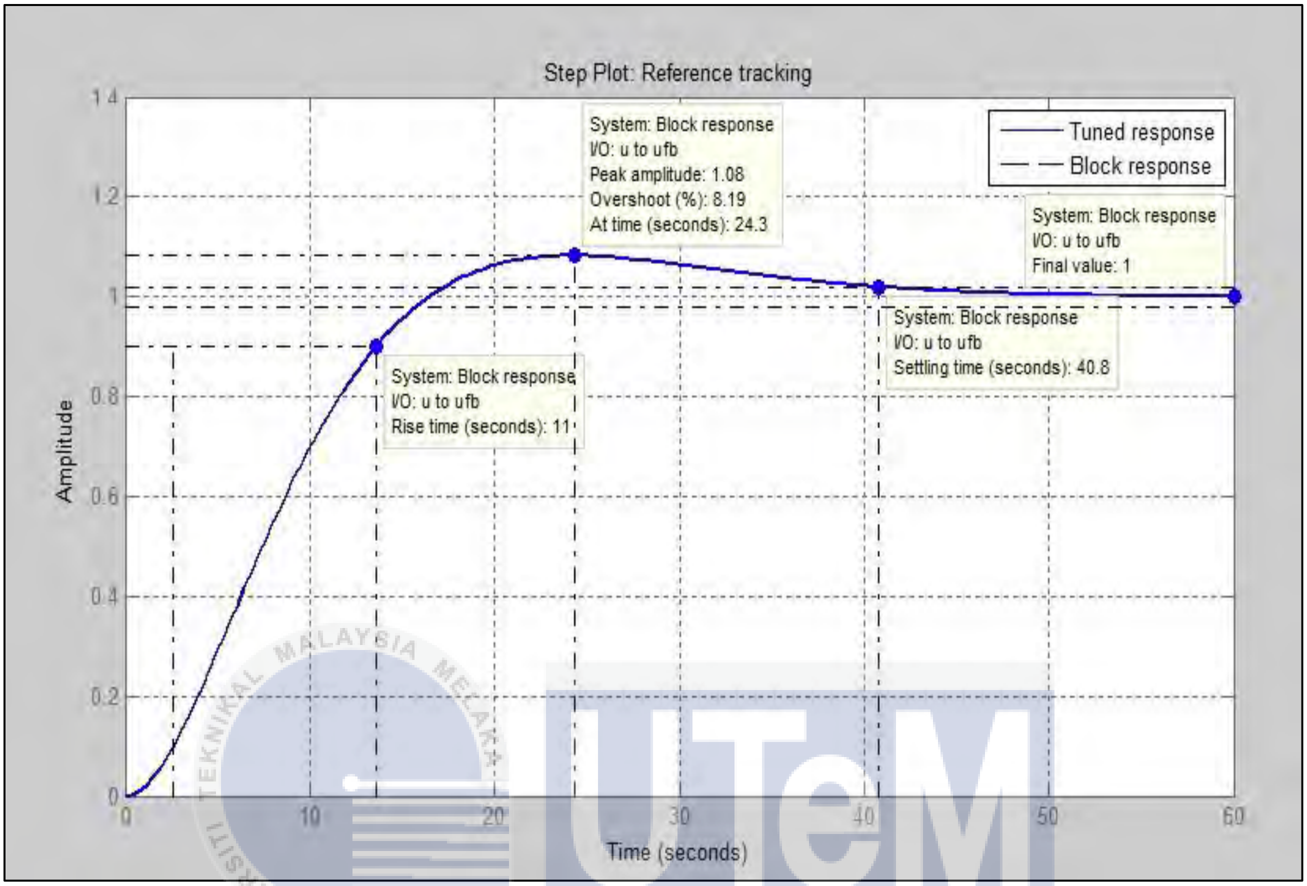

Figure 4.10: Step Response for the PID controller

Table 4.3: Characteristics of curve response

Rise time (sec)	11
Overshoot (%)	8.19
Settling time (sec)	40.8

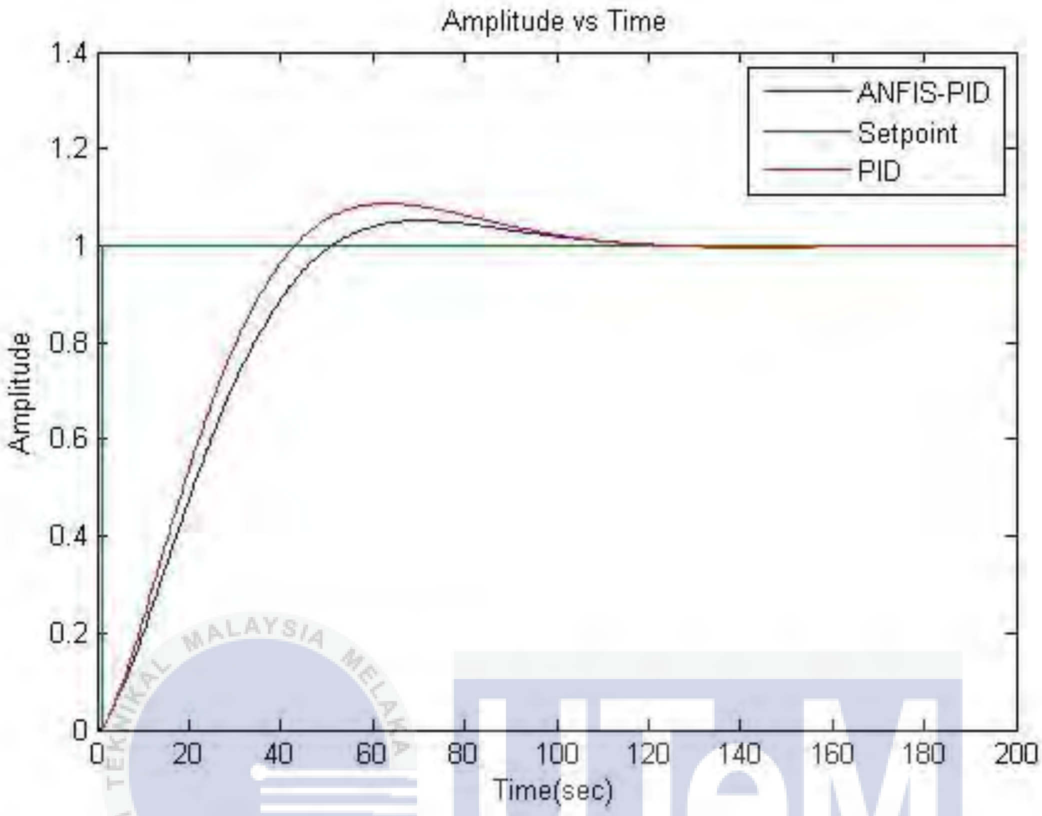

Figure 4.11: The simulation results of position control by ANFIS-PID and PID controller

Based on Figure 4.11, it shows that the performance of ANFIS-PID controller obviously slightly better than PID alone controller. While, the performance of PID alone controller is a bit slower than ANFIS-PID controller because the position trajectory traced the desired set point poorly. This is because, after combining the ANFIS controller with the PID controller to compensate the residual tracking errors, which is caused by disturbance and modeling error it specify that the ANFIS-PID controller improved the response of position tracking.

4.4 Integrate EMG Model with Control System

As previous 4.1, the EMG is modeled using ANN, then it is applied into the control system to replace the step input and compare which one gives the better performance. Figure 4.12 below illustrates the block diagram of the control system configuration.

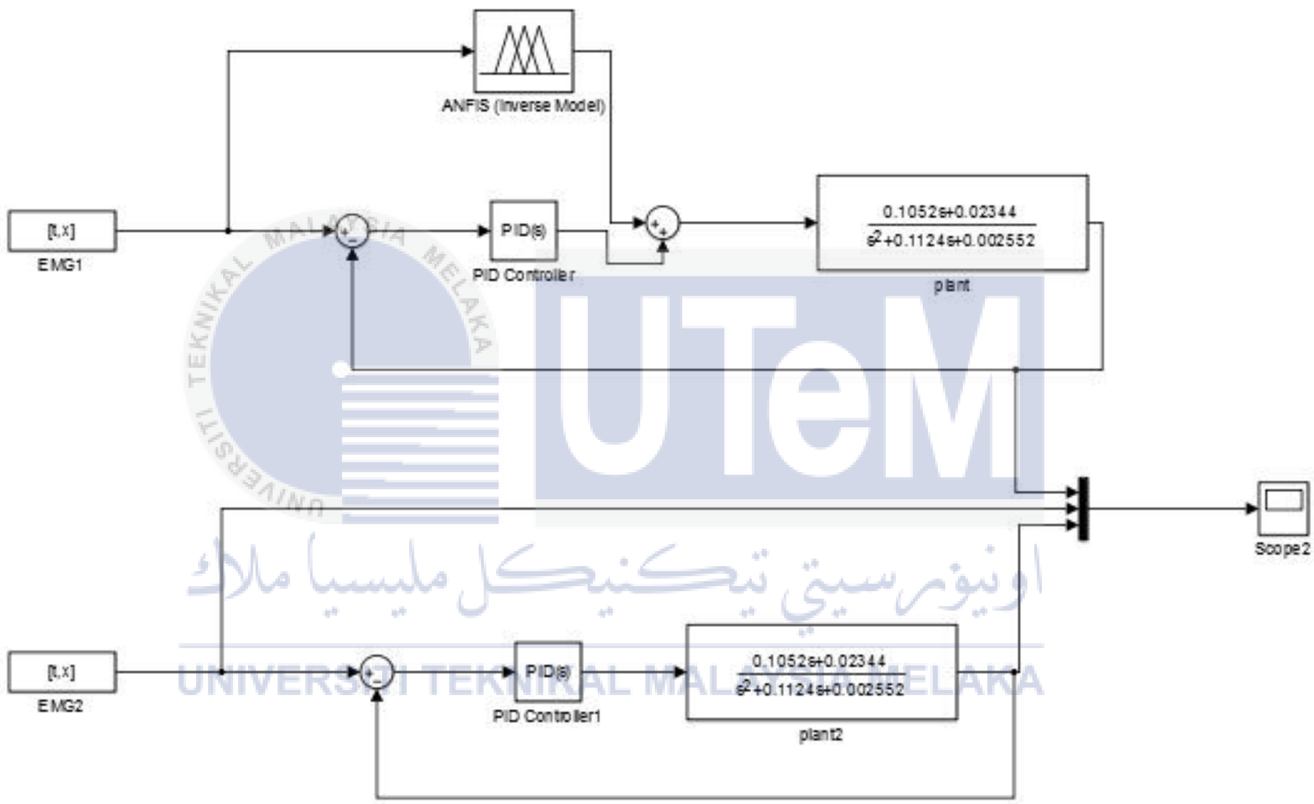

Figure 4.12: Block diagram with integrated EMG model

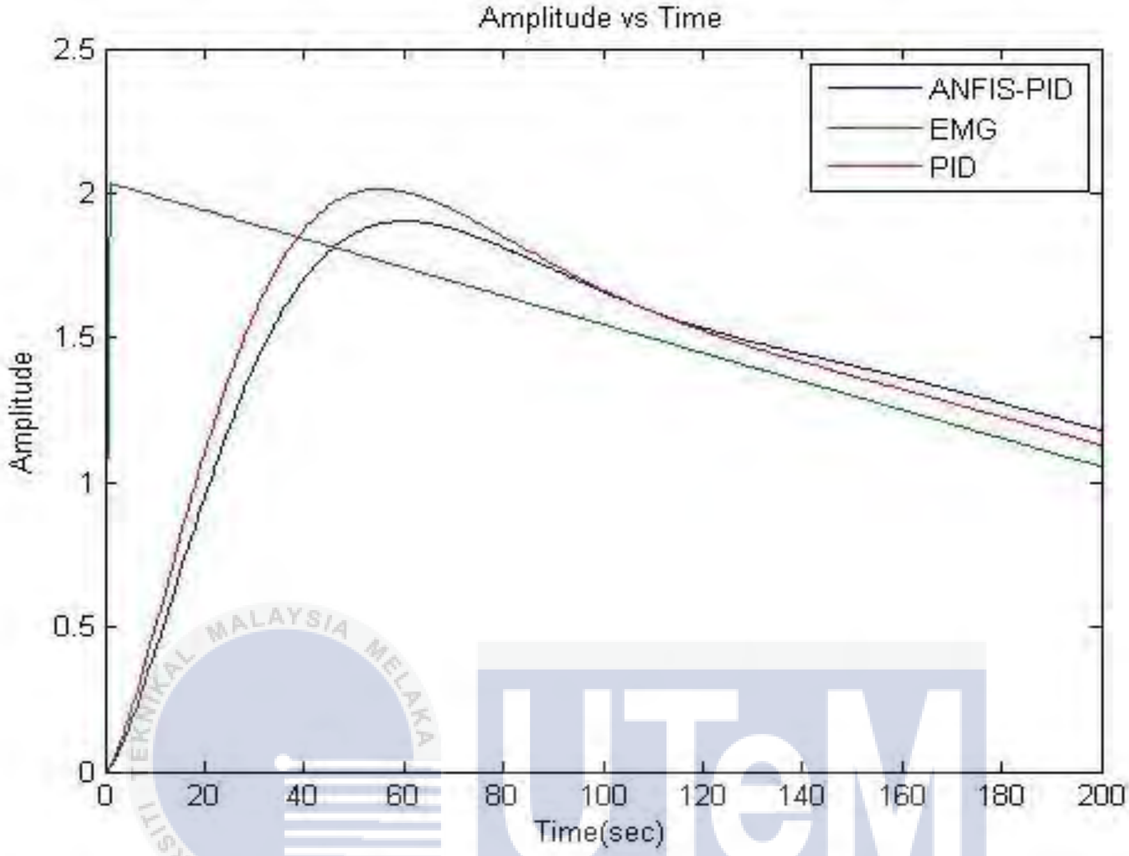

Figure 4.13: The simulation results of integrated EMG model by ANFIS-PID and PID controller

Table 4.4: Performance of ANFIS-PID and PID controller

Specifications	ANFIS-PID Controller	PID controller
Rise Time (sec)	32.6686	26.4167
Settling Time (sec)	383.8041	384.1554
Overshoot (%)	61.4388	78.3966

Based on the performance of ANFIS-PID controller and PID controller in Table 4.4 indicates that the rise time of PID controller is faster than ANFIS-PID controller which is 26.4167s. Whereas ANFIS-PID controller is slightly better than PID controller for the settling time and overshoot percentage. The settling time for ANFIS-PID controller is 383.8041s while PID controller is 384.1554s. So, the time required for the ANFIS-PID controller to settle and remain within final value is faster than PID controller with its percentage overshoot of 61.4388% which is lower than 78.3966% by the PID controller.

ANFIS is nonlinear controller. It has the ability to approximate nonlinear function liked EMG model better than PID controller as PID usually relies on accurate nonlinear model while ANFIS it doesn't need to accurate nonlinear model and don't have to be tuned after training compared to PID controller which have to be tuned again in some conditions [6]. Based on Figure 4.13, it shows that the best performance integrated EMG model is achieved by ANFIS-PID controller where it is the best approach to regain the adaptiveness for the nonlinear system case.

4.5 Robustness of the Controller

To test the robustness or effectiveness between proposed controller ANFIS-PID and PID controller, both controllers are compared with noise rejection. Figure 4.14 (a) and (b) show that the control system is applied with Gaussian noise at the input and feedback of the system.

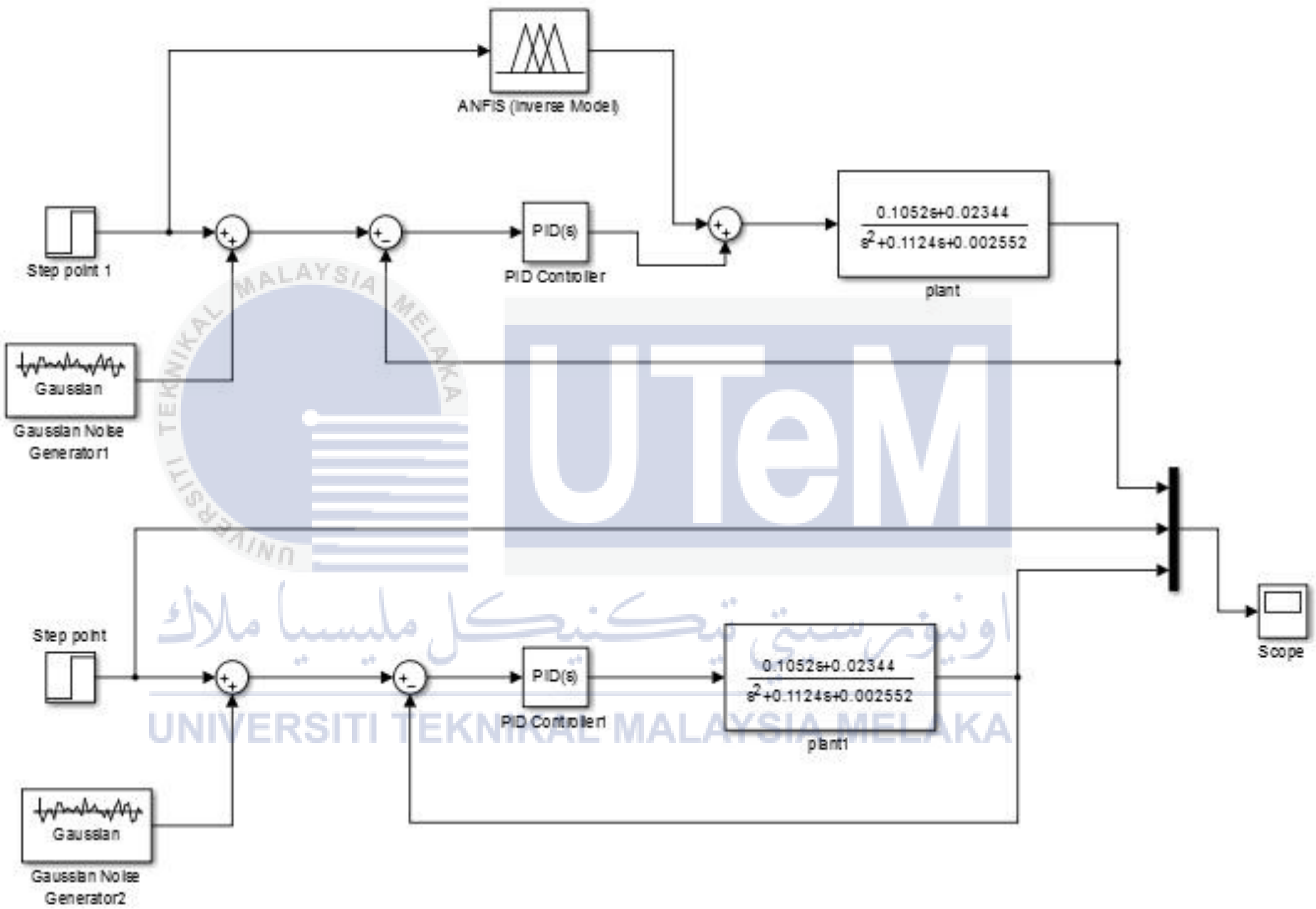

Figure 4.14(a): Gaussian noise is applied at the input of the system

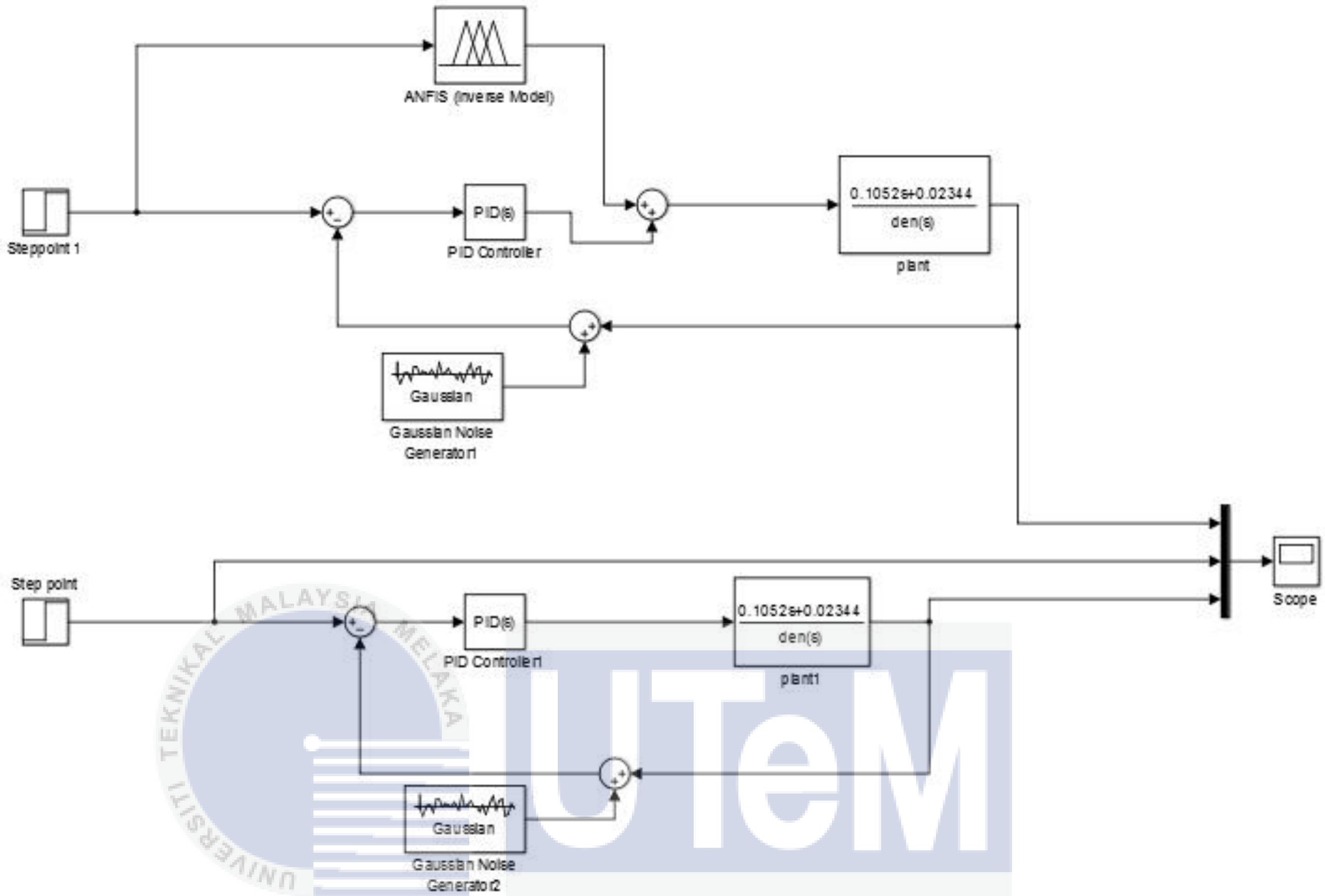

Figure 4.14(b): Gaussian noise is applied at the feedback of the system

Based on Figure 4.15 (a) and Figure 4.16 (a) below, it shows the comparison of the response by ANFIS-PID controller and PID controller when a Gaussian noise is applied at the input and at the feedback of the system. It indicates that the ANFIS-PID controller response can adapt faster even when there is noise exerted to the system compared to the PID controller. From Figure 4.15 (b) and Figure 4.16 (b), the results can be seen clearly the slightly difference of the response between these two controllers. From the result obtained, ANFIS-PID distinguishes the process variation faster and gives a better performance. Thus, ANFIS-PID controller is more robust compared to PID controller.

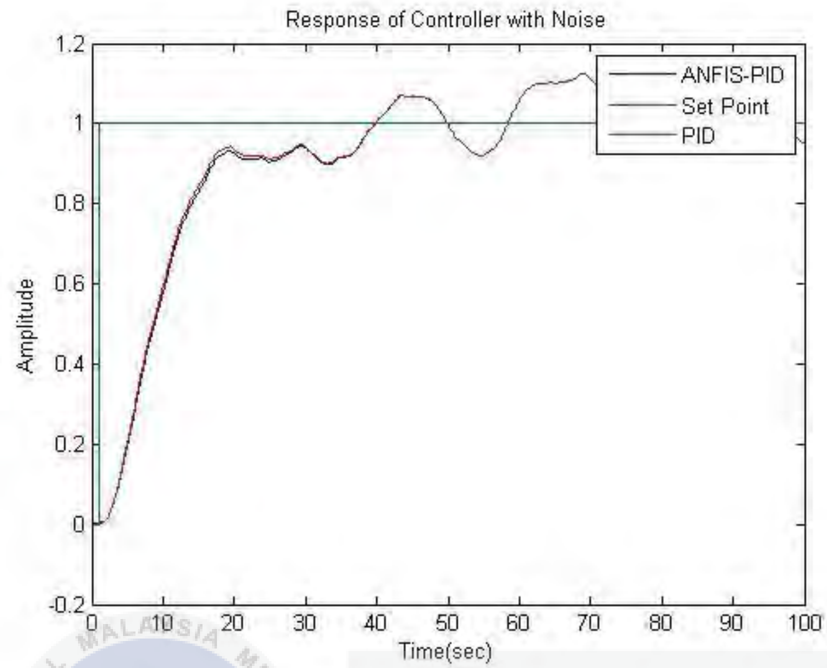

Figure 4.15 (a): Response of controller with noise at the input of the system

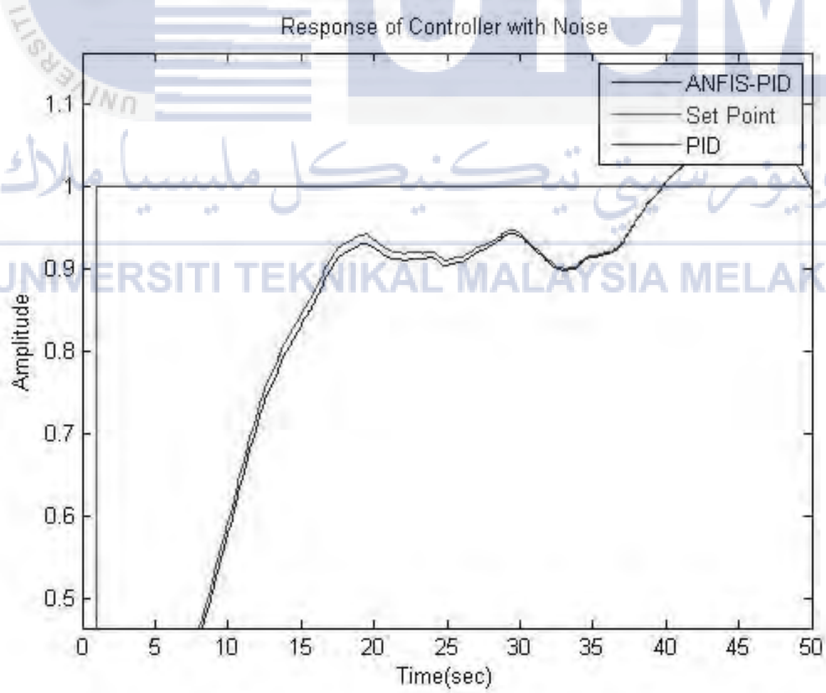

Figure 4.15 (b): Zoom In response from Figure 4.15(a)

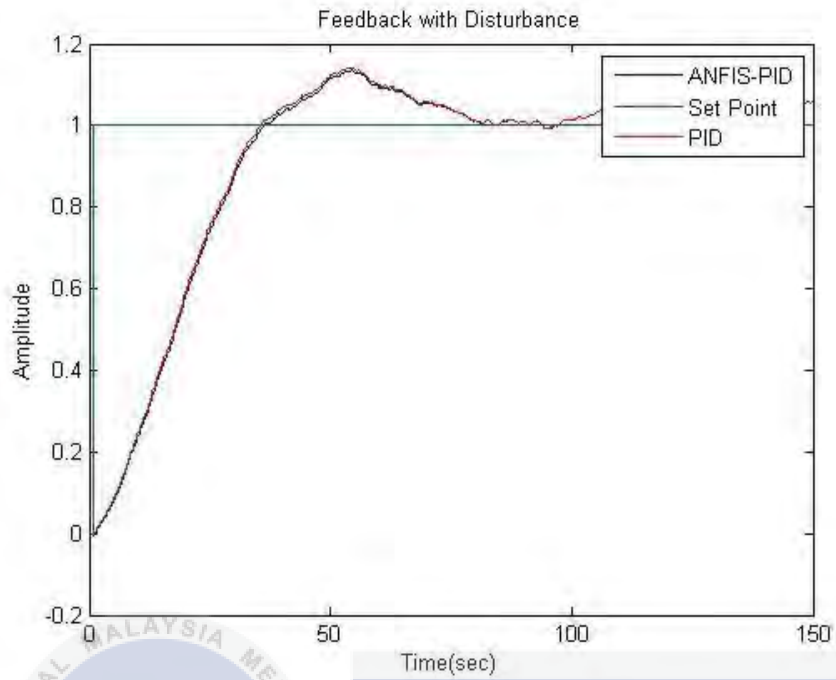

Figure 4.16 (a): Response of controller with noise at the feedback of the system

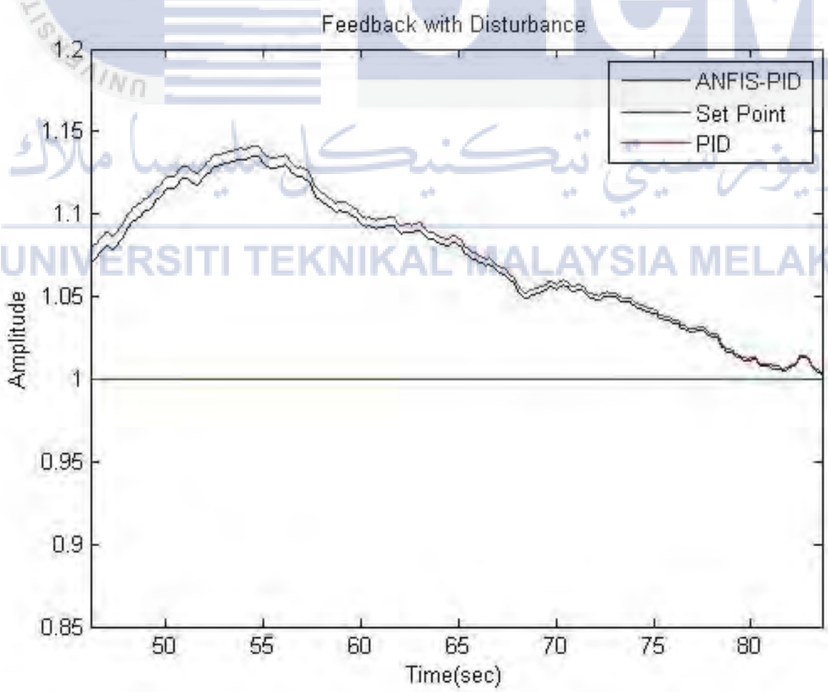

Figure 4.16 (b): Zoom In response from Figure 4.16(a)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the arm rehabilitation device is modeled by using System Identification and the transfer function validation is analyzed for stability analysis. In order to control the position of the motor, ANFIS-PID controller had been implemented. From the simulation results, the response of position tracking by ANFIS-PID controller is enhanced after the PID controller and ANFIS inverse model is combined to compensate the residual tracking errors that caused by disturbances and modeling error. The performance of the response is compared with conventional PID controller where the ANFIS-PID controller gives a better performance in the control system.

In addition, the system performance that is integrated with EMG model is also validated via simulation where the EMG is modeled using ANN method. Based on the results, ANFIS-PID controller has the ability to approximate nonlinear function liked EMG model better than PID controller. The best performance integrated EMG model is achieved by ANFIS-PID controller where it is the best approach to regain the adaptiveness for the nonlinear system case.

Furthermore, both controllers are tested with implemented of Gaussian noise in the system to compare the effectiveness and robustness between ANFIS-PID controller and PID controller. Gaussian noise is exerted at the input system and at the feedback of the system. Hence, from the system response it indicates that the ANFIS-PID controller is more robust to the system as it can adapt faster even when there is noise exerted to the system compared to the PID controller.

5.2 Recommendation

From the analysis, ANFIS-PID controller gives a better performance rather than the PID controller. However, this proposed controller might not be the best controller in order to control the position in the system. Further research with other intelligent technique is required to compare the performance of the system.

REFERENCES

[1] N. Venketasubramanian, "Epidemiology of stroke in south east asia: A Systematic Review," *Cerebrovasc. Dis.*, vol. 27, pp. 9–14, 2009.

[2] E. L. Miller, L. Murray, L. Richards, R. D. Zorowitz, T. Bakas, P. Clark, and S. A. Billinger, "Comprehensive overview of nursing and interdisciplinary rehabilitation care of the stroke patient: a scientific statement from the American Heart Association.," *Stroke.*, vol. 41, no. 10, pp. 2402–2448, 2010.

[3] S. E. Oltean, M. Dulau, and R. Puskas, "Position control of Robotino mobile robot using fuzzy logic," *Autom. Qual. Test. Robot. (AQTR), 2010 IEEE Int. Conf.*, vol. 1, 2010.

[4] R. Hussain, R. Massoud, and M. Al-mawaldi, "ANFIS-PID Control FES-Supported Sit-to-Stand in Paraplegics : (Simulation Study)," no. March, pp. 208–217, 2014.

[5] M. I. AL-Saedi, H. Wu, and H. Handroos, "ANFIS and Fuzzy Tuning of PID Controller for Trajectory Tracking of a Flexible Hydraulically Driven Parallel Robot Machine," *J. Autom. Control Eng.*, vol. 1, no. 2, pp. 70–77, 2013.

[6] A. M. Farid, S. M. Barakati, and A. Info, "UAV Controller Based on Adaptive Neuro-Fuzzy Inference System and PID," vol. 2, no. 2, pp. 73–82, 2013.

[7] J. Wang and Y. Li, "A Cooperated-Robot Arm Used for Rehabilitation Treatment with Hybrid Impedance Control Method," pp. 451–462, 2010.

[8] A. W. Dromerick, P. S. Lum, and J. Hidler, "Activity-Based Therapies," *NeuroRx*, vol. 3, no. 4, pp. 428–438, 2006.

[9] H. Mehdi and O. Boubaker, "ROBOT-ASSISTED THERAPY : DESIGN , CONTROL AND OPTIMIZATION," vol. 5, no. 4, pp. 1044–1062, 2012.

[10] H. Mehdi and O. Boubaker, "Stiffness and Impedance Control Using Lyapunov Theory for Robot-Aided Rehabilitation," *Int. J. Soc. Robot.*, vol. 4, no. SUPPL.1, pp. 107–119, 2012.

[11] P. C. Kung, M. S. Ju, and C. C. K. Lin, "Design of a forearm rehabilitation robot," in *2007 IEEE 10th International Conference on Rehabilitation Robotics, ICORR'07*, 2007, pp. 228–233.

[12] D. Erol, "Design of an Intelligent Control Architecture for," 2007.

[13] W. J. M. Kickert, "Analysis of a Fuzzy Logic Controller," *Fuzzy Sets Syst.*, vol. 1, pp. 29–44, 1978.

[14] H. Le-Huy, P. Viarouge, and I. Kamwa, "Model reference adaptive fuzzy control of a permanent-magnet synchronous motor," *Proc. IECON '95 - 21st Annu. Conf. IEEE Ind. Electron.*, vol. 2, 1995.

[15] S. K. Das, N. Mondol, and N. A. Sultana, "DESIGN AND IMPLEMENT OF A STATE FEEDBACK POSITION OUTPUT CONTROLLER FOR A MAXON S-DC MOTOR WITH dSPACE," vol. 2011, no. December, pp. 18–20, 2011.

[16] P. Solatian, S. Hamidreza Abbasi, and F. Shabaninia, "Simulation Study of Flow Control Based On PID ANFIS Controller for Non-Linear Process Plants," *Am. J. Intell. Syst.*, vol. 2, no. 5, pp. 104–110, 2012.

[17] M. H. Jali, T. A. Izzuddin, Z. H. Bohari, M. F. Sulaima, and H. Sarkawi, "Predicting EMG Based Elbow Joint Torque Model Using Multiple Input ANN Neurons for Arm Rehabilitation," *2014 UKSim-AMSS 16th Int. Conf. Comput. Model. Simul.*, pp. 189–194, 2014.

APPENDIX A

	FYP 1													
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
TITLE SELECTION														
FYP BRIEFING														
LITERATURE REVIEW														
SOFTWARE (SIMULATION)														
REPORT PROGRESS (SUBMIT)														
SEMINAR 1 (PRESENTATION)														
	FYP 2													
HARDWARE (DATA COLLECTION)														
SOFTWARE (SIMULATION)														
FULL REPORT														
SEMINAR II (FINAL PRESENTATION)														