FACULTY OF ELECTRICAL ENGINEERING

DESIGN OF PID TUNING GAIN SCHEDULING TECHNIQUE FOR TEMPERATURE CONTROL SYSTEM

NURIZZATUL AQILA BINTI NORBI

BACHELOR OF ELECTRICAL ENGINEERING

(CONTROL, INSTRUMENTATION AND AUTOMATION)

2017

ACKNOWLEDGEMENT

First of all, I am thankful to Allah s.w.t who made give me the opportunity to do this project. Without His numerous blessings, it would not have been possible.

I also would like to give my deepest gratitude to my supervisor, Encik Mohamad Riduwan Bin Md. Nawawi for his valuable comments guidance and patience. Without his support, I would face a problem in completing this project.

I also would like to thank my friends who give supports and motivations and stands beside me throughout this whole semester for me to able complete the full report of this project.

Last but not least, I also would like to praise my parents and family for supporting me all the time during my year of study.

ABSTRACT

In this thesis, a PID controller is designed to control the performance of the process temperature control system. The designed PID controller is applied in the process of temperature control system by using fuzzy gain scheduling technique to improve the performance of transient response of the temperature control system. MATLAB/Simulink software is used in order to design the PID controller and thus, to obtain the analysis of the performance of the transient responses for the temperature control system. As a result, the simulation from the MATLAB shows the temperature control system performance which is in transient response analysis, parameter variation and statistical analysis. The transient response analysis gives the results in term of percentage overshoot, rise time, settling time and steady-state error. Next, to get a better performance in the temperature control system, the fuzzy gain scheduling technique is applied until the desired temperature without a disturbance is achieved. From this, it has been found that PID controller tuned by the fuzzy gain scheduling technique gives the best performance compared to PID controller using Cohen-Coon and Ziegler-Nichols method. It is because the rise time and settling time of the system from fuzzy gain scheduling is faster compared to the other two methods which is 0.004ms and 0.013ms respectively.

ABSTRAK

Dalam tesis ini, pengawal PID direka untuk mengawal prestasi dalam sistem proses kawalan suhu. Pengawal PID yang direka digunakan dalam proses sistem kawalan suhu dengan menggunakan teknik keuntungan penjadualan kabur untuk meningkatkan prestasi sistem kawalan suhu. Perisian MATLAB/Simulink digunakan untuk mereka bentuk pengawal PID dan justeru itu, mendapatkan analisis prestasi untuk sistem kawalan suhu. Hasilnya, simulasi dari MATLAB menunjukkan prestasi sistem kawalan suhu yang di analisis dalam bentuk sambutan fana, perubahan parameter dan analisis statistik. analisis sambutan fana memberikan hasil dalam bentuk peratusan terlajak, masa naik, menetap masa dan ralat keadaan mantap. Seterusnya, untuk mendapatkan prestasi yang lebih baik dalam sistem kawalan suhu, teknik keuntungan penjadualan kabur digunakan sehingga suhu yang dikehendaki tanpa gangguan dicapai. Melalui teknik ini, telah terbukti bahawa pereka PID yang direka oleh teknik keuntungan penjadualan kabur memberikan prestasi yang terbaik berbanding pengawal PID menggunakan kaedah Cohen-Coon dan kaedah Ziegler-Nichols. Hal ini adalah kerana masa naik dan masa penetapan sistem daripada penjadualan keuntungan kabur yang lebih cepat berbanding dua kaedah lain iaitu 0.004ms dan 0.013ms.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

1. PID : Proportional Integral Derivative
2. RTD : Resistance Temperature Detector
3. SE : System Stored Energy
4. LPV : Linear Parameter Varying
5. GSBC : Gain Scheduling Backstepping Control
6. PLI : Power-Line Inspection
7. EML : Equilibrium Manifold Linearization
8. SI : System Identification
9. EM : Electromagnetic
10. GUI : Graphical User Interface
11. ADC : Analogue to Digital Converter
12. PV : Photovoltaic

CHAPTER 1

INTRODUCTION

1.1 Introduction

There are many types of process that implement the gain scheduling technique into their system such as temperature control system, aircraft system, water level control system and others. The temperature control system are widely used in the researches as temperature is one of the most important parameter that usually influenced the process of a certain system. The control of temperature is important for the performance of the end product. The characteristics of the temperature control systems in the industry mainly have long delay time and large time constants. Because of the long delay time and large time constant, the difficulties of the temperature control system is increasing [1]. In order to obtain a good performance of the system, a gain scheduling technique is implemented into the system.

The gain scheduling technique is basically used for non-linear systems where the control system is decomposed into a several linear sub-parts. Gain scheduling technique had been defined as a linear parameter varying feedback regulator whose are changed as a function of operating conditions. This technique occurred in the early 1950s when the researchers use this technique in the design of autopilots for high performance aircraft [2]. It can also alter the linear controller parameters in a non-linear mode depend on the process state and scheduling variable [3]. The main ability of the gain scheduling technique is able to design the linear sub controllers based on a set of linearized model of the non-linear plant [4]. So, the gain scheduling technique is one of the most popular technique to design non-linear control and has been successfully implemented into several systems [5].

It is because the gain scheduling technique has many advantages as most of the researches apply this technique in order to obtain a high performance of the process control. This technique is scheduled along with the time-varying parameters and can adjust the parameters to adapt the changes in real time environment [6]. Usually, the use of this technique is to allow a high performance system across the scheduling parameter interval. Many approaches are designed for gain scheduling such as interpolation, Youla parameterization and fuzzy logic [7]. So, each of the approaches are suitable for a certain type of process control.

In this project, a temperature control system is considered in the research study. So, in order to implement the gain scheduling technique into this system, a mathematical modelling is derived based on the model of the system. The transfer function of the system is obtained from the system identification tool to compare with the transfer function of the real-time experiment where Simulink/MATLAB is used. The model diagram of the process system is in the open-loop system. A Microbox 2000/2000C is used to interface the data of the system into the software so that the transfer function can be estimated by using system identification tool.

1.2 Objectives

1. To identify the transfer function of Lab Volt Process Control Trainer by using System Identification Tool.
2. To design a PID controller by tuning the PID gain using fuzzy gain scheduling technique.
3. To analyse the transient response of the temperature control system based on the implementation of PID controller using fuzzy gain scheduling, Cohen-Coon and Ziegler-Nichols technique.

1.3 Motivation

The main motivation of doing this project is to design the PID controller of the temperature control system until a good result of performance is obtained. As the Lab-Volt Process Control Trainer was used as the temperature control system, the plant that mainly used as a trainer in a laboratory is always non-effective. It is because the trainer has been used as a trainer for the students for a long time. So, the functions of the trainer may be not achieve the requirements. Therefore, by doing this project, a PID controller can be easily designed just by using the MATLAB software than using the manual designed of PID controller. It will resulting in a good performance of the temperature control system.

1.4 Problem Statement

As the temperature control system used which is Lab-Volt Process Control Trainer is not that effective, it is very hard to carry out since its behaviour can change during the process. Besides that, it is shown that the parameter of the system which is temperature is always changeable. Besides that, a fixed gain PID controller cannot give a satisfactory results as the controller used is less efficient and this will lead to instability of the system. And lastly, it has a hard way to obtain the transient response graph for the performance without using any software.

So, to overcome the problems occurred above, a PID controller is implemented into the system to give a good performance of transient response of the system. As a fixed gain PID controller cannot gives a satisfactory results, the gain scheduling technique is applied for the changing of the parameters until the desired requirements are met. Last but not least, the system is then implemented into the MATLAB/Simulink software to obtain the transient response of the system so that the system can be observed easily and it also can varying the parameters until the desired performance is obtained.

1.5 Scopes

This project is divided into two parts which are hardware and software. For the hardware part, the plant used is Lab-Volt Process Control Trainer which acts as the temperature control system. The sensor used to detect the radiator temperature is thermocouple and the transmitter is used to measure the reading of the temperature. The Microbox 2000/2000C acts as an interface of the system to send the data from the plant to the PC host. The Ethernet cable is connected between the Microbox and the PC host. For the Simulink to receive the data from the plant, the plant acts as xpctarget.

For the software part, the MATLAB software is introduced. The data received from the plant is stored in the workspace of the software in term of timelog and outputlog. The switch used is varied with input 0 until 5V. The analog to digital converter sampling time is 0.001s as the frequency of the Microbox is 1 kHz. The analog to digital converter (AD1) is connected to the temperature transmitter output while the digital to analog converter (DA11) is connected to the control input.

Besides that, the system modelling of the plant is important for the transient response of the system to be obtained. Therefore, a transfer function is needed. To obtain the transfer function of the plant, the System Identification Tool is used. The purpose of this identification is to determine the characteristics of the control process. The input and output data collected from the experiment is used where a few estimation are made regarding the structure of the plant model [8].

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

A temperature control system has been used in this project to analyse the performance of the system. A Lab-Volt Process Control Trainer is used to undergo this project to obtain the performance of the temperature control system. In this project, a PID controller must be designed by using gain scheduling technique to implement it into the plant. The PID controller is designed to improve the transient response and the steady-state error of the system.

The parameters required are the voltages and temperatures. These parameters is a must in order to obtain the relationship between voltage and temperature that occurs in the plant. After that, the open-loop control system input and output data is imported into the System Identification Tool to obtain the modelling system transfer function.

This project requires several equipment such as Lab-Volt Process Control Trainer, Microbox 2000/2000C and MATLAB software. In this literature review, the description of each equipment are properly described.

2.2 Temperature Control System

A temperature control system widely used in the industrial area and many researches have been done in order to improve the performance of the control process. A temperature control system is basically divided into two parts which are automatic and manually control system. The system is called automatic when the when there is a sensor used to sense the temperature while the system is called manual when the system reads the temperature and adjusts the heat and cooling input in the direction of up and down until the temperature reach its desired value.

A research has been conducted about the industrial furnace temperature process control. The furnace system is divided into two systems which are the main controlled variable and sub controlled variable. The main variable shows the temperature of raw material while the sub variable shows the temperature of the hearth in the furnace. The disturbances that involved in this system are the flow of the raw material and temperature of the material at the inlet [9]. There also another experiment which is conducted in the process furnace control system. This experiment is about the disturbances involved that effect the performance of the temperature in the furnace control system. The temperature control system of process furnace also consists of two parts which are branch temperature balanced control to prevent coking in tubes and outlet temperature control to provide appropriate temperature for crude installation [11].

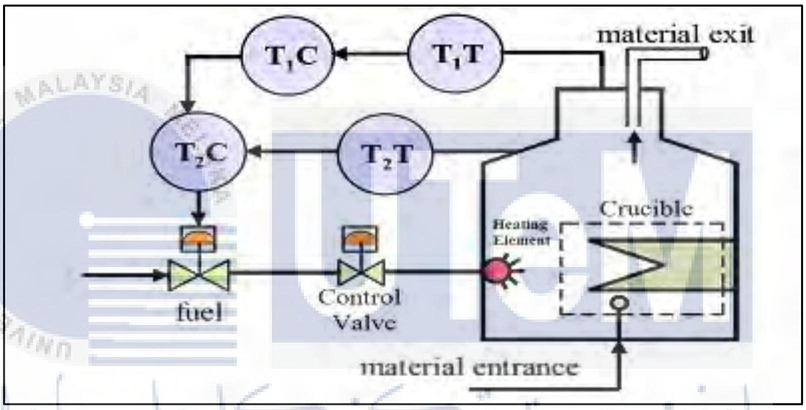

Figure 2.1: The Furnace Temperature System [11]

Besides that, there is another research of temperature control system for cement raw meal calcination process. It is a process where raw cement materials are processed and transformed into clinker after preheating, decomposition and calcination. The main components involved in the calcination process are calciner which are used to decompose the raw meal and fuel combustion and preheaters that are used to heat raw meal [10].

Another research of temperature control system has been conducted using virtual air temperature oven. The oven consists of resistance temperature detector (RTD), thermocouple and the heating element. The sensors acts as a feedback to measure the air temperature in the oven. The controller is used to control the heater power through a selector either in time proportional relay control or current continuous in a unit of mA [12].

Figure 2.2: The Air Temperature Oven [12]

Therefore, for this project, Lab-Volt Process Control Trainer which consists of the radiator temperature process is used. This is called an automatic temperature control system as sensor is used in this system and the accuracy of the value of the parameters is a must. Besides that, the temperature changes are quite fast in order to obtain the relationship between the temperature and voltage.

2.3 Parameters

In all process control system, parameters need to be taken into consideration as the parameters involved has a relationship to obtain the performance required. For an example, in the blade of wind turbine process, the length takes the important rule in the making of the blade. It is because when the length increases, the weight also increases. The vacuum is used to reduce one side pressure of the blade body and the heating process takes place to increase the blade strength [13].

In the temperature control of catalytic cracking process, the mathematical modelling involved are riser model and regenerator model. In the riser model, the mass and the mass flow rate of reactor product and spent catalyst are involved in the calculation to obtain the reactor bed temperature. The regenerated catalyst feed rate acts as the input. The heat of reaction and combustion are constant. For the regenerator model, the mass and the mass flow rate of flue gasses, air temperature and air rate are used to calculate the regenerator temperature [14].

A research has been conducted on emulated inertial response from wind turbines where the parameters involved in power system modelling are infeed trip size, load levels, system stored energy (SE) and governor droop settings. The system comprises of variable speed and fixed speed wind plant. Therefore, the load conditions are varied for instantaneous wind penetration levels of 20, 40 and 60% [15].

In the decoupled temperature control system, the temperature of the plastic in injecting-moulding machine is taken into account because it decides the quality of the plastic products. The input voltage has strong influences to every output. Therefore, the relationship of voltage and temperature has huge function in order to obtain the transfer function with different time delay [16].

In this paper, the parameters involved has been identified which are voltage and temperature. This relationship is taken into consideration in order to do calibration of the Simulink for the display block diagram displays the value of temperature. This is because, when the system is running, the data saved in the workspace in the MATLAB will be temperature instead of the voltage.

2.4 Controllers

A controller is very important in all types of control systems. The function of the controller is to improve the performance of each system. It improves the performance of the systems in terms of percentage overshoot, rise time, steady-state error and settling time. It is a must to have the controller in the system to improve the transient response and steady-state error of the system.

In one of the researches of temperature process that have been done, a traditional PI controller has implemented in the system to improve its performance, but it produces high overshoot and the design procedure seems complex. Therefore, the usage of intelligent controller has been proposed because it offers a better overshoot and settling time and thus increases the robustness of the system [17]. There is also another system which use direct synthesis method based PI controller in control level of a single conical tank system. The PI controller used takes a longer time for the system to reach the set point. Thus, the performance of the system is then compared with the use of the adaptive control based PI controller and it shows that the controller tracks the set point faster with less rise time [18].

An experiment of tuning methods for PID controller parameter of DC motor has been conducted. The PID controller has been designed using three methods which are Ziegler-Nichols method, Simulink Response Optimization Toolbox and Fuzzy Gain Scheduling. Based on the three methods used, it has been found that the fuzzy gain scheduling based PID controller gives efficient position of DC motor compared to the other two methods [19]. Same method is used in controller design for the position control of a DC motor. In this research, the use of sliding mode controller gives off high robustness against uncertainties but it can lead to chattering phenomena that can harm the plant. Therefore, in order to enhance the sliding mode controller performance, PID tuned by fuzzy logic is used. The result shows that the chattering has been avoided [20].

In another research of temperature control, the PID controller based Scr Control system is used. The PID controller is used in order to eliminate the contactor-based ON/OFF control for the heating applications. This is because, the ON/OFF controller consumes large consumption and gives damages to the equipment. So, the PID controller based Scr control system replaced the old controller because it ensures a longer life period for the equipment and it also reduces the energy losses [21].

Literally, the adaptive or intelligent control based controller gives a better performance compared to direct synthesis method based PI/PID controller. Usually, the direct synthesis method or traditional method takes much time to reach the set point. Thus, the use of intelligent based controller are widely used in the industry as it gives minimum rise time, quick settling time response and tracks the set point faster [22].

2.5 Gain Scheduling

The gain scheduling technique is basically used for non-linear systems where the control system is decomposed into a several linear sub-parts. This technique is used when it is possible to find the parameters which related well with the changes of the process behaviour. Many efforts have been devoted to develop methods of gain scheduling to reduce the time spent on optimizing the choice of controller parameters.

A research has been conducted on fuzzy gain scheduling of PID controller that is implemented on real time level control. In this system, non-adaptive conventional PID controllers do not provide desired response. However, using fuzzy algorithm is not as easy as defining PID controller gains. Therefore, the advantages of both fuzzy algorithm and PID controller are mixed to form a fuzzy-PID gain scheduling controller that satisfies the response parameters for the level control system [23].

There is also another research has been made where the paper addresses the LPV gain scheduling method for controller design of turbo fan jet engines. This method used a process description of linear parameter varying system. The mapping of linear controllers are not necessary but the transformation of non-linear process model to a LPV system is a hard task. Therefore, most LPV method use modern techniques such as H_2 or $H\infty$. It is because modern techniques has resulting a stable controller and the performance is guaranteed [24].

In another research paper, a gain scheduling backstepping control (GSBC) has been proposed for the motion balance adjusting of the power-line inspection (PLI) robot. As usual, the function of gain scheduling is to convert the non-linear dynamic model of the PLI robot into a linear model. The linear model is then transformed into an equilibrium manifold linearization model (EML) using a scheduling variable. This method extends the operational area of the closed-loop system and overcomes the initial non-linearities of the model. The results show that the proposed GSBC technique proved the efficiency and feasibility [25].

As a conclusion, for this project, a fuzzy gain scheduling has been proposed to improve the performance of the temperature control system. This type of technique determines the controller parameters of the PID controller and it will generate the control signal and it gives a better performance of the system than using the PID controllers with fixed parameters [26].

2.5.1 Fuzzy Gain Scheduling

The fuzzy logic gain scheduling technique is implemented in this project. Based on previous research, fuzzy logic scheduling consisted of two inputs and three outputs and every research used different types of output's tuning. There was also some research that tuned two outputs to design PI or PD controller.

In the research paper of subspace predictive controller, the fuzzy logic gain scheduling was implemented into the system to update the subspace predictive controller gains. The output parameters used were controller gains, K_e and $K_{\Delta ep}$ and proportional gain of the current, $K_{\Delta up}$. The SPC gains were tuned by applying fuzzy logic rules. Therefore, the simulation result showed that the proposed fuzzy gain scheduling with SPC gave more robust tracking performance compared to the conventional SPC [27].

Meanwhile, in order to improve the power system transient stability by PV farm, the PV farm was equipped with a fuzzy gain scheduling of PID controller for transient stabilization of a multimachine power system. This controller was used to control the PV inverter, so that the PV output can stabilize the transient power when the faults took place. This controller tuned the parameters outputs of value K_p, K_i and K_d [28].

In this project, the parameters outputs that had been tuned were K_p, K_d and α. The value of K_i was calculated by using the value of α that has been tuned by the fuzzy logic controller. Some equations were involved in this technique.

2.6 Lab-Volt Process Control Trainer

Lab-Volt process control trainer is used as a plant that is mainly used in the laboratory. It is a flexible teaching and demonstration tool for the students of control electrical engineering as it shows a wide range of control engineering principles. The process control trainer is designed to perform the temperature process control. This plant consists of electrical driven fan which induces air flow through a duct. The incoming air is heated by the heater that is placed near the fan. The light of the heater will turn on when there is overheat occurred. The heater power is obtained by using a linear amplifier. The output power of the plant is proportional to its input voltage [29].

Besides that, this plant also comes with a built in proportional controller which are PID controller that can be used in order to improve the performance of the required process control. This plant also can be interfaced with other devices to implement external control in order to obtain accurate results of the performance of the control system.

In this project, Lab-Volt process control trainer is connected to the Microbox 2000/2000C to obtain the accurate data of the system. The control input, output of the transmitter and the ground are connected to the Microbox for them to transfer the analog signal into digital signal to the MATLAB software.

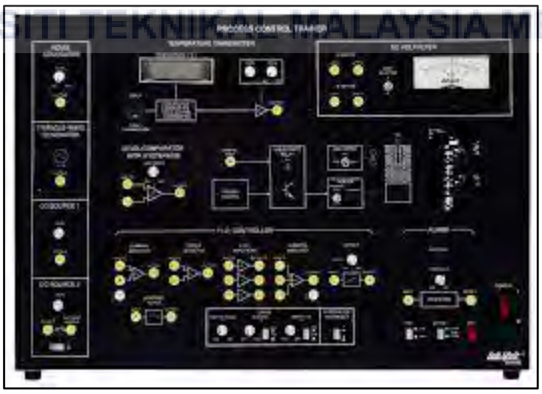

Figure 2.3: The Lab-Volt Process Control Trainer

2.7 Thermocouple

Thermocouple is a sensor that measure the reading of the temperature with an electric output signal. It consists of two dissimilar conductors in contact that produce a voltage when heated. The size of the voltage is depend on the difference of temperature of the junction to the other parts of the circuit. This sensor is widely used for measurement and control and can also be used to convert temperature gradient into electricity [21].

There are many types of thermocouples which are type J, K, T and E for base metal and type R, S and B for noble metal. Commercial thermocouples can measure a wide range of temperatures and are inexpensive. The main limitation of the thermocouples is accuracy because the system errors of less than one degree Celsius can be difficult to achieve.

In this project, the J type thermocouple is used as it is the most common types of thermocouples. The thermocouple sensor is used because of their low cost, high temperature limits and wide temperature ranges.

2.8 Temperature Transmitter

The temperature transmitter is one of the part that involved in the Lab-Volt Process Control Trainer. Temperature transmitter is an electrical instrument that interface the temperature sensor used which is thermocouple to a measurement or control devices. It converts the input signal from the thermocouple and then transmits the output signal to the control device. The reading of the temperature from the plant will be displayed on the process control trainer by using this temperature transmitter.

2.9 Microbox 2000/2000c

Microbox is a microcontroller and acts as a XPC target machine. This component is machine device used to interface the hardware model with the MATLAB software. It is a solution for testing, prototyping and developing real time systems using standard PC hardware for running real time applications. It also supports all PC hardware such as video, mouse and keyboard. This Microbox can run real-time modelling and simulation of control systems and hardware in the loop testing [30].

Figure 2.4: The Microbox 2000/2000C

This hardware allows sampling time of 0.001s which is 1 kHz. It is a driver that communicates between input and output devices on the target PC and the temperature control system. It enables the interaction between the real-time application and the plant. Besides that, it contains a code that runs on the target hardware for interfacing with input and output devices such as analog-to-digital converters, encoders, digital signals and communication parts.

These driver are implemented as block diagram in the SIMULINK of the MATLAB. The xPC target works with the code generated from the SIMULINK and a C compiler to build the real-time target application. The real-time target application represents the plant of the temperature control system and it can run on the PC once it is downloaded.

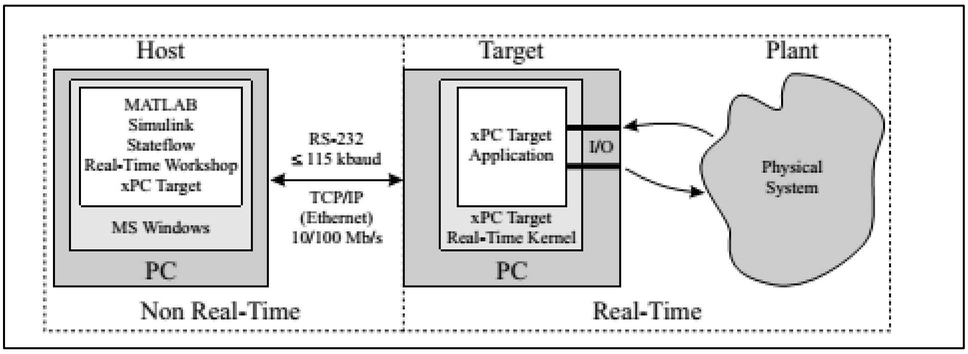

Figure 2.5: The Connection of the Plant and MATLAB software using Microbox

2.10 PC Interface and Calibration

In this project, the temperature control system is programmed in the SIMULINK and the plant is interfaced with the MATLAB real-time target using Microbox 2000/2000C. For the first step, the voltage value used is in range of 0V to 5V as the Microbox can produce maximum output voltage of 5V. The switch used is varied between 0V to 5V and it sends the input voltage signal to sensoray analog output diagram. The process mentioned is called interfacing as the data from the hardware system is interfacing with the PC hardware by using Microbox.

The readings of temperature are recorded corresponding to their output voltage. The graph of the output voltage against the temperature is plotted to obtain the relationship between the output voltage and the temperature. This relationship need to be taken into account in order to convert the output voltage into temperature reading that will display in the Simulink [30]. It is because the Microbox only measure the readings of the system in voltage. Therefore, a calibration is needed.

2.11 System Identification Tool

System identification tool is a tool to estimate a transfer function of the process control. This tool is provided in the MATLAB software. The system identification (SI) method is presented in the known input and the computed output time series from a time domain full wave simulation to derive the state vector and system matrices that defines the modelling of the model.

A research about representation of electromagnetic responses in time domain has been conducted using state-space system identification method. It uses this method to derive state matrices and system dynamics of simulated time domain electromagnetic (EM) responses using both input and output data. This method is applied to obtain the model transient response, root locus and transfer function [29].

Another research has been conducted using the system identification method for the modelling of the thruster. By using the ident command in the MATLAB software, the system identification toolbox is opened. In the “Import Data” section, the time-domain data is selected to insert the input, output and sampling time of the system. Under the “Estimate” section, the linear parameter GUI was selected. The range of order selected was from 1 to 10 and normally the red line shows the default choice [31].

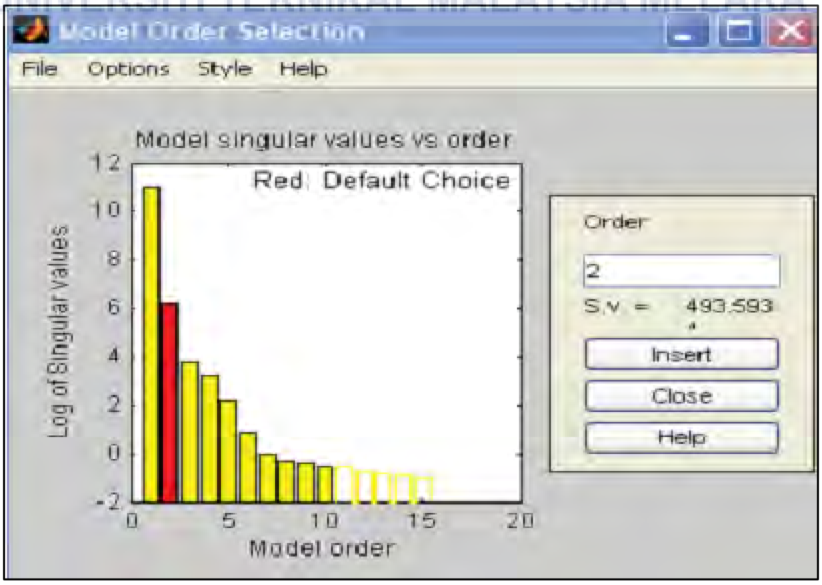

Figure 2.6: The Model Order Selection [29]

For this project, system identification tool is used to obtain the transfer function of the temperature control system. In the "Estimate" section, the transfer function model is selected. By using this method, the transfer function of the system can be estimated by the probability on how many poles and zeros are required. After several probabilities, the transfer function of the system is selected based on the best fits because the higher the best fits, the system tends to be more accurate.

CHAPTER 3

METHODOLOGY

3.1 Mathematical Modelling of the System

A radiator is a component where the exchange of heat from the engine coolant to the air passing takes place. The radiator must continue to give efficient heat transfer to make the exchange of heat from the engine cooling fluid with the external environment.

For the heat balanced equations, the radiator is modelled as a lumped system with N elements in series which is given by:

$$\frac{C_{rad}}{N}\dot{T}_N = c_w q(T_{n-1} - T_n) - \frac{K_{rad}}{N}(T_n - T_a) \quad \text{– (1)}$$

in which:

C_{rad}= The heat capacity of the water and the radiator.

T_n = The temperature of the radiator at n^{th} element with n=1,2,…N.

K_{rad}= The radiator equivalent heat transfer coefficient.

The heat power transferred to the room by the radiator is given by:

$$Qr = \sum_{n=1}^{N} K_{rad}\ (T_n - T_a) \quad \text{– (2)}$$

While the heat balance equations of the room is described by:

$$C_e\dot{T}_e = U_eA_e(T_{amb} - T_e) + U_eA_e(T_a - T_e) \quad \text{– (3)}$$

$$C_f\dot{T}_f = U_fA_f(T_a - T_f) \quad \text{– (4)}$$

$$C_a\dot{T}_a = U_eT_e(T_e - T_a) + U_fA_f\left(T_f - T_a\right) + Q_r \quad \text{– (5)}$$

where:

T_e= The temperature of concrete floor.

T_f = The room's air temperature.

Q_r= The heat power transferred to the room by the radiator.

By assuming a constant pressure drop across the valve, the equation of the valve opening, δ to the flow rate q is:

$$q = -3.4 \times 10^{-4}\delta^2 + 0.75\delta - (6)$$

The above mathematical modelling of the radiator is non-linear and is not suitable for design of controller; therefore a simplified control oriented LPV model has been developed. For the transfer function of the room's air temperature and the radiator output heat, it is in first order transfer function which is:

$$\frac{T_a}{Q_{rad}}(\mathrm{s}) = \frac{K_a}{1+\tau_{rad}s} - (7)$$

Several simulations and experiments have been done and it has been confirmed that a first order transfer function of the radiator output heat to input flow rate is defined as:

$$\frac{Q_{rad}}{q}(\mathrm{s}) = \frac{K_{rad}}{1+\tau_{rad}s} - (8)$$

The parameters of the radiator LPV model are K_{rad} and τ_{rad} which is derived based on first order approximation of the power radiator step response. Therefore, the steady state gain is given by:

$$K_{rad} = c_w(T_{in} - T_{out,1}) - (9)$$

where $T_{out,1}$ is corresponding to the flow rate of $q1$. By using the tangent to Q(t) at t=0, the time constant can be obtained.

$$\tau_{rad} = \frac{Q_{final} - Q_0}{k_1 - \beta k_0 - \tau k_2} - (10)$$

$$\beta = \frac{K_{rad}}{C_{rad}} - (11)$$

The above equations show that the radiator gain and time constant of the heat flow transfer function depend on the flow rate. Therefore, the radiator mathematical modelling can be written as:

$$\frac{T_a}{q}(s) = \frac{K_{rad}K_a}{(1+\tau_{rad}s)(1+\tau_a s)} - (12)\ [32]$$

3.2 System Modelling Using System Identification

The System Identification Toolbox was used to build the model from the real-time data. It creates system modelling of dynamic systems based on measured input and output data. Estimation data was the data set that is used to estimate the transfer function with the best fits of accuracy.

Experimental data has been collected from the temperature control system. There are more than 1000 data has been collected from the process. The sampling interval is 0.001s as the sampling time Microbox is 1 kHZ. The data is imported to the MATLAB in term of timelog. By using commands in the MATLAB command window, the input and output will be set. Then, the system identification tool is opened.

```
>> TIME = tg.TimeLog;
>> TEMPERATURE = tg.OutputLog;
>> ident
```

In the “Import Data” section, Time Domain Data was selected and the input, output and sampling time were inserted. Then, the data was imported as mydata. In the “Estimate” section, transfer function model was selected. In this part, the transfer function can be estimated by determining of number of poles and zeros. After several probabilities obtained, the model output box was ticked to know which transfer functions have the largest accuracy. The transfer function obtained is in the form of:

$$G(s) = \frac{X(s)}{Y(s)} - (13)$$

3.3 PID Controllers

A PID controller is implemented into the temperature control system to have a better performance of transient response and steady-state error.

1. <u>Kp (Proportional Gain)</u>

   High value of Kp gives faster response since the error has become larger. But, a very large of proportional gain can lead to instability and oscillation.

2. <u>Ki (Integral Gain)</u>

   A large value of Ki means that the steady-state error can be eliminated quickly. But, it will produce large overshoot and rise time. The negative error integrated during the transient response must be integrated away by the positive error before the process reaching its steady-state.

3. <u>Kd (Derivative Gain)</u>

   High value of Kd decreases the overshoot and will slow down the transient response and may lead to instability due to signal noise amplification.

The basic equation of the PID controller is:

$$K(s) = K_p + \frac{K_i}{s} + K_d s \quad – (14)$$

$$= K_p(1 + \frac{1}{T_i s} + T_d s) \quad – (15)$$

where:

$$K_i = \frac{K_p}{\tau_i} \quad \text{and} \quad K_d = K_p \tau_d$$

In MATLAB, the tuning of PID controller can be done automatically without the need to tune every value of gain by using trial and error method.

3.3.1 Cohen-Coon PID tuning method

From the open loop system, a PID controller was designed by using Cohen Coon tuning.

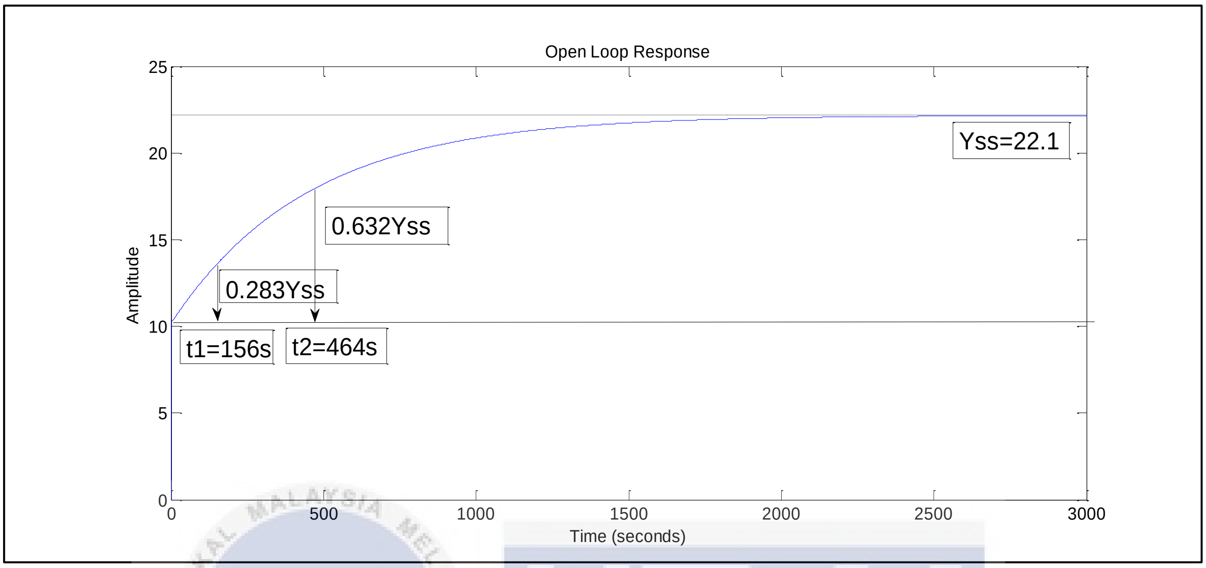

Figure 3.1: Open Loop Response of Cohen-Coon Method

$$\tau_m = \frac{3}{2}(t_2 - t_1)$$

$$= \frac{3}{2}(464 - 156)$$

$$= 462s$$

$$t_d = t_2 - \tau_m$$

$$= 464 - 462$$

$$= 2s$$

After obtaining the value of τ_m and t_d, the value of Kc, Ti and Td were calculated by using the calculation in the following table:

Table 3.1: Formula of Cohen-Coon Method [33]

	K_p	t_i	t_d
P	$\frac{1}{K_m}\frac{\tau_m}{t_d}(1+\frac{t_d}{3\tau_m})$	-	-
PI	$\frac{1}{K_m}\frac{\tau_m}{t_d}(0.9+\frac{t_d}{12\tau_m})$	$t_d x \frac{30+3\frac{t_d}{\tau_m}}{9+20\frac{t_d}{\tau_m}}$	-
PID	$\frac{1}{K_m}\frac{\tau_m}{t_d}(1.33+\frac{t_d}{4\tau_m})$	$t_d x \frac{32+6\frac{t_d}{\tau_m}}{13+8\frac{t_d}{\tau_m}}$	$t_d x \frac{4}{11+\frac{2t_d}{\tau_m}}$

$$K_c = \frac{1}{K_m}\frac{\tau_m}{t_d}(1.33+\frac{t_d}{4\tau_m})$$

$$= \frac{1}{12.1}(\frac{462}{2})(1.33+\frac{2}{4(462)})$$

$$= 25.4116$$

$$\tau_i = \frac{32+\frac{6t_d}{\tau_m}}{13+\frac{8t_d}{\tau_m}} x\, t_d$$

$$= \frac{32+\frac{6(2)}{462}}{13+\frac{8t_d}{462}}(2)$$

$$= 4.914$$

$$t_d = t_d x \frac{4}{11+\frac{2t_d}{\tau_m}}$$

$$= 2x \frac{4}{11+\frac{2(2)}{\tau_m}}$$

$$= 0.7267$$

Therefore, the equation of PID controller obtained is:

$$C(s) = 25.4116 + \frac{5.1713}{s} + 18.47s$$

3.3.2 Ziegler-Nichols PID Tuning Method

To design the PID controller using Ziegler-Nichols method, the parameters of Kp, τ_m and t_d must be obtained. These parameters were obtained from the open loop response.

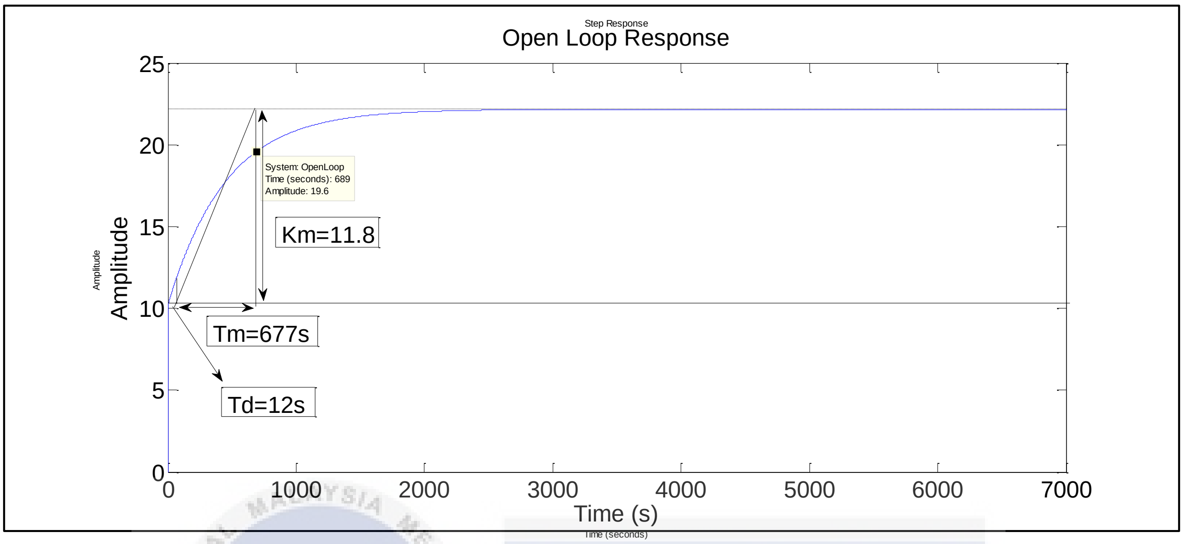

Figure 3.2: Open Loop Response of Ziegler-Nichols Method

The parameters were obtained by drawing a tangent line to the step response. After the parameters had obtained, the value of Kp, t_i and t_d can be calculated by using the following table:

Table 3.2: Formula of Ziegler-Nichols Method [34]

	Proportional gain, Kc	Integral Time, t_i	Derivative Time, t_d
P	$\frac{1}{K_m}(\frac{\tau_m}{t_d})$	-	-
PI	$\frac{0.9}{K_m}(\frac{\tau_m}{t_d})$	$3.33t_d$	-
PID	$\frac{1.2}{K_m}(\frac{\tau_m}{t_d})$	$2t_d$	$0.5t_d$

$$K_c = \frac{1}{11.8}(\frac{677}{12})$$
$$= 5.737$$
$$t_i = 2(12)$$
$$= 24$$
$$t_d = 0.5(12)$$
$$= 6$$

Therefore, the equation of PID controller obtained is:

$$C(s) = 5.737 + \frac{2.572}{s} + 36.638s$$

3.4 Fuzzy Gain Scheduling

Fuzzy control has been successfully used in many control applications. But, there is no guarantee that the fuzzy controller obtains a good performance within certain time for particular applications. Therefore, fuzzy gain scheduling is implemented into the system.

Fuzzy gain scheduling is one of the techniques to change linear controller parameters in a non-linear mode depends on the process state and scheduling variable. This technique works where the PID controller gains are altered during the process through fuzzy logic and reasoning [35].

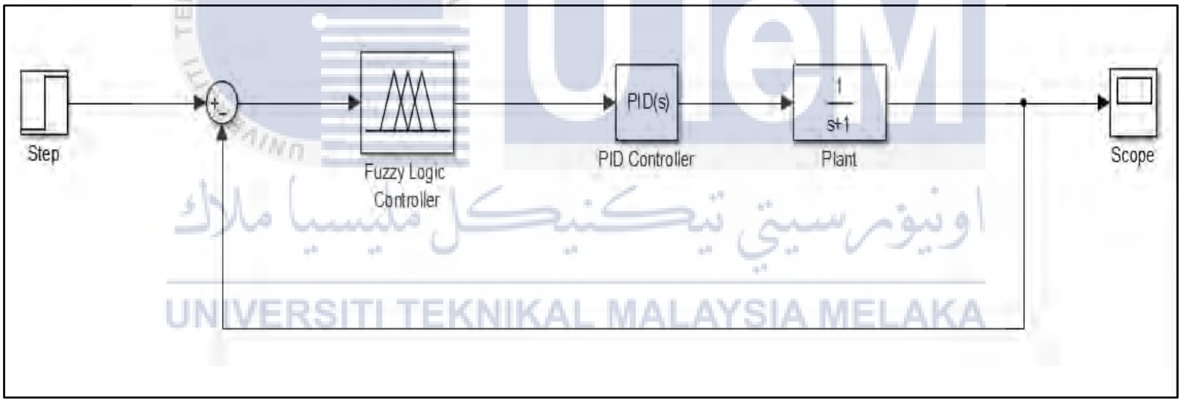

Figure 3.3: The Block Diagram of Fuzzy Gain Scheduling

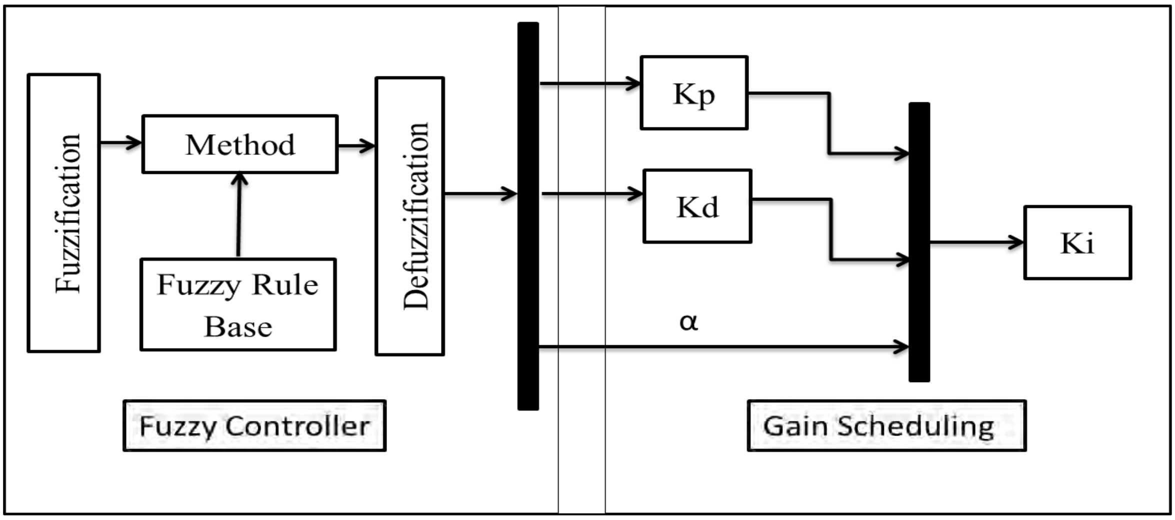

Figure 3.2: The Block Structure of Fuzzy Gain Scheduling

To designed fuzzy gain scheduled of PID controller, the transfer function of PID controller is:

$$G(s) = K_p + K_i s + \frac{K_d}{s} \quad (14)$$

where K_p, K_i and K_d are proportional, integral and derivative gains respectively. A Mamdani type of Fuzzy Logic Controller was used to tune the gains of PID controller. The system consisted of two inputs which were the error, e(k) and the change of error, ce(k) that were used to determine the control parameters [36].

The membership function of the error and change of error include negative big (NB), negative small (NS), zero (Z), positive small (PS) and positive big (PB). To design the gain scheduling, the fuzzy membership functions of the outputs were K_p, K_d and α. The membership function of outputs K_p and K_d were big (B) and small (S) while for α, it consists of value range from two to five [37].

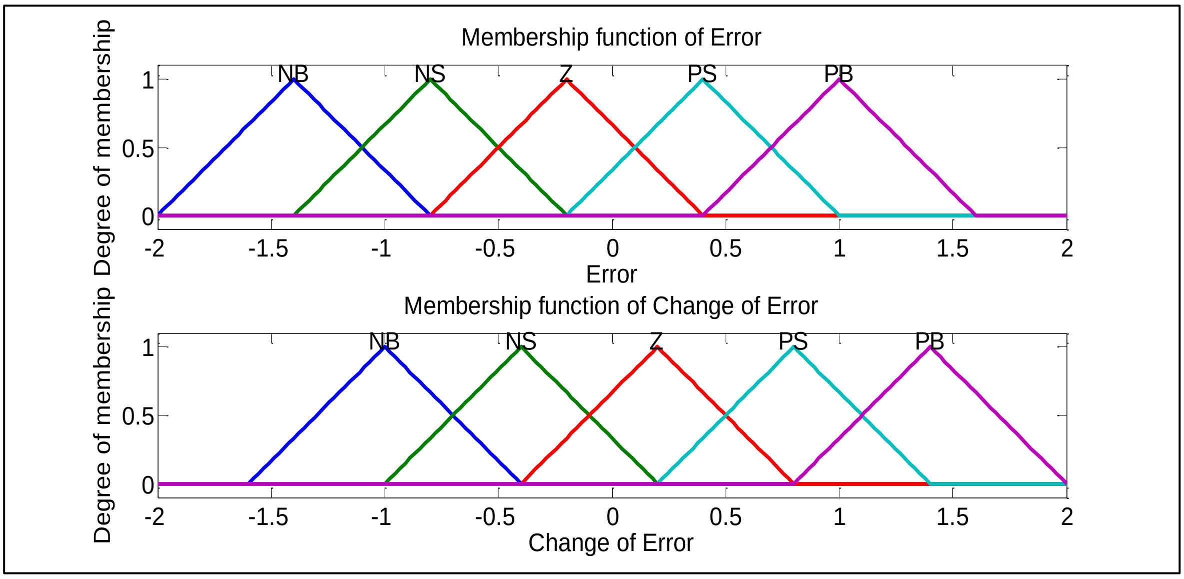

Figure 3.3: Defined Membership Function for Inputs of PID Controller

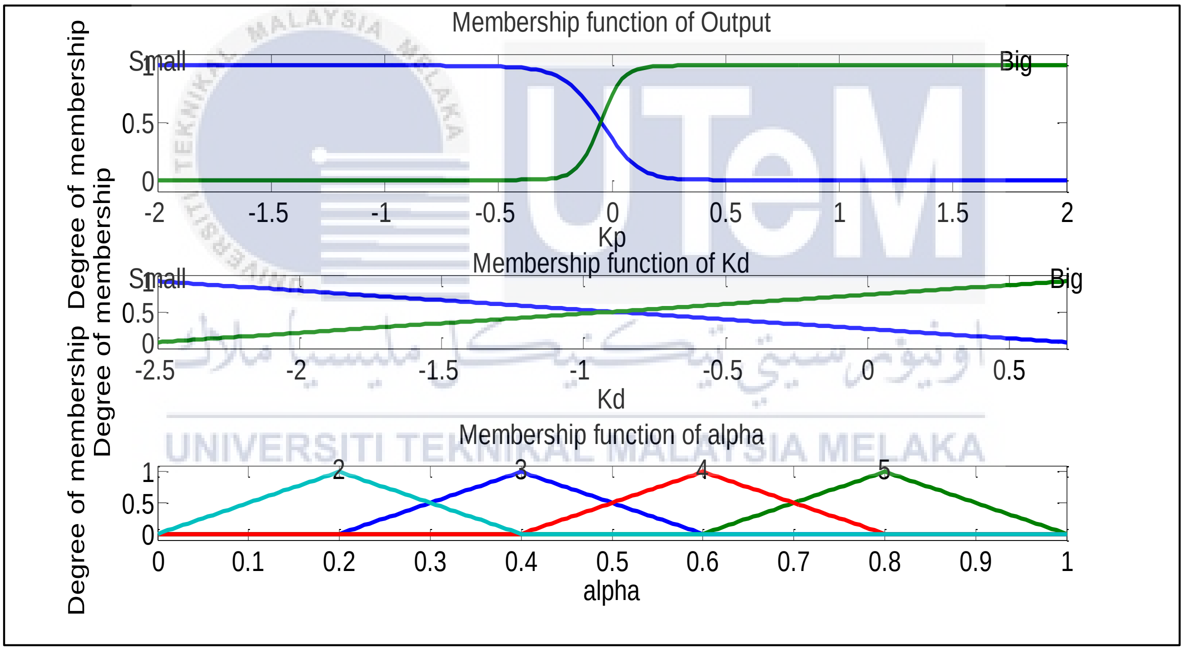

Figure 3.4: Defined membership function for outputs of PID controller

The value of K_p and K_d are prescribed in the ranges of $[K_{p,min}, K_{p,max}]$ and $[K_{d,min}, K_{d,max}]$ respectively. The value of K_p and K_d were normalized into the range between zero and one by the equation of:

$$K_p = [K_{p,min} + (K_{p,max} - K_{p,min})]xK_{pi} - (15)$$

$$K_d = [K_{d,min} + (K_{d,max} - K_{d,\mathrm{min})}]xK_{di} - (16)$$

and the value of K_i was obtained by:

$$K_i = {K_p}^2/(\alpha K_d) - (17)$$

Table 3.3: The Tuning of K_p

		Change of Error(k)				
Error(k)		**NB**	**NS**	**Z**	**PS**	**PB**
	NB	B	B	B	B	B
	NS	S	B	B	B	S
	Z	S	S	B	S	S
	PS	S	B	B	B	S
	PB	B	B	B	B	B

Table 3.4: The Tuning of K_d

		Change of Error(k)				
Error(k)		**NB**	**NS**	**Z**	**PS**	**PB**
	NB	S	S	S	S	S
	NS	B	B	S	B	B
	Z	B	B	B	B	B
	PS	B	B	S	B	B
	PB	S	S	S	S	S

Table 3.5: The Tuning of α

		Change of Error(k)				
Error(k)		**NB**	**NS**	**Z**	**PS**	**PB**
	NB	2	2	2	2	2
	NS	4	3	2	3	4
	Z	5	3	3	3	5
	PS	4	3	2	3	4
	PB	2	2	2	2	2

The parameters of K_p, K_d and α were determined by a set of fuzzy rules in the form of:

If e(k) is NB and ce(k) is Z, then K_p is Big, K_d is Small and α is 2.

3.5 Interfacing and Calibration

The open-loop test was conducted in order to provide sufficient information before undergoes a closed-loop test. The test was done by connecting the temperature control system to the Simulink by interfacing using the Microbox. Next, the Simulink block will be used to read the signal from the temperature control system for signal interpretation.

For the first step, Simulink has to be set to read the signal from the plant and to send the signal to the plant. An analogue to digital sensor was used to read the measurement from the thermocouple and displayed in in the display of the Simulink. The supply of the plant is constant at 5V from the Microbox driver.

A calibration process took place here as the display showed the reading in voltage. Therefore, to convert the signal of output voltage to temperature, the graph of output voltage against temperature is plotted. A linear equation was obtained from the graph. The expression of the linear equations obtained:

$$y = mx + c \quad (18)$$

A gain is added between analogue to digital converter (ADC) with the setting of 1/m was displayed. With the new gain added, the display block diagram showed the value in temperature unit of °C. An offset value is added when the display in the Simulink and the display in the process control trainer is difference.

3.6 Experimental Setup

An experiment has been conducted to obtain the data of time and temperature to obtain the transfer function of the system. The experiment is conducted in open loop condition.

1. The power switch of the Process Control Trainer was set to off position.
2. The connector of the thermocouple probe was connected to the temperature transmitter input of the Process Control Trainer.
3. The analogue-to-digital converter was connected to the temperature transmitter while the digital-to-analogue converter was connected to the control input.
4. AC/DC adapter was connected to the Microbox 2000/2000C.
5. Ethernet cable was connected between the host PC and the Microbox 2000/2000C LAN1 port.

Figure 3.5: The Connection of Experimental Setup

3.7 SIMULATION SETUP

The simulation is done to obtain the data from the temperature control system. The temperature control system is connected to the Microbox 2000/2000C to interface the data between the system and the MATLAB software.

1. The power switch of the process control trainer was set to on position.
2. MATLAB 2013a was started and MATLAB and xPC environment were configured.
3. The connection between the host PC and Microbox 2000/2000C was tested with the command of xpctest.
4. A new Simulink model was opened and the ADC block was set to:
    a) Channel is set to 1
    b) Sampling time is set to 0.001s.
5. The DAC block was set with:
    a) Channel to 1.
    b) Reset vector to 0.
6. A saturation block was added with the limitation of 0 to 5.
7. The display was added into the model to visualize the signals on the host PC.
8. In Simulation menu, Configuration Parameters was selected for xPC target parameters settings.
9. The System target file configuration was changed to xpctarget.tlc as system target file configuration.
10. From the Solver tab, the following were set:
    a) Type as Fixed-step
    b) Solver as discrete mode
    c) Fixed-step size as 0.001
11. On the icon menu, the Simulation mode was changed to External and the Simulation End Time was set to inf.
12. After the model was built, click Connect and followed by the Run button.

3.8 Project Implementation

Table 3.6: Gantt Chart Table for FYP 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project Briefing	■	■														
Meeting with Supervisor		■	■	■	■	■	■	■	■	■	■	■		■	■	■
Introduction of Project		■	■	■	■	■	■	■								
Literature Review		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Analysis of Data								■	■	■	■	■	■	■		
Report Preparation												■	■	■	■	■
Report Submission																■
Project Presentation																■

For the first week, a project briefing about the title of final year project has been conducted. To understand more about the project, many research papers have been read and it has been included in the literature review. After 7 weeks, the data of the temperature control system started to be collected in order to achieve the first objective of the project which is to obtain the transfer function of the system. After that, the report preparation has been done to submit it to the panel and supervisor.

Table 3.7: Gantt Chart Table for FYP 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Meeting with Supervisor	■			■		■		■		■		■	■	■	■	■
Introduction of Project		■	■	■												
Literature Review		■	■	■	■	■	■	■	■	■	■	■	■	■		
Analysis of Data		■	■	■	■	■	■	■	■	■	■	■	■	■		
Report Preparation									■	■	■	■	■	■	■	■
Report Submission																■
Project Presentation																■

In the semester two, the final year project continued to take place. In this project, PID controller is designed to implement it into the temperature control system. PID controller is designed by using three methods which are Cohen-Coon, Ziegler-Nichols and fuzzy gain scheduling. The analysis of data took a longer time as it requires mathematical equations and simulation of the system.

CHAPTER 4

PRELIMINARIES RESULTS AND DISCUSSION

4.1 Interfacing and Calibration

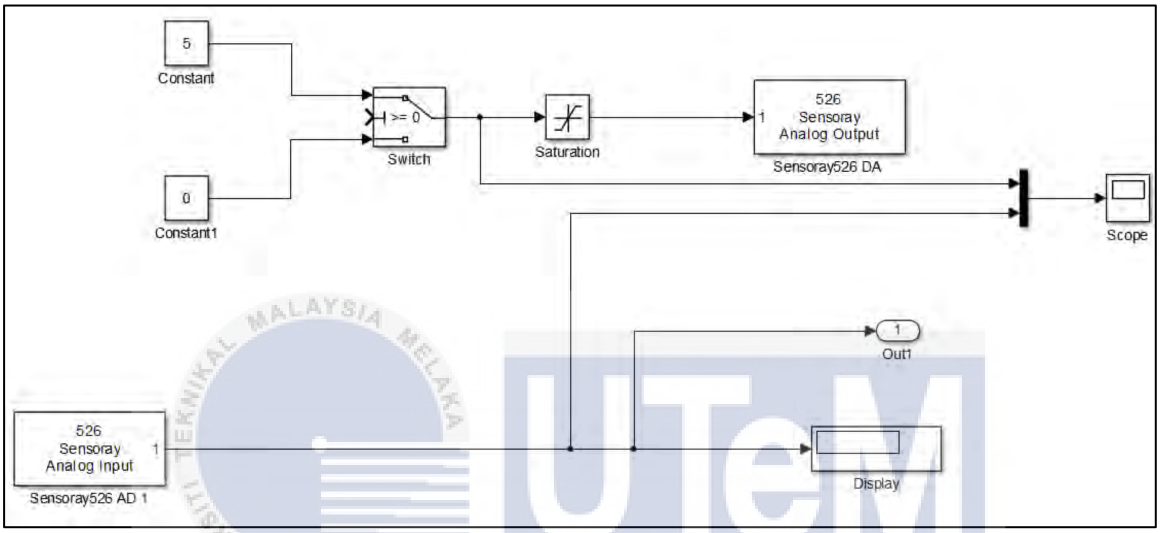

Figure 4.1: The Block Diagram before Calibration

Since the display shows the reading of temperature of voltage, a calibration is needed in order for the display shows the reading of temperature in °C.

Table 4.1: The reading of temperature and output voltage

Time, (sec)	Temperature, (°C)	Output Voltage, (V)
0	20.9	1.138
30	21.4	1.190
60	23.7	1.426
90	26.9	1.769
120	31.0	2.170
150	35.4	2.610
180	39.9	3.100
210	44.0	3.506
240	48.0	3.916
270	52.0	4.321
300	55.8	4.688
330	58.6	4.982

After obtaining the data of the temperature and output voltage, the graph of temperature versus time is plotted in order to convert the display of output voltage into temperature.

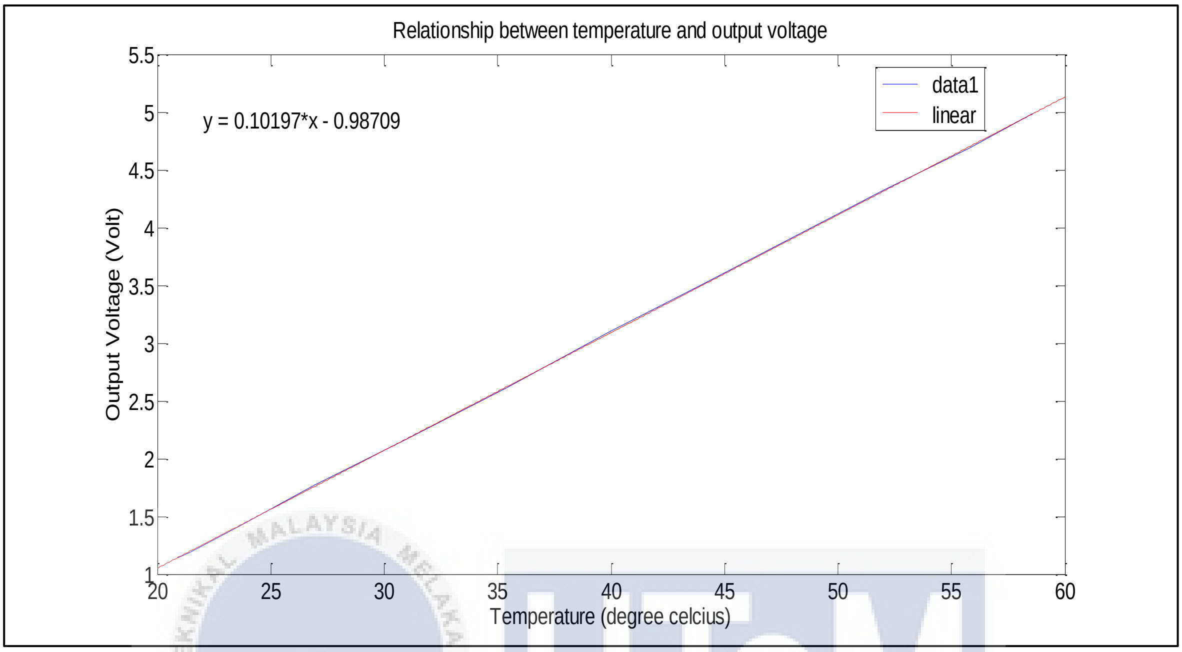

Figure 4.2: The Relationship between Temperature and Output Voltage

From the graph above, it shows that the relationship between the temperature and output voltage is linear. Therefore, the linear equation obtained is:

$y = mx + c,$

$\quad = 0.10197x - 0.98709$

The value of gain that needed to be inserted in the block diagram in order to convert the reading of voltage into temperature is:

$$\text{Gain} = \frac{1}{m}$$

$$= \frac{1}{0.10197}$$

$$= 9.80681$$

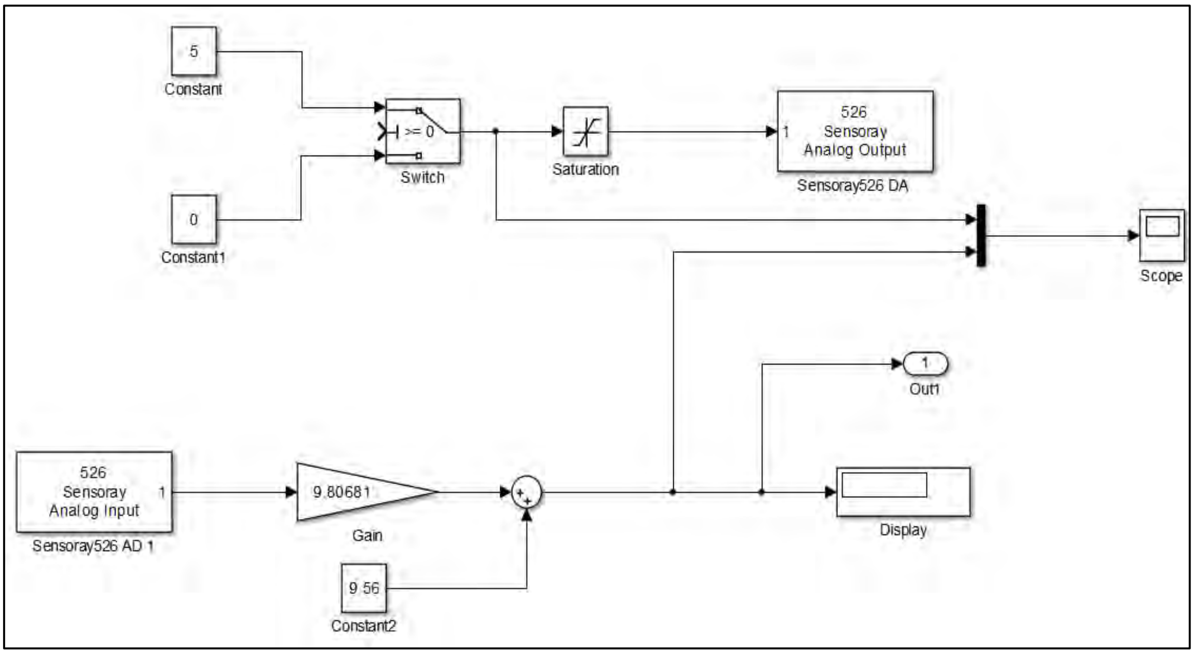

Figure 4.3: The Block Diagram after Calibration

Since the gain is added, the display shows the reading in °C but the reading on the transmitter and the display shows some difference. So, an offset value of 9.56 is added into the model of the block diagram to equalize the reading of the temperature in both block diagram and the plant.

After the calibration has been done, the experiment is conducted once more. The purpose of the calibration is to save the data obtained from the temperature control system in term of temperature. This is because the data of the temperature is needed in order to obtain the transfer function of the system by using System Identification Tool.

4.2 System Modelling Using System Identification Method

By using the calibrated block diagram, the simulation is run once again. The data which are in term of time, input voltage and temperature that obtained from the simulation is saved in the workspace. The block is in open-loop in order to obtain the transfer function of the plant. The graph of temperature against time is plotted.

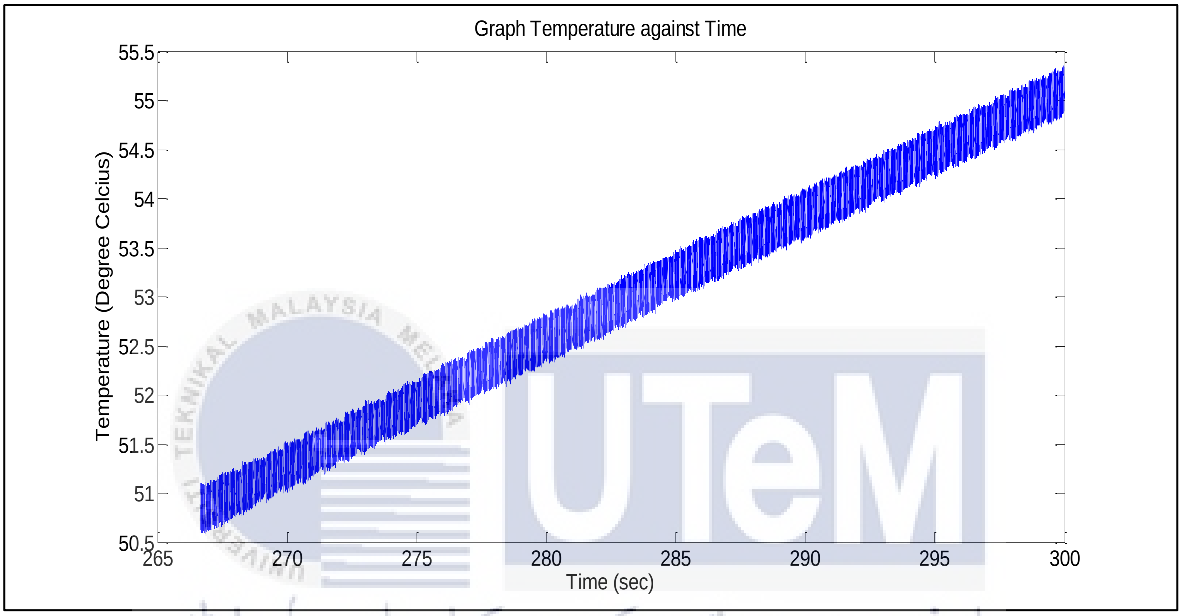

Figure 4.4: Graph of Temperature against Time

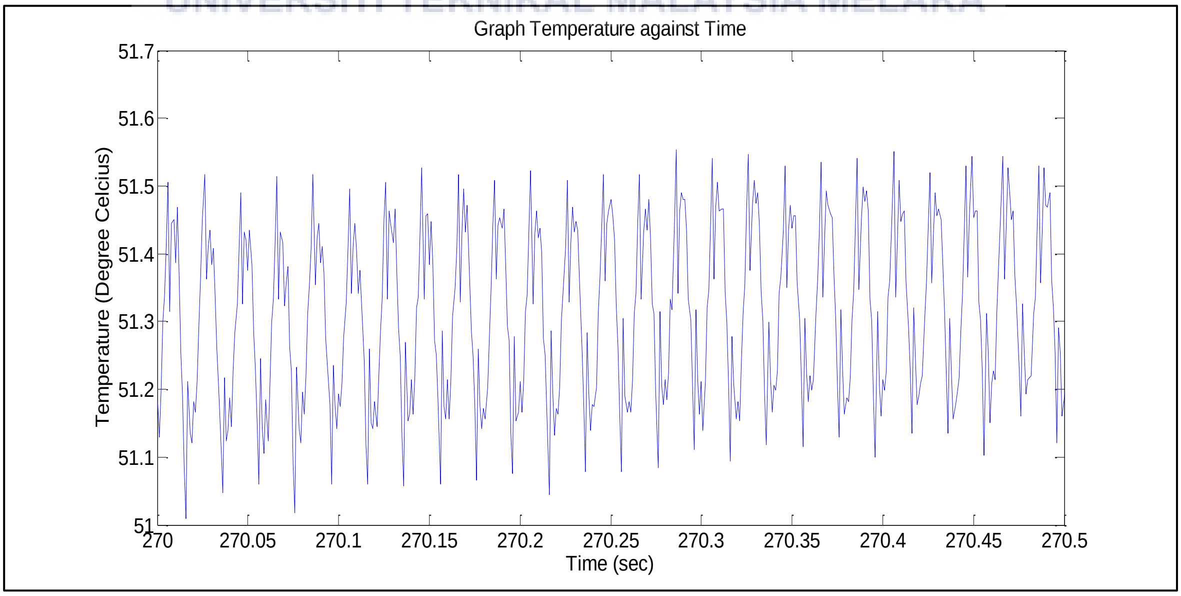

Figure 4.5: Graph of Temperature Response

To obtain the open-loop transfer function of the plant, the system identification tool is opened. The data used is in time-domain. The input is the input voltage of 5V and the output is the temperature. The sampling time is 0.001s.

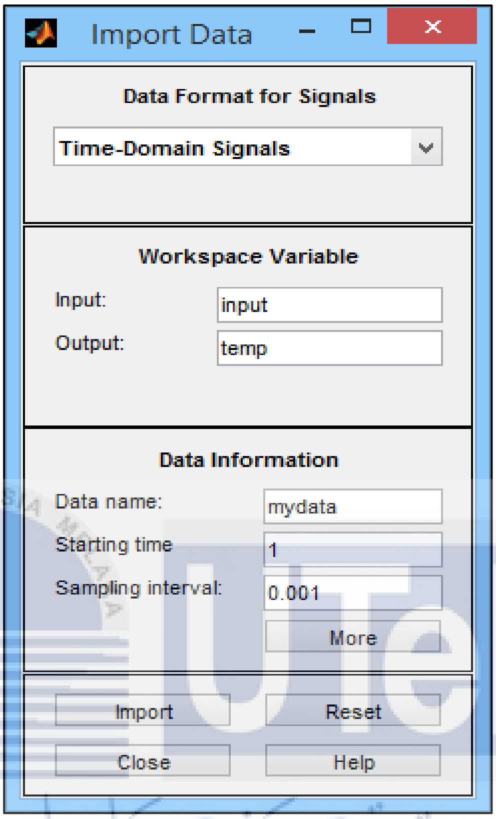

Figure 4.6: The Import Data Tool

After the data has been imported to the system identification tool, the data is put in the working data to estimate the transfer function models. By doing this, the transfer function can be estimated by inserting the number of zeros and poles required.

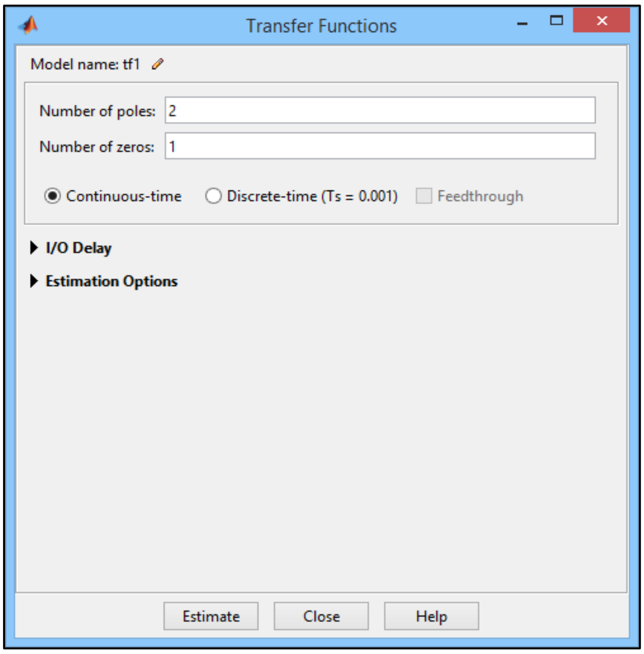

Figure 4.7: The Estimation of Transfer Function

The transfer function is estimated by estimating various number poles and zeros. But, the number of zeros should not be higher than number of zeros. As the mathematical modelling is in second order system, there are five probabilities in determining the most accurate transfer function of the system.

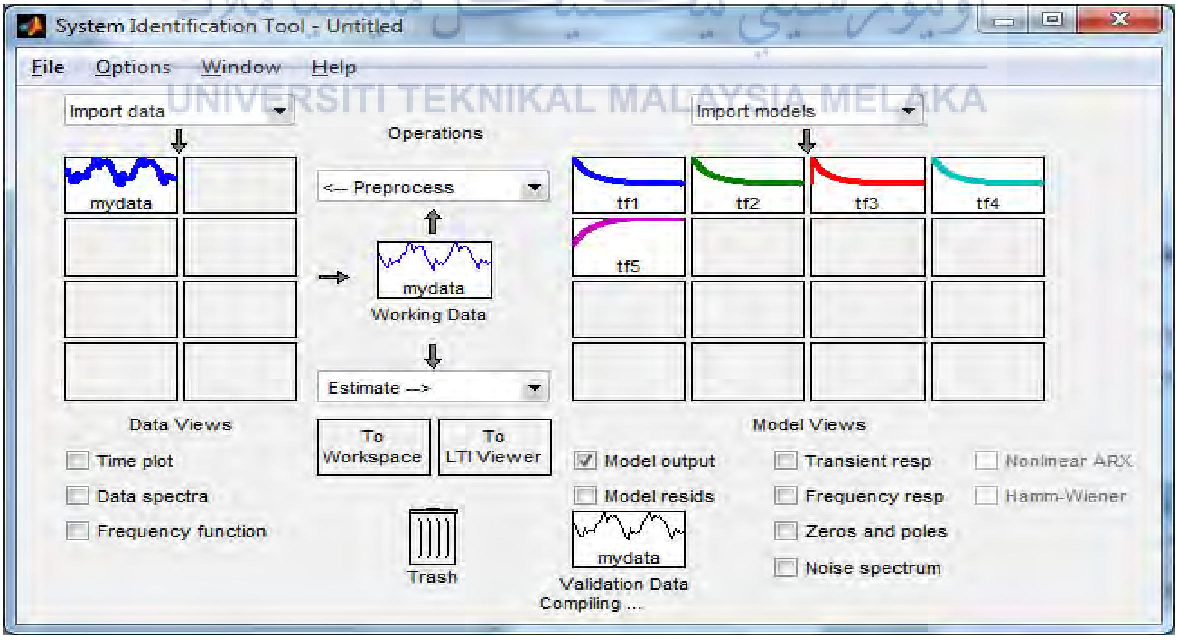

Figure 4.8: Probabilities of Transfer Function Obtained

There are 5 transfer functions that can be obtained with the highest number of poles of 2. After the possibilities of transfer function have been made, the model output's box is selected to observe the highest accuracy of the transfer function. The transfer function of the temperature control system is accurate when the percentage of the best fits shows the percentage of 85 and above.

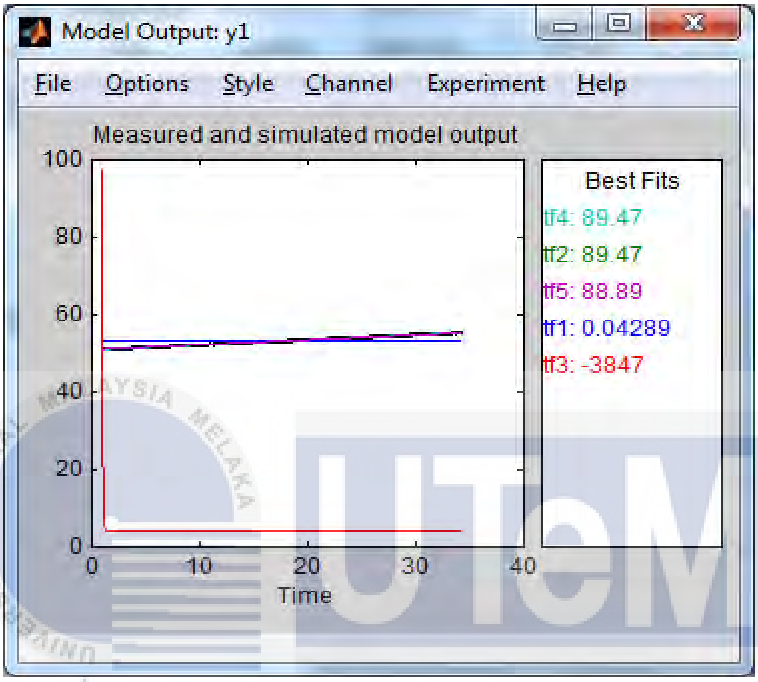

Figure 4.9: The Accuracy of the Transfer Functions

From the figure above, tf means transfer function that has been estimated. Therefore, the highest best fit is transfer function number four which has percentage accuracy of 89.47%. The transfer function of the temperature control system obtained is:

$$G(s) = \frac{X(s)}{Y(s)}$$

$$= \frac{(5.809x10^6 s)+28060}{s^2+571300s+1266}$$

The transfer function is in second order system which has 2 poles and 1 zero.

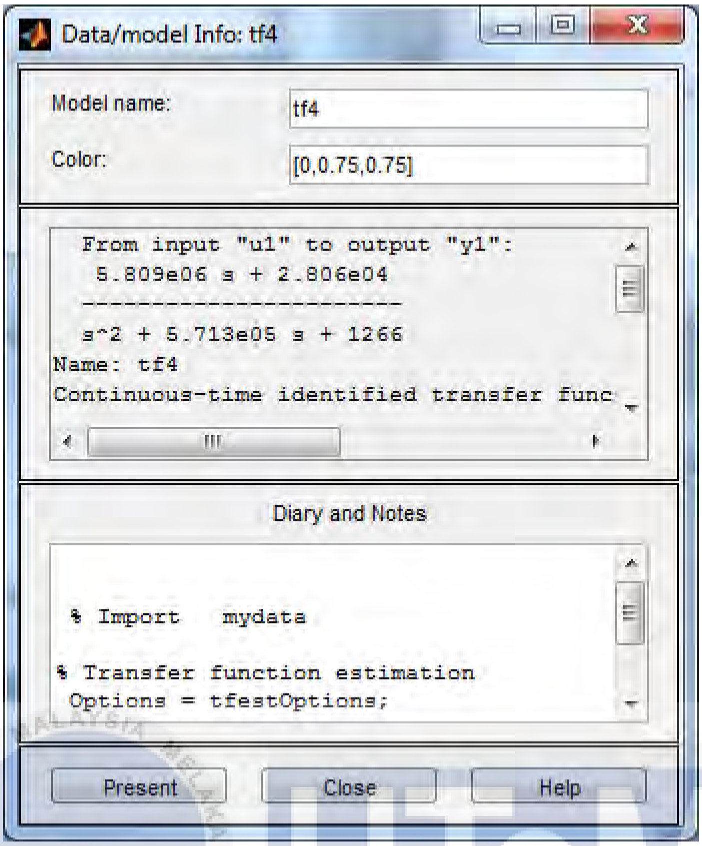

Figure 4.10: The Value of Transfer Function

4.3 PID Controllers

4.3.1 Cohen-Coon Method

In this experiment, the PID controller is tuned using the Cohen-Coon method. In order to design PID controller, it is necessary to find the value of K_p, τ_m and t_d. The equation of PID controller is obtained by using Cohen-Coon open loop method. The equation is:

$$C(s) = 25.4116 + \frac{5.1713}{s} + 18.47$$

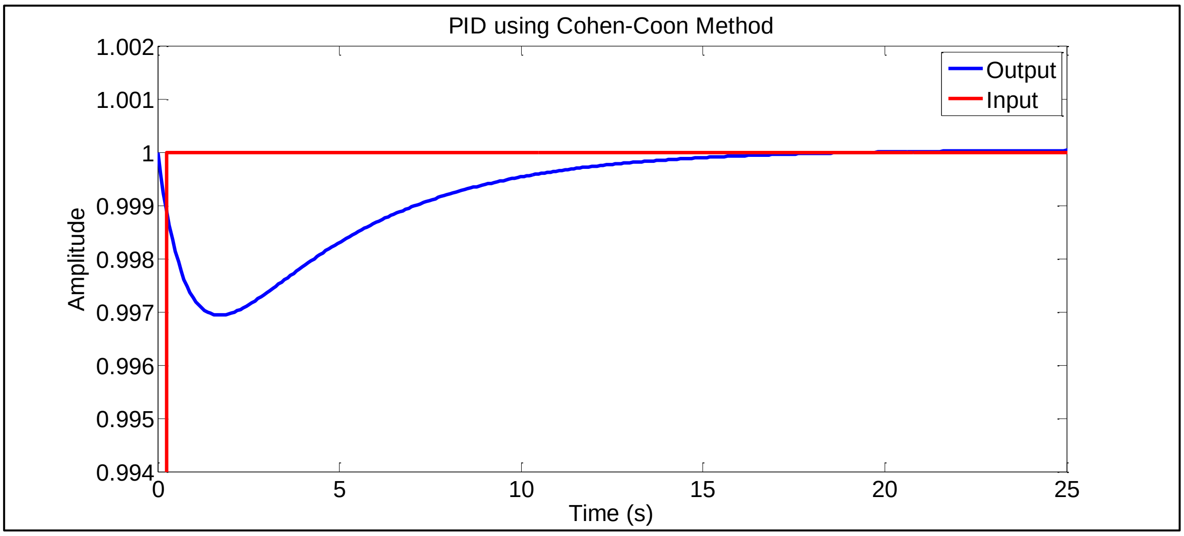

Figure 4.11: The System with PID of Cohen-Coon Method

The graph above is considered to have negative value as the performance is begin to fall first before it rise to steady-state. The rise time starts at 0.0007s while the settling time is at 16.3s. The percentage overshoot almost gives a zero value which is 0.004% and there is no steady-state error.

Table 4.2: Transient Response with Cohen-Coon Method

% Overshoot	0.004
Rise Time	0.7ms
Settling Time	16.3s
Steady-State Error	0

4.3.2 Ziegler-Nichols Method

In this Ziegler-Nichols method, the experiment is conducted in open loop response. From the calculation, the equation of PID controller is:

$$C(s) = 5.737 + \frac{2.572}{s} + 36.638s$$

The controller is then implemented into the system and the result of the performance is shown below:

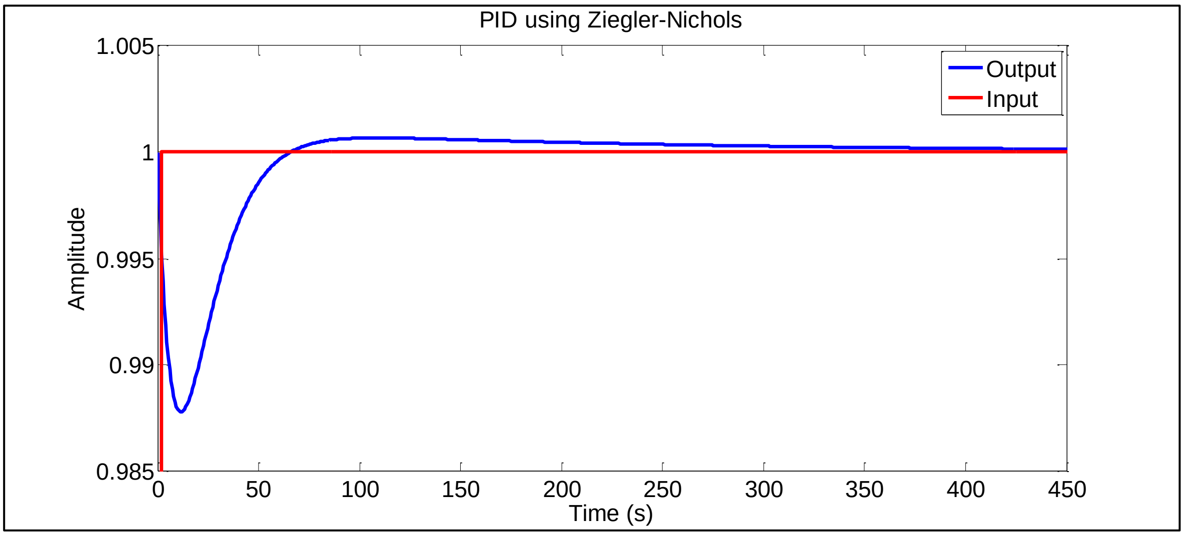

Figure 4.12: The System with PID of Ziegler-Nichols Method

The analysis that can be made from the graph above is the settling time is 333s. It takes too much time for the temperature system to reach steady-state. But, the result also shows that the percentage overshoot is very small which is 0.067% and the steady-state error is also very small.

Table 4.3: Transient Response with Ziegler-Nichols Method

% Overshoot	0.067
Rise Time	0.076ms
Settling Time	333s
Steady-State Error	0

4.4 Fuzzy Gain Scheduling

For the fuzzy gain scheduling technique, the PID controller is designed by tuning the parameters of K_p, K_d and α. The tuning of the involved parameters takes place in the fuzzy logic controller. The PID controller tuned by the fuzzy gain scheduling technique is designed by Simulink in MATLAB software.

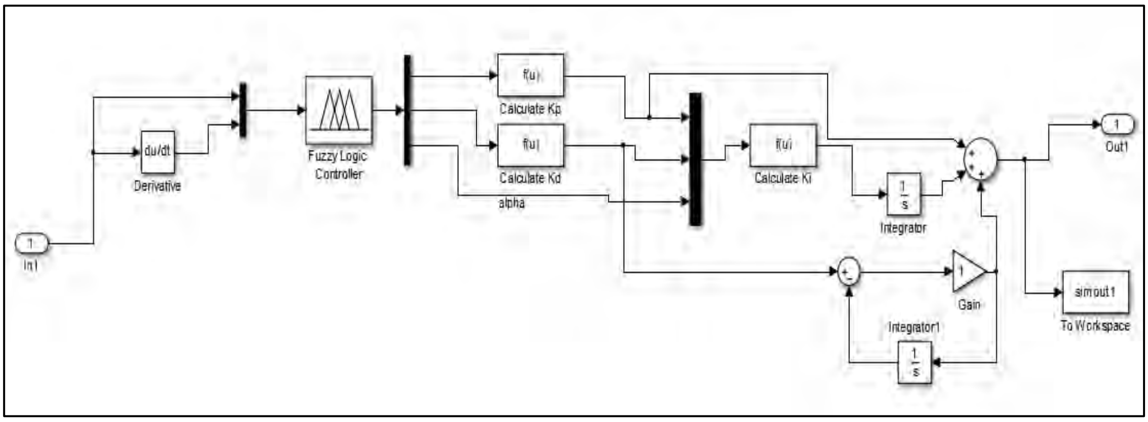

Figure 4.13: The Block Diagram of PID Controller Tuned by Fuzzy Gain Scheduling

The tuning of the parameters takes place in the fuzzy logic controller by following the tables of tuning of K_p, K_i and α. To design the PID controller, there are three mathematical equation involved to calculate the value of K_p, K_i and K_d. In the last stage, PID controller is designed with the calculated value of K_p, K_i and K_d.

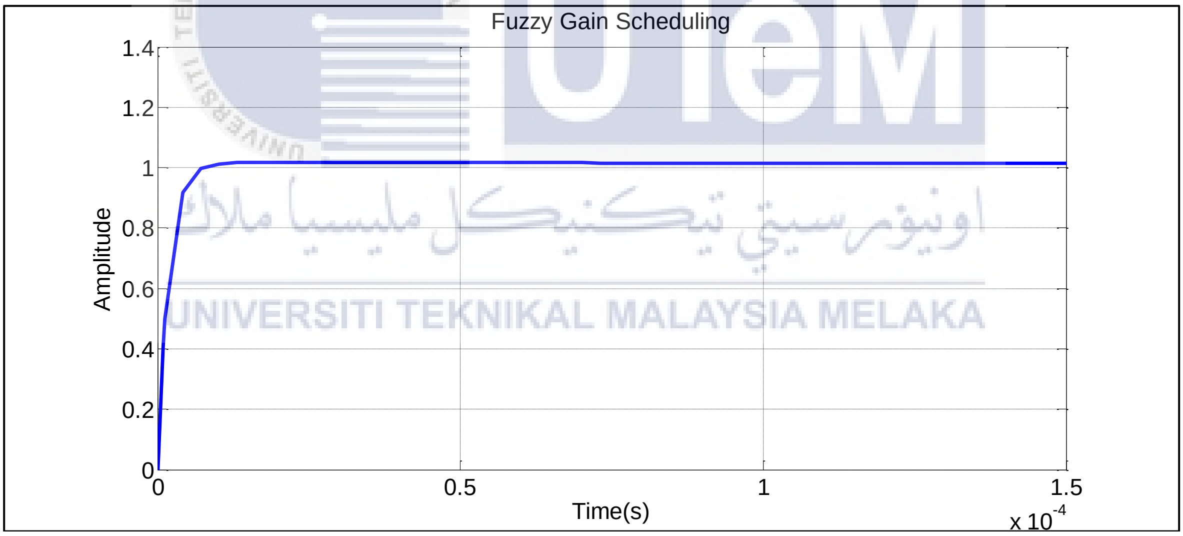

Figure 4.14: The System of Fuzzy Gain Scheduling

The analysis of the tuning of PID controller by using fuzzy gain scheduling gives a better performance than using only PID controller. It can be seen that there is no overshoot and the settling time and rise time are much faster than PID controller even though there is a steady-state error of 0.015. The settling time is at 0.013ms and the rise time is 3.882μs.

Table 4.4: Transient Response with Fuzzy Gain Scheduling

% Overshoot	0
Rise Time (s)	0.004m
Settling Time (s)	0.013m
Steady-State Error	0.015

4.5 Overall Results

Table 4.5: Comparison of Transient Response Analysis

	Cohen-Coon	**Ziegler-Nichols**	**Fuzzy Gain Scheduling**
%Overshoot	0.004	0.067	0
Rise Time (s)	0.7m	0.076m	0.004m
Settling Time (s)	16.3	333	0.013m
Steady-State Error (s)	0	0	0.015

From the above comparison, Fuzzy Gain Scheduling has the best percentage overshoot as it has no overshoot compared to the other method. Besides that, the rise time and settling time are faster than Cohen-Coon and Ziegler-Nichols and it shows that fuzzy gain scheduling can operate the system in time without waiting much. But, fuzzy gain scheduling technique relatively gives small value of steady-state error which is 0.015 compared to the other two methods which has no steady-state error.

CHAPTER 5
CONCLUSION

As a conclusion, the temperature control system plant can be interfaced with the host PC by using the interconnection with Microbox 2000/2000C. The connection of the plant is in open-loop in order to obtain the transfer function of the system. By using the system identification method, the plant can be modelled. It is an easier and faster way to model the system without using derivation of mathematical equations. Different types of plants will yield different value of transfer function as there are many factors that can affect the system of the plant such as room temperature, humidity and mass. The improvement of the system can be made by adding the controllers but the controllers must be designed as simple as possible.

Besides that, the temperature control system has been analysed by simulation using MATLAB/Simulink software. The analysis shows that the PID controller using the tuning of fuzzy gain scheduling gives the best performance compared to PID controllers with Cohen-Coon and Ziegler-Nichols method. It is because by using fuzzy gain scheduling, there is no overshoot occurred and the rise time and settling time are faster compared to the other two methods. Therefore, it has been proved that the fuzzy gain scheduling is more effective than the other PID controllers.

For the recommendation, the PID controller tuned by the fuzzy gain scheduling can be applied to any types of system as it gives the best performance to the system. Moreover, it is a system that uses artificial intelligence system that can reduce the cost of maintenance of the system. Besides that, the performance of the system can be improved by using other artificial intelligence system such as neural network and sliding mode controller.

REFERENCES

[1] S.G. Fabri, J. Agius, R. Ghirlando & R. Axisa, "Modelling and Temperature Control of a Wine Fermentation Process with Solar Cooling", 24th Mediterranean Conference on Control and Automation (MED), pp. 985-990, 2016.

[2] E.B.M. Costa & G.L.O Serra, "Fuzzy Gain Scheduling Design Based on Multiobjective Particle Swarm Optimization", Latin America Congress on Computational Intelligence (LA-CCI), pp. 1-6, 2015.

[3] A. Aziz, A. MTO & A. Stojcevski, "Fuzzy Gain Scheduled Load Frequency Controller in Presence of Grid Code Frequency Responsive Wind Power Penetration", Australasian Universities Power Engineering Conference-AUPEC, 2016.

[4] A. Walsh & J.R. Forbes, "A Very Strictly Passive Gain-Scheduled Controller: Theory and Experiments", IEEE/ASME Transactions on Mechatronics, Vol. 21, Issue. 6, pp. 2817-2826, 2016.

[5] M.W.S. Atman & R.T. Bambang, "Design and Implementation of Gain-Scheduling Flight Control System on PC/104 Platform", the 5th International Conference on Electrical Engineering and Informatics, pp. 241-246, 2015.

[6] Y. Luo, Z. Wang, J. Hu & G. Wei, "H∞ Gain-Scheduling Control for 2-D Stochastic Nonlinear Systems: The F-M Case", 35th Chinese Control Conference, pp. 1764-1769, 2016.

[7] L. R. S. Theisen, J. F. Camino & H. H. Niemann, "An Application of Gain-Scheduled Control Using State-Space Interpolation to Hydroactive Gas Bearings", IEEE Conference on Control Applications (CCA), pp. 1117-1122, 2016.

[8] A. Sumalatha & A. B. Rao, "Novel Method of System Identification", International Conference on Electrical, Electronics and Optimization Techniques (ICEEOT), pp. 2323-2328, 2016.

[9] B. V. Murthy, Y. V. P. Kumar & U. V. R. Kumari, "Fuzzy Logic Intelligent Controlling Concepts in Industrial Furnace Temperature Process Control", IEEE International Conference on Advanced Communication Control and Computing Technologies (ICACCCT), pp. 353-358, 2012.

[10] J. Qiao & T. Chai, "Intelligence-Based Temperature Switching Control for Cement Raw Meal Calcination Process", IEEE Transactions on Control System Technology, Vol. 23, No. 2, pp. 644-661, 2015.

[11] G. Liu, L. Chai, S. Fei & P. Wang, "Application of Disturbance Observer-Based Enhanced Composite Cascade Control Scheme to Outlet Temperature in Process Furnace Control System", IEEE, 2015.

[12] M. S. A. Rahman, Z. Janin & N. Hambali, "Application of Virtual Air Temperature Oven in Process Control Laboratory", IEEE 5th Conference on Engineering Education, pp. 144-148, 2013.

[13] N. Minouchehr, P. Tavakoli, N. Vaezi & S. K. H. Sani, "Temperature Control of Heating Procedure in Blade Production Process", 24th Iranian Conference on Electrical Engineering (ICEE), pp. 271-276, 2016.

[14] A. P. Jaimon & P. S. H. Jose, "Temperature Control of Catalytic Cracking Process", IEEE Sponsored 2nd International Conference on Innovations in Information Embedded and Communication Systems (ICIIECS), 2015.

[15] L. Ruttledge & D. Flynn, "Emulated Inertial Response from Wind Turbines: Gain Scheduling and Resource Coordination", IEEE Transactions on Power Systems, Vol. 31, No. 5, pp. 3747-3755, 2016.

[16] H. Shu & Y. Pi, "Decoupled Temperature Control System Based on PID Neural Network", ACSE 05 Conference, 2005.

[17] D. Pamela & T. Jebarajan, "Intelligent Controller for Temperature Process", International Journal of Control and Automation, Vol. 6, No. 5, pp. 191-198, 2013.

[18] M. N. Naik, C. M. Desiree & S. N. Monterio, "Design and Simulation of Gain Scheduled Adaptive Controller using PI Controller for Conical Tank Process", International Journal for Innovative Research in Science & Technology (IJIRST), Vol. 2, No. 4, pp. 132-136, 2015.

[19] H. Ahmed & A. Rajoriya, "Performance Assessment of Tuning Methods for PID Controller Parameter used for Position Control of DC Motor", International Journal of u- and e- Service, Science and Technology, Vol. 7, No. 5, pp. 139-150, 2014.

[20] M. Fallahi & S. Azadi, "Fuzzy PID Sliding Mode Controller Design for the Position Control of a DC Motor", International Conference on Education Technology and Computer, pp. 73-77, 2009.

[21] R. Suguna, V. Usha & S. Chidambaram, "A Temperature Control by Using PID Based Scr Control System", IOSR Journal of Electronics and Communication Engineering (IOSR-JECE), Vol. 9, No. 2, pp. 51-55, 2014.

[22] P. Aravind, M. Valluvan & M. Saranya, "Simulation based Modelling and Implementation of Adaptive Control Technique for Nonlinear Process Tank", International Journal of Computer Applications, Vol. 68, No. 16, pp. 1-6, 2013.

[23] A. M. O. Fini, M. B. Gogani & M. Pourgholi, "Fuzzy Gain Scheduling of PID Controller Implemented on Real Time Level Control", 4th Iranian Joint Congress on Fuzzy and Intelligent Systems (CFIS), 2015.

[24] F. Bruzelius, "LPV-Based Gain Scheduling", 2002.

[25] S. Dian, S. Hoang, M. Pu, J. Liu & L. Chen, "Gain Scheduling based Backsteepping Control for Motion Balance Adjusting of a Power-line Inspection Robot", 35th Chinese Control Conference, pp. 441-446, 2016.

[26] Z. Y. Zhou, M. Tomizuka & S. Isaka, "Fuzzy Gain Scheduling of PID Controllers", pp. 168-703, 1999.

[27] S. Sedghizadeh & S. Beheshti, "Fuzzy Gain Scheduling of Subspace Predictive Controller", American Control Conference, pp. 2693-2698, 2016.

[28] T. Chaiyatham & I. Ngamroo, "Improvement of Power System Transient Stability by PV Farm with Fuzzy Gain Scheduling of PID Controller", IEEE Systems Journal, pp. 1-8, 2014.

[29] K. Naishadham & J. E. Piou, "Respresentation of Electromagnetic Responses in Time Domain Using State-Space System Identification Method", pp. 1404-1415, 2016.

[30] P. Wang, N. Li & S. Li, "Interval Type-2 Fuzzy T-S Modelling for a Heat Exchange Process on CE117 Process Trainer", International Conference on Modelling, Identification and Control, pp. 457-461, 2011.

[31] M. S. M. Aras, S. S. Abdullah, A. A. Rahman & M. A. A. Aziz, "Thruster Modelling for Underwater Vehicle Using System Identification Method", International Journal of Advanced Robotic Systems, pp. 1-12, 2013.

[32] F. Tahersima, J. Stoustrup & H. Rasmussen, "Eliminating Oscillations in TRV-Controlled Hydronic Radiators", IEEE Conference on Decision and Control, 2011.

[33] J. C. Basilio & S. R. Matos, "Design of PI and PID Controllers with Transient Performance Specification", IEEE Transactions on Education, Vol. 45, No. 4,

pp. 364-370, 2002.

[34] M. F. M. Noris, “Comparison between Ziegler-Nichols and Cohen-Coon Method for Controller Tunings”, 2016.

[35] A. Aziz, A. MTO & A. Stojcevski, “Fuzzy Gain Scheduled Load Frequency Controller in Presence of Grid Code Frequency Responsive Wind Power Penetration”, Australasian Universities Power Engineering Conference, 2016.

[36] S. Sardar & M. B. Kadri, “Autonomous Control of a Quadcopter via Fuzzy Gain Scheduled PD Control”, 12th International Conference on Frontiers of Information Technology, pp. 73-78, 2014.

[37] M. R. Nayeri, S. Khosravi & M. A. Sh., “Design and Implementation Double Input Fuzzy PI and Fuzzy Gain Scheduling PI Controller on Hydraulic Plant”, 13th Iranian Conference on Fuzzy Systems, 2013.