ELECTRONIC THROTTLE BODY TUNING USING MODEL REFERENCE ADAPTIVE CONTROL PID

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This report is submitted
in fulfillment of the requirement for the degree of
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DECLARATION

I declare that this project report entitled “Electronic Throttle Body Tuning Using Model Reference Adaptive Control PID” is the result of my own work except as cited in the references

Signature	: ....
Name	: ....
Date	: ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive).

Signature :. ....

Name of Supervisor : ....

Date : ....

DEDICATION

Dedicated, in thankful appreiation for support, encourangement and understanding to my beloved mother, father, sister, brothers and friends.

ABSTRACT

The electronic throttle body (ETB) have been widely used in many kind of vehicles recently. Even thought, the ETB is one of the new technology it still has some defect in it. The non-linearity that lies inside the system such as stick-flip friction, gear backlash and the discontinuous nonlinear of the spring that make the valve plate to return to its original position affect the performance of the ETB. In this project, the ETB will be tuned using Model Reference Adaptive Control (MRAC) PID controller. The project is start by creating an ETB model by using the Matlab/Simulink software. Then, PID controller is tune to gain the proportional gain, Kp, integral gain, Ki and derivative gain, Kd. Those gain will be used in the MRAC. Then, the project is continuing by applying the MRAC PID to the ETB Model. Next is the result for the MRAC PID is compare to the conventional PID. Lastly, the simulation is tested on different angle.

ABSTRAK

Sejak kebelakangan ini, Badan Pendikit Elektronik (ETB) telah digunakan secara meluas dalam pelbagai jenis kenderaan. Walaupun ETB adalah salah satu teknologi yang masig baru, namun masih terdapat beberapa kecacatan dalam system tersebut. Ketidaklinearan yang terletak di dalam sistem seperti geseran 'stick-flip', tindak balas gear dan ketidaklinearan yang tidak berterusan spring yang membuatkan plat injap untuk kembali kepada kedudukan asalnya telah menjejaskn prestasi ETB. Dalam projek ini, ETB akan ditala menggunakan Model Rujukan Adaptive Control (MRAC) PID. Projek ini akan dimulakan dengan membina model ETB menggunakan perisian Matlab/Simulink. Kemudiannya, PID akan ditala untuk mendapatkan proportional gain, Kp, integral gain, Ki and derivative gain, Kd. Gain tersebut akan digunakan dalam MRAC. Kemudiannya projek ini di teruskan dengan mengaplikasikan MRAC PID didalam model ETB. Seterusnya, hasil daripada MRAC PID akan dibandingkan dengan PID konvensional. Akhir sekali, simulasi diuji pada sudut yang berbeza.

ACKNOWLEDGEMENT

First of all, I am very grateful to meet Allah with His Grace I manage to complete my Final Year Project and the report.

I wish to express my sincere appreciation and thanks to my supervisor, Encik Faizul Akmar Bin Abdul Kadir for his valuable advice, effort and guidance throughout this project. His suggestion and patience always inspire me to produce a better work. Without him, I will never finish this project in time.

Apart from that, I also would like to take this opportunity to express my appreciation and thanks to MathWorks for developing the Mathlab/Simulink software so that I can use it in my project. This software has help me in solving the problem regarding to the project.

Not forgetting, it is an honour to work with my course mates and friends during this two semester for completing this final year project. Their ideas and support have driven me to produce a better works. Without their help, I would encounter many problems while throughout the whole project.

Finally, deepest thanks to my family for their support and care in making this research project.

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EEV	Earth Efficiency Vehicles
ETB	Electronic Throttle Body
PID	Proportional Integral Derivative
MRAC	Model References Adaptive Control

CHAPTER 1

INTRODUCTION

1.1 Background Study

During this area of globalization, the automotive sector has been one of the major contributor to the nation income. With Proton and Perodua lining up our local automotive manufacturer with some other global manufacturer such Toyota, Honda, Ford and BMW, our automotive sector look quite promising in the next few years. Nowadays, all of the car manufacturer are targeting to build an earth efficiency vehicle (EEV) that can improve the driveability, fuel economy and the emission of the vehicle (Pavković et al. 2006). One way to achieve these is by using the Electronic Throttle.

Generally, the conventional vehicles use the mechanical parts that link the gas pedal to the throttle plate. The gas pedal works when the driver is pushing on the pedal. As the pedal is pushing, there is a pivot that pulling a throttle wire that connected to the throttle linkage. The throttle linkage will open and close the valve plate in the throttle body that allows certain amount of air into the engine. But there will be a system of sensors that sense more amount of the air coming to the engine, the more fuel will be injected into the engine. Nowadays, as the technology keeps rising, the researchers found a way to control electronically the amount of the air fuel ratio that been supply to the combustion chamber during the combustion process. The Electronic control system controlled this ratio by changing the opening angle of the valve plate according to how much the driver is pushing the gas pedal (Pan et al. 2008).

Figure 1: The Throttle Body.

Besides that, the Electronic Throttle Body also can perform as a mechanism that improve significantly the engine and vehicles performance. There is a research that shows the driver can choose the powertrain responsiveness to match his or her desire (Mckay et al. 2000). By choose a certain mode, the electronic throttle body or control will adjust the gain or sensitivity of the accelerator pedal in response to the driver input selection. To choose the mode, the driver only need to push a certain button and the rest will be up to electronic throttle control to fulfil those requirements such as the driving condition and the driver mood. Lately, there are three kinds of that is available at the market which are normal mode, power mode and winter mode. There is still more mode to add to the vehicle but those three mode are currently commonly being used.

In this research, PID Model References Adaptive Control. controller using a Matlab Simulink is more favourable than the conventional passive method(Rao 2014). Matlab is a high-performance language for technical computing. It integrates computing, programing and visualizing in an easy-to-use environment where problem and solutions are expressed in familiar mathematical notation. For Simulink, it is a program that integrated with Matlab. It is very useful when designing a dynamic system and make a performance test. Simulink use some block diagram to represent a dynamic system (Mathworks 2014). So, modelling an electronic throttle body using this software, it can give us advantages such as a simulation, optimization and data analysis.

For Model Reference Adaptive Control(MRAC), it is a control system that make the plant to be as close as possible to the model references. The input or the control parameter of the plant are being adjusted automatically for time to time(R. Isermann, K.-H. Lachmann and Matko 1992). As the parameter of the plant continuously being change, the output of the system will be based on the desired response that have being set for the references model. The existence of the MRAC controller will compensate the disturbance that have been create by the nonlinearities of the Electronic Throttle Body. Adaptive control also very good at tracking the performance of the system.

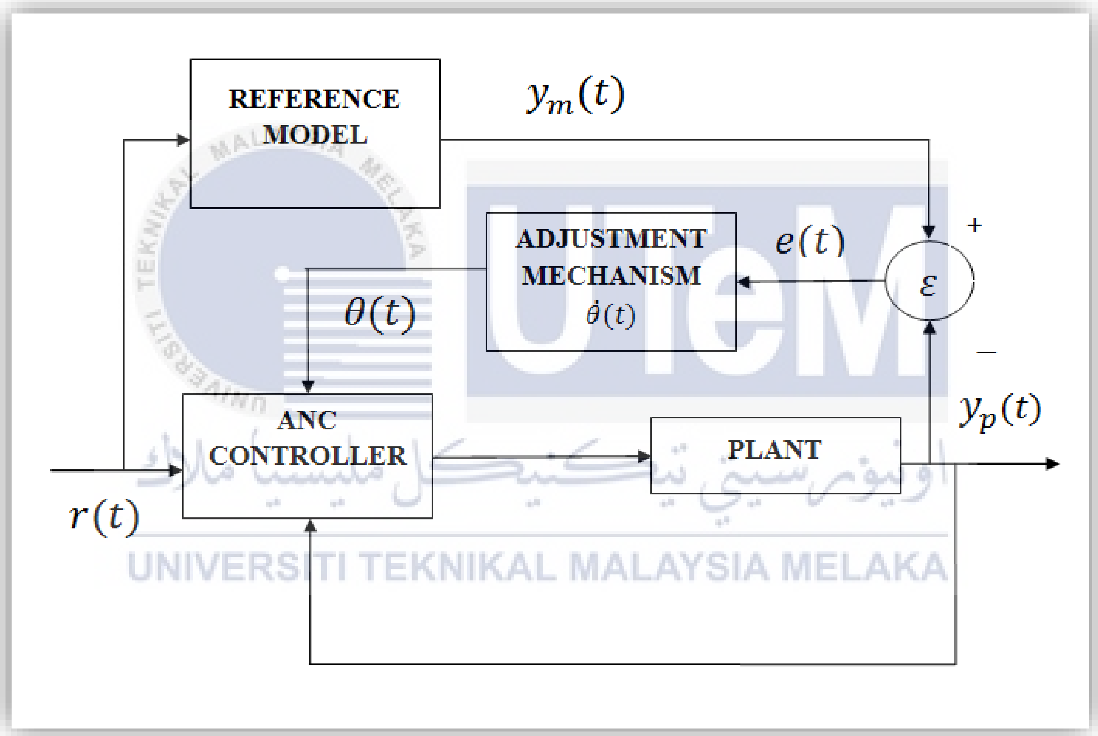


Figure 2: The block diagram of the Model References Adaptive Control.

1.2 Problem Statement

Electronic throttle body is one of essential part that needs in current vehicles so that it can adjust the ratio between the air and fuel that enter the combustion chamber. The problem is that the electric throttle body have some non-linearity such as stick-flip friction, backlash that occurs between the gear and the discontinuous nonlinear of the spring that use to return the valve plate to its initial position. This non-linearity causes the disturbance that can affect the performance of the electronic throttle body.

So, in order to overcome this problem, a proper controller will be needed to compensate the disturbance by the non-linearity. The propose controller that will be used in this project is Model References Adaptive Control (MRAC) PID. To apply the controller, a model of Electronic Throttle Body will be model by using Matlab/SIMULINK. Then, MRAC will be applied in the ETB model.

1.3 Aim and Objective

The aim of this research project is to tuning the Electronic Throttle Body using Model References Adaptive Control PID

The aim and the research objective of the thesis are:

- To develop an Electronic Throttle Body(ETB) model in Matlab Simulink.
- To apply Model Reference Adaptive Control PID controller to obtain the desired throttle angle.
- To compare the result with conventional PID.

1.4 Scope of Project

The scope of this project are:

1. Study about the throttle body on how to control the disturbance created by the non-linearity of the system.
2. This project only focus on simulation only.
3. The simulation will be perform using Matlab (Simulink) software.
4. Model the ETB provide by (Pan et al. 2008) by using matlab/simulink
5. Apply the Model reference adaptive control PID to the ETB model.
6. Compare the result for conventional PID with MRAC PID.
7. Do various simulation for different throttle opening angle such as 30^{o}, 45^{o}, 60^{o}, 75^{o} and 90^{o}.

1.5 Thesis Outline

The First chapter is an introduction part which discusses briefly on the background, problem statement, aim and objective of the project. Besides that, this chapter will briefly mention about the outline of the project.

Chapter Two will discuss about the literature review. All the concept and operation that related to the Electronic Throttle Body will be discus. The study about the controller and the method of the control will be discus.

Next, chapter Three will discuss about the method used to carry out this project. The steps to complete this project also will be discussed in this chapter, including the tuning method and the simulation. The step to model the plant and the controller also being discuss in this chapter.

Chapter Four will mention about the result and discussion of the performance. The data from the simulation will be graphed. The comparison between the MRAC PID and the conventional PID is discussed.

The last chapter will be the conclusion. All other future suggestion and recommendation will be mentioned in this chapter. Hopefully all the opinions and ideas will provide benefits for the future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the relevant literature review in application related to research of electronic throttle body, type of controller, type of manual tuning method, automatic tuning method and modelling

2.2 Throttle Body

For every vehicle, to control the speed either to increase the speed or to decrease it is very importing characteristic that should be include in the vehicles. One way to control the speed is by controlling the air fuel ratio that enter the combustion chamber. So, throttle body is the one who control the ratio. The throttle body works by adjusting the valve plate that place inside the throttle body(Pan et al. 2008). When the acceleration pedal is pushed, a mechanical linkage that link the pedal and the valve plate will pull a spring that open the throttle angle(Panzani et al. 2011)(Rossi et al. 2000). As the valve is open, it will allow the air and fuel to enter the combustion chamber.

Figure 3: The Throttle Body.

With now advance technology, the mechanical linkage now not directly connected to the gas pedal anymore. The existence of the Electronic Throttle Body (ETB) is widely used in modern car now days. It is because of the reliability of the throttle body itself. For ETB, the gas pedal not connected to the throttle body but to the sensor. The sensor will sense the position of the gas pedal and will send the Engine Control Unit (ECU)(Mckay et al. 2000). The function of ETU is to determine the opening angle of the valve. By taking others input parameter from the engine such as the slop of the road, road condition, and the driver behaviour, the control unit will determine the best opening angle of the valve. The advantage of using ETB is the fuel efficiency, a comfortable drive experience, and less emission.

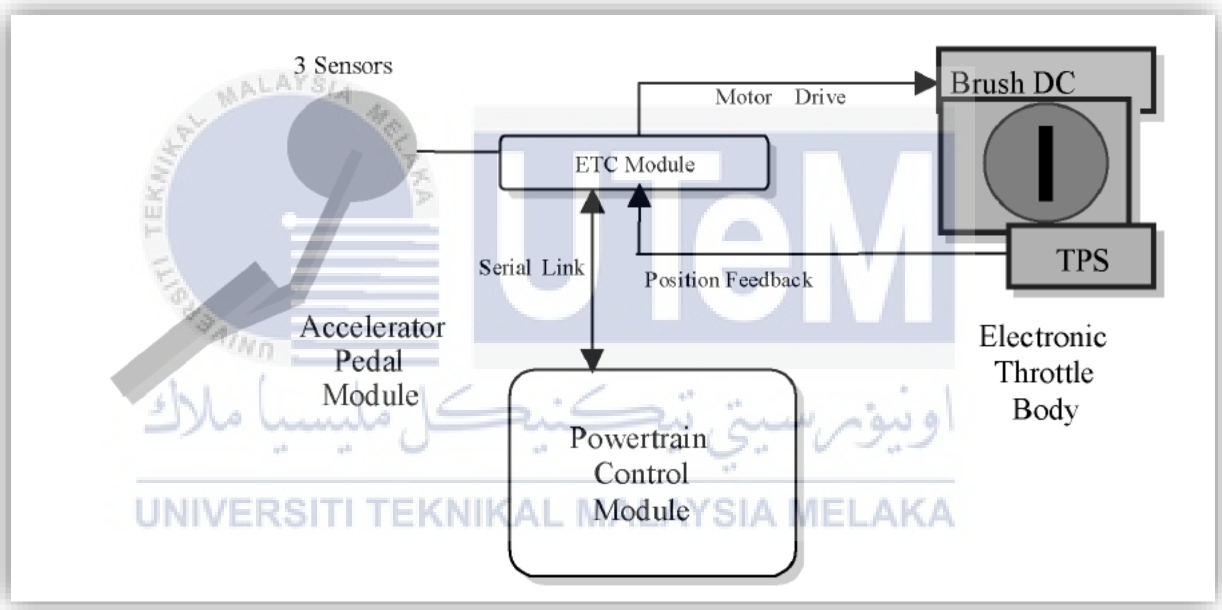


Figure 4: The Electronic Throttle Body schematic diagram.

2.3 Gear Backlash

One of the problem that occurs in Throttle Body is that there is lies the backlash of the gear that need to turn the valve plate. The existence of the gearing backlash has cause the disturbance of the Throttle body system and may have affected its performance. Gear backlash exist because of the gap between the gear tooth(Engineering 1996). These phenomena are common in servomechanism especially in mechanical system that involve the gear-driven system.

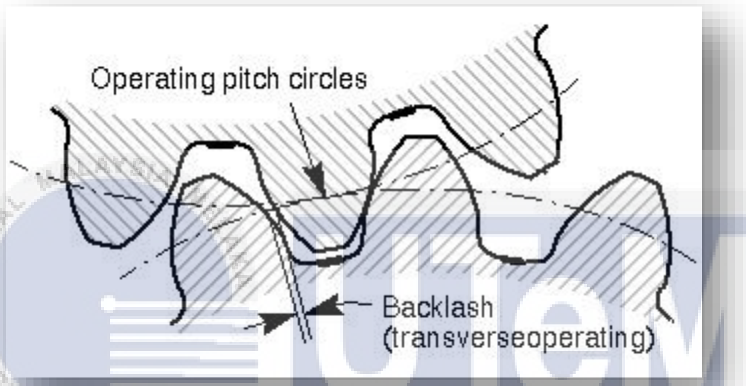


Figure 5: The backlash of the gear.

Backlash is not necessarily a bad thing for the gearing system. With a certain amount of the backlash, the system can operate in an optimum performance but once the amount of the backlash greater that the maximum allowed, it can cause the positioning error and make the system to become unstable. To eliminate the backlash nonlinearity is quite challenging itself(Shi & Zuo 2015). It is because as long the gear system is being used, there will be the backlash nonlinearity. As for the research, the propose control system which is the Model References Adaptive Control will compensate the disturbance that have been created by the backlash nonlinearity.

2.4 Mathematical Modelling

Modelling is the process of identifying the physical dynamic effects to be considered in analysing the system. The modelling can involve many mathematical equation such as ordinary differential equation (ODEs), partial differential equations (PDEs), differential algebraic equations (DAEs) and ODEs interfaced with discrete-time algorithms (DTAs)(Taylor 2001). The purpose of the mathematical modelling is to predict the response of the system before applied into the real system. Actually this project is about modelling a nonlinear system. A nonlinear system is a system in which the output of the system is vary within the time and not directly proportional to the input (Heij & van Schagen 2007). The performance of the Electronic Throttle Body will depend on the efficiency of the control system and the dynamic model of the system. The mathematical modelling of the Electronic Throttle body will be discussed in Chapter 3.

2.5 PID Controller

PID is consider as the best controller in the control system family. PID controller is a short form for Proportional-Derivative-Integral control. A controller is to control a process so that the resulting control stem will reliable and safely achieved high-performance operation(Passino, Kevin M. Yurkovich 1998). Besides that, PID also is a feedback mechanism which is used in a control system. A feedback control means that the controller will uses the information from the measurement of the error. The basic how PID works is by reading an input sensor and then compute the desired output by calculating proportional, integral and derivative responses. Next, sum all three responses and compute the output. There is two type of feedback control which is positive feedback and negative feedback. Positive feedback is used to increase the input value while the negative feedback does the opposite which is down size of the input. Each of the response have different role.

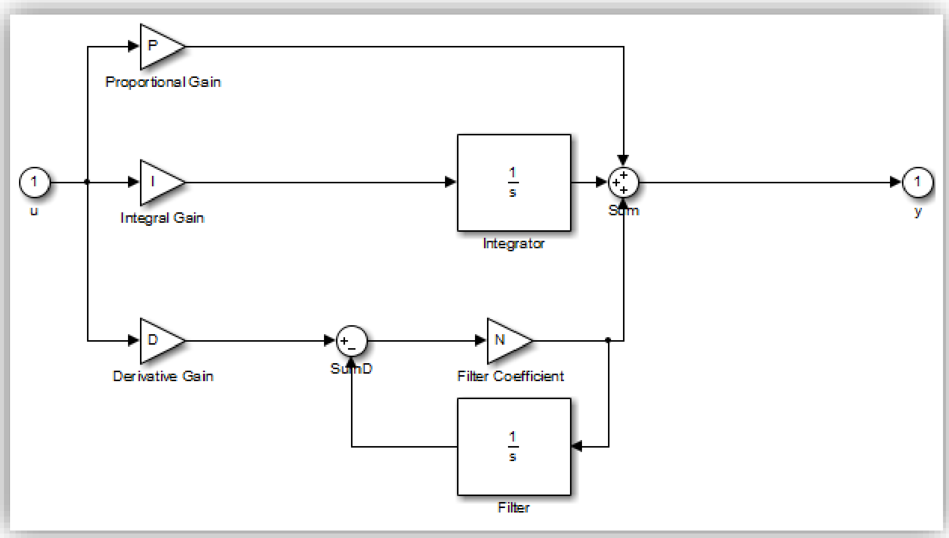


Figure 6: The PID controller in MATLAB Simulink

For the proportional response, it only depends on the different between the set point and the process variable. The different also can be known as the error. The proportional gain (K_c) will determine the ratio between the output response to the error signal. For proportional respond, increase the proportional gain to much will result the system to become unstable. But if the proportional gain too small, only little response will affect the system disturbances(Tehrani & Mpanda 2012). Proportional response also can be express in given term:

$$P_{out} = K_P e(t) + p_0 \tag{1}$$

Where:

i. P_{out} = Output of the proportional Controller
ii. K_p = Proportional gain
iii. $e(t)$ = instantaneous error at certain time, s
iv. p_0 = proportional output with zero error.

For integral response, the response is depending on both magnitude of the error and the time of the error. The integral component is the sum of the error over time. Even with the small error will cause the integral component to increase slowly. The integral response will stop from responding only when the error is zero. So, an integral control (K_i) will eliminate the steady-state error.

$$I = K_I \int_0^t e(t)\, dt \tag{2}$$

Where:

i. I = integral output.
ii. K_i = integral gain
iii. e(t) = error at certain time, s.

Next is the derivative response which is cause the output to decrease if the process variable is increasing rapidly. The error in derivative response is calculate by determining the slope of error over time and then will be multiply by the derivative gain, K_d. By increasing the derivative time parameter will cause the control system to react more strongly to changes of error and will increase the speed of the overall control system response. If the sensor feedback of the signal is noisy or if the control loop is too slow, the derivative response will make the control system become unstable.

Table 1: The effect of each controller on a close-loop system.

Parameter	**Rise time**	**Overshoot**	**Settling time**	**Steady-state error**
K_p	Decrease	Increase	Small change	decrease
K_i	Decrease	Increase	Increase	Decrease significantly
K_d	Minor decrease	Minor decrease	Minor decrease	No effect

2.6 Fuzzy Controller

Fuzzy logic is a study of logic that have various of value. The fuzzy logic system only accepts the term 100% true or 100% false. There is not partially true or partially false in fuzzy control system. The variable in fuzzy control system can be any value between the 0 and 1. This variable is called linguistic variable. The fuzzy controller is one of the alternative for solving the nonlinear system problem. It is one of the convenient method beside using the PID controller.

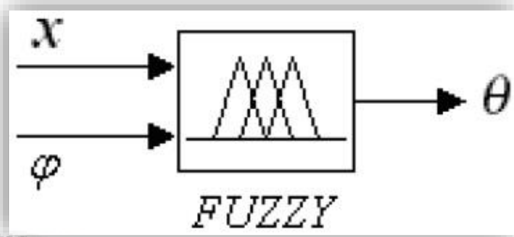


Figure 7: The structure of fuzzy controller.

There are four main components in fuzzy controller. The first one would be the 'rule-base'. The 'rule-base' is the component that possessed the knowledge which is in state of rules. The rules will the determine how best to control the system. The next component is the inference mechanism. For this component, it's function is to figure out which rules should be applied at current time. Then it will choose the input of the model.

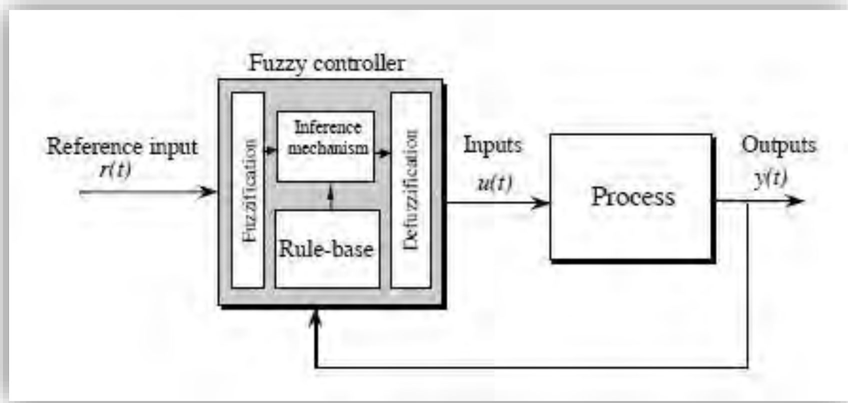


Figure 8: The architecture of fuzzy controller.

The third component is the fuzzification. The fuzzification is where the input of the plant is changed so that it can match and correlated to the rules in ‘rule-base’. Lastly the is the defuzzification component where the outcome of the inference mechanism is fine tune input of the plant(Moore et al. 2009). Fuzzy has the advantage of compensate the disturbance that have create by the nonlinearity of a certain system. But the disadvantage is the fuzzy control system is hard to understand when to compare with the PID controller.

2.7 Cohen-Coon Method (C-C)

There is a lot of methods to find the value for the proportional, integral and the derivative parameter when PID controller is used to optimize the dynamic system. One of the ways to determine the PID parameter is by using the Cohen-Coon method. Based on the recent research, Cohen-Coon method rank second behind Ziegler-Nichols tuning method. A certain control engineer prefers to use Cohen-Coon method rather than Ziegler-Nichols. It is because of the flexibility of the method offered by this method. If the dead time below that two times the length of the time constant, the Cohen-Coon works greatly in this condition.

$$G_{PRC(S)} = \frac{\bar{y}_m(S)}{\bar{C}(S)} \approx \frac{Ke^{-td}}{\tau s+1} \quad (3)$$

By using the Cohen Method, the system feedback is modelled to a step change as a first order response with dead time. According to the response, there are three parameters will be found which are τ , K and t_d. τ is the effective time constant of the first order response while K is the output of the steady state over the input of the step change. t_d is the dead time. After the value of the parameter is obtained, the parameter is then derived for the best controller setting using the one-quarter decay ration. After that, the PID parameter are being calculated from using the following formulas(Praveena et al. 2014).

$$K_p = (1/K) \times (T/t_d) \times [(4/3) + (t_d/4T)] \quad (4)$$

$$T_I = t_d \times \left[\left(32 + (6 \times t_d/T)\right)/\left(13 + (8 \times t_d/T)\right)\right] \quad (5)$$

$$T_d = t_d\left[4/\left(11 + (2 \times t_d/T)\right)\right] \quad (6)$$

Where,

K_p : proportional gain

T_I : Integral Time

T_D : Derivative Time

2.8 Sensitivity Analysis

A sensitivity analysis is method the used to find how vary value of an independent variable impact a particular dependent variable under a set of assumption. This method is used within a certain rule that depend on one or more input variable. So in field of control engineering, the sensitivity analysis can be used in tuning a PID controller.

Sensitivity analysis is one of the offline ways to tune the PID. The sensitivity analysis starts by taking an initial condition. For an example, the PID value is set as 1, 0 and 0 respectively. Then, takes the Proportional Gain ,K_P as the variable and fixed the value of K_i and K_d. After that, run the simulation to find out the error between the desire and the actual value. The least value of error will be the K_p for the next step.

So, for the next step is the value of K_i will be the variable and K_p and K_D will be the fixed. Run the simulation to find the least value of error and then the value of K_i can be determining. The steps for determine the K_D also same with the previous steps. The after the 3 value P, I and D have been found, it will be the ideal condition for the PID controller.

2.9 Model Reference Adaptive Control (MRAC)

To encounter the nonlinear system, one of technique that can be used is the Model Reference Adaptive Control (MRAC) technique. This technique is popular among the control engineering and known for its efficiency (Engineering & Neumann 2010)(Tar et al. 2010)(Prabha & Paul Joseph 2016). Basically, a MRAC control system is an approaches where the plant is automatically adjusted so that it can followed the references model. The control parameter, θ is being adjusted from time to time .

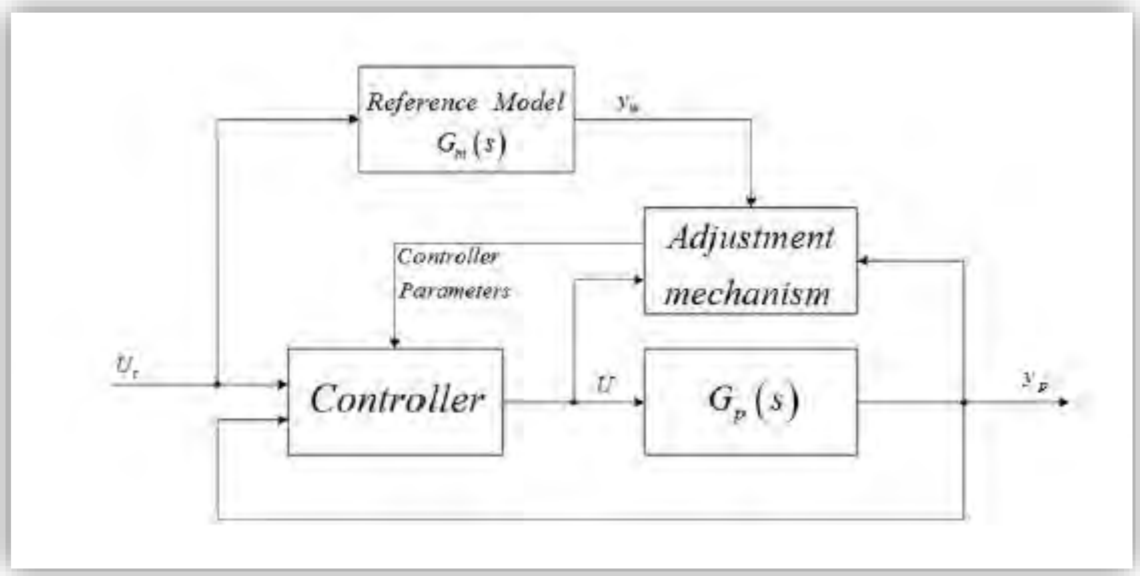


Figure 9: The general structure of MRAC.

To design the MRAC, there a few methods that can be followed. The first one is the MIT rule and the second is Lypunov method. In some research conclude that the Lypunov method had some disadvantage that effect the performance when being used in a system. When using this method, it can be a difficult task to located the most suitable Lypunov function. Even though the it is stable, but the application of this method is an easy task(Engineering & Neumann 2010). The other method is the MIT rule. This method is a popular even though there is some problem with the stability. But one of the advantages of this method is that its less complex if compare to the Lypunov method. For its simplicity, this MIT rule will be used to design the MRAC PID controller in this project.

2.10 Cruise Control

We can see that today technology have help human in many ways to make an easier life. One of the technology that popular among automotive industry is Cruise Control or also can be called by Autocruise. The function of a Cruise Control is that when the driver turns it on, the vehicle can be drive at a constant speed without need to press the acceleration pedal. Actually, the technology first was discovered by an American inventor name Ralph Teetor in 1945. He was inspired to create a system that can make the vehicles stay at a constant speed when he had a conversation in a car with his lawyer who is driving it. It makes Teetor so discontented when his lawyer always changing the vehicle's speed. So, he so determined to create a system that we called Cruise Control in nowadays.

(a) (b)

Figure 10(a) shows the cruise control button. 10(b) shows the cruise control light indication.

To use the cruise control, the driver must drive the vehicles until a certain speed and then use the cruise control buttons to set the current speed. For the safety of the driver, the cruise control only can be set when meet the minimum speed requirement which is normally at 60km/h. The cruise control works when the solenoid is pulling the throttle cable as the cruise button is pushed. Usually, the throttle cable is pulled by the acceleration pedal.

But in the latest study, with the existence of the electronic throttle control, the cruise control become more reliable these day(Pananurak et al. 2009). This is because when the car using ETB system, adjusting the throttle position become a lot more precise as a lot of sensor is used in the ETB system. The ETB will maintain the position of the throttle valve that allow the vehicles to have a constant speed.

CHAPTER 3

METHODOLOGY

3.1 Introduction

On this chapter, there will be some explanation on the method that have been applied in this project in order to ensure the successfulness of the project objectives. This project will use Matlab/Simulink Software to build the Electronic Throttle Model. But before that, a certain equation must be find to represent the ETB in the Simulink model. After done model the ETB in Simulink, the project is continuing by doing the simulation with the desire throttle opening angle.

3.2 Project Flowchart

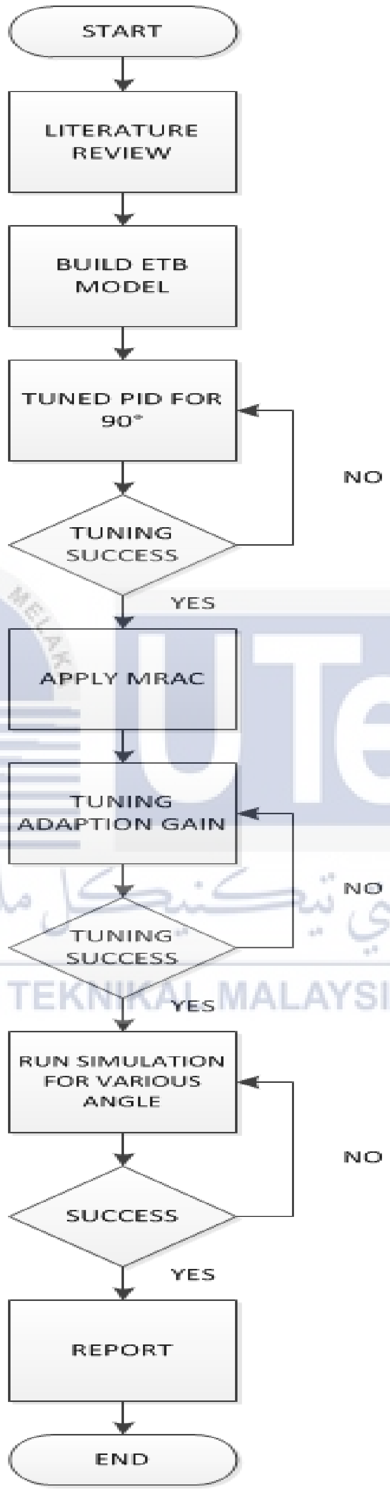


Figure 11: The project flowchart.

3.3 ETB Model Development

For the purpose of this project, the ETB model that have used is obtained from the (Pan et al. 2008). The reason behind this chosen model is that the model is a lot simpler if being compare to other ETB model that have been found. With all the parameter have being given, this will make the project progress become smoother. The first step that need to begin is to model the electronic throttle body without the backlash. The valve plate position and rotor angular velocity is defined as θ and ω respectively. The total damping and total inertia coefficient are determined by,

$$B_{tot} = B_m + K_{g1}^2 B_{int} + \left(K_{g1}K_{g2}\right)^2 B_{ps} \tag{7}$$

$$J_{tot} = J_m + K_{g1}^2 J_{int} + \left(K_{g1}K_{g2}\right)^2 \left(J_{ps} + J_{sect}\right) \tag{8}$$

Then consider the nonlinear spring torque and friction, the dynamic equation is obtained as,

$$J_{tot}\dot{\omega} = -B_{tot}\omega - T_f(\omega) - T_{sp}(\theta) + K_t z \tag{9}$$

where z is the current through the dc motor windings. The relationship between the valve plate position and the motor angular velocity is described by the following:

$$\dot{\theta} = \left(K_{g1}K_{g2}\right)\omega \tag{10}$$

As the result, including the motor electrical part, the model of the electronic throttle valve is given by,

$$\dot{\theta} = \left(K_{g1}K_{g2}\right)\omega \tag{11}$$

$$\dot{z} = -\frac{K_v}{L}\omega - \frac{R}{L}z + \frac{1}{L}u \tag{12}$$

$$\dot{\omega} = -\frac{B_{tot}}{J_{tot}}\omega - \frac{1}{J_{tot}}T_f(\omega) - \frac{1}{J_{tot}}T_{sp}(\theta) + \frac{K_t}{J_{tot}}z \tag{13}$$

Where u is the input voltage to the dc motor. Then, the nonlinear function $T_{sp}(\theta)$ and $T_f(\omega)$ can be described with the signum function as,

$$T_f(\omega) = F_s sgn(\omega) \tag{14}$$

$$T_{sp}(\theta) = \begin{cases} D + m_1(\theta - \theta_0)\,, & if\ \theta_0 < \theta < \theta_{max} \\ -D - m_1(\theta_0 - \theta) & if\ \theta_{min} < \theta < \theta_0 \end{cases}$$

$$= m_1(\theta - \theta_0) + Dsgn(\theta - \theta_0) \tag{15}$$

Then, assume that $x_1 = \theta$ and $x_2 = (K_{g1}K_{g2})\omega$, the aforementioned dynamic equation can be simplified as,

$$\dot{x}_1 = x_2 \tag{16}$$

$$\dot{x}_2 = a_{21}(x_1 - x_{10}) + a_{22}x_2 + a_{22}z - \mu sgn(x_2) - \kappa sgn(x_1 - x_{10}) \tag{17}$$

$$\dot{z} = a_{32}x_2 + a_{33}z + b_3u \tag{18}$$

Where,

$a_{21} = K_{g1}K_{g2}m_1/J_{tot}$ $\qquad$ $a_{22} = -B_{tot}/J_{tot}$

$a_{23} = K_{g1}K_{g2}K_t/J_{tot}$ $\qquad$ $a_{32} = -K_v/(LK_{g1}K_{g2})$

$a_{33} = -R/L$ $\qquad$ $b_3 = 1/L$

$\mu = K_{g1}K_{g2}F_s/J_{tot}$ $\qquad$ $\kappa = K_{g1}K_{g2}D/J_{tot}$

Table 2: The Parameter Value for the simplified Model.

Parameter Names	Parameter Values
a_{12}	1/18
a_{21}	-1.6e3
a_{22}	-32.9
a_{23}	4.2e3
a_{32}	-11.6
a_{33}	-5.2e2
b_3	4.7e2
κ	4.6
μ	2.1

3.4 Modelling the Electronic Throttle Body

As have been mention earlier in Chapter 1, the first objective is to model the Electronic Throttle Body using Matlab/Simulink. So, Matlab Software version R2016a will be used for the rest of the of the project. After the equation for the model is obtained, the Matlab/Simulink need to be open first. The interface is shown in Figure 12 below. Modelling the ETB start by clicking the Simulink button that shown in the red circle in figure 12. By clicking the button, it will directly open the Simulink Start Page which then need to proceed by selecting the Blank Model. After that, a new window of Simulink blank model will open.

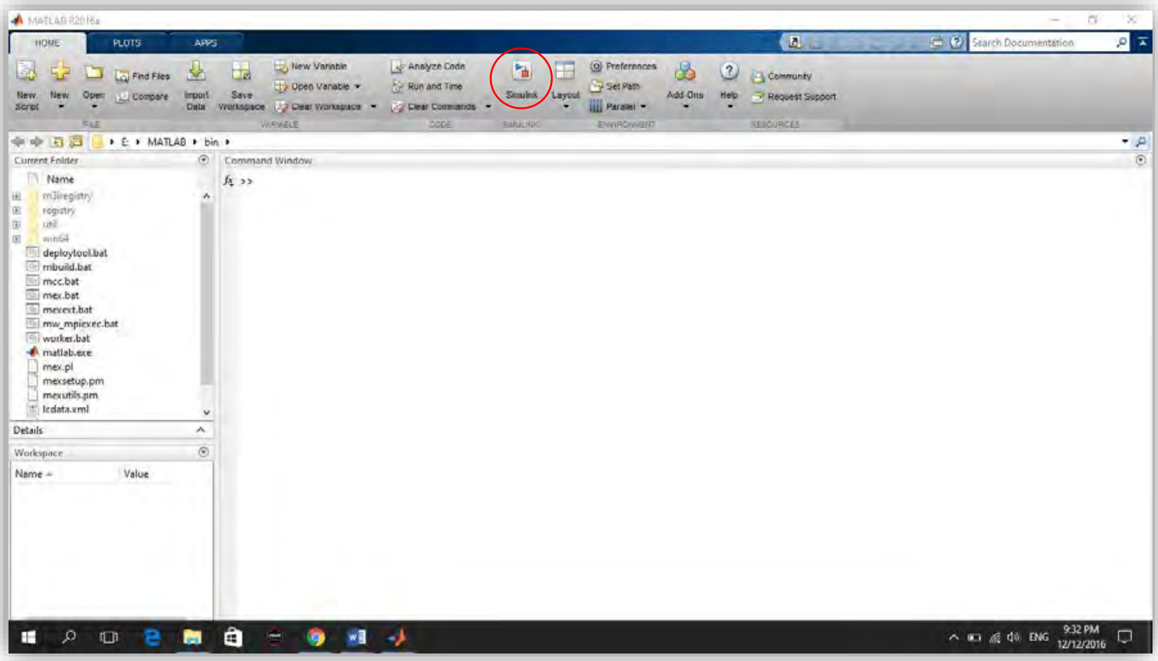


Figure 12: The interface of Matlab Software.

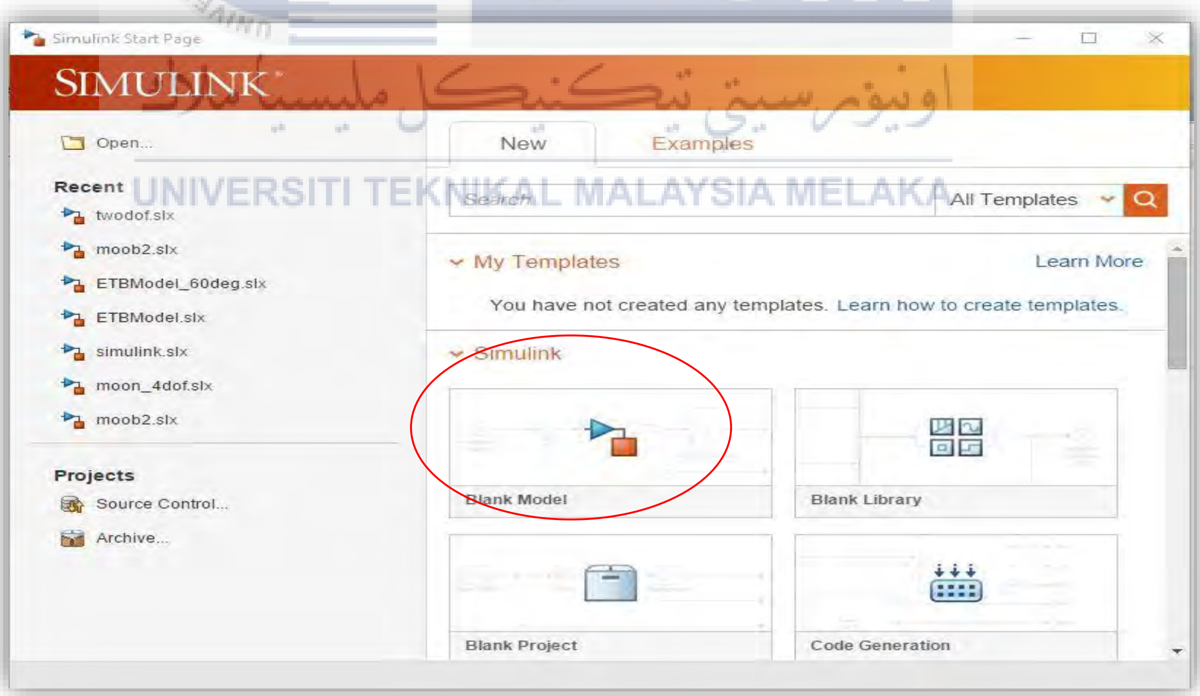
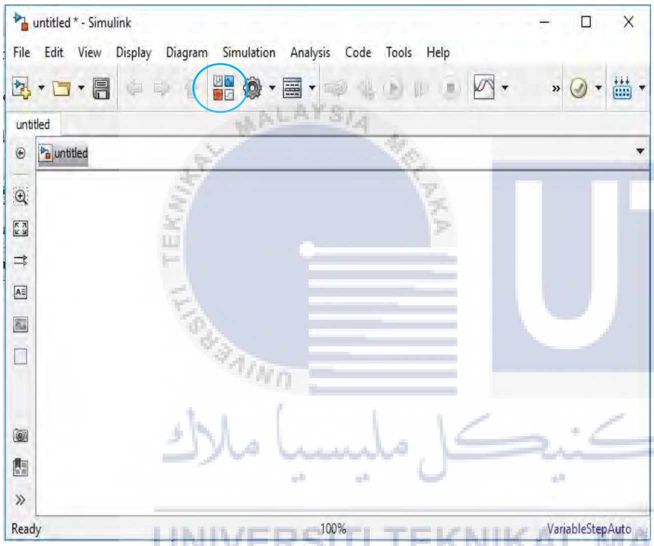


Figure 13: The Simulink Start Page.

As in the Simulink window, to create the model, click the Libraries Browser (red circle in Figure 13) button to choose for the block to represent the equation in the Simulink. There block have been sort into a certain category such as Continuous, Math Operation, Commonly Used Blocks, Sinks and Sources. The Continuous block contain such as Derivative and Integrator. The derivation and integration is commonly used in mathematical operation. Next is the Math Operation category which include the add block, divide block, gain block, product block and sum block. Sink is for the output block while Source is for the input block. Each of this block is very essential to learn as to complete the mathematical modelling of the ETB.



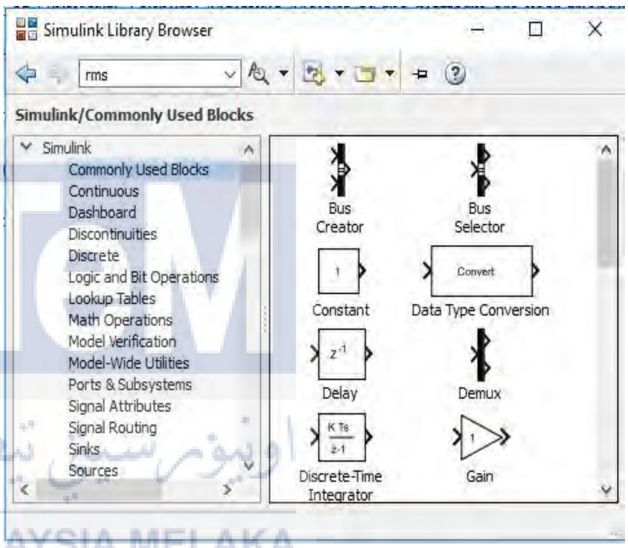


Figure 14: The Simulink Interface

Figure 15: The Simulink Library browser

Next step is to model the ETB. First, choose the first equation to model in Simulink. For example, start with equation (7). The equation has been rearranging so the process is being continue by choosing the right block. In the Simulink Library Browser, choose the right block before click and drag the block in to the Simulink window. To connected two different block, just left click and hold on the arrow at the output of the first block before drag it to the input of the second block. To save time, the same block can be copy if the block has been used. It can be copy by simply right click and then drag to some other place. The name of each block must be name in order to avoid any confusion when enter the parameter of the model.

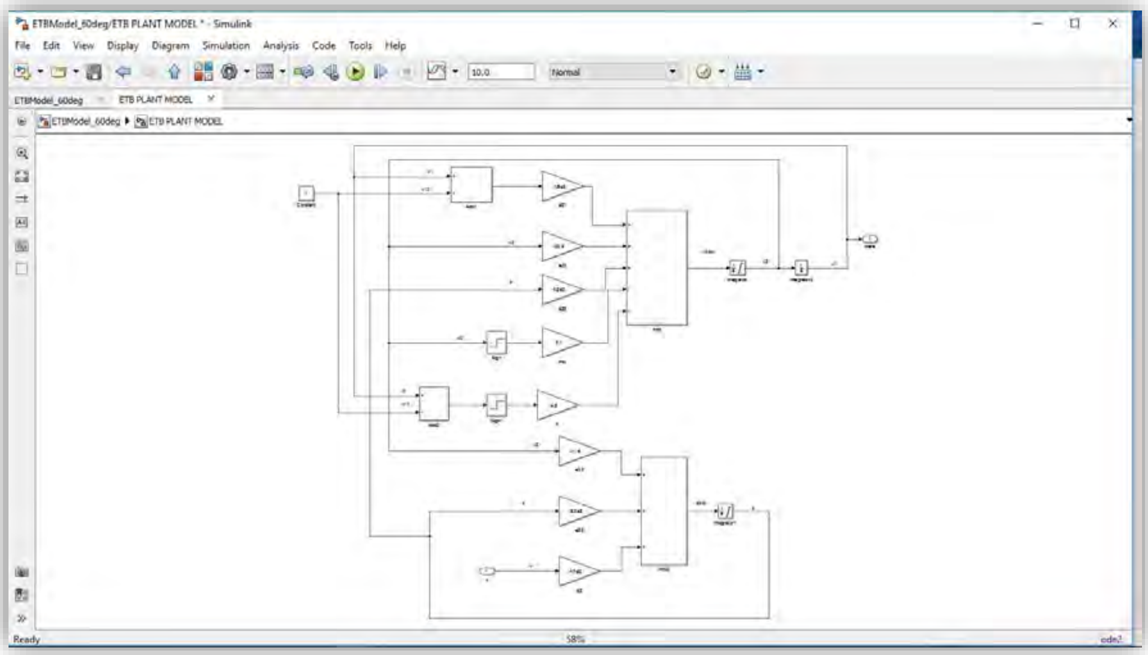


Figure 16: The ETB plant Model.

After that, the project is continued by creating a subsystem from the plant model above. Select all the block in the Simulink and then right click at any of the block. A selecting tab will come out on the screen, then chose the ‘Create Subsystem from Selection’ tab. After that, the Simulink software will simplify the block into one simple block that called Subsystem with only one input and one output according to the mathematical model. The input will be ‘u’ and the output is ‘theta’. Besides step above, subsystem also can be created by selecting all and then push ‘Control + G’ buttons.

Next step is to put the controller. As have been mention earlier in this project, the controller that used in this project is PID controller. Select the PID controller block from continuous category in Simulink Library Browser and drag it into the subsystem screen. Connect it to the input of the subsystem. Then add ‘Sum’ and ‘Step’ block in front of the PID controller. The step block will act as the desire input of the throttle opening. The Sum block used to add or subtract operation. The operation changed by changing the sign in Sum block properties where ‘+’ for plus operation and ‘−‘ for subtraction. The sum block can accept any real or complex data such as floating point, built-in integer, fixed point and Boolean.

To collect the data of the simulation, a ‘To workspace’ block is being used. The block is available in sink category in Simulink Library Browser. The data that have been collected will be transfer into the workspace in Matlab. Next, another ‘to workspace’ is connected to the step input of the desire throttle angle. This is due to compare the output throttle opening with the desire input. After that, a clock also being connected to the ‘to workspace’ block. The function of clock block is to record the time of response of the throttle angle opening.

In order to calculate the error between the desire throttle angle and the output throttle angle, a ‘RMS’ block is used in the ETB model. ‘RMS’ stand for ‘Root Mean Square’. The error will be used in determining the suitable PID controller via manual tuning method or sensitivity analysis. This method will be explained later in the report. Then, a ‘display’ block is connected to the RMS. The ‘display’ block is used to display the value of the RMS error. After finished with the model, the simulation for the throttle body is done. By setting the step time equal to 1, initial value equal to zero and final value equal to 90, the simulation is set for the desire throttle opening angle of 90 degrees. To run the simulation, click the play button on the Simulink window (red circle in figure 17).

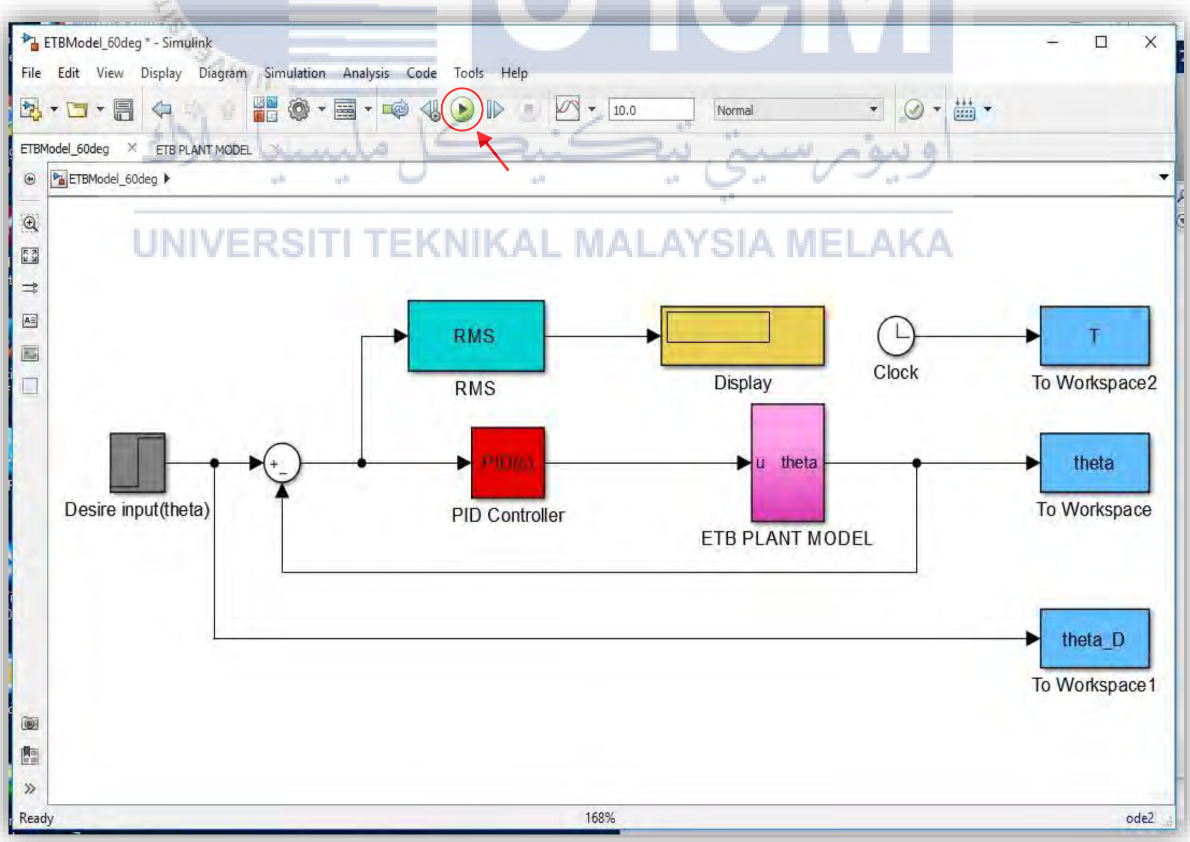


Figure 17: The ETB model with PID controller.

The next step is to create a graph to compare the desire throttle angle with the output throttle angle. As have been mention earlier, after done the simulation the data will be bring to the workspace in the Matlab. So to plot a graph using Matlab, a certain coding will be used. By typing the ‘plot (x, y) ‘in the command window, a new figure window that show the graph will pop-up. So as the example, in PID the value of P is set as 1 and the other two will be set as zero. so, to plot the graph, the command will be ‘plot (T, theta, T, theta_d). As shown in figure below, the red line for the desired throttle angle and blue line for the output throttle angle.

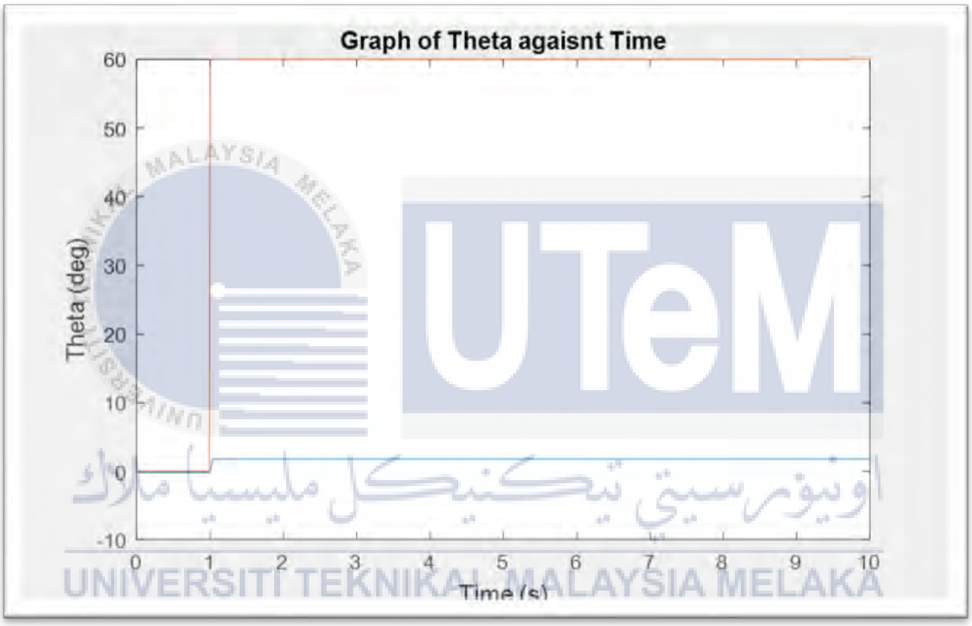


Figure 18: The graph of desire throttle opening angle and the output of the throttle opening angle.

3.5 Manual Tuning of PID for Electronic Throttle Body

The objective of tuning the PID is to ensure that the output of the throttle valve opening angle follow the desire throttle valve opening angle. So, for this project, the desired throttle valve angle that have been set is 90°. One ways to manually tunes the PID is using the Sensitivity Analysis method. This method is one of the offline tuning that available in field of control engineering.

This method began by choosing the desired input or in this project is the desired throttle opening angle. To set the desired throttle opening angle, double click on the step input block and new window of block parameter of the step input block will pop up. Set the step time as one to ensure that the increment of the step is one. Next the initial value set as zero to start the step by zero and final value as 90 so that the desired throttle opening angle will set as 90 degrees.

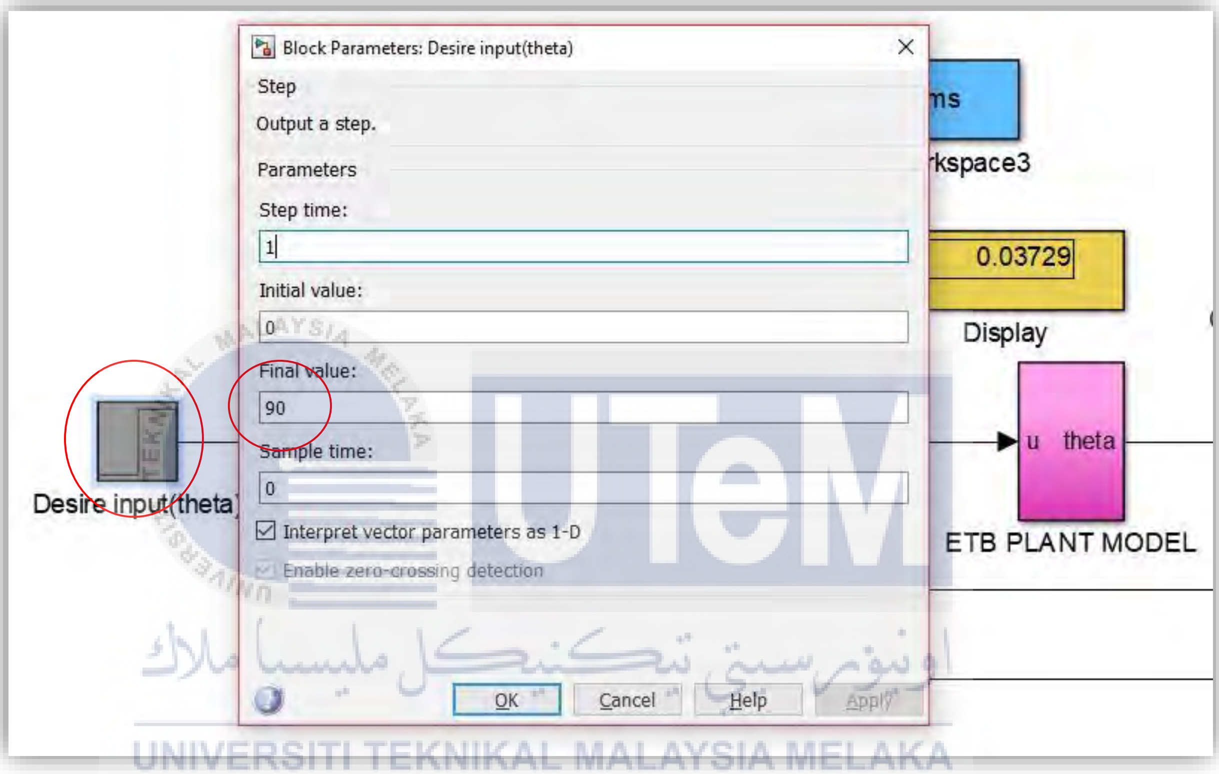


Figure 19: The Block Parameter of Desire input (theta_D).

The next step is to insert the value of P, I, and D in the PID controller. Like usual, double click on the PID Controller block and the block parameter for the PID controller will pop up. In Sensitivity Analysis method, one of the parameter must be set as variable and the other two parameter set as fixed. For the initial condition, the parameter will be set as; P=1, I=0, and D=0. Then, the simulation for this value of PID parameter is run. After that, record the value of RMS error in the Microsoft EXCEL. The next things are to plot the graph. The purpose of the initial condition is to determine the increment value of the P value in PID controller.

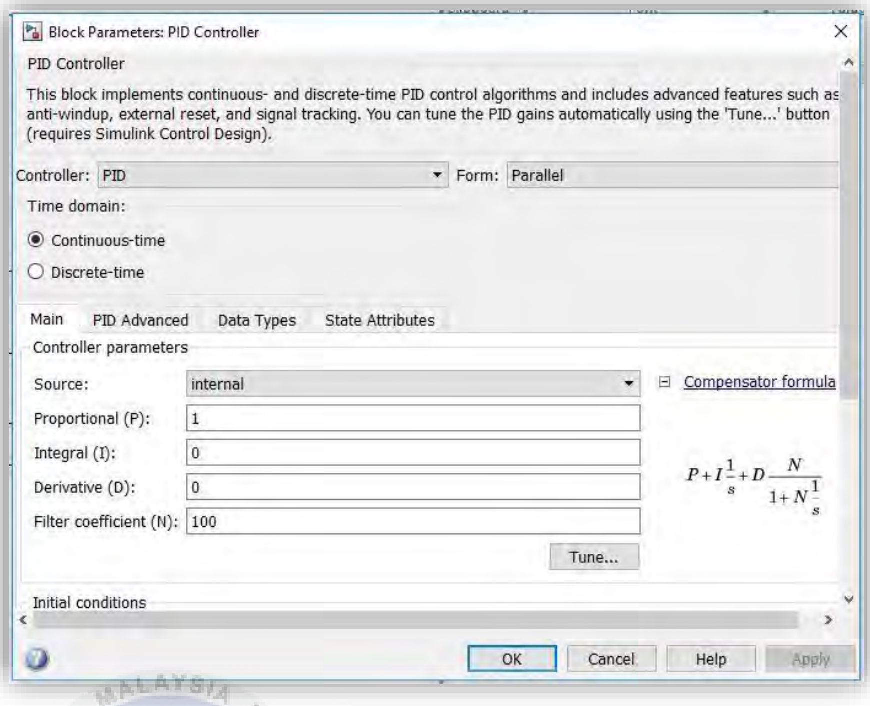


Figure 20: The block parameter of PID Controller.

Then, plot the graph of the desired throttle opening compare to the output throttle opening. From the graph, it shows that the different is so marginal.

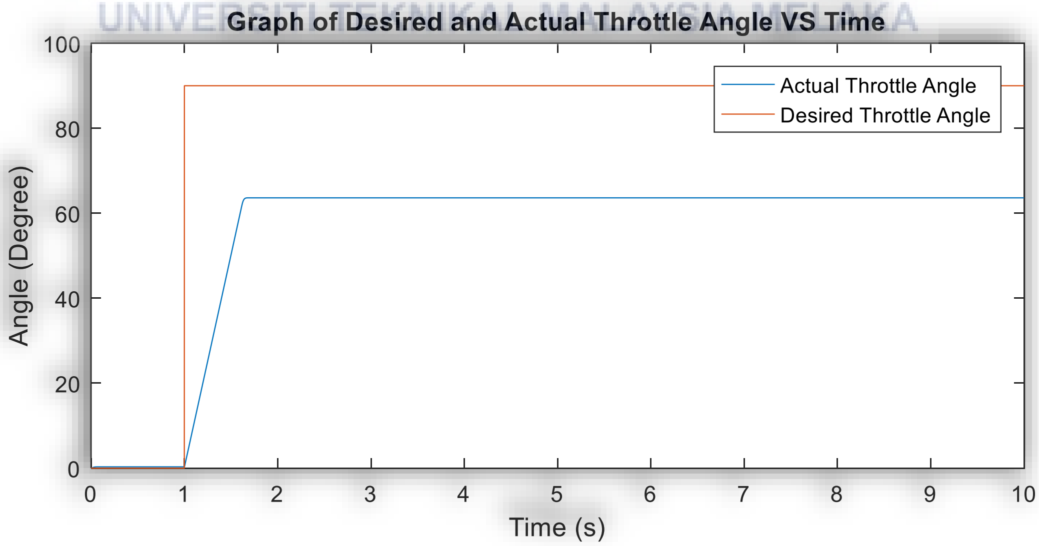


Figure 21: The graph of initial condition.

So, for the next value of P, it has been set at 10. This is because the different between the desire throttle opening angle and the actual throttle opening is massive. The increment of the value of P is 10 while the value of I and D should remain at zero. Each time the simulation is running, the value of the Root Mean Square (RMS) error is being recorded. After the simulation being run a few times, it seems that the range of P is lies between the 250 and 400. Finally, the most suitable value of P is 350.

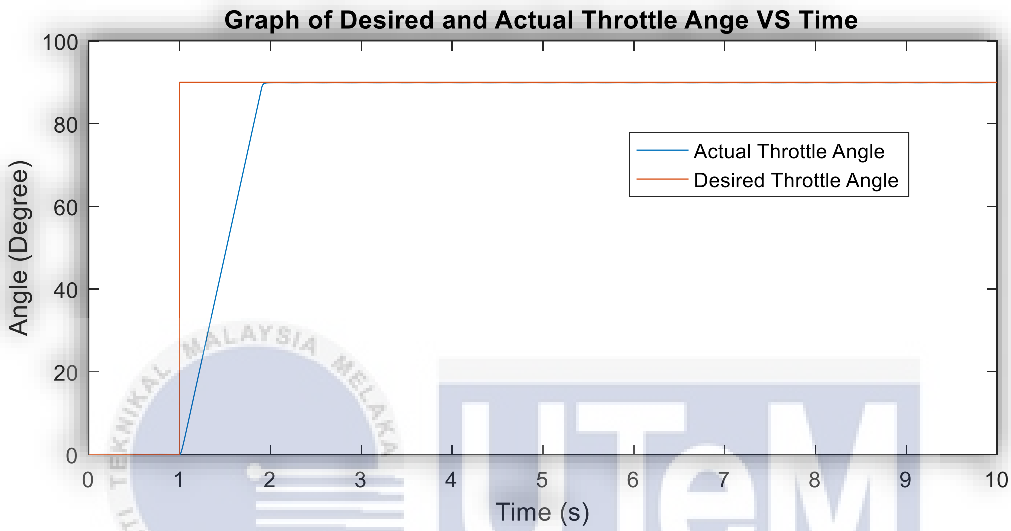


Figure 22(a): The graph of the response of throttle when p is change.

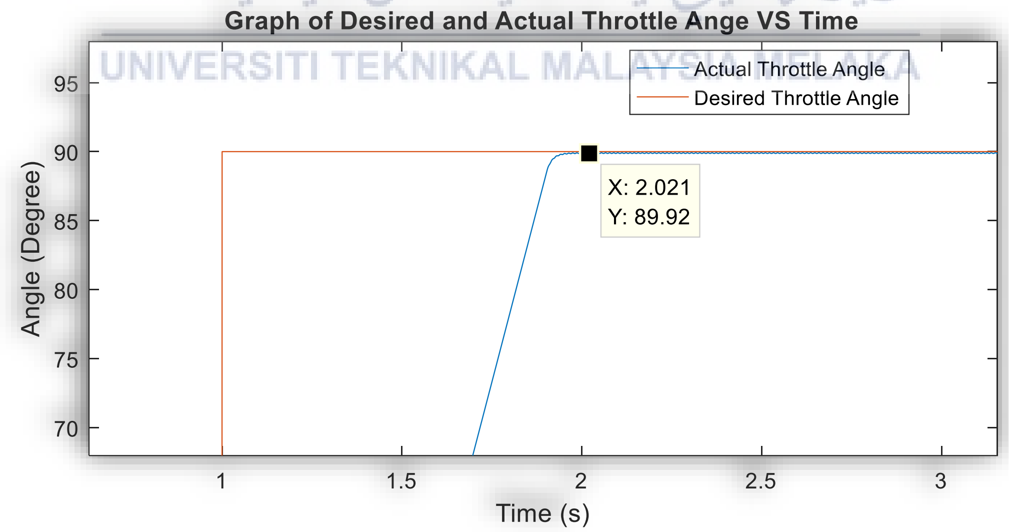


Figure 22(b): Close up from figure 22(a).

For the next step, to find the value of the integral, I, the value of P and D is now being set to be constant. The value of P is taken from the previous test which is 350 and the value of D is remained at 0. For this step, the value of the I will be changed so that to observe which value of I have the lowest RMS errors. For starting, the value of I is set at 0.2 with the increment of 0.2 for the next test.

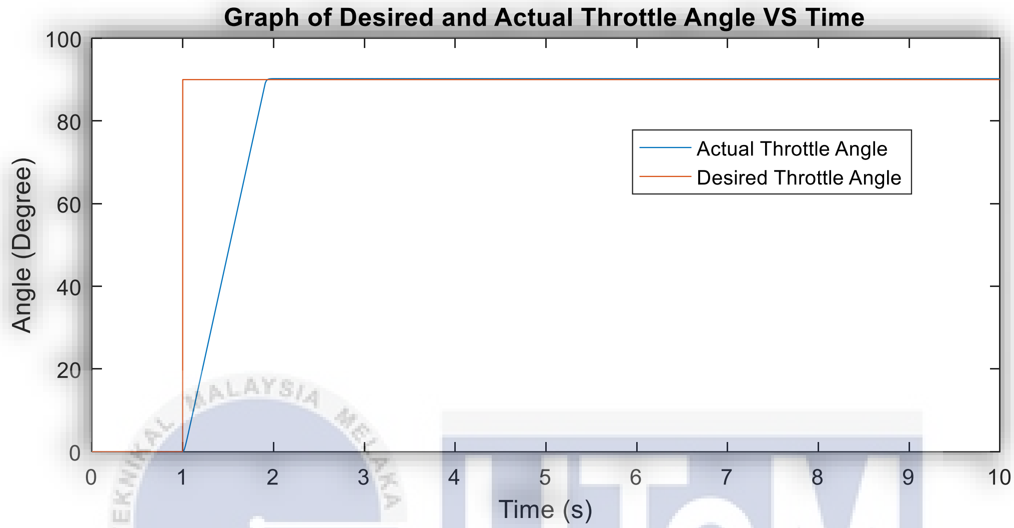


Figure 23(a): The graph of the response of throttle when I is change.

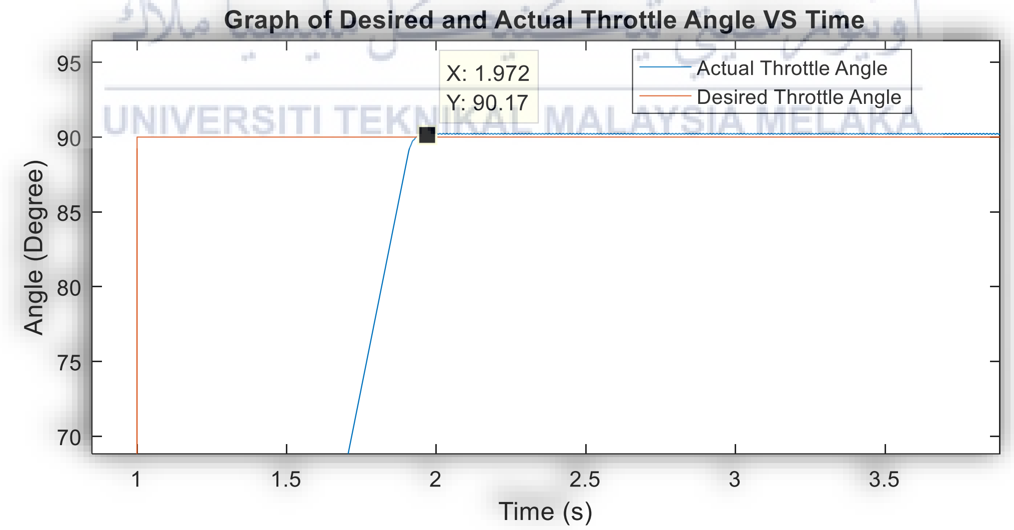


Figure 23(b): Close up from figure 23(a).

So, in determining the value of D, the same method is used with P and I is now set to be fixed at 350 and 2.8 respectively. For the D, the test is started at value of D is 5 and the increment for the next value is 5. After a few test, the most suitable value of D is 60.

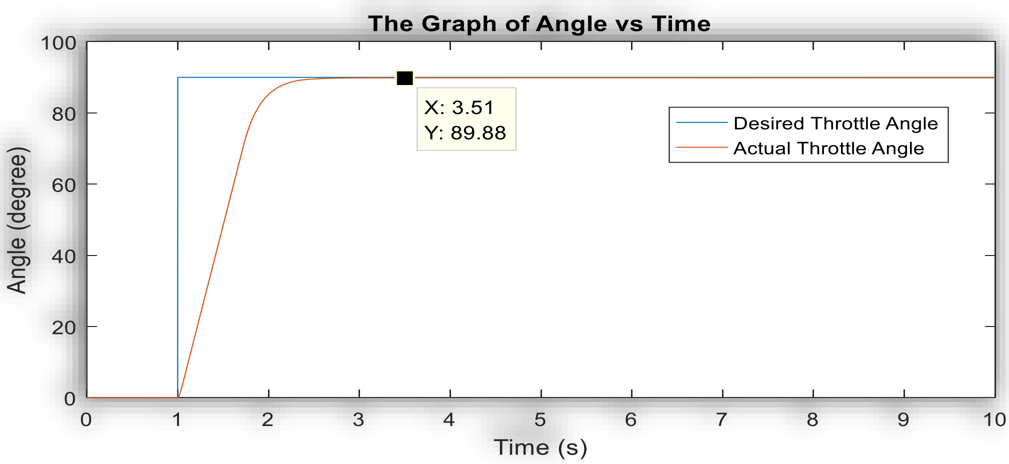


Figure 24(a): The graph of the response of throttle when D is change

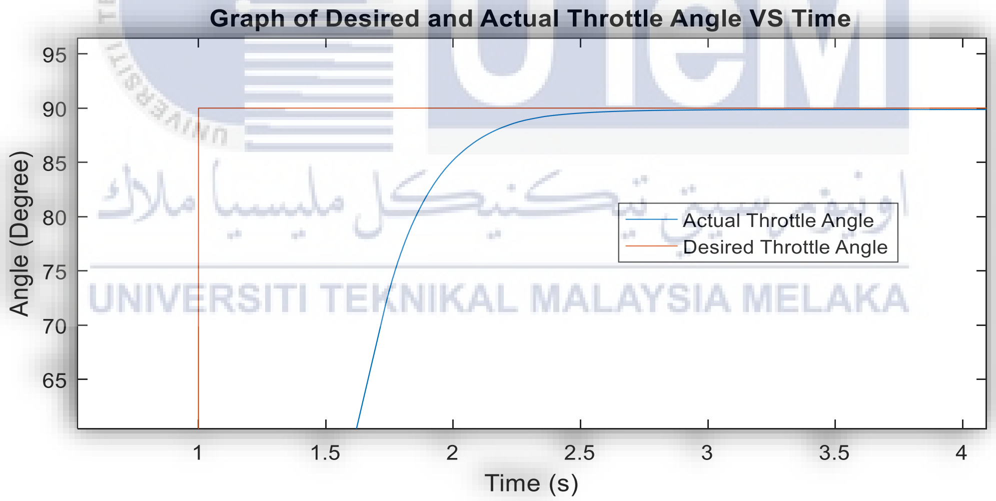


Figure 24(b): Close up from figure 24(a).

So, for this sensitivity analysis method that have been done, the value of the tuned PID for 90 degrees of throttle opening angle have been achieved. The value of P, I and D is 350, 2.8, and 60 respectively. From figure 24(a), it is shown that the steady state error of the actual throttle opening is slight lower than the desire throttle opening whereas the actual throttle opening is 89.88. from the graph, it also can be seen that the settling time for the actual is slower is to compare to the desired. This value of the tuned PID will be used in the Model Reference Adaptive Control.

3.6 Designing the Model Reference Adaptive Control PID

To design a controller with the MRAC control strategies, there two approaches that can be used which are MIT rule and Lyapunov theory. But the MIT rules will be used in this project. To start using this rules, a cost function is defined as,

$$J(\theta) = \frac{1}{2} {e_m}^2 \tag{19}$$

Where e is the error between the output of the plant and the model, and θ is the adjustable parameter. The control parameter in this project is k_p,$k_i$and k_d.Next, in order to find out on how to update the parameter θ, an equation is formed for the change in theta. To minimize the error, it is sensible to move toward the negative slope of J. Therefore, the differentiation of theta is equivalent to the negative change in J, that is

$$\frac{\delta(\theta)}{\delta t} = -\gamma \frac{\delta J}{\delta \theta} = -\gamma e_m \frac{\delta e_m}{\delta \theta} \tag{20}$$

Where , the partial derivative term $\frac{\delta e_m}{\delta \theta}$ is called the sensitivity derivative of the system. This term demonstrates how the error is changing regarding the parameter θ. While γ is the adaption gain of the controller. Next, MRAC is defining the tracking error, e_m. This is simply the different of the plant and the model. Assume that $y_m = 0$.

$$e_m = y_p - y_m \tag{21}$$

$$e_m = y_p \tag{22}$$

$$e_m = G_p . u . e \tag{23}$$

Where is u is the control parameter,

$$e_m = G_p . \theta . e \tag{24}$$

Then, differentiate equation (15) respect to θ and change the control parameter into it respective gain which are k_p , k_i , and k_d. Then will get,

$$\frac{\delta e_m}{\delta k_p} = G_p . e \tag{25}$$

$$\frac{\delta e_m}{\delta k_p} = \frac{G_p . e}{s} \tag{26}$$

$$\frac{\delta e_m}{\delta k_d} = G_p . e . s \tag{27}$$

Next is substitute equation (16), (17) and (18) into equation (11) and change the control parameter to its respective gains which are k_p , k_i , and k_d.

$$\frac{\delta k_p}{\delta t} = -\gamma . e_m . G_p . e \tag{28}$$

$$\frac{\delta k_i}{\delta t} = \frac{-\gamma . e_m . G_p . e}{s} \tag{29}$$

$$\frac{\delta k_p}{\delta t} = -\gamma . e_m . G_p . e . s \tag{30}$$

Therefore, the equations (28), (29) and (30) is the adjustment mechanism of the system where this component is used to alter the parameter of the controller so that plant model can track the references model.

Next step is to build the references model for the ETB system. The function of the model reference is to give the ideal response of the adaptive control system to the references model. Noted that the order of system for the ETB model is the first order system. To estimate the transfer function for this model, the System Identification Toolbox has been used in this project. The first step to use this toolbox is by entering 'ident' in the Matlab command window. Then, the System Identification Toolbox window will pop-up on the screen as shown in figure below.

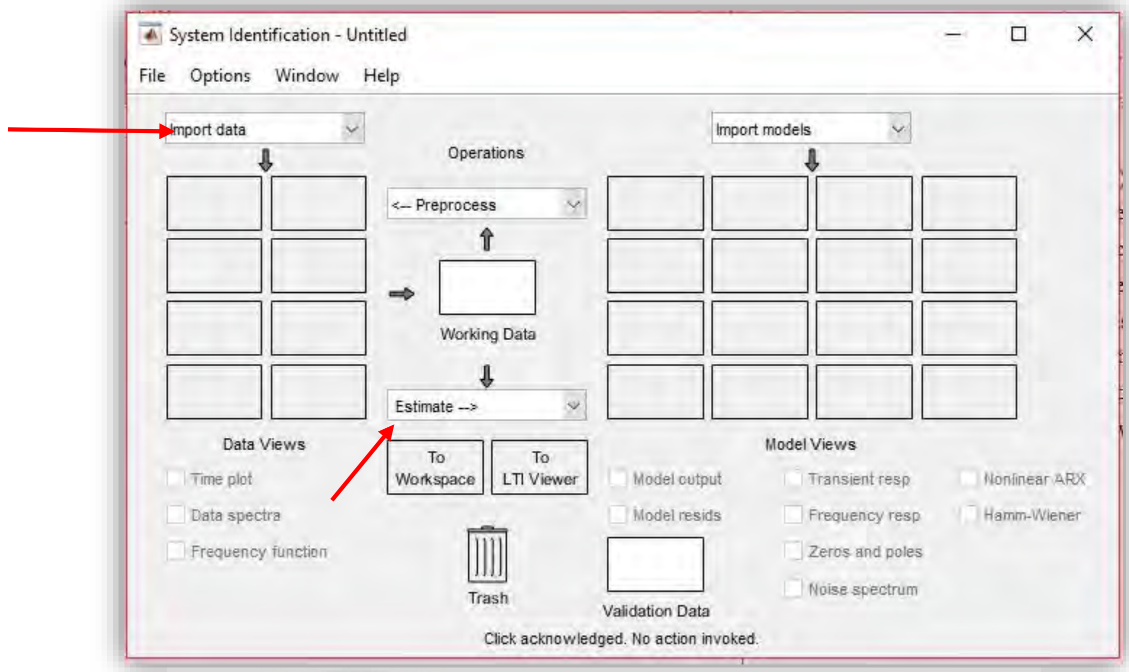


Figure 25: The system identification toolbox window.

To import the data in the toolbox, click on the 'Import data' and select the 'time domain data' as the data for this project is in the time domain and a window in the figure 25 will pop-up on the screen. Insert the theta desired data into the input and the actual theta into the output work space variable. Then click import to import the data into the toolbox.

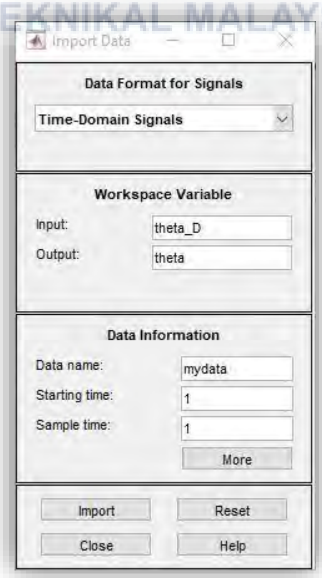


Figure 26: The import data window.

Then, click on the estimate and choose the 'Transfer Function Model'. Consider the ETB model is a system described by 1st order model ,$G(m) = \frac{K}{s+a}$. Set the number of poles and the number of zeroes of the transfer function to 1 and 0 respectively. Then click estimate. The model of the estimated transfer function is shown at the import model on the right of the system identification toolbox. To observed the transfer function, select the data that have been import and the estimated model, and then click the 'Model output'. A graph like in figure 26 will appears. The green line is the transfer function model.

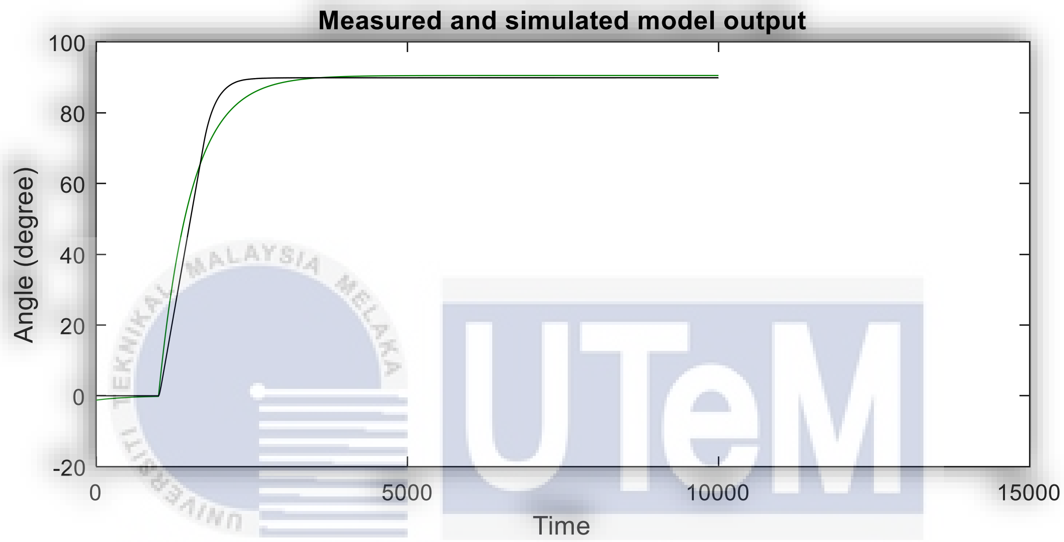


Figure 27: The transfer function model.

To get the value of K, s and a for the transfer function is by double clicking of the estimated model. The transfer function is,

$$G(m) = \frac{3.086}{s + 3.073} \tag{22}$$

But the transfer function model steady state error is slight higher compare to the desired input. So, in order to lower the steady state, a gain with 0.995 is put in front of the transfer function block.

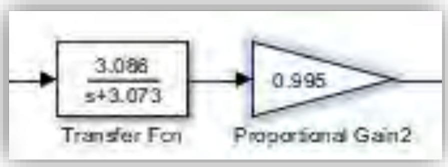


Figure 28: The transfer function block and gains block in Simulink.

For the next step is to model the equation (28), (29) and (30) into the Simulink. Like the previous method when modelling the ETB, open the Simulink library and chose the block diagram that will be used and then model equation (28) first. The equation (28) will look like,

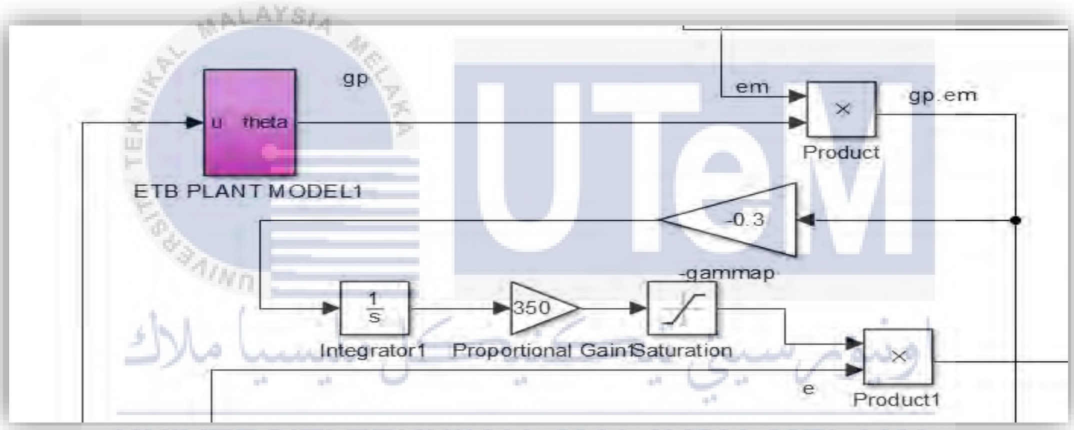


Figure 29: The model of equation (28).

From the figure above, there is a saturation block after the Proportional Gain block because the saturation block will limit the input signal to the upper and lower saturation values. So for the equation (28) the lower limit is set equal to 350. Then, the project is continued by model the equation (29).

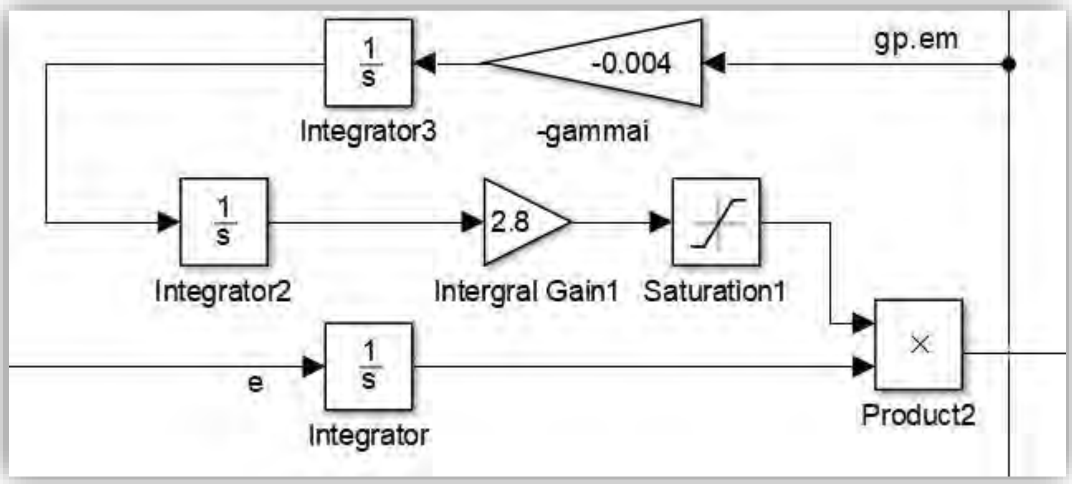


Figure 30: The model of equation (29).

The saturation in equation (29) is set at 2.8. Next is equation (30) is modelled in the Simulink. The procedure is the same and only need to follow equation (30). For the next step is, the product of the equation (28), (29) and (30) is sum up altogether then it will be the input of the ETB plant Model.

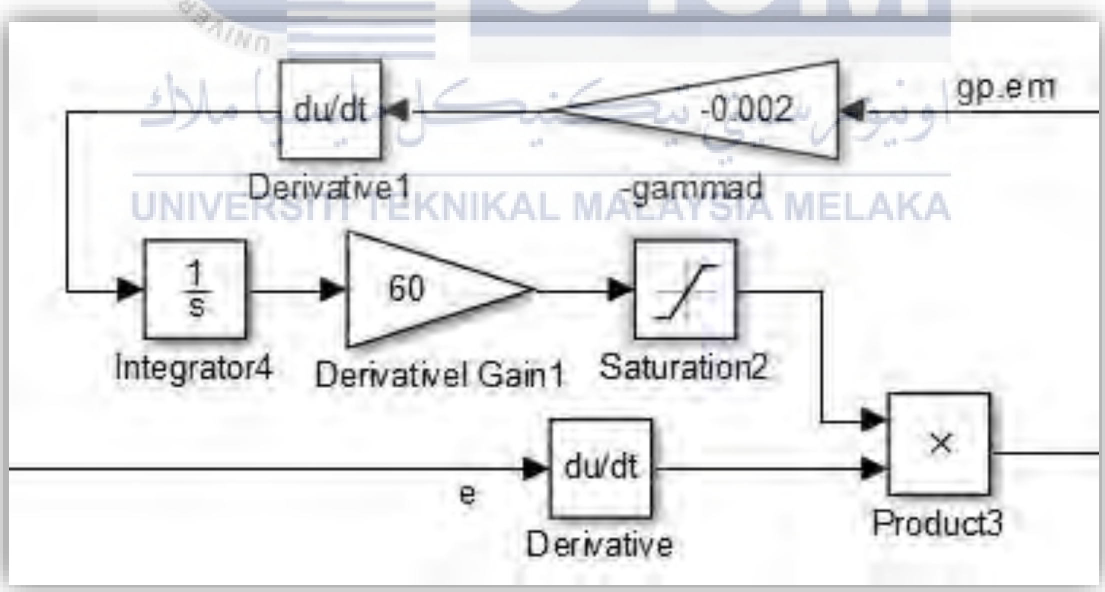


Figure 31: The model of equation (30).

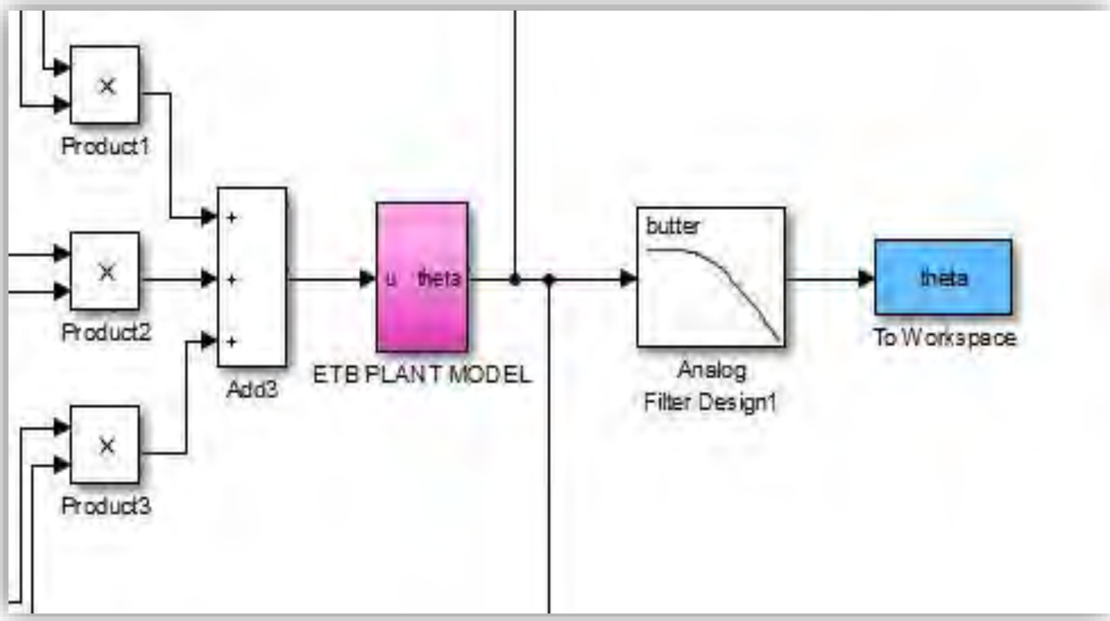


Figure 32: Sum of the three products.

The insertion of the analog filter in the control structure (ETB model with MRAC) is to remove the noise in the result. The next thing to do is to determine the adaption gain for proportional, integral and the derivative. First, change the adaption for the proportional, γ_p and observed the graph. Find any effect on the graph when changing the γ_p . When the γ_p have been determined, changed the γ_i next until get the satisfy result. Then, change the γ_d to effect the time response of the throttle angle. If the result is still not satisfying, change any adaption gain so that the result is close to the references model. Finally, the ETB model with the MRAC control scheme have been finished. The full control structure located in the APPENDIX.

Table 3: The adaption gain, γ.

Adaption Gain, γ	**Value**
γ_p	-0.3
γ_i	-0.004
γ_d	-0.002

The next step is to run the simulation. Set the step input to 90 and click run. Then type ‘plot (T, theta_D, T, theta, T, theta1) in Matlab command window to plot the graph. Repeat the simulation for throttle opening angle of 30,45, 60 and 75. The result and the discussion will be discussing in the next chapter.

3.7 Summary

In this chapter, the Electronic Throttle Body (ETB) model with Model Reference Adaptive Control (MRAC) is proposed. The consideration of designing and overview of analysis for the control structure is summarized in this chapter. The opening angle of the throttle body was simulated in term of control parameter.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

On this chapter, the result for the simulation that have been carried out throughout this project will be discussed. The simulation that have been done is to gain the information about the performance of the ETB when the MRAC PID is applied to it. So, in order to do, the result for ETB with the Tuned PID is compared to the ETB with the MRAC PID for the 90 degree of throttle opening angle. Next, to monitor the effect of the MRAC PID to other angle, it will be compared to the untuned PID. The untuned PID is used for the 30, 45, 60 and 70 degrees as the value of PID for 90 degrees is as the references. The value of proportional, integral and derivative gain is 350, 2.8 and 60 respectively.

4.2 Throttle Opening Angle of 30 Degrees

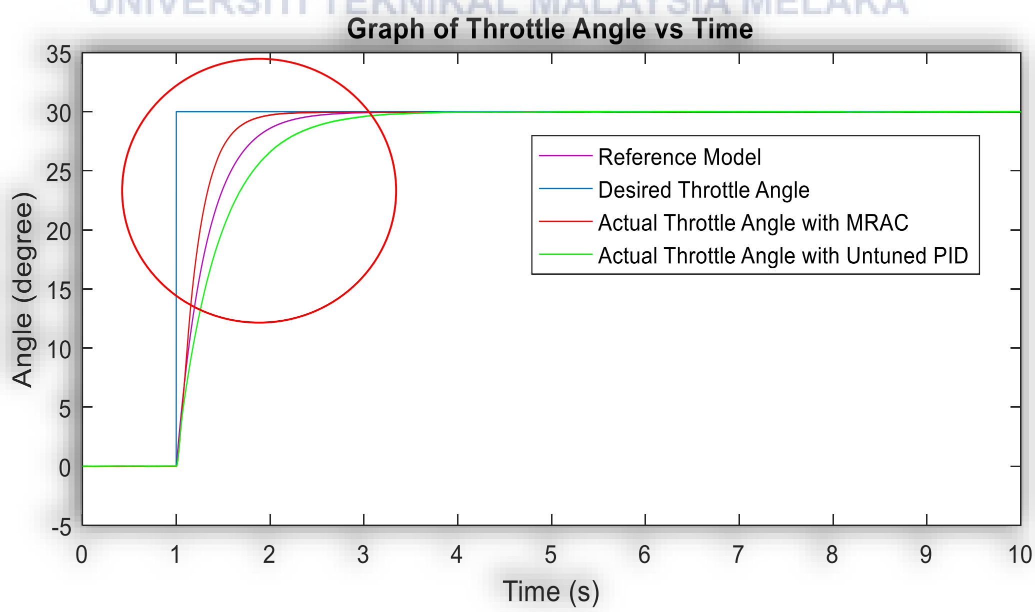


Figure 33: The comparison between the throttle angle for 30 degrees.

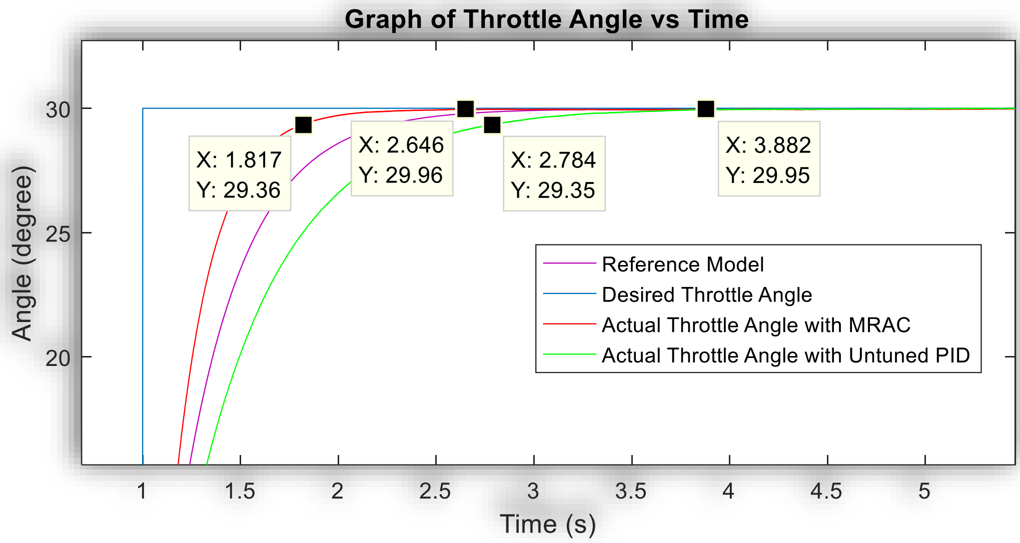


Figure 34: The zoom in the red circle at figure 33.

From both of the graph above, the performance of the ETB can be observed by the settling time, T_s and the steady state error. First is to analyse the steady state error. For the ETB model with the MRAC PID controller, the steady state error is at 29.96 degrees while the ETB model with the untuned PID is at 29.95. Both of the steady state error is not equal to the desired angle but with MRAC PID, it is closer compare to the conventional PID.

Next is to observed the T_s of both graph. When using the MRAC PID controller, it takes only 1.817 s to settle. But, for the ETB with the conventional PID, it took longer time to settle where it need 2.784 s. The different of the settling time of both graph is 0.967 s. Clearly that the performance of the ETB with MRAC PID is much better compare to the performance of the ETB with the conventional PID.

4.3 Throttle Opening Angle of 45 Degrees

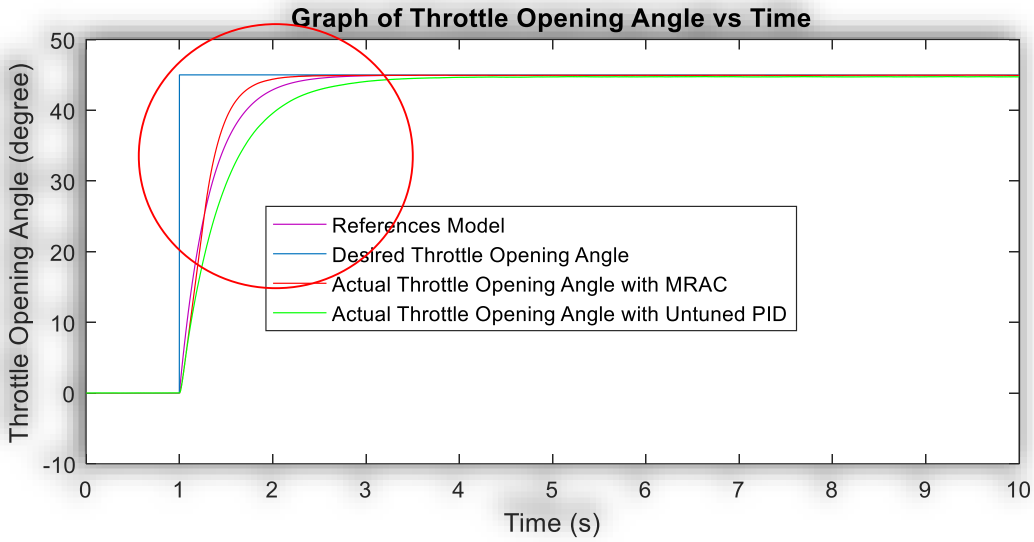


Figure 35: The comparison between the throttle angle for 45 degrees.

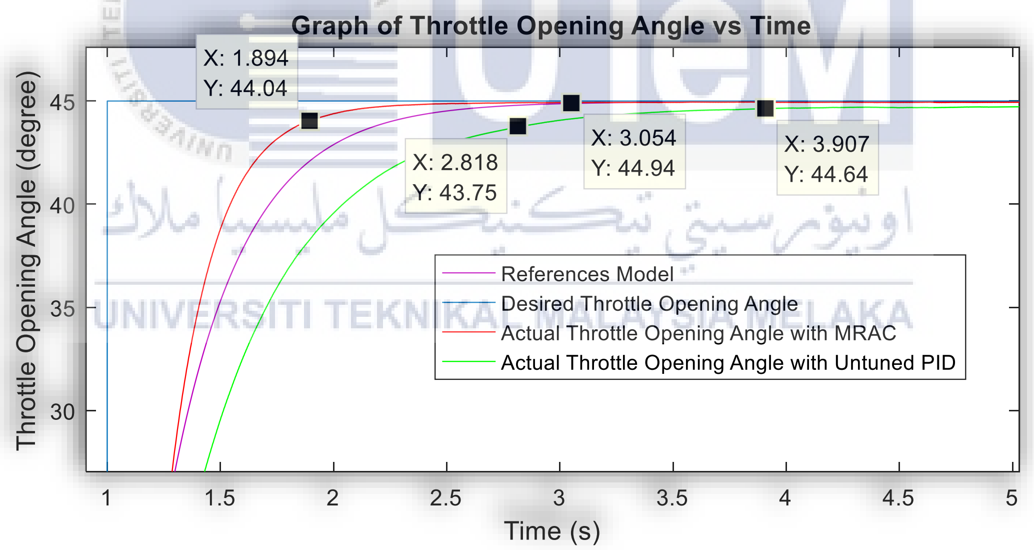


Figure 36: The zoom in the red circle at figure 35.

From figure 32 and 33, it can be seen that there is quite a different response between the ETB model with the MRAC PID controller and the ETB model with the conventional PID. The performance of the ETB for the 45 degrees of the throttle angle can be evaluated by describing the settling time, T_s and its steady state error.

The red line describes the response of the ETB with the MRAC PID. As shown in figure 33, the settling time, T_s is 1.8494 s. That means the ETB with MRAC PID took only 1.8494 seconds before it settled. On the other hand, the result for the conventional PID is a bit slower compared to the MRAC PID. The settling time for the conventional PID is 2.818 seconds. The different of time is 0.9686 seconds.

Next is the comparison of steady state error. First is the steady state error of the ETB model with the MRAC PID where the value is 44.94 degrees. Even though, final value did not achieve the desire input but the value is close enough. For the ETB with conventional PID, the value of the steady state error is 44.64 degree. The different is larger when compare to the desired input. Therefore, the performance of the ETB with the MRAC PID is much better compare to the ETB with the conventional PID.

4.4 Throttle Opening Angle of 60 Degrees

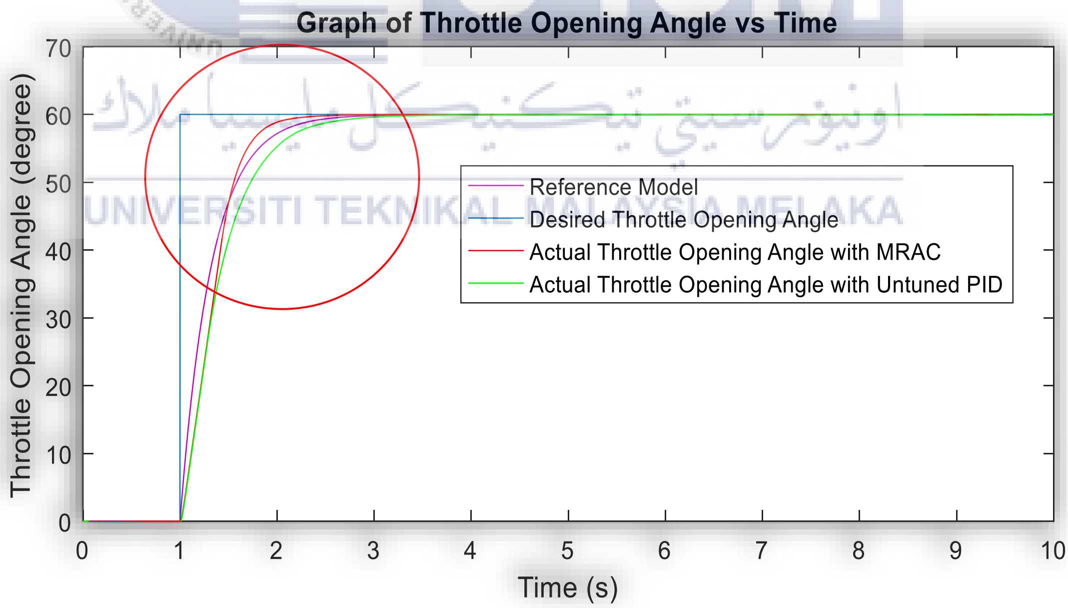


Figure 37: The comparison between the throttle angle for 60 degrees.

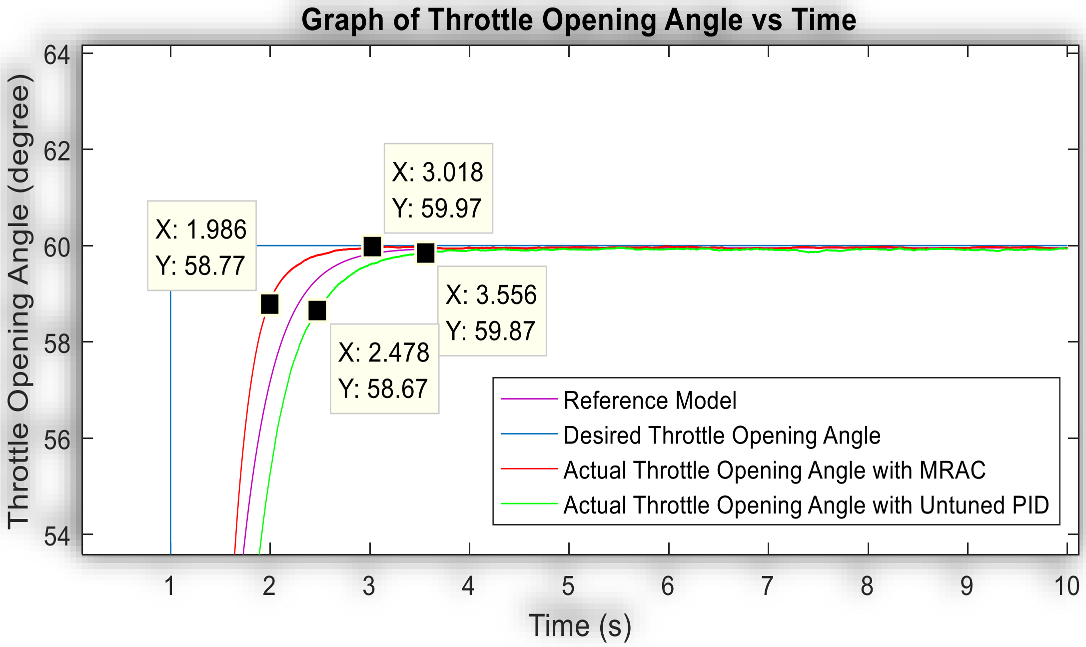


Figure 38: The zoom in the red circle at figure 37.

From both of the graph above, it can describe the performance of the ETB by reviewing the steady state error and the settling time, T_s . For the steady state error, the final value of the graph is taken. The ETB with the MRAC PID have the steady state error of 59.97 degrees. The value is 0.03 degree different from the desired input. While 59.87 degree is the value for the ETB model using conventional PID. The steady state error for the MRAC PID is higher compare to the conventional PID.

Meanwhile, for the settling time, T_s, the ETB with MRAC PID use mainly 1.986 second to settle. The settling time is the time for the graph to reach 98% of the final value. However, the time taken for the ETB using the conventional PID to settle is 2.478 second. In contrast, the conventional PID is much slower if being compare to the MRIC PID. As the conclusion, the MRAC PID give a better performance than the conventional PID for the 60 degree throttle angle.

4.5 Throttle Opening Angle of 75 Degrees

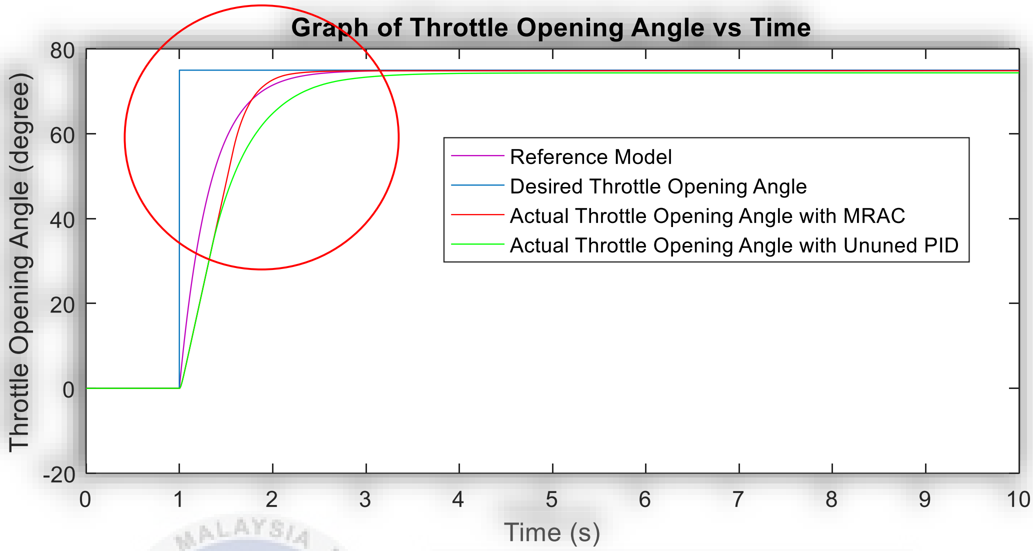


Figure 39: The comparison between the throttle angle for 75 degrees.

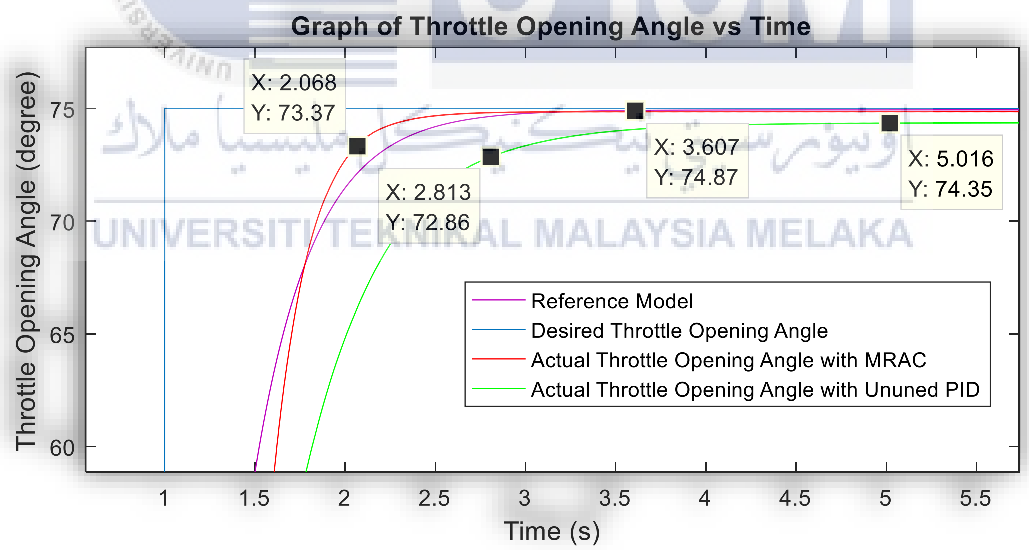


Figure 40: The zoom in the red circle at figure 39.

In order to determine which of the ETB that performed better, the analysis have been done on the steady state error and the settling time, T_S. First, the steady state error for the ETB with MRAC PID is 74.87 degree even though desired input need 75 degree. For the conventional PID, the steady state error is lower that the MRAC PID. The value of the steady state error is 74.35 degree. The different from the desired input is 0.65 degree.

After that, the settling time for both ETB with MRAC PID and conventional PID is analyse and compare. As show in figure 37, the settling time, T_s for the result with MRAC PID is 2.068 seconds. But for the ETB with conventional PID, the time taken for its to settle is 2.813 seconds. This mean that the ETB that using conventional PID move 0.745 second slower than the ETB with the MRAC PID. Therefore, it clearly proves that the MRAC PID have a better performance.

4.6 Throttle Opening Angle of 90 Degrees

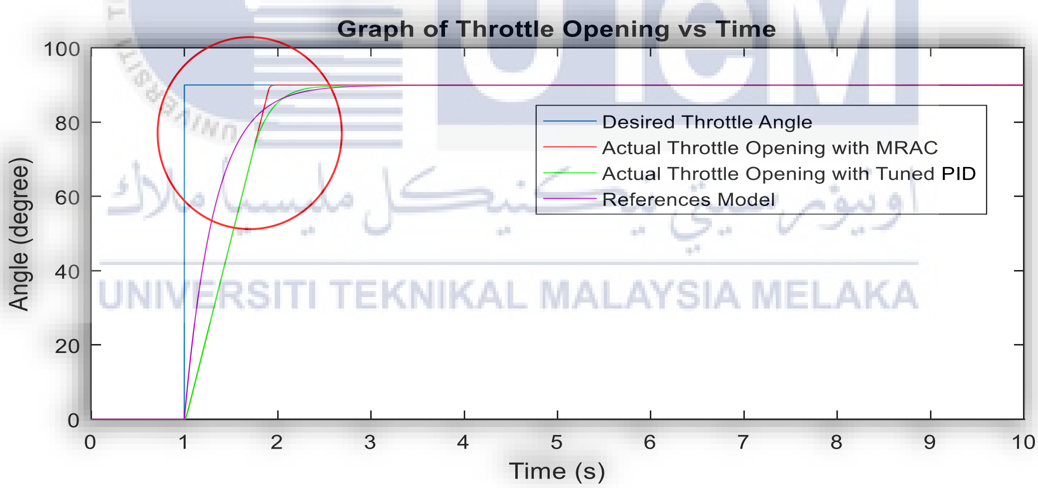


Figure 41: The comparison between the throttle angle for 90 degrees.

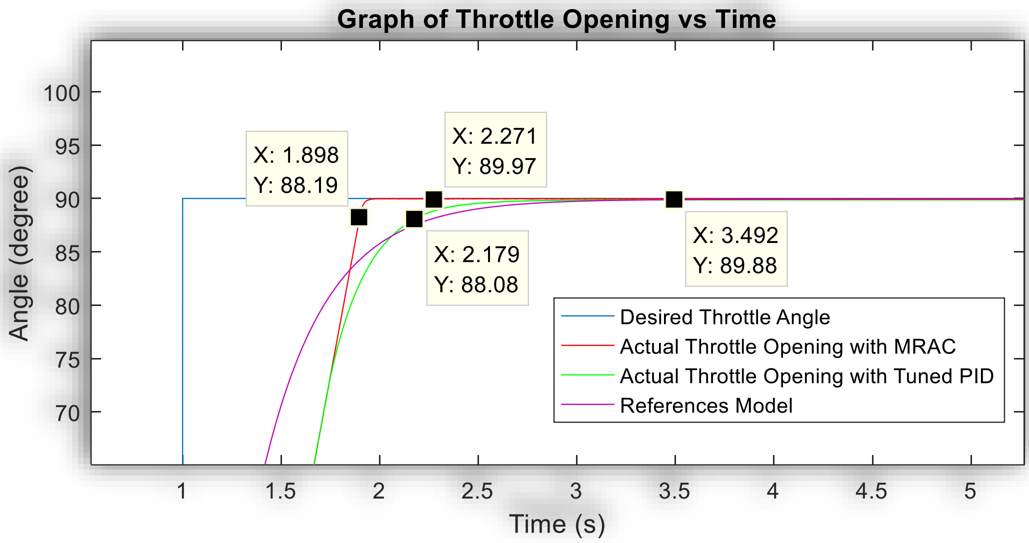


Figure 42: The zoom in the red circle at figure 43.

For 90 degree of throttle opening angle, the value of PID have been tuned and the value being used to other angle. To find which of the ETB produce a better performance , the analyse being done on the settling time, T_s and the steady state error of the graph. As shown in the figure above, the settling time, T_s for the MRIC PID is 1.898 seconds while the conventional PID took 2.179 seconds to settle. It means that the conventional PID delay 0.281 seconds from the MRIC PID.

Next is to analyse the steady state error of both MRIC PID and the conventional PID. For the MRAC PID, the value of it steady state error is 89.97 degree where is only short 0.03 degree from the desired input. But for the conventional PID, it has the steady state error of 89.88 degree. The MRAC PID have higher steady state error compare to the conventional PID. Therefore, the performance of the MRAC PID is higher compared to the conventional PID.

CHAPTER 5

CONCLUSION AND SUGGESTION

5.1 Conclusion

After two semesters of work, this project had been completed in the time given. An Electronic Throttle Body (ETB) model with a Model Reference Adaptive Control (MRAC) PID controller had been design from the draft of paper. Then, it followed by the simulation to observed the performance of the throttle body.

In order to design the ETB model in Matlab/Simulink software, the basic concept and theories need to be study in detail. The ETB is the devices that control the ratio of the air fuel that enter the combustion chamber. It controls the ratio by adjusting the valve plate that place inside the throttle body.

In this project, the first objective is to develop an ETB model in Matlab/Simulink. This objective has been achieved in the first semester of this project where the model is being develop by using the model provided by [pan]. The reason of using this model because there is not many research using this model compare to model which using a simple transfer function. The second objective being complete when the MRAC PID controller is design and applied into the ETB model in the Matlab/Simulink. The design of the MRAC is using the MIT rule. Then the complete control structure is used to obtain the desired throttle angle. The last objective is accomplished when the result for the MRAC PID and the conventional PID being discuss in the previous chapter.

For the conclusion, all of the objective is achieved. The value of the tuned PID using in this project is 350, 2.8 and 60. From the result, it is clearly shown that the performance of the ETB with the MRAC PID is better compare to the ETB using the conventional PID. Therefore, the project is successfully complete as all the objective is accomplished.

5.2 Suggestion

After develop this project, there are many things that have being learn about the Electronic Throttle Body and the controller. There many modifications that can be make for the future study.

First is to change the method of designing the MRAC PID. As have been mention before, there two approach in order to build the MRAC. The first one is MIT rule and the second is the Lypunov function. Hopefully, there a research on the ETB performance when using the MRAC PID with Lypunov approach.

Lastly, the other recommendation is that to change the control method. Besides MRAC, there are other control method such as non-linear, sliding mode and variable structure. Each of the method have different robustness so it has different effect on the performance of the ETB.

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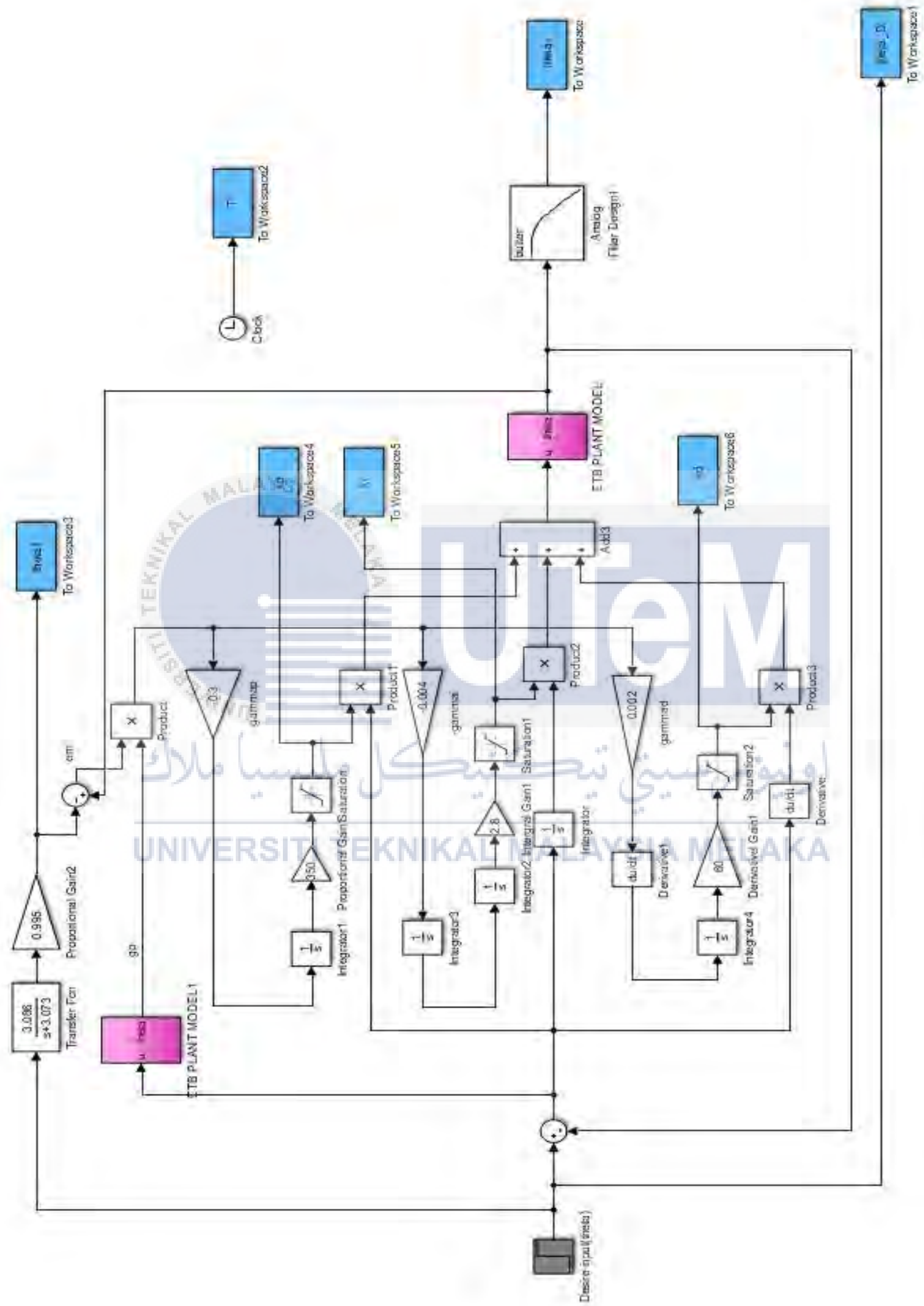
APPENDICES

a. The Full Model of MRAC PID for ETB model in Simulink



b. The ETB model in Simulink