ELECTRONIC CONTROL UNIT (ECU) DEVELOPMENTOF A FUEL INJECTION SYSTEM

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical – Mechatronic and Automatic Control)

Faculty of Electrical Engineering
University Teknologi Malaysia

JUNE 2013

To my beloved parents and family.

ACKNOWLEDGEMENT

First of all, I would like to express my deepest gratitude to my supervisor, Dr Hazlina Binti Selamat, for her moral support, guidance, and the willingness to supervise this project. She has provided me with her valuable advice and suggestion so that I can follow the right track in performing all necessary tasks and complete the project as well. Besides, she also acts as language supervisor to check on my documentation. I believe that without her assistance, my project will not be able to operate smoothly and complete on time.

I am also indebted to librarians for their assistance in supplying the relevant literatures. My sincere appreciation also extends to my friends who have provided assistance at various occasions. Their views and tips are useful indeed. Finally, I would like to thank my family, husband, son and daughters for their encouragement and support who had helped me go through all the difficulties that I faced throughout my project.

ABSTRACT

In order to meet the limits imposed on automotive emissions, engine control systems are required to constrain air/fuel ratio (AFR) in a narrow band around the stoichiometric value, due to the strong decay of catalyst efficiency in case of rich or lean mixture. This project focuses on the design and development of a control system to reduce the waste of automotive exhaust emission. A model of a sample sparks ignition engine and Simulink's capabilities to model an internal combustion engine from the throttle to the crankshaft output are demonstrated based on analytical engine models that clearly describe engine's air and fuel dynamic with no loss of engine system performance. Various mathematical models for the air to fuel ratio and control for spark ignition (SI) engines have been proposed to satisfy technical specifications. On this paper the mean value model and a simple effective linear engine model is used to get the value of air to fuel ratio. The controller is designed by using PID tuning method and FLC to develop for the engine dynamics model in order to target the desired output response. Simulation results demonstrate that better performance can be achieved with PID controller than FLC. The actual response specification with PID controller and FLC matched the desired response specifications.

ABSTRAK

Dalam usaha untuk memenuhi had yang dikenakan ke atas pengeluaran automotif, sistem kawalan enjin yang diperlukan untuk mengekang nisbah udara atau bahan api (AFR) dalam jalur yang sempit di sekitar nilai stoikiometri, kerana kerosakan yang kukuh kecekapan pemangkin dalam kes campuran "rich" atau "lean". Projek ini memberi tumpuan kepada reka bentuk dan pembangunan sistem kawalan untuk mengurangkan sisa pelepasan ekzos automotif. Satu sampel model percikan penyalaan enjin dan keupayaan dalam Simulink untuk model enjin pembakaran dalaman dari pengeluaran pendikit crankshaft yang ditunjukkan berdasarkan model enjin analisis yang jelas menggambarkan udara enjin dan bahan api yang dinamik tanpa kehilangan prestasi sistem enjin. Pelbagai model matematik untuk AFR dan kawalan untuk mencetuskan pencucuhan (SI) enjin telah dicadangkan untuk memenuhi spesifikasi teknikal. Di dalam projek ini mean value model dan model enjin linear yang mudah telah gunakan untuk mendapatkan nilai nisbah AFR. Model ini direka dengan menggunakan kaedah penalaan PID dan FLC untuk dibangunkan untuk model enjin dinamik untuk mensasarkan sambutan keluaran yang dikehendaki. Simulasi keputusan menunjukkan bahawa prestasi yang lebih baik boleh dicapai dengan menggunakan pengawal PID berbanding dengan FLC. Spesifikasi sambutan sebenar dengan PID dan FLC dipadankan spesifikasi tindak balas yang dikehendaki.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AFR	-	Air Fuel Ratio
FLC	-	Fuzzy Logic Control
CO	-	carbon monoxide
HC	-	Hydrocarbons
NOx	-	Nitrogen Oxides
PID	-	Proportional Integral Differentiator
PI	-	Proportional Integral
PD	-	Proportional Differentiator
e	-	system error
ECU	-	Electronic control units
TWC	-	Three way catalytic
EGR	-	Exhaust gas recirculation
DBW	-	Drive-by wire
MVE	-	Mean Value Engine
RBF	-	Radial basis function
MPC	-	Model predictive Control
SI	-	Spark Ignition
IC	-	Internal combustion
AFFC	-	Adaptive Feed Forward Controller
APC	-	Adaptive Posicast Controller
FCS	-	Fuzzy Control system
RPM	-	Revolutions Per Minute

LIST OF SYMBOLS

m_a	-	mass rate of air in the intake manifold
m_a	-	mass of air in the intake manifold
m_{ai}	-	mass rate air entering the intake manifold
m_{ao}	-	mass rate of air leaving the intake manifold and entering the combustion
MAX	-	the maximum flow rate corresponding to full open throttle
TC	-	Normalized throttle characteristic
PRI	-	Normalized pressure influence function
α	-	the throttle angle
P_m	-	intake manifold pressure
P_{atm}	-	atmosphere pressure
M_a	-	constant value
R	-	gas constant
T_m	-	gas temperature
V_m	-	intake manifold volume
ω_e	-	engine angular velocity
η_{vol}	-	volumetric efficiency
m_{fi}	-	fuel rate entering the combustion chamber
m_{fc}	-	command fuel rate
τ_f	-	effective fueling time constant
β	-	desired air fuel ratio
Δt_{it}	-	intake to torque production delay
Δt_{ct}	-	compression to torque production delay
AFI	-	normalized air fuel ratio influence function

CI	-	normalized compression influence function
c_T	-	the maximum torque production capacity of an engine given that *AFI*=*CI*=1
A/F	-	actual air fuel ratio of the mixture in the combustion chamber
CA	-	tuning parameter of cylinder advance at the Top Dead Center
MTB	-	minimum tuning such that best torque acquire
I_e	-	effective inertia of the engine
T_i	-	engine indicated torque
T_f	-	engine friction torque
T_a	-	accessories torque
J_{LQ}	-	Cost function
P^r	-	Ricatti gain
x	-	expected states

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the problem

“The Engine Control Unit (ECU) is the main controller in most of the new engine. Speed, temperature, pressure and pilot throttle are used to be the input of ECU (Engine Control Unit) to ensure the required fuel flow for the given set of inputs.” [1] .Engine Control Units control the operating parameters, to make sure that the engine gets proper inputs. Advanced micro-processors and comprehensive software used to help increase the engine life and ensure safety. ECU is a globalization in engine technology and growing new markets, as well as increasing emission and fuel consumption requirements, which is beneficial to the vehicle manufacturers and their supplier to develop new engine control strategies in shorter time periods.

According to this statement, the Engine Control Unit (ECU) can disrupt as a “closed-loop control, a control scheme that monitors the outputs of a system to control the inputs to a system, to manage the emissions and fuel economy of the engine (as well as a host of other parameters)”. [2]

Electronic control unit (ECU) development is the process of an electronic device, basically a computer, in an internal combustion engine that reads several sensors in the engine and uses the information to control the fuel injection and ignition systems of the engine.

Fuel injection is a representation of a system for introducing atomized liquid fuel under pressure directly into the combustion chambers of an internal-combustion engine without the use of a carburetor. The simulation is mainly used in this project is the main tool to determine the quantity of fuel to inject based on a number of parameters.

Before this topic is discussed in further, it is precise that air is an important factor in life, but with the increasing development of cities and industrial centers, air quality has changed. Before this, the air is fresh and now the qualities of air are dry and dirty. This change is due to the entry of pollutants into the air.

On 25 January 2002, the Minister of Health announced that 340,000 children in the country, has been suffering from asthma are thought to stem from exposure to toxic agents in the environment. During the press conference the World Health Organization (WHO) 3/3/2002 pad, at the international conference on environmental threats to children's health in Bangkok to inform you that at least 3 million children under the age of 5 die each year from exposure against agents of environmental contamination. [9]

An important motivation behind this study is that automatic control of internal combustion engines leads to several benefits such as a reduction in emissions, improvement in fuel efficiency, and power delivery. Perhaps the most significant benefit is an emission reduction especially when it comes to developing countries like Malaysia.

The transportation sector is one of the important sectors that drive the country's economy. Statistic from Malaysia Department of Transport shows that from 2005 until March 2011, the total number of vehicles registered is 21.2 million. These numbers will definitely increase in the coming years. The presence of these vehicles bring along the problem of air pollution because of the incomplete combustion by product that is emitted from the engine exhaust pipe such as Carbon monoxide (CO), Hydrocarbons (HC), Nitrogen Oxides (NOX) and particulate emission.

Air pollutant sources in Malaysia can be classified under four main sectors; motor vehicles, power stations, industries and other sources like open burning and trans-boundary sources [3]. The latest Malaysia environmental quality report by the Department of Environment reported that the emissions load from all sources has increased in year 2005 than 20011 as shown in Figure 1.1. If not have any action to prevent this situation, it's becoming more serious because of the emissions effect day till days. It's such silent death to the human and environmental. Although Malaysia has a good environment to stabilize the pollutant but it has reached a critical level as witnessed during the recent haze crisis [4] because of the effects to the public and the environment.

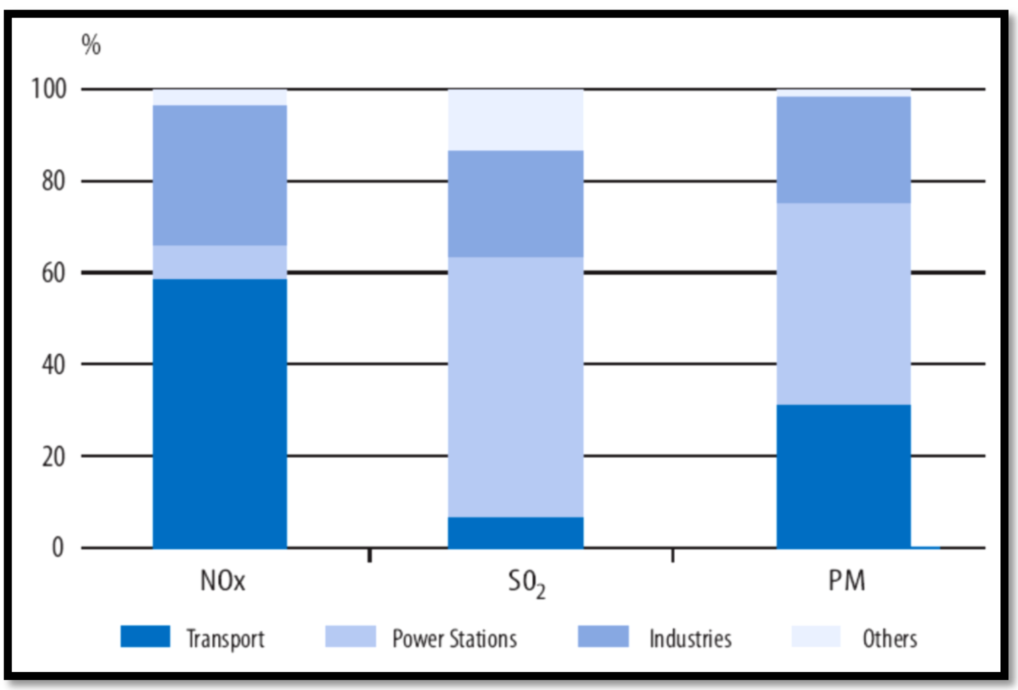

Figure 1.1 : Air pollutant emission load from all sources, 2005-2011. [5]

Among all types of vehicles, motorcycle became the largest contributor of the pollutants. In Malaysia, statistics have shown that nearly five million units or over half of the motor vehicle in Malaysia are motorcycles. These are mostly small capacity, two or four – stroke engine motorcycles owned by the lower income group. The Malaysian government has been very pro-active in attempting to control vehicle emission pollution. Measured steps such as phases out of existing two-stroke motorcycle and new models have to comply with emissions regulations in the future. Besides, several actions have been taken to support the use of clean fuels and natural gas vehicles, namely incentive policies, mandates, financial support for research and development of vehicle emission standards.

There are different control methods available for reducing pollutant components, such as control of engine speed, engine torque, fuel injection timing, AFR and so on. Among all, control of AFR is related to fuel efficiency, emission reduction and drivability improvement, furthermore maintaining AFR at stoichiometries level can obtain the best balance between power output and fuel consumption [6]. Control of AFR also guarantees a reduction of pollutant emission to the atmosphere since the variation of AFR greater than 1% below 14.7 can result in a significant increase of CO and HC emission. An increase of more than 1% will produce more NOx up to 50% [7].

Progression of the European Union emission standards for PETROL cars as shown in Figure 1.2. It shows that the allowable nitrogen oxide emission was reduced from 0.9 g/km in the year 1992 to less than 0.1 g/km in the year 2008. Emission legislation Euro II at year 1996 shows limits on allowable vehicle NOx emission, which reduce to less than 0.5 g /km, and thus, has been achieved through the application of higher injection pressure to result in low particulate emission and retarded injection. Therefore, the environmental standards were calling for more efficient and accurate engine management systems in order to meet legislative requirements. As a result of these higher environmental standards and the need for increased performance, the designers were forced to use new technology.

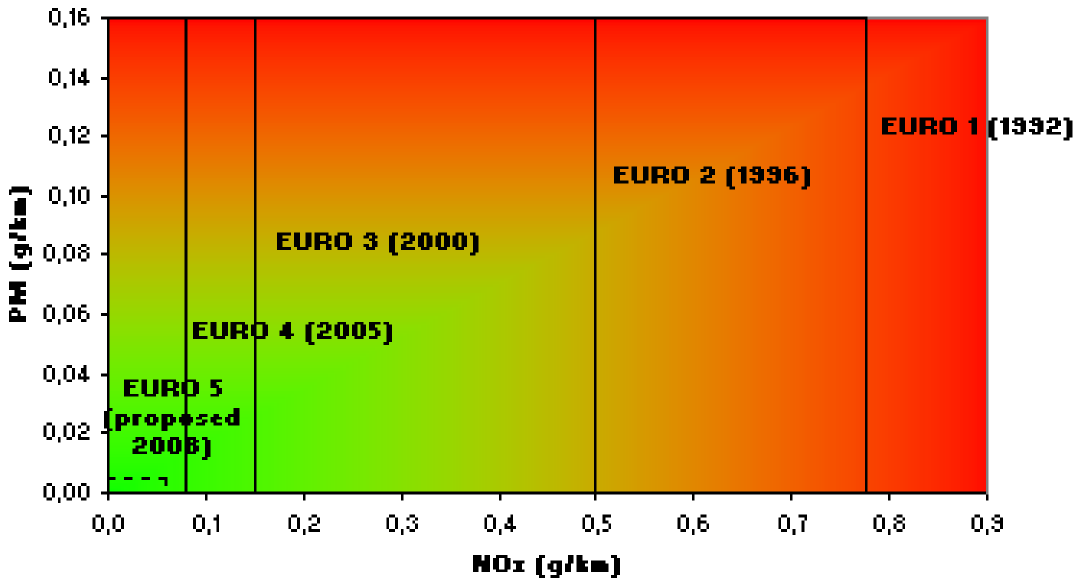

Figure 1.2 : Progression of the European Union emission standards for PETROL cars

The engine-out pollutant emission of SI engines (mainly hydrocarbon (HC), carbon monoxide (CO) and nitrogen oxide (NOx) greatly exceed the levels mandated by most regulatory boards, and future emission legislation will require substantial additional reductions of pollutant emission levels. These requirements can only be satisfied if appropriate exhaust gas after treatment systems are used.

The key to clean SI engines is a three-way catalytic converter (TWC) system whose stationary conversion efficiency is depicted in Figure 1.3. The fundamental reaction in 3-way catalyst is between CO, HC and NOx. Only for a very narrow air/fuel ratio “window,” whose mean value is slightly below the stoichiometries level, can all three pollutant species present in the exhaust gas be almost completely converted to the innocuous components water and carbon dioxide. In particular, when the engine runs under lean conditions, the reduction of nitrogen oxide stops almost completely, because the now abundant free oxygen in the exhaust gas is used to oxidize the unburned hydrocarbon and the carbon monoxide. Only when the engine runs under rich conditions, do the unburned hydrocarbon (HC) and the carbon monoxide (CO) act as agents reducing the nitrogen oxide on the catalyst, thereby causing the desired TWC behavior.

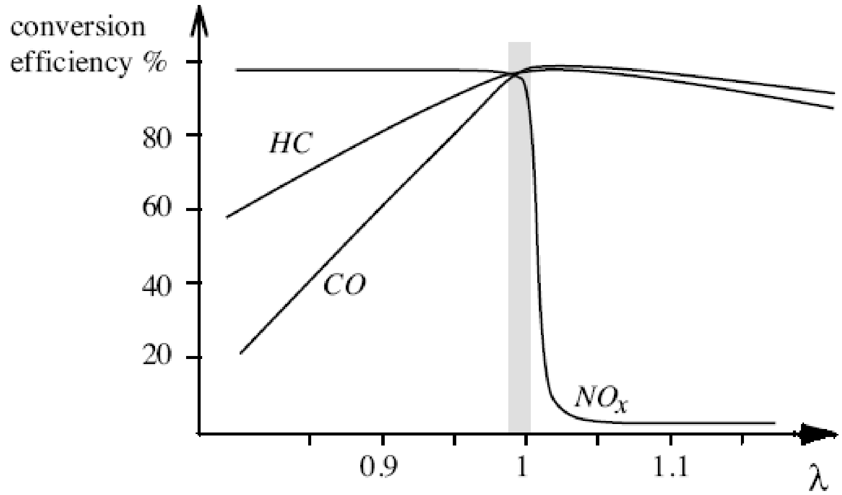

Figure 1.3 : Conversion efficiency of a TWC due to engine lambda or air to fuel ratio 14.7 [8].

However, there is no way both of the components can meet stoichiometric ratio all the time, since concentrations of pollutants in the exhaust gas are highly depend on the fuel mixture composition. For example, at lean fuel mixtures the exhaust gases contain little carbon monoxide and hydrocarbons but high concentrations of NOx. On the other hand, at rich fuel mixtures the exhaust gas contains high concentrations of carbon monoxide and hydrocarbons but low concentration of NOx. Therefore, amount of engine's fuel injection should be controlled in such a way so that engine's air fuel ratio (AFR) is at the stoichiometric value of 14.7 and achieve full conversion of pollutant components as shown in Figure 1.3.

1.2 Background of the Study

The model of the engine is transferred into simulation and suitable controller are applied in an engine's system such that engine's AFR can be maintained in stoichiometric range, which will make in high conversion efficiency of pollutant components

The simplified engine are used that consists for three subsystem which are the manifold subsystem, the fuel supply subsystem and the crank shaft subsystem as shown in Figure 1.4. The model has a modular structure and can easily be adapted to other engines.

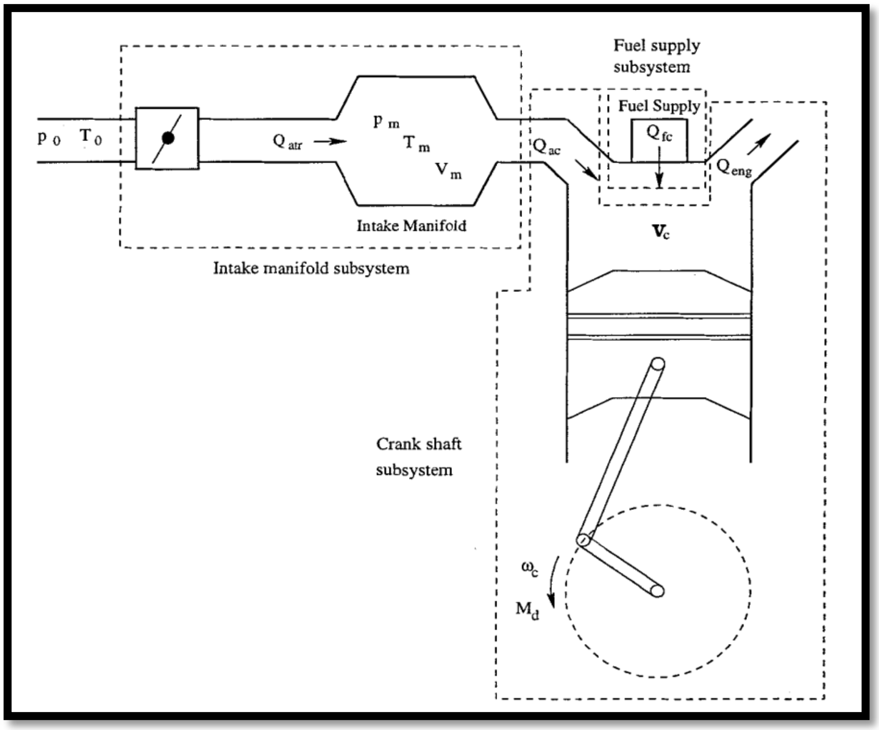

Figure 1.4: Schematic view of a spark ignition engine and the subsystems

The intake manifold is the part of the air filter to the cylinder inlet valves. In this model the air filter is not taken into account, so the manifold subsystem consists of the throttle body, plenum and plenum runners. The function of the plenum is to realize a reasonably constant pressure in stationary situations.

The model of the subsystem relates the pressure *pm* between the throttle valve and the cylinder ports to the flow through the throttle and the flow into the cylinders. This pressure and the temperature *Tm*, are supposed to be the same everywhere in the manifold. *Tm*, is supposed to be constant. The manifold is modeled as a rigid volume *Vm*, with an input air mass flow *Qatr* and an output air mass flow *Qac*. The gas in the manifold is assumed to behave as an ideal gas.

The state equation for the intake manifold can be derived with the law of conservation of mass and the ideal gas law [12], is

$$pm = \frac{RaTm}{Vm}(Qatr - Qac) \quad (1)$$

Here ,pm is the time derivative of *pm* and *Ra* is the specific gas constant of air.

The crankshaft speed is derived based on the conservation of the rotational energy on the crankshaft.

$$n = -\frac{1}{n}\ Pf\ \ pm,n\ \ + Pp\ \ pm,n\ \ + Pb\ \ n\ \ \ + \frac{1}{n}Hu\eta(Pm\iota,n,\lambda)mf(t - \Delta\tau d) \quad (2)$$

Both the friction power *Pf* and the pumping power *Pp* are related with the manifold pressure *pm* and the crankshaft speed n. The load power *Pb* is a function of the crankshaft speed n only. The indicated efficiency η a function of the manifold pressure *pm* the crankshaft speed and the air/fuel ratio λ.

The engine port fuel mass flow *mf* from Hendricks's model is described by the following equation :

$$mf = \frac{map}{Lth} \quad (3)$$

It shows that the simulation works at the ideal condition, that is the AFR value is always equal to its stoichiometric value.

The engine simulation model used is an expanded system based on the generic mean value engine model developed by Hendricks [11]. In figure 5 shown the three sub-models that describe the intake manifold dynamics including air mass flow and the fuel injection. Then the simulation model has two inputs, the throttle angle u and the injected fuel mass, and one output which is AFR value.

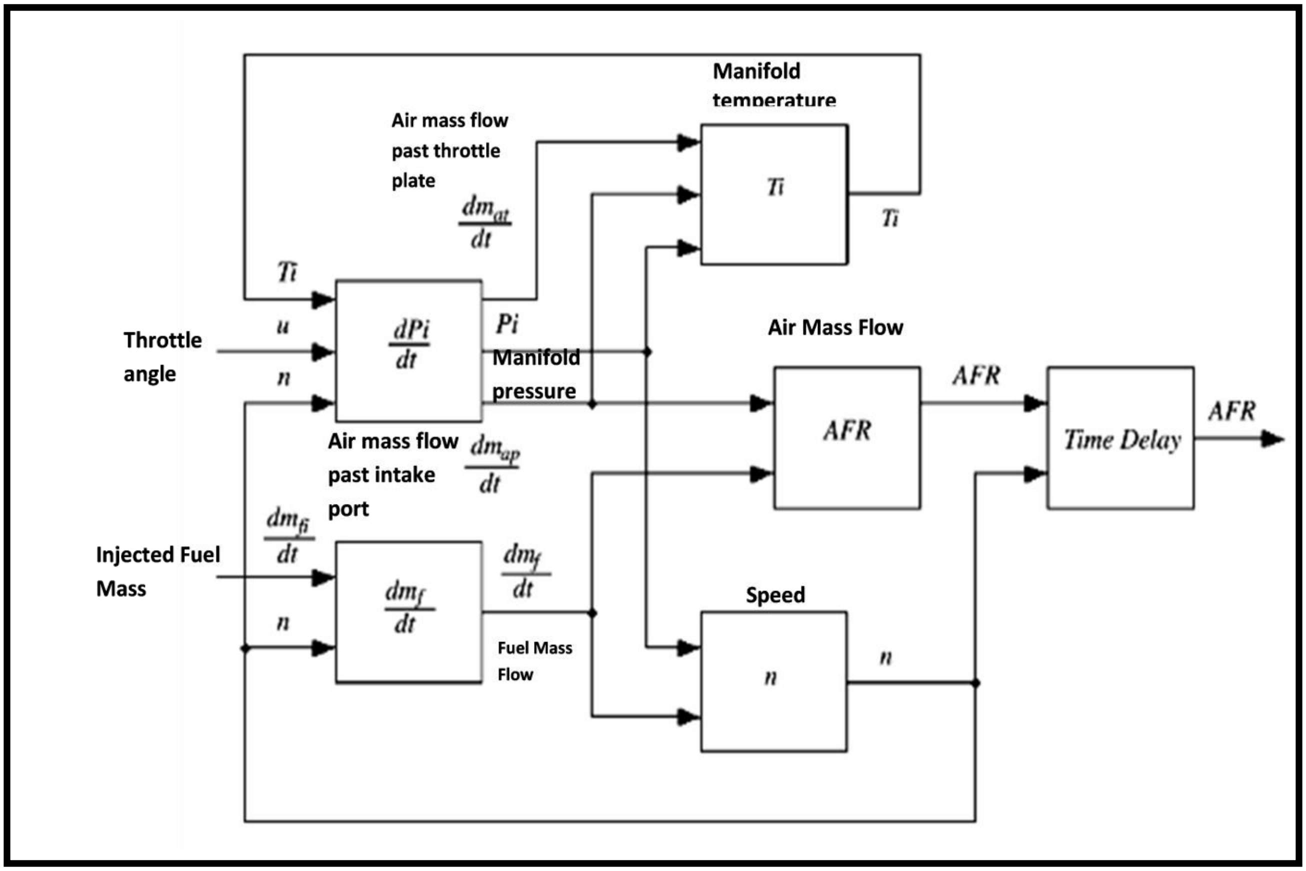

Figure 1.5 : The engine simulation model

Further, among all of the engine control variables, AFR is related to fuel efficiency, emission reduction and drivability improvement. Maintaining AFR to be the stoichiometric value (14.7) can obtain the best balance between power output and fuel consumption [10]. AFR can also influence the effect of emission control because its stoichiometric value ensures the maximum efficiency of three way catalysts (TWC).

As a result, a compatible and suitable controller is required to be applied in an engine's system such that engine's AFR can be maintained at stoischiometric range, thus resulting in high conversion efficiency of pollutant components.

1.3 Objectives of the Research

Based on the issue that variation of AFR deviating away from stoichimetric ratio can result in high concentration of pollutant from exhaust emission , the objective of this project is to maintain the engine's Air Fuel Ratio at stoichiometries level. This objective can be achieved through the following efforts:

i. To identify a suitable model of the engine system for air to fuel ratio (AFR) control.

ii. To design and develop a PID controller and Fuzzy Logic Controller for the AFR control towards cleaner exhaust emission and better fuel economy.

1.4 Scope of the study

The scope of work in this project concentrates on the engine and control system modeling follows by ascertain of control system performance using MATLAB-SIMULINK. This report will be built up by 5 chapters, which are introduced in chapter 1, methodology in chapter 2, literature review in chapter 3, result and discussion in chapter 4, last but not least conclusion and future work in chapter 5. The following are important content and description of each chapter.

Chapter 2 will concentrate on a literature review of engine and controller modeling method. In this project, the mean value method has been applied to engine modeling. Besides that, there are several controller methods are used previously. For example, Adaptive Fuzzy Control-PID method, Neural Network Parameter Adaptation, PI controller, Proportional Derivative (PD) control and so on. Performance and advantages of each controller will be discussed for deciding and decision making purposes on suitable controller.

Chapter 3 is disrupting the methodology of engine plant and control system modeling. The simulated engine model is modeled by three blocks: Fuel dynamic, Air dynamic and rotation torque dynamic. Each block is correlating between each other. Sets of model equation and formula which contribute to each block will be explained and describe in this chapter. There are 2 types of controller will be discussed in this report:-PID controller and Fuzzy Logic Controller (FLC).

Chapter 4 will discuss PID and FLC controller performance in controlling engine model's AFR. Simulation result of PID and FLC controller will be compared and investigated to determine suitable controller, which work well with engine plant. Last but not least, chapter 5 is the project conclusion and future work description.

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