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ANTILOCK BRAKING SYSTEM USING FRACTIONAL GAIN PID CONTROLLER

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MASTER OF MECHANICAL ENGINEERING
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A report submitted
in fulfillment of the requirements for the degree of
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2016

DECLARATION

I declare that this report entitled "Antilock Braking System Control Using Fractional Gain PID Controller" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature for any degree.

Signature : ....

Name : AZHAR BIN IBRAHIM

Date : JUNE 2016

APPROVAL

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

Signature : ....

Supervisor Name : ASSOCIATE PROFESSOR DR. NOREFFENDY TAMALDIN

Date: 22 JUNE 2016

DEDICATION

To my beloved family Khadijah Shahrin, Muhammad Amjad, Nur Dayyinah ,

my mother Mariam Yusup and my father Ibrahim Ismail

ABSTRACT

ABS system is a common technology which is broadly used in automotive field nowadays. Many researchers put their effort on developing the right controller in order to merge with existing ABS system. This determination led to development of several systems for example the implementations of PID controller. Under this project, the main objective is constructing or developing an accurate a quarter vehicle traction model with good ABS controller. Significant vehicle behaviour were examined specifically body and wheel speed, tire longitudinal slip and distance travel experience by the vehicle to investigate the behaviour of ABS under influence of PID and the latest development of FGPID controller. Outcome of the validation experiment shows that response between vehicle model and experimental vehicle are match with an acceptable error. As overall, by the ability of the controller in tracking the changes in slip and changes in the velocity of the vehicle, it is verified that the proposed FGPID controller is very suitable to be used as the controller for the ABS system. The previous FOPID then modified to be $P^{1-\alpha} I^{1-\beta} D^{1-\gamma}$ with the intention to make the controller more efficient, effective and more robust to the changes in parameters and references.

ABSTRAK

Sistem ABS merupakan teknologi yang digunakan secara meluas dalam bidang automotif hari ini. Kebanyakan penyelidik meletakkan usaha mereka untuk membangunkan sistem kawalan bagi digunakan bersama dengan sistem ABS yang sedia ada.Pembangunan teknologi mendorong kepada penggunaan sistem kawalan seperti PID.Di dalam projek ini pembinaan suku model kenderaan yang tepat dengan sistem ABS menjadi objektif utama. Keutamaan diberikan kepada parameter seperti kelajuan badan dan tayar kenderaan, gelincir membujur tayar dan jarak pergerakan bagi mengetahui dan menyiasat keadaan system ABS dibawah penggunaan PID dan yang terkini FGPID. Secara keseluruhan berdasarkan kepada kebolehan kawalan mengesan sebarang perubahan pada kelinciran,FGPID dikenalpasti berupaya dan sesuai digunakan didalam kawalan ABS. pengubahsuaian dari FOPID yang terdahulu kepada $P^{1-\alpha} I^{1-\beta} D^{1-\gamma}$ *adalah bertujuan untuk menjadikan kawalan lebih berkesan,cekap dan lebih kukuh terhadap sebarang perubahan parameter dan rujukan.*

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TITLE	SYMBOL
Quarter vehicle mass	m
Vehicle velocity	v
Tire longitudinal force	Fx
Aerodynamic force	Fa
Air density	ρ
Drag coefficient	C_d
Effective frontal area	A_f
Normal force	F_z
Wheel rolling radius	R
Road adhesive coefficient	μ
Wheel angular velocity	ω
Traction torque	τ_a
Braking torque	τ_b
Tire longitudinal slip	S

CHAPTER 1

INTRODUCTION

1.1 Overview

The ABS system is a common technology which is broadly used in automotive field nowadays .The implementation back then was only in aeronautic field now also can be found in the two wheel vehicles like motorcycle. This is because of the awareness for drivers and passenger safety during braking and to avoid accident from happens. As ABS system important to prevent wheel lock during sudden heavy braking, it is compulsory to make sure that the system to runs responsively and accurately.

The situation of braking becomes critical under difference surface which the researcher has categorized into icy, snow, wet and normal road condition. These conditions commonly become a source of a steering stability lose due to long stopping distance (Lennon *et al.*, 1997).

From here the ABS should responsively control the wheel slip so that a maximum friction is obtained and the steering stability is maintained so that the vehicle will stop in shorter distance while maintaining the directional control. ABS is pressurized by hydraulic valve control during antilock operation. The brake efficiency and steering controllability are depending on the amount of time required to open, close or hold the hydraulic valve. By understanding this, precise controller can be provided and developed in order to improve the ABS system.

According to Ming (1997), the ABS controller must deal with the brake dynamics and the wheel dynamics as a whole plant. The main difficulty in the design of ABS control arises from the strong nonlinearity and uncertainty of the problem. It is difficult and in many cases impossible to solve this problem by using classical linear, frequency domain methods (Drakunov *et el.,* 1997).

1.2 Motivation of Study

The configuration of ABS system is run by combining the parameters of different systems like hydraulics, sensors and control electronics. With minor changes in the controller software, the outputs of different system components are also interchangeable since the systems are reliant on each other. Then with advance development in control field, a large amount of types of controllers were introduced. The most basic and widely used in other area instead of ABS control system is PID.

Although from the implementation point of view, PID controller seems easier but tuning it into an appropriate combination is a very tedious job and this is the exact reason which gives scope of developing several tuning algorithms. Particularly for complex mechanical system with certain lag or hysteresis, the PID controller does not yield good result due to nonlinearity. A good control system should ideally have smaller rise time, less overshoot, smaller settling time and steady state error.

After several investigations on related soft computing method, the PID controller is reliable due to the effectiveness on real application. An improvement has been made recently by the addition of FOPID controller .Any change of the parameters and input shows small response in the system.

This brought the idea of enhancing the controller by emphasizing on P characteristic. Gain is added to the P and it is observed that the elasticity of FOPID can be increased. Classical PID controller also improved since there is flexibility in changes of input and parameters. Named as FGPID fractional gain PID ($P^{1-\alpha} I^{1-\beta} D^{1-\gamma}$) in this project, the controller that concerning a fractional proportional, fractional integrator and fractional differentiator are introduced.

1.3 Objective of the Study

1. To model and validate the quarter vehicle traction model to be used as representative of ABS system.
2. To investigate the performance of ABS by using fractional gain PID compared to PID controller.

1.4 Scope of the study.

1. Literature review on related fields.
2. Model developments and validation of quarter vehicle traction model using real vehicle.
3. Control design by simulation by using PID controller.
4. Control design by simulation by using FGPID controller.
5. Performance evaluation of PID controller and Fractional Gain PID. Only three parameters are observed in this project which is longitudinal speed, stopping distance and body speed comparison.

1.5 Report organization

The research methodology implemented in this study is described as the following steps of works:

1.5.1 Modelling and validation of quarter vehicle traction model.

This study begins with the modelling and development of an accurate vehicle dynamic model to describe analytically the dynamic behaviour of a vehicle in longitudinal direction. In this stage, a 2 degree-of-freedom (DOF) quarter vehicle dynamic model is developed. The model that includes hydraulic brake subsystem is then validated experimentally using an instrumented experimental vehicle. Several dynamic braking tests were conducted, which are sudden braking test. The tests are implemented at low speed and medium speed. The behaviours of the vehicle models were then verified with the behaviour of the experimental vehicle.to ensure the effectiveness of the data measured; the same input brake and vehicle speed are used.

1.5.2 Control design by simulation of anti-lock braking system using PID controller.

This study then proceeds with the control design by the simulation of antilock braking system (ABS). PID controller were added and evaluated on a quarter car model in the same speed of vehicle such as used in normal braking and validation stages. Performance evaluations of the PID were characterized by the ability of the control strategies to stop a vehicle in shortest period of time and the shortest stopping distance as well as their consistency in providing the optimum target slip.

1.5.3 Performance evaluation of FGPID in ABS system in simulation.

The final stage in this study is the experimental investigation of the effectiveness of the FGPID compared to previous controller which is PID. All the simulation studies in normal braking and ABS were then evaluated experimentally and compared with the simulation results. The robustness of the control strategy to tire slip variation was also studied. This is due to the fact that in practical; tire slip of the vehicle may vary depending on the road conditions. The optimum controller then was also implemented on the full vehicle model to examine the efficiency of the controller in full vehicle braking system. It should be noted that all numerical computations and computer simulations were conducted using the MATLAB SIMULINK programming software version R2009B developed by the Math Works, Inc.

1.5 Structure and Layout of Thesis

This project report is organized in five chapters. A brief and comprehensive overview of the main points of the research process is shown in Figure 1.1. The thesis contains an introductory chapter which gives a brief introduction on controller involving in ABS control system. This chapter presents previous research findings leading to the objectives of this study. Under this chapter comprises of explanation about how and why the objective is obtained .Following of the project report is includes under this brief description.

Chapter 2: This chapter presents the literature reviews on related subjects concerning this report. In this chapter, the introduction of ABS system controller, Antilock Braking System Control Strategies including the different types of controller and Optimization Tool Selection are reviewed. Review on recently published articles related to ABS control, which relies on PID, is also presented. Finally, the potential of using PID controller for ABS control based, FGPID system is discussed.

Chapter 3: The methodology of this study regarding the modelling and validation of 2 DOF quarter vehicle traction model is presented in this chapter. Some vehicle modelling approaches and modelling assumptions are introduced. Development of instrumented experimental vehicle used to ensure the model validity is also reviewed. PID and FGPID implementation are discussed in detail. The potential benefit of the proposed controller structure will then be finally discussed and presented.

Chapter 4: This chapter presents the controller design for ABS namely PID and FGPID. The results of validation in sudden braking test are discussed and reviewed. There are also discussions about performance evaluation of PID and FGPID under difference road conditions. The findings will be concerning on longitudinal speed, stopping distance and body speed comparison only.

Chapter 5: This chapter summarizes the works done in this entire study, infers conclusions that can be drawn, highlights of the study contributions and is concluded with recommendations for future research work.

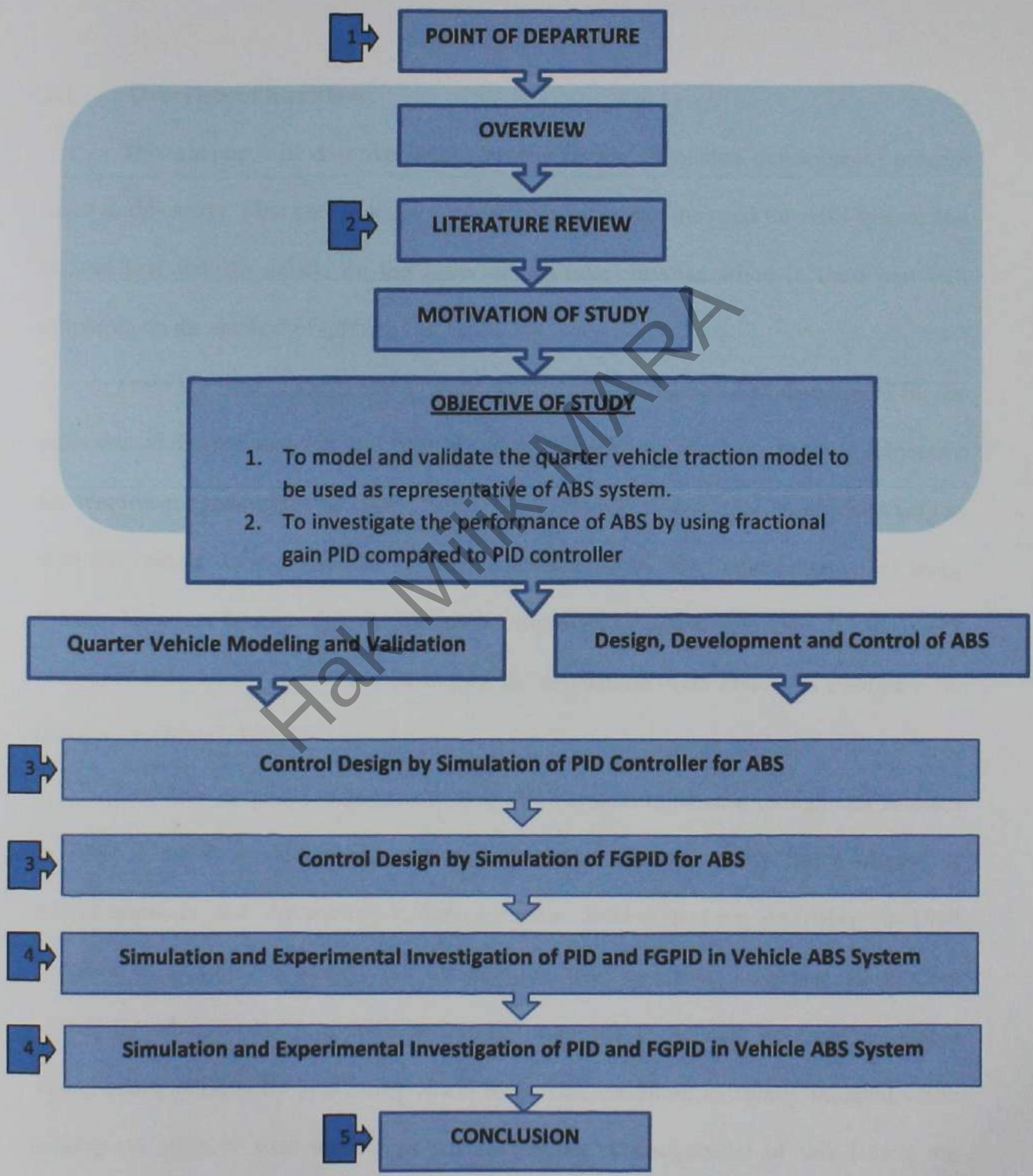

Figure 1.1: Summary of the research process in chapter 1.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of literature.

This chapter will describe details on the review of related development process incur in this study. First part of the review will explain about the need for ABS system and second part will be details on the types of controller involve while in third part will emphasis on the method of tuning.

From the time since the occurrence of the first driving accident dated in 1770, the reduction of driving accident and vehicle safety improvement has been the main objective for researchers and engineers (Hart, 2003). It is strongly proven that an efficient way to stop the vehicle during speed or to prevent accident is by the implementation of brake system. However braking system still can be improved by assisting system. In year 1930, aerospace industry researcher has developed the mechanical ABS system as a solution for this matter. (Maier, 1996).

This development brings the rear only ABS system to be used in high end vehicles in 1960 (Fling *et al*, 1981) and after a few decade, influenced by fast evolution of microcomputers and electronics technologies the movement keep on rising in 1980 (Yoneda *et al.*,1983).Nowadays the technologies has been used in almost all modern vehicle including motorcycle. ABS is designed to ensure the vehicle steerable and stable during heavy braking by preventing wheel lock. This condition is usually initiated while braking on slippery road surface or severe braking. Consequential of this factor, the distance of the vehicle to stop immediately will be far hence lead to uncontrolled steering stability (Lojko, 2002).

ABS mechanisms work by manipulating the wheel slip so that a maximum friction is gained while the steering stability is maintained. The effective desired, measured by vehicle shortest stopping distance possible and still in directional control.The core on developing the suitable control design is to regulate the wheel velocity. Currently the traction control system (TCS) and vehicle dynamic stability control (VDSC) are also implementing the ABS technologies (P. Hart,2003).

Basic ABS components include: vehicle's physical brakes, wheel speed sensors (up to 4), an electronic control unit (ECU), brake master cylinder, a hydraulic modulator unit with pump and valves.Advanced ABS systems also contain accelerometer to determine the deceleration of the vehicle. Figure 1 below visually explains about the typical ABS involved.

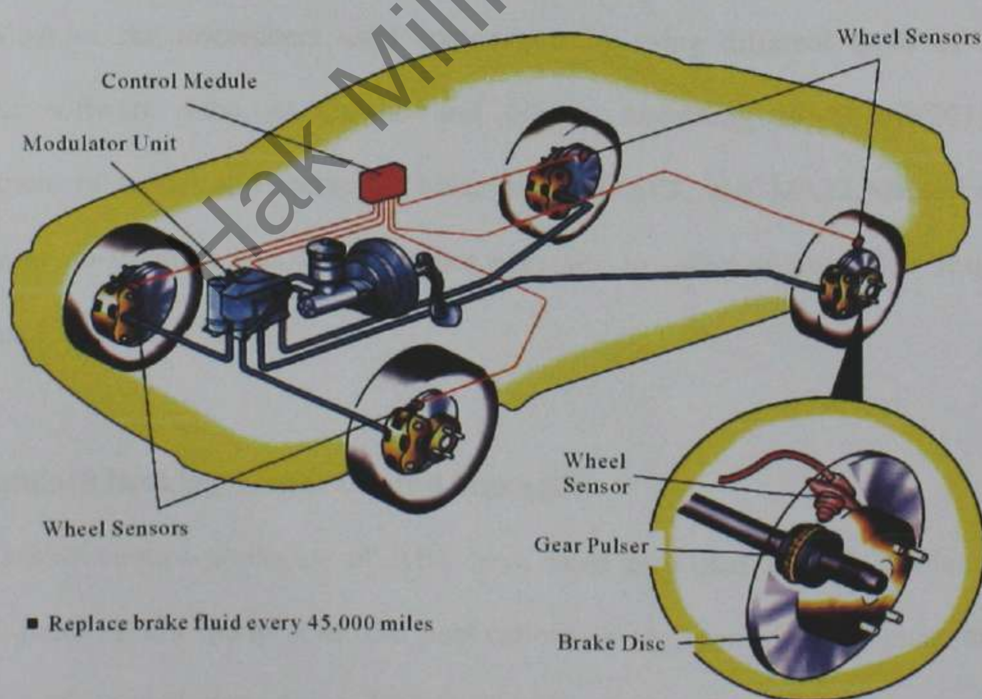

Figure 2.1: ABS component in vehicle (Ulsoy, 1997)

2.2 Modelling And Validation Review

The development modern vehicle required more sophisticated system to evaluate. Many researcher struggles to investigate the behaviour on certain system by experimenting it. Computer simulation always had been a choice in order to avoid the cost and risk in actual experiment to build a model of the system.

However the model must be created as close as to the actual system and this only can be done by validating it. Hudha, (2005) said fully validation on a real vehicle is necessary during experiment, other than that will reflected on unpractical model. In this project the quarter vehicle is modelled and validated by actual experiment. The validation with experiment is acceptable when the tendency of the simulation and the experimental data results show similar or significantly match (Ahmad,2014). But validation by actual experiment is not the only way for validation.

Most of the researchers used comparison by using different types of related simulation software such as Carsim and others. According to Shaoyi(2011) the establishment of model and controller based on SIMPACK and MATLAB software is necessary to co-simulate and to get higher accuracy in order to play their respective advantages.

2.3 Antilock Braking System Control Strategies

Various control strategies of ABS have been presented in both academic and industrial fields. From many scientific publications in the area of ABS, most of them discussed ABS control strategies and some of them will be reviewed in this section. To simplify the explanation, the topics that will be reviewed in this section are selected for widely known control approaches in the area of ABS.

In designing the ABS brake controllers there are certain unique challenges required: a) For optimal performance, the controller must operate at an unstable equilibrium point, b) Depending on road conditions, the maximum braking torque may vary over a wide range, c) The tire slippage measurement signal, crucial for controller performance, is both highly uncertain and noisy, d) On rough roads, the tire slip ratio varies widely and rapidly due to tire bouncing, e) brake pad coefficient of friction changes, and f) The braking system contains transportation delays which limit the control system bandwidth (Mauer,1995).

ABS consists of a conventional hydraulic brake system combine with antilock components. These arrangements affect the control characteristic of the system. It is understood that ABS control is highly a nonlinear control problem due to friction and slip relation. Another obstacle in development process is that the linear velocity of the wheel is not directly measurable and it has to be estimated. Researcher also must figure out the right method to measure the friction between the road and tire. Usage of complex sensors is necessary to gather the data. Various controllers has been develop and implemented in order to fulfill the satisfied and accurate results. Below in figure 2.2 shows the various field of controller involve in ABS enhancement.

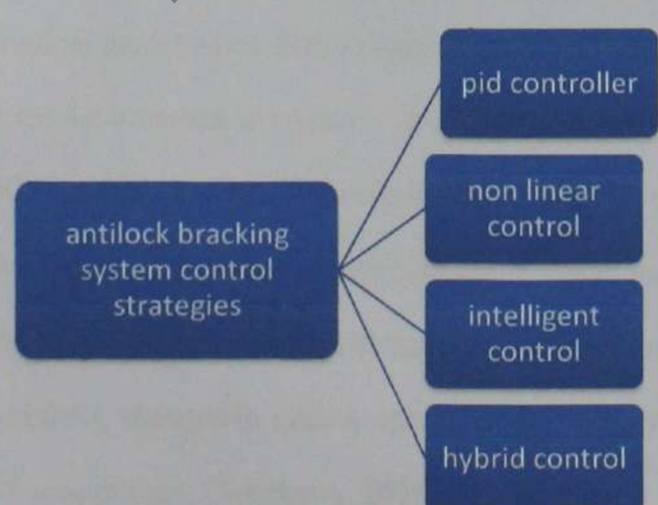

Figure 2.2: Various controller in ABS system research

2.3.1 PID Controller

Proportional-Integral-Derivative or also known as (PID) controllers are prominent between researcher based on its structure simplicity, easy to implement and reliable performance. It can be said that, beyond 90 percent of control loops are PID type as the controller strategy used in industrial field (Tang *et al.*, 2005). PID has successfully developed in a long history in control field and mainly influenced in all of feedback form until today (Astrom *et al*, 2000). This is mainly due to the fact that PID controller possesses robust performance to meet the global change of industry process, simple structure to be easily understood by engineers, and easiness to design and implementation (Ahn *et al.*, 2012; Biswas *et al.*, 2009 and Ahmad *et al.*, 2010).

Practically the conventional PID controller is simple and the applications are easy, yet the controller always conflicted when in use with significant nonlinearities. The performance of PID accordingly disturbed. To overcome this barricade, the PID controllers are often merged with other method in order to enhance the usage. Related to this topic, the PID controller has been promoted in the ABS system. Combination of method has developed the various controllers such as neural network, genetic algorithm and sliding mode. Previous research is related to ABS for example the dynamic behaviour of a 5 DOF vehicle longitudinal model when ABS system fit with PID controller (Aparow *et al*, 2013). Another case can be observed in (Aparow *et al.*2014) research are using PID controller to control a 2 DOF quarter vehicle to improve the slip tracking. Sophisticated development of PID has been suggested to improve it, particularly in situations where providing a control action to even a minimal degree of satisfaction is a problem. In addition of automatic tuning-tool can track changes in system operation and compensate for drift, due to aging and parameter uncertainties. (Sharkawy, 2010).

2.3.1.1 Performance Of Antilock Braking System Using PID Controller

As mention before, PID controller is used to improve the ABS performance. To be specific, the PID is used to control the brake torque for front and rear. PID controller works by adjusting the process control inputs to minimize the error. Table 2.1 below summarizes the PID terms and their effect on the control system.

Table 2.1: PID terms and effects on control system

Description terms of PID Term	Effect on Control System
P (Proportional)	Typically the main drive in a control loop that reduces a large part of the overall error.
I (Integral)	Reduces the final error in a system. Summing even a small error over time produces a drive signal large enough to move the system toward a smaller error.
D (Derivative)	Counteracts the P and D values when the output changes quickly. This helps reduce overshoot and ringing. It has no effect on final error.

With all simple PID capabilities in controlling ABS system, the necessity of high-performance control which always fluctuate in operating conditions or environmental parameters are becoming significance nowadays. The reason of this matter is classical PID controller always stressed on straight forward design to attain best result in controlling the system.

2.3.1.2 Fractional Order PID

This topic discussed related topic on FOPID. Podlubny (1999) has proposed the Fractional Order PID (FOPID) which led to problem solving concerning linearity and straight forward. The effectiveness of FOPID has been established by various of usage and application according to (Petráš, 2009; Xue *et al.*, 2006) motion control of DC motor, (Fan *et al.*, 2007) servo press control system. Birbil *et al.* (2004), Chang *et al.* (2009), (Domingues *et al.*, 2010) in irrigation canal control, (Tehrani *et al.*, 2010) in boost converter control and (Changmao *et al.*, 2010) hypersonic flight vehicle control. Regularity of study using FOPID resulting from the proficiency of FOPID to encounter the changes input flexibility and better performance if compared to conventional PID.

2.3.2 Non-linear Control

By comparison of the applications of non-linear design methodologies and linear method, it is shown that even when they are always signified as complicated system they can achieve better performance. One of the methods that are well known to handle non-linear system behaviour is the sliding mode control (SMC). According to Huang and Chen, (2006) the implementation for complicated dynamic system with unknown information are not easy to obtain. The obstacle of this matter is, in traditional SMC designers require system dynamic model and uncertain bound.

Above that matter the construction of ABS in quarter car model by using concept of sliding mode control has been proposed by (Mao *et al.*,(2010) Antic *et al.*,(2016), and Okyay *et al.*,(2013). SMC is also proven in experimental result when compared to the linear ABS based on PID control theory and the passive system. It is efficient due to improve braking performance of vehicle and also achieving target slip. Another significant proposed of SMC method to control ABS system named as proportional-integral sliding mode control (PISMC). As the PISMC was test with hydraulically actuated ABS, the performance attained all requirements of ABS (Sam *et al.*, 2007).Another idea is to tune the linear controller like PID by adopting the MIT rule model reference and as a solution to solve complex model. According to (Ahmad *et. al.*, 2009), PID controller has been recognized to be used in many request; hence this controller occasionally works perfectly during variation condition. This is the main motivation to enhance the capability by familiarizing the controller with tuning mechanism law.

2.3.3 Intelligent Control

Gupta *et al.* (1988) was among the earlier to propose the concept of intelligent control. At first control research community does not pay much attention to their concept. Model based control approach which includes process like modelling, analysis, simulation; implementation and verification are prioritized by them. By implementation of this conventional method, the main intentions for computations are precision and certainty.

Complex systems intend to create various irregularities that will lead to difficulties in the analysis and control. It is also challenging to model the complex system analytically using conventional mathematical approaches. From here it can be clarified why it became one of the most leading areas of study in developing control system. Contradict to analytical method, intelligent control methods simulates understanding and realisation of certain key aspect .For example of the key aspect is the ability of learning from experience, the ability to generalize into domains where direct experience is absent, and so on. But the consequence of this applied method is a decrease of accuracy. This representative of method of intelligent literally has known as Artificial Intelligence (AI). Under AI methods, the researchers explored this approach under different names and categories such as neural network computing, probalistic reasoning, genetic algorithms and fuzzy logic. Though with the different kind of approaches, the widely held methods in ABS intelligent control application is fuzzy logic. The advantage of the fuzzy controller which can be accompanied through a set of local humanistic (expert-like) controllers governed by linguistic fuzzy IF-THEN rules make it is a good choice for researchers in ABS control field.

Several researchers have involved this method to control ABS, such as David *et al.*, (2012), Aras, (2013) and Subbulakhsmi, (2014) Modi *et al.*, (2012) who controlled ABS with a proposed tuneable fuzzy controller version in a quarter car setting. The Fuzzy logic controller is used to track the target slip and wheel sleep reduction. The simulation result indicated that the proposed ABS control greatly improves the slip in dynamic of a vehicle. Some suggested the use neural network (NN) with ABS.For example Oniz *et al,*. (2013) using spiking NN and Eneh and Okafor (2014) using artificial NN with simulation based quarter car model. However the usages are only idealistic when fuzzy logic controller is used to encoded the parameters of NN and then replace the controller with NN during simulation. Resulting from this many researcher find out that the controllers are able to detect the reference slip value approaching closely to ideal working conditions.

2.3.4 Hybrid Control

By definition hybrid can be defined as combination of two or more system to generate same output. In control strategies it is a common to merge two control methods for their own benefits. The arrangement accepted and recognizes in this area (ABS) is including fuzzy neural network, fuzzy PID controller and fuzzy sliding mode controller. Al-Mola (2012), Lu *et al.*, (2010), Jidu *et al.*,(2012) and Aldair (2014) shared the same interest in hybrid controller on the fuzzy PID control for ABS. The development of fuzzy neural controller, John and Pedro (2013) runs it under simulation environment. Overall understanding from this area, it is shown that the result replies with the effectiveness of ABS as compared to the traditional (PID) controller.

2.4 Optimization Tool Selection

According to Korkmaz *et al.*, (2012), Ziegler Nichols method, Chien Hrones Reswick PID tuning algorithm and Wang Juang Chan Tuning formulae Method are widely used methods in determining the right optimum parameter for PID controller. From the method listed before, Ziegler Nichols Method is the most popular method used in determining the parameters of PID controller. Even though it was proposed in mid-20th century, the ability of the method to stabilize the system and very practical in parameter tuning makes it broadly used in optimizations. Besides, this method is very useful for plants of which mathematical models are unknown or difficult to obtain.

By referring to Ziegler and Nichols, (1942) there are two ways of applying their tuning rules and controller parameters get from the Z-N empirical tables. If the researchers are considering set point regulation or disturbance rejection, the Chien-Hrones-Reswick (CHR) PID tuning method will be the best option. According to Dingyu *et al.*, (2007) the time constant T of the plant in CHR method is obviously if compared to Ziegler-Nichols tuning formula. Lastly, Cohen–Coon tune formula also suitable for PID controller. Like Ziegler-Nichols, Cohen–Coon used rule table that is gained empirically.

2.5 Literature Summary

ABS control is always known for a highly nonlinear control problem. In searching for perfect control method of improving the ABS system, many types of different control method were introduced. Some of the methods are effective while certain method struggle to fulfill an adequate performance under the changes of various road conditions (Aly *et a.l*,2011).This brings the implementation of soft computing method such as PID in the system.

After several investigations on related soft computing method, the PID controller is reliable due to the effectiveness on real application. An improvement has been made recently by addition of FOPID controller It happens that the fractional-order ($PI^{\lambda}D^{\mu}$) is working smoothly in dynamic system since the controller is not subtle to the alterations of the input limitation.

Zhang and Zhang,(2008) mentions that this result occur from the characters of the I and D gains that more reaction to the time changes while the P gain in the FOPID controller is still a linear gain . It is found that proportional gain (P) play a very significant role to the changes in the system parameters and references over the integral (I) and derivative (D) gains (Wu *et al.,* 2009).

This brought the idea of enhancing the controller by emphasizing on P characteristic. Gain is added to the P and it is observed that the elasticity of FOPID can be increased. Classical PID controller also is improved since there is flexibility in changes of input and parameters. Named as FGPID fractional gain PID ($P^{1-\alpha}\ I^{1-\beta}\ D^{1-\gamma}$) in this project, the controller that concerning a fractional proportional, fractional integrator and fractional differentiator are introduced.

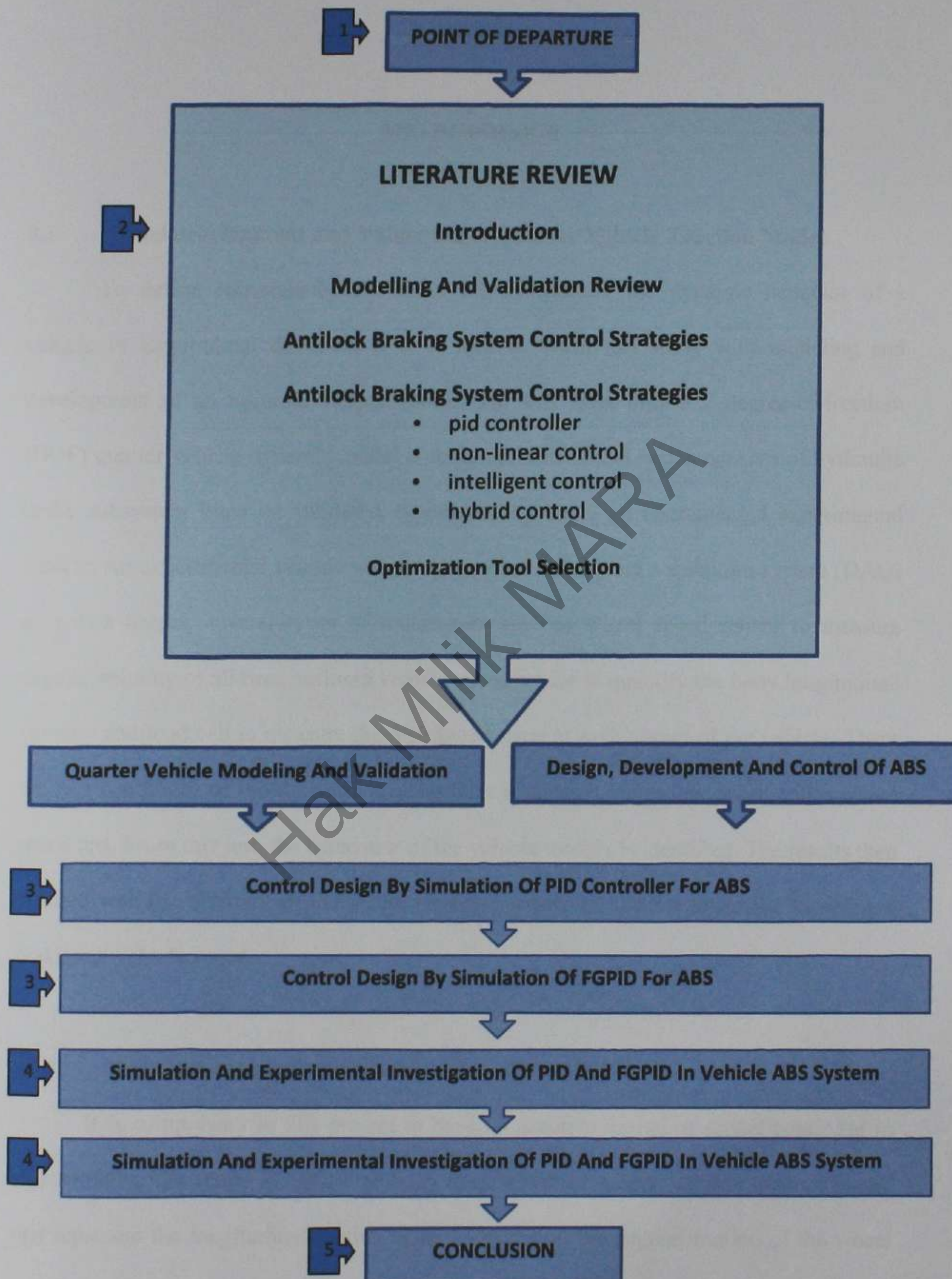

Figure 2.3: Summary of the research process in chapter 2.

CHAPTER 3

METHODOLOGY

3.1 Model development and Validation of Quarter Vehicle Traction Model.

To define comprehensively about the analytically the dynamic behavior of a vehicle in longitudinal direction, it is a must to begin this study with modeling and development of an accurate vehicle model. For this level only a 2 degree-of-freedom (DOF) quarter vehicle dynamic model is required. This model which consists of hydraulic brake subsystem must be validated experimentally using an instrumented experimental vehicle. An experimental vehicle was setup together with a data acquisition system (DAQ) as a data logger, several types of transducers such as wheel speed sensor to measure angular velocity of all tires, infrared vehicle speed sensor to quantify the body longitudinal velocity and load cell to measure the distributed mass at each corner of the vehicle. There are two conditions of the dynamic braking tests conducted under low speed and medium speed test. From this test, the behaviour of the vehicle models is identified. The results then verified with the behavior of the instrumented experimental vehicle under the same input brake and vehicle speed.

3.1.1 Modeling Assumption

It is compulsory in this project to have an accurate design of model controller to representative the actual system. Free body diagram of the quarter vehicle traction model that represent the longitudinal motion of the vehicle and the angular motion of the wheel under accelerating and braking operation are shown in Figure 3.1 below. During modeling some simplifications on the actual system have been implemented, however the change does not influence the model since the fundamental characteristics is still preserves. For the purpose of developing the dynamic equation of the system derivation, some rules is suggested which are:

(i) Only longitudinal dynamics of the vehicle are considered;

(ii) The lateral forces acting upon the vehicle are neglected since the forces involved during steering to change lanes have a relatively small effect and act for small times period (Short and Pont, 2004);

(iii) The vehicle is assumed to be remains grounded at all times and the tire never lost contact with the ground during dynamic;

(iv) The movement of a vehicle in latitudinal direction is neglected as the effect of the vehicle suspension system is ignored;

(v) In simulation tire vertical behaviour is not involve but vehicle drag force which produced by acceleration and braking in simulation are counted.and also the lateral and longitudinal behaviours are represented by magic formula tire model (Bakker *et al.*, 1989).

For this equation, supposedly there is zero interaction among four wheels of the vehicle since all four tires are not directly connected.

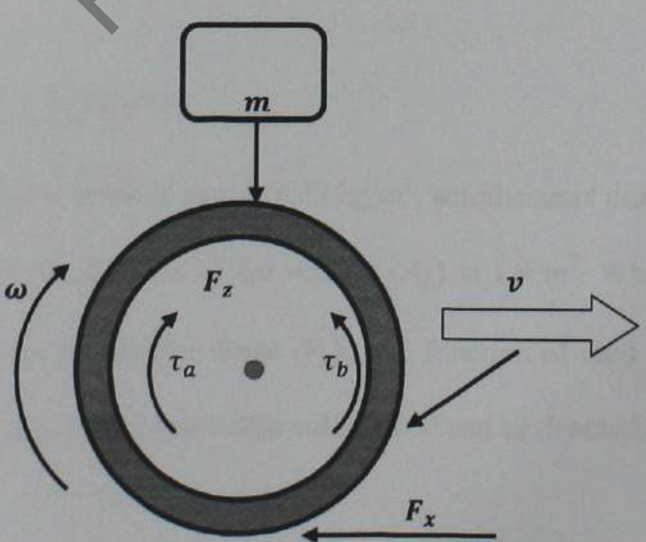

Figure 3.1: Free body diagram of quarter vehicle traction model

3.1.2 Vehicle Dynamics

Vertical forces and load distribution playing big role in determining the vehicle body dynamics. It can be split by two parts which are dynamic forces and static forces for load distribution. Also static load can be determined by summing the forces at each contact point of vehicle geometry and the grade angle. During the vehicles acceleration and braking, a dynamic load distribution which transfer load between the front and rear wheels can be provided. The equation of motion of the simplified vehicle model can be obtained by considering a free body diagram shown in Figure 3.1.

By using the Newton's second law, mathematically the system can be expressed as (3.1) where the nomenclatures used are described in list of symbol.

$$m\dot{v} = -F_x - F_a \tag{3.1}$$

Where the aerodynamics force, F_a is depends on the shape, size as well as the instantaneous linear velocity of the vehicle (ref). The aerodynamics force can be described as:

$$F_a = \frac{1}{4}\left(\frac{\rho}{2} C_d A_f v^2\right) \tag{3.2}$$

where the air density that denoted as ρ is 1.23 kg/m^3, aerodynamic drag coefficient, (C_d) is 0.54 and the effective frontal area of the vehicle (A_f) is 1.9 m^2. While the friction force which is known as tire longitudinal force (F_x), is a function of road adhesive coefficient that proportional to the normal force of the vehicle and can be denoted as:

$$F_x = \mu F_z \tag{3.3}$$

3.1.3 Wheel Dynamics

Wheel dynamics can be obtained by summing the torques of each wheel. The summation of torques of each wheels are including torques delivered by the engine to each wheel, torque applied to each wheel due to the brakes and reaction torque on each wheel due to the tire tractive force. The rolling resistance can be neglected since the rolling resistance force of the wheel is much smaller than the friction force between the wheel and road during braking, therefore the equation of motion of the wheel can be written as:

$$I\dot{\omega} = \tau_t - \tau_b \tag{3.4}$$

where

$$\tau_t = F_x R \tag{3.5}$$

It is understood that as the body is directly connected to the wheel, the linear velocity of the wheel is assumed to be same as the forward velocity of the vehicle.

Then during braking the forces are generated at the interface between the wheel and the road surface, which causes the wheel speed to decrease. While the force (friction force) at the wheel is increases, slippage will occur between the tire and the road surface, and causing the wheel speed to lower down than the speed of the vehicle.

This condition is defined as the tire longitudinal slip and mathematically, it can be described as:

$$S = \frac{v - R\omega}{\max v/R\omega} \tag{3.6}$$

The friction between the tire and road surface has various characteristics and depend not only the slip, but also upon the driving surface and the road conditions (Stichin, 1984). Mostly road conditions can be categorized as a 'normal' road condition, a 'wet' road condition and a 'snowy/icy' road condition. The normal road condition can be define through road dryness and approaches maximum traction conditions; the wet road condition occurs when the surface is damp, and the traction condition is reduced to about 80% of the normal condition. While snowy/icy road condition can be divided into two characteristics, the vehicle will lose traction up to 65% in unpacked snow conditions and 85% reduction in traction in packed frozen snow (ice). Graphically the four slip characteristics can be described in Figure 3.2.

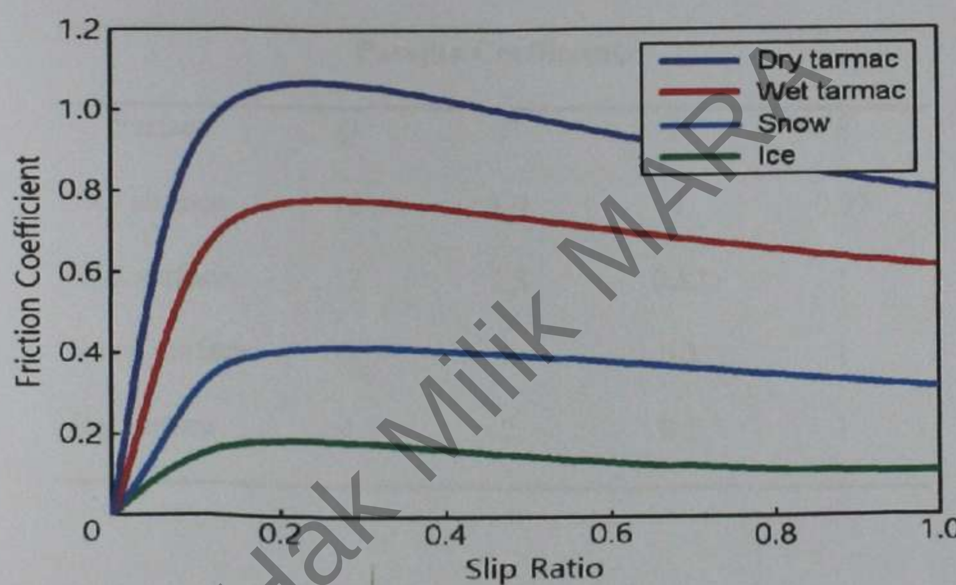

Figure 3.2: Typical $\mu \sim \lambda$ curve for different road conditions

Referring to Mizuno (2003), in order to design good control system for anti-lock braking system and vehicle stability control, an accurate description of the tire characteristics are extremely important to the study of a wide range of vehicle behavior.

Thus,the Pacejka magic formula tire model is used in this study (Bakker *et al.*, 1989). The magic formula tire model is a standard empirical model which can describe (in a very precise way) the relationship between slip, road surface conditions and friction. The expressions of the tire model are given by:

$$\mu(S) = D\, sin\Big(P \arctan\big(Q\,S - E(Q\,S - \arctan(Q\,x\,S))\big)\Big) \quad (3.7)$$

The overall model coefficients in the Pacejka tire model (*Q, P, D* and *E*) loosely represent stiffness factor, shape factor, peak value and curvature factor and some typical values are given in Table 3.2.

Table 3.2: Tire parameters

Pacejka Coefficients				
Surface	*Q*	*P*	*D*	*E*
Dry surface	10	1.9	1	0.97
Wet surface	12	2.3	0.82	1
Snow surface	5	2	0.3	1
Icy surface	4	2	0.1	1

3.1.4 Validation of Quarter Vehicle Traction Model

For validation of the vehicle traction model purpose, the experiment by using instrumented vehicle car has been performed to obtain the information. The specification of the vehicle is hatch back body type powered with 1300 cc engine capacity and five speed forward gear manual transmissions as the power train system. As the study intended to developed based on the quarter vehicle model, the validations were made by considering the response of a quarter vehicle only specifically on the front right side.

The results of the validation shows the response of the vehicle model are significantly match with the response of the experimental vehicle and will be comprehensively explain in chapter 4.

3.1.4.1 Validation of Vehicle Model Using Instrumented Experimental Vehicle

In order to verify the validity of the quarter vehicle model for ABS model, several validation tests need to be performed using a real vehicle. In table 3.3 below briefly explain about the specifications required to run the experiment. The installation of the DAS and sensors in the experimental vehicle can be seen in Figure 3.3

Table 3.3: Validation Experiment Specifications

Validation Experiment Specifications		
Instrumented Experiment Vehicle	Proton Iswara	1300 cc, 4-cylinder inline, 5 speed manual transmissions.
Data acquisition system (DAQ) ⬇ MUSYCS system Integrated Measurement and Control (IMC)	Wheel Speed Sensor	Measure angular velocity of the tire
	Infrared Vehicle Speed Sensor	Quantify the body longitudinal velocity
	Load Cell	Measure the distributed mass at each corner of the vehicle.
Software	FAMOS	Real time data processing, display and data collection.

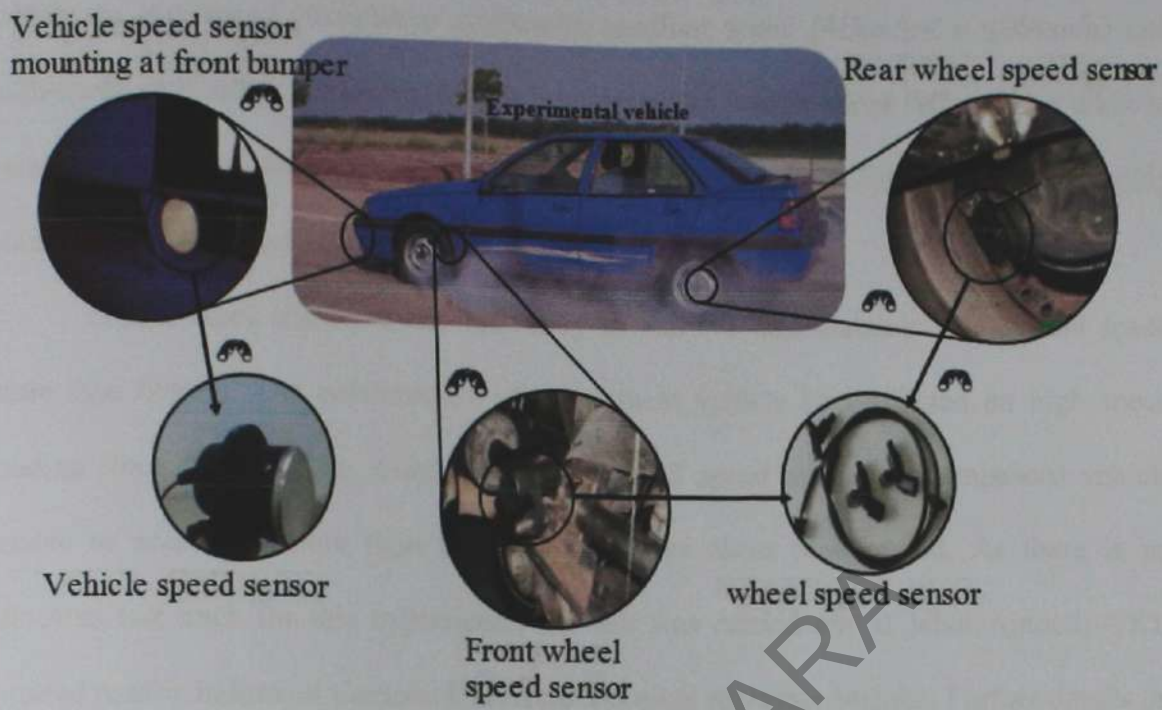

Figure 3.3: Experimental vehicle and instrumentations

3.1.4.2 Validation Procedures

In experiment, the accuracy and precision are necessary in order to perform detail experiment and data gathering. It is also to ensure the data will represent as it supposed to be for validation purpose. This experiment start with measurement of vehicle weight by using set of load cell sensor place under each tire. Another parameter needed is wheel radius. Data measured for vehicle weight is 920 kg and 0.2m for wheel radius.

After measurement process, the dynamic validation can be determined by sudden braking test. The procedure of test start with the driver accelerates the vehicle until it reaches constant speed. In this case preferable constant speed is around 40kmh and 60kmh due to some limitation. Then the driver applies braking to the vehicle until it completely stopped.

In this experiment, the data measured consider on three speed conditions conditions which are low speed (0km/h$< v \leq$40km/h), medium speed (41km/h$\leq v \leq$89km/h) and high-speed (90km/h$\leq v \cong$km/h).Yet the test parameter at high-speed (90km/h$\leq v \cong$km/h) cannot be perform due to track distance limitation (200meters).So the validations only consider on 40kmh and 60kmh.

Longer track distances are necessary to achieve and maintain the vehicle speed more than 60kmh. The performance of experiment vehicle also affected on high speed reading since this 1300 cc, 4-cylinder inline and 5 speed manual transmissions vehicle unable to accelerate more than 60kmh in required short time period. As there is no allocated test track for this experiment, the test was carried out at Jalan Autocity-TKB situated nearby Industrial Campus Universiti Teknikal Malaysia Melaka. Further details on test track location can be observed in Appendix B.

The validations were made by considering the response of one of the quarter vehicle only which is front right side illustrated in figure 3.4. Thus, the mass of the vehicle was reduced to a 240 kg according to the load cell data. The detail technical specification of the vehicle can be observed in the Appendix A.

Figure 3.4: Quarter vehicle validation test.

3.2 ABS Control Using PID

One of the conventional controllers developed to calculate the errors obtained from the actual plant model with the desired input is PID. The acronym of PID controller can be refer to P = proportional, I = Integral and D = Derivative. These three parameters can be adjusted accordingly to errors.

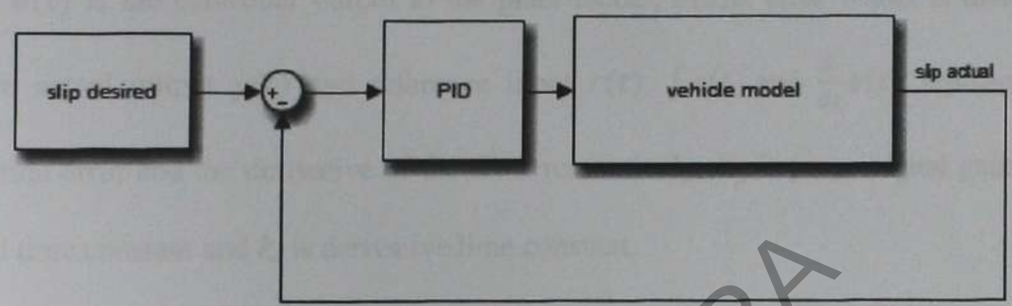

Figure 3.5: ABS with PID controller simple structure

There is plenty of different method for parameters function to diminish the errors from plant model. The P value represents the errors that occurred in current condition. Where else, I value represents the errors gathered from past condition and D value represents the prediction of future errors based on the changes occurred during current condition. Signal builder input can be replace into passive braking by implementation of PID controller. The brake actuator added with hydraulic lag in the form of transfer function to represent delay from controller to the hydraulic response. The input for the hydraulic lag is the electrical current, *i is* shown in Figure 3.6 below.

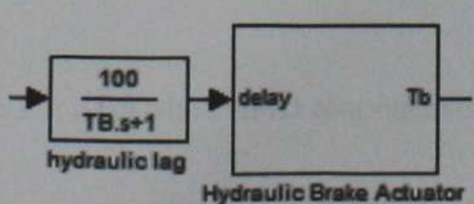

Figure 3.6: Hydraulic Lag Implementation

By summing all the resulted weighted signal, the controller signal *u(t)* will be produced, hence can be applied to the plant model. In the form of mathematic, the PID controller can be written as:

$$u(t) = k_p(t)\, e(t) + k_i(t) \int e(t)dt + k_i(t) \frac{d}{dt} e(t) \qquad (8)$$

where, $u(t)$ is the controller output to the plant model, $e(t)$is error which is difference between actual output $y(t)$ and reference input $r(t)$, $\int e(t)$,and $\frac{d}{dt}e(t)$ represent the integration error and the derivative of the error respectively, k_p is proportional gain, k_i is integral time constant and k_d is derivative time constant.

3.3 Fractional Gain PID Controller

In enhancing the performance of the linear PID controller, a nonlinear integer$(1 - \alpha), (1 - \beta)$ and $(1 - \gamma)$are added to the gain of the controller. By adding the nonlinear integer to the conventional PID gains, the PID controller is transformed to be fractional PID controller.Below is the simple structure of FGPID controller.

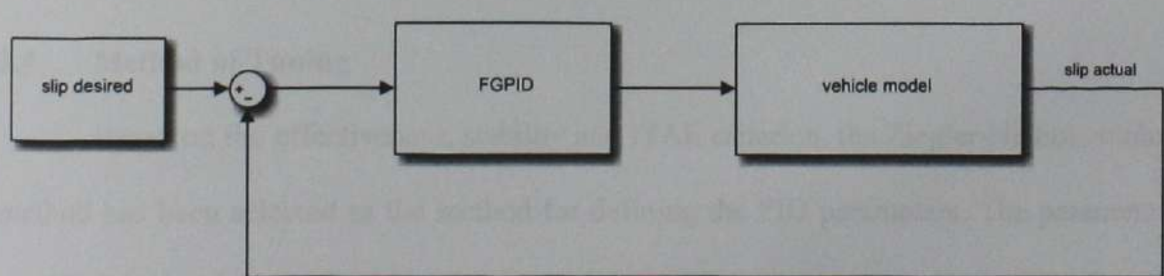

Figure 3.7: ABS with FGPID controller simple structure

The proposed FGPID controller is consists of a sector bounded nonlinear integer and combine in cascade with PID controller and mathematically, the FGPID controller can be written as in equation (X) where $(1-\alpha)$ is the fractional integer for the k_p, $(1-\beta)$is the fractional integer for $k_i$and $(1-\gamma)$is the fractional integer for k_d. In this FGPID when $\alpha = 0$, $\beta = 0$ and $\gamma = 0$, the classical integer order PID controller is obtained, while when $\alpha = 1$, $\beta = 1$ and $\gamma = 0$ define PI controller, whereas when $\alpha = 1$, $\beta = 0$ and $\gamma = 0$, the P controller is acquired.

$$u(t) = k_p{}^{1-\alpha}(t)\, e(t) + k_i{}^{1-\beta}(t) \int e(t)dt + k_i{}^{1-\gamma}(t) \frac{d}{dt} e(t) \qquad (9)$$

To achieve an adequate system response for wide area of system operating condition, the PID controller must be properly chosen. This is because of the system performance depends on controller parameter. By considering two major factors, less overshoot and fast response system the optimization of parameter is compulsory. Affected from this, any upgrading of the controller later will come out with a vary significant results to the system performances.

3.4 Method of Tuning

Based on the effectiveness, stability and ITAE criterion, the Ziegler-Nichols tuning method has been selected as the method for defining the PID parameters. The parameters are 4500 for kp, 240000 for ki and -16.1 for kd. While the parameters setting for α,β and γ are nominated by looking the smallest RMS error of relative velocity (different between wheel speed and body speed) and the shortest stopping distance experienced by the vehicle from 343 simulations. All the parameters and the RMS values that have been used in these simulations can be observed at probability table under chapter result and discussion. From assessment, the best parameter for α,β and γ are 1, 0.95 and 0.03 respectively, in which the result no. 285 in the table.

Such as Figure 3.8, it can be said that the FPID generalizes the integer PID controller and expands it from point to plane. This expansion adds more flexibility to the controller design which can control the real world process more accurately.

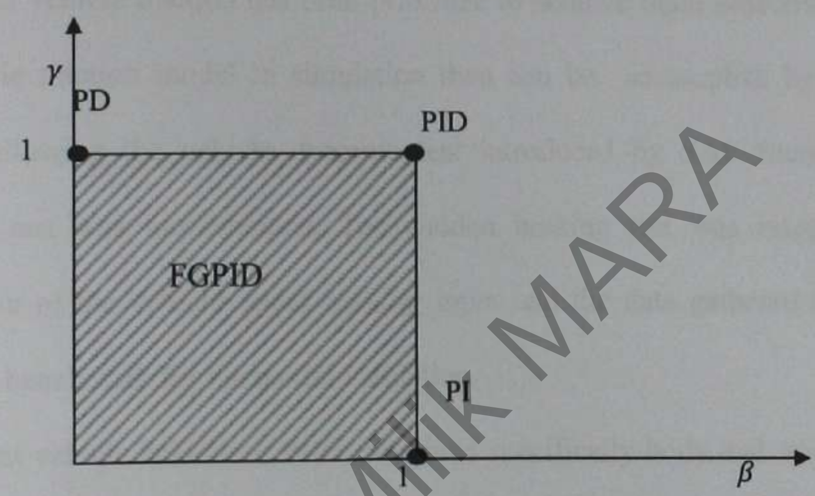

Figure 3.7: Expending from point to point

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result and Discussion Overview

From the beginning of this project, the important of constructing or developing an accurate a quarter vehicle traction has been prioritize to achieve main objective.The useable of quarter vehicle traction model in simulation then can be accomplish by experimental validation.By following the vehicle dynamic test introduced by SAE Standard J266,the sudden braking test was implemented. The sudden braking test was intended to study transient response of the vehicle under braking input and the data gathered from the tests were used as the benchmark for the model validation.

Significant vehicle behaviour were examined specifically body and wheel speed, tire longitudinal slip and distance travel experience by the vehicle. Outcome of the validation experiment shows that response between vehicle model and experimental vehicle are match with an acceptable error.It is understood that the acceptable error occur by considering the difficulties for the driver to keep a constant ideal speed during maneuvering and also due to the irregularities of road surface.This two factor is completely ignore in the simulation environment.

4.2 Validation Results

In order to get the best result from the model built, the data gathered must be validated. Validation is defined as the comparison of model's performance with the real system. Under this project, the validation for the model built in Matlab is by using visual technique. As agreed, comparison between experimental data and simulation results with same input signals was arrange for validation purpose.Noted that the validation does not mean the fitting of simulated data exactly to the measured data, but as gaining confidence that the vehicle simulation is giving insight into the behavior of the simulated vehicle reference.

From here the realistic of vehicle model input parameters can be examined and comparable whether it is reasonable or otherwise. For better understanding, model validation can be defined as determining the acceptability of a model by using some statistical tests for deviance measures or subjectively using visual techniques. Butterworth low pass filter, filter order 8 and pass band edge frequency 30 were used as filter for experimental data.

4.2.1 Validation of Quarter Vehicle Model at Constant Speed of 40 km/h

Under this section detail explanation on validation of quarter vehicle model at constant speed of 40 km/h are discussed. The results of model verification are shown in Figure 4.1. Figure 4.1 consists of different graph under this test. Figure 4.1(a) shows the vehicle speed applied for the test. For observation, trends between simulation results and experimental data are almost similar with acceptable error.

Resulting in an actual situation, that it is very hard for the driver to maintain the in a perfect speed, there are small difference in magnitude between simulation and experimental results compared to simulation.However from observation of body longitudinal acceleration validation, it can be seen that there are quite good comparisons during the initial transient phase as well as during the following steady state phase.

In Figure 4.1 (b) longitudinal slip responses of the tire also show satisfactory matching with only small deviation in the transition area between transient and steady state phases. Again, this deviation occurs resulting from difficulties of driver handling during maneuvering. Noted that in simulation the vehicle is set to be move on flat road during step steer maneuver. Another source of deviation on longitudinal slip response of the tires can be affected from irregular surface on track road profiles. Hence, this behavior has resulting the distance travel of the vehicle is up to 90 meters such as shown in Figure 4.1(c).

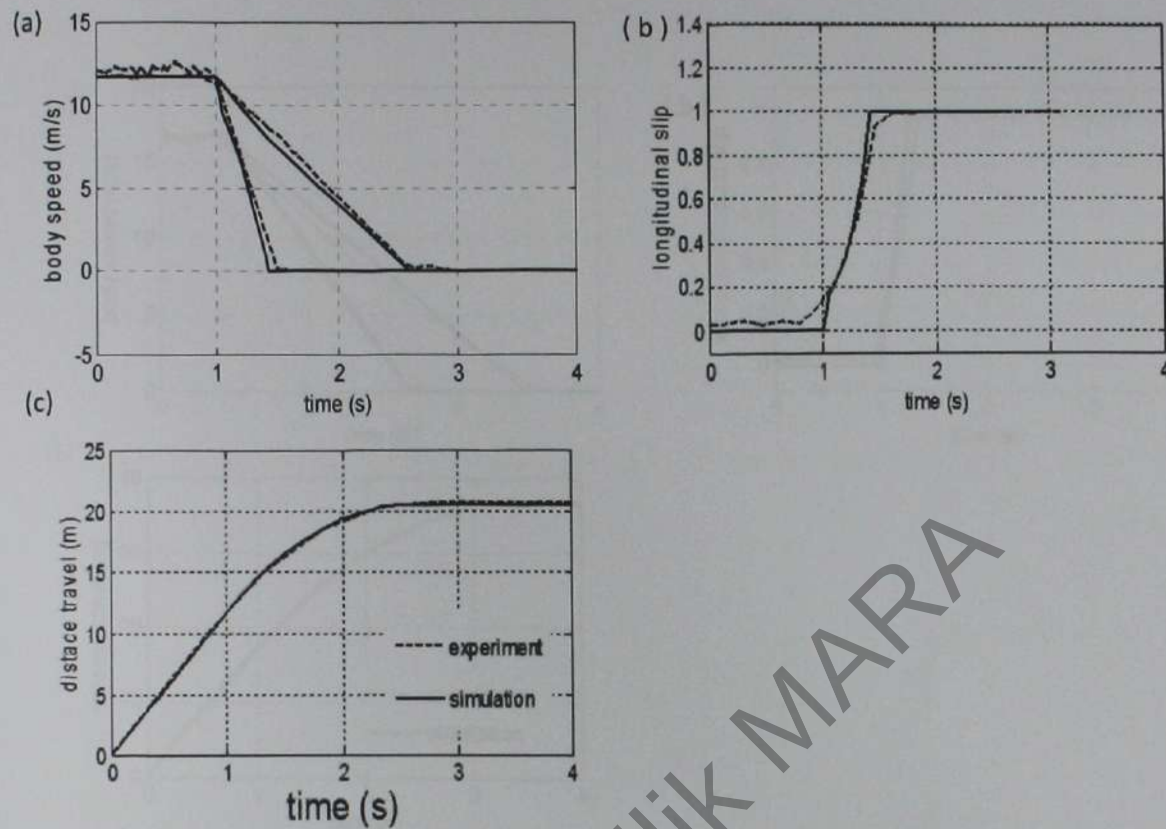

Figure 4.1: Response of quarter vehicle for sudden braking test at 40 km/h

4.2.2 Validation of Quarter Vehicle Model at Constant Speed of 60 km/h

Under this section detail explanation on validation of quarter vehicle model at constant speed of 60 km/h are discussed. Figure 4.2 shows all the validation results for sudden braking test at a 60km/h speed. Refer to Figure 4.2(a); responses of 2DOF quarter model are similar with experimental vehicle results for vehicle speed.

While in observation of tire longitudinal slip responses in Figure 4.2(b), the simulation response shows that there is a deviation during the braking phase and it is similar to experimental responses when the vehicle is completely stop. Some simplification and idealization are responsible for this deviation. However the distance travels responses between simulation and experimental are similar with acceptable error such as shown in Figure 4.2(c).

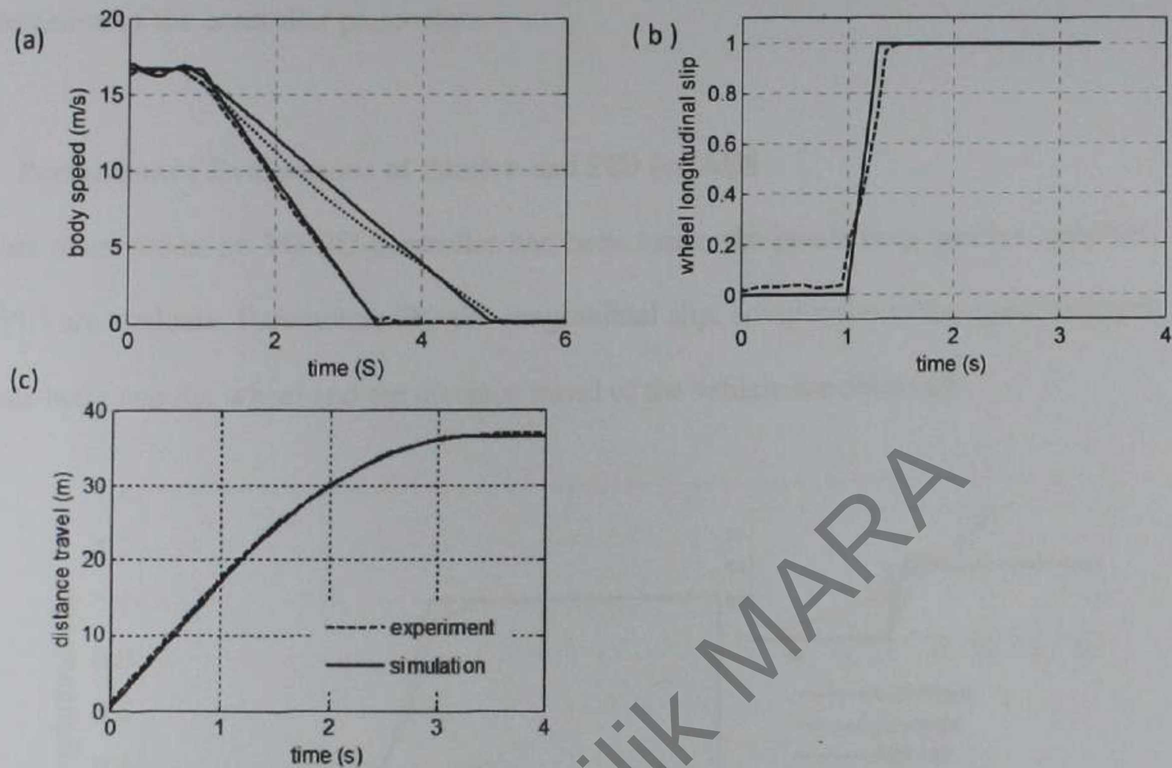

Figure 4.2: Response of quarter vehicle for sudden braking test at 60 km/h

For conclusion it can be seen that trends between simulation results and experimental data show good agreement with acceptable errors and suitable for this project purposes. Discussing on deviations involved , the response are believed to be caused by various simplifying modeling assumptions, mostly the consideration of negligible contributions due to constant forward speed, absence of wheel hop, and linear rolling radius properties.

Promoting fine tuning for both vehicle and tire parameters should significantly reduce the error augmentation. Yet, in this project purpose, excessive fine tuning works can be neglected since in control oriented model, the most important characteristic is the general trend of the model response. And their effect concern in this study of vehicle under sudden braking. From observation, the results suggest that the vehicle model with the two and six degree of freedom can predict or simulate the dynamic responses along the longitudinal axes reasonably well. The vehicle models behaviour indicates positive similarity to real vehicle. Objectively it can be established that the model is realistic and suitable to be used for optimization of the controller parameters.

4.3 Performance Evaluations of Passive and PID for ABS

Before observation on FGPID controller has been made, the result from passive condition and PID are evaluate. Parameters like tire longitudinal slip, comparison of the speed between vehicle body and the wheel and the distance travel of the vehicle are observed

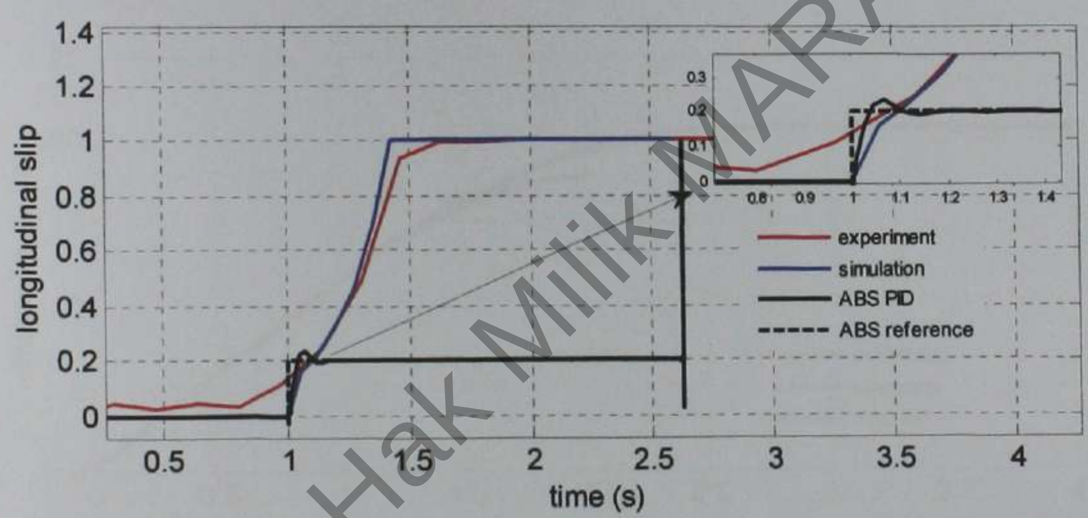

Figure 4.3: Longitudinal Slip response of quarter vehicle for sudden braking test at 40 km/h for Passive and PID controller

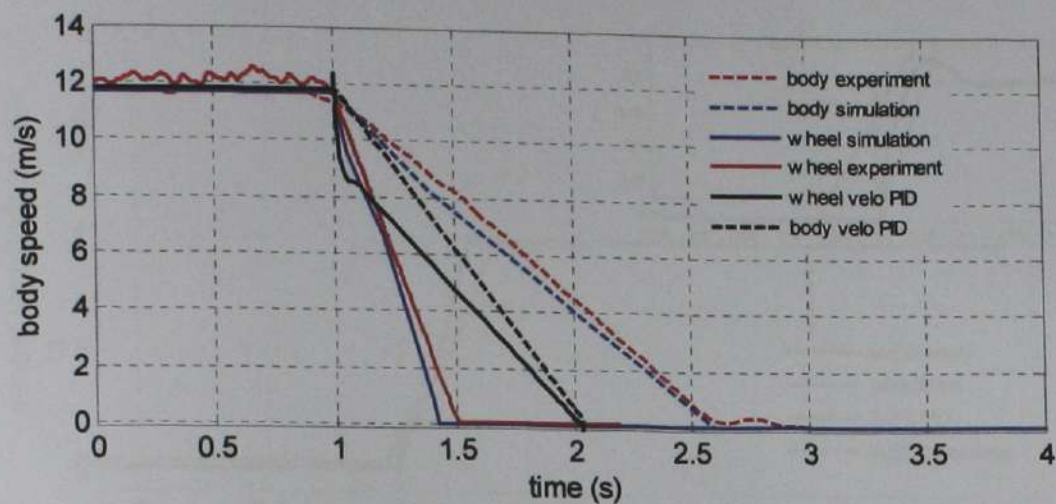

Figure 4.4: Body Speed comparison response of quarter vehicle for sudden braking test at 40 km/h for Passive and PID controller

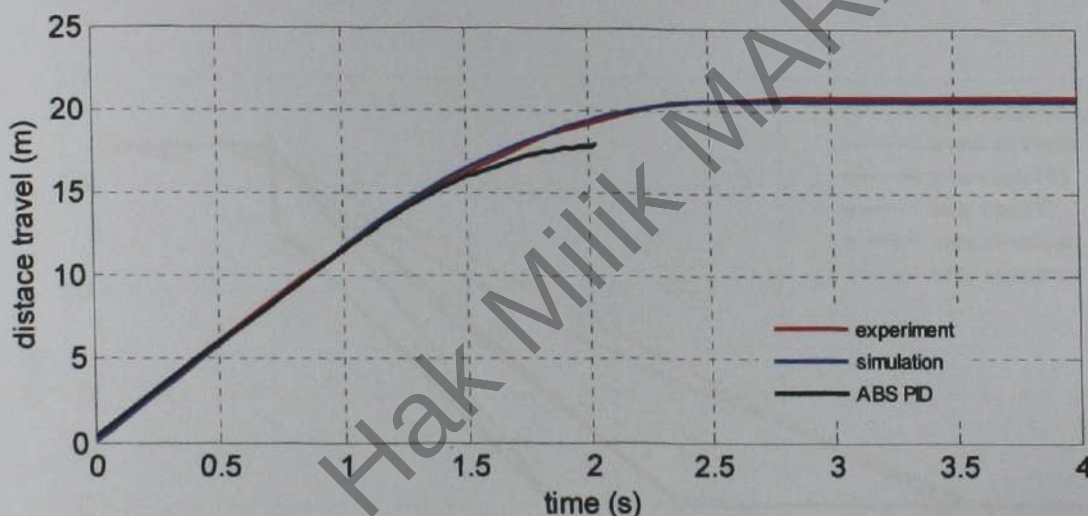

Figure 4.5: Distance Travel response of quarter vehicle for sudden braking test at 40 km/h for Passive and PID controller

. Sudden braking test will be performing under 40kmh and 60kmh only.figure 4.3,4.4 and 4.5 shows the response of quarter vehicle for sudden braking test at 40 km/h for Passive and PID controller and figure 4.6,4.7,4.8 for 60kmh. However the road coefficient is different since the Passive experiment are produce on dry road surface conditions while the PID result are based on icy road condition in simulation.

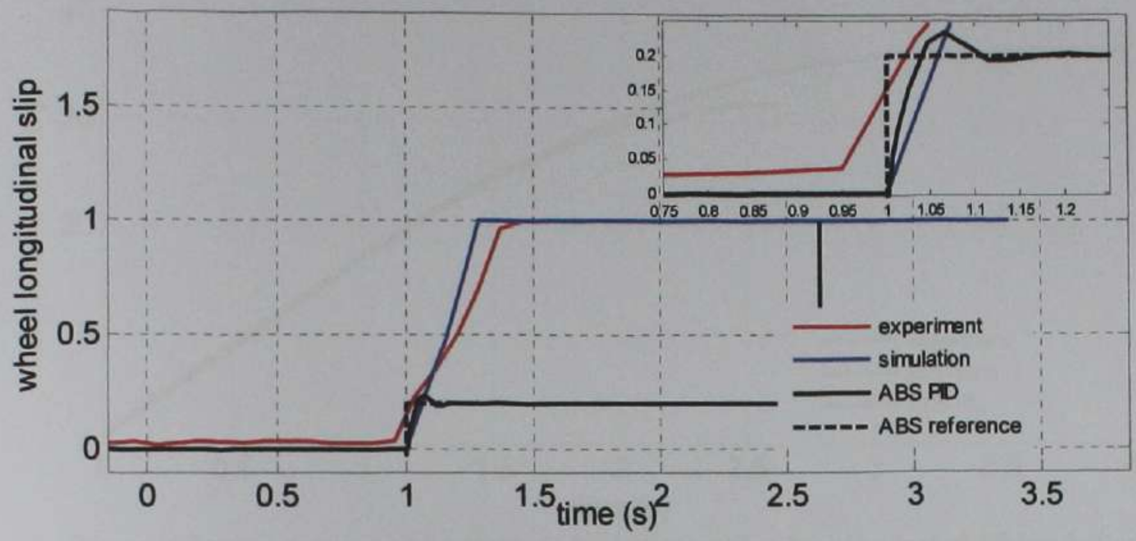

Figure 4.6: Longitudinal Slip response of quarter vehicle for sudden braking test at 60 km/h for Passive and PID controller

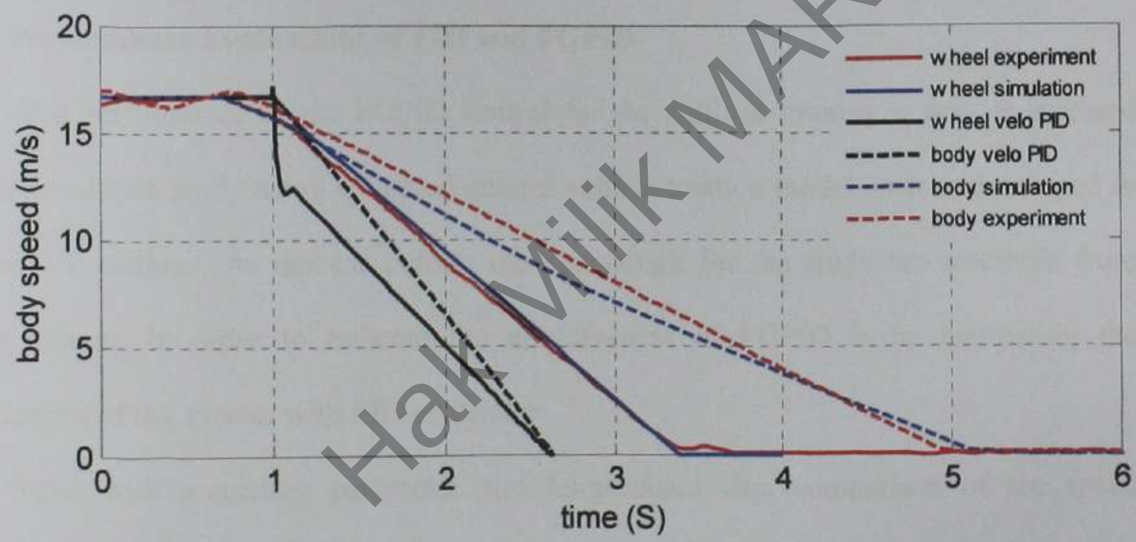

Figure 4.7: Body Speed comparison response of quarter vehicle for sudden braking test at 60 km/h for Passive and PID controller

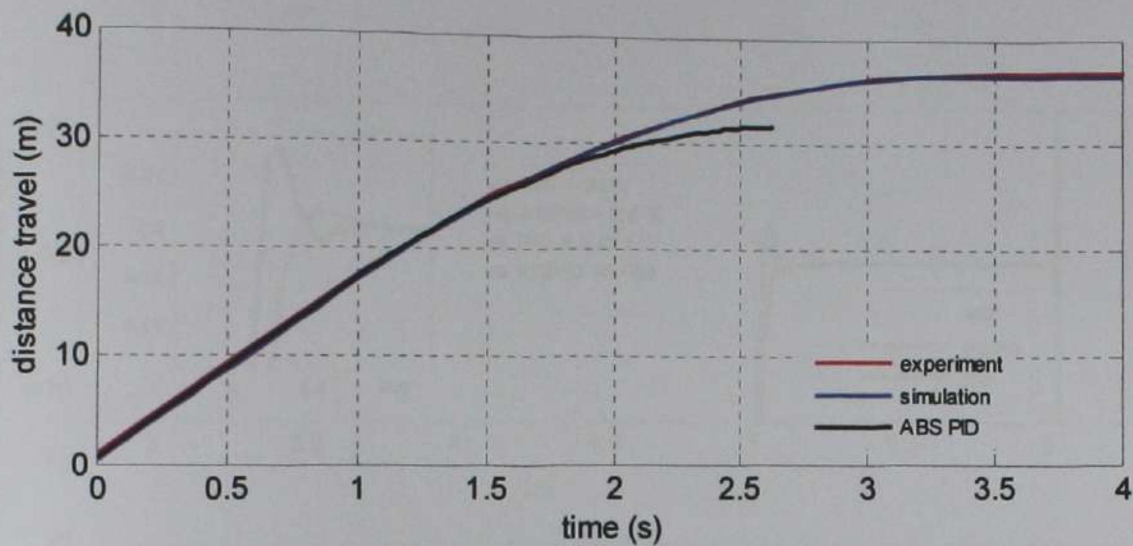

Figure 4.8: Distance Travel response of quarter vehicle for sudden braking test at 60 km/h for Passive and PID controller

4.4 Performance Evaluations of PID and FGPID

The performance of the FGPID control for the antilock braking system is assessed through simulation study using validated quarter vehicle traction model such as developed in previous 4.1 sections. As discuss before, the benchmark for the study are assemble from passive system. In order to indicate the effectiveness of FGPID is by comparing the performances of the system with PID controller.

Same with preceding parameter, tire longitudinal slip, comparison of the speed between vehicle body and the wheel and the distance travel of the vehicle are observed. This performance also will use the numerical parameters of validated model of quarter car model. Sudden braking test will be performing under 40kmh, 60kmh and 110kmh.

4.4.1 Sudden Braking Test at Constant Speed of 40 km/h

Figures 4.9 shows the simulation results on sudden braking test at 40kmh.From graph itself, the trend of both parameters can be perceive and it clearly visualize that Fractional Gain PID controller is better than PID controller.

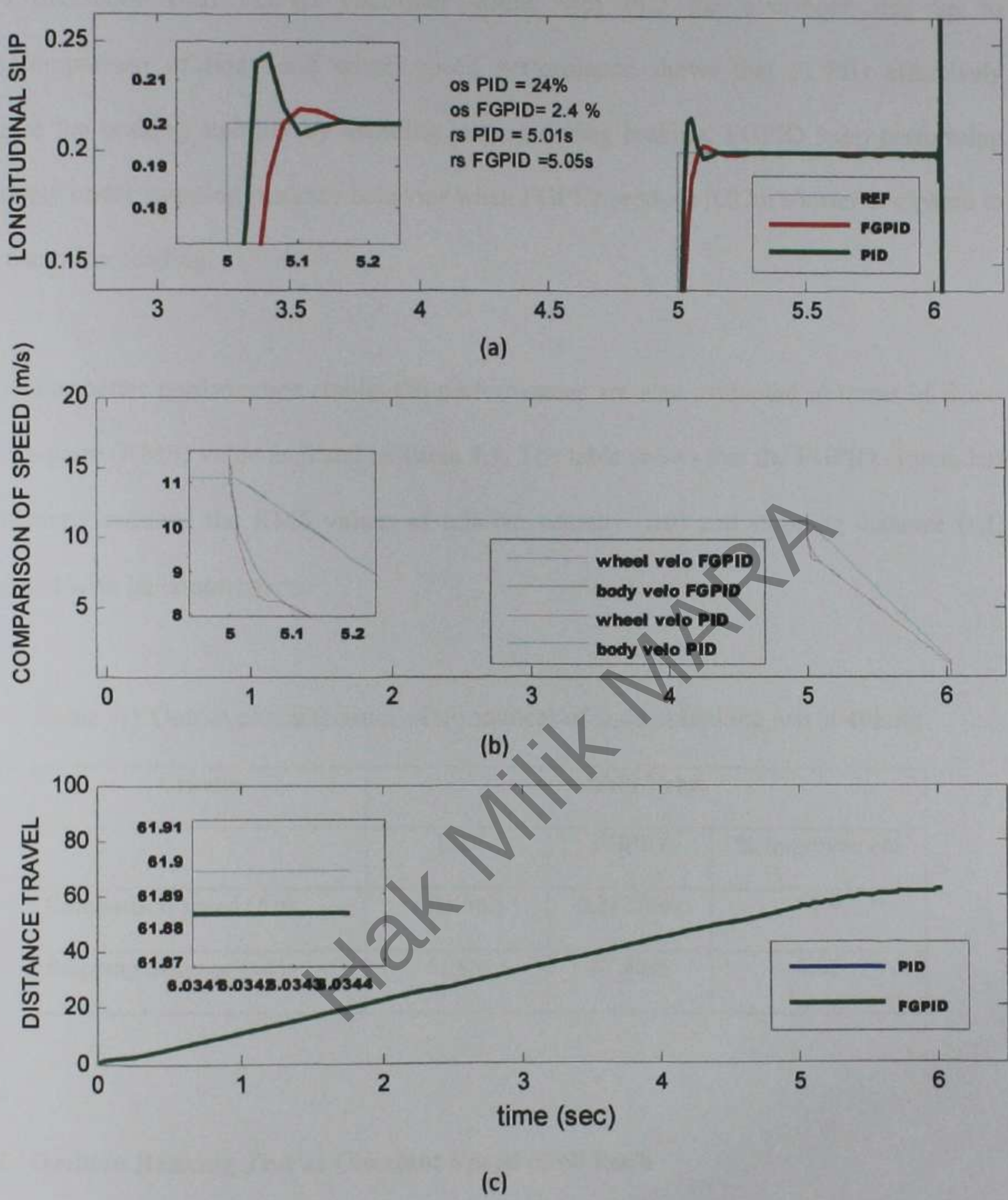

Figure 4.9: Responses of the proposed controller on sudden braking test at 40kmh for PID and FGPID controller

It is proven under observation of figure 4.9(a) where slip response indicates only 2.4% overshoot with FGPID controller while with PID the overshoot rise up to 24%.Comparison of body and wheel speed performance shows that FGPID effectively enhance the braking stability by avoiding jerking during braking. FGPID keep performing positively under stopping distance behavior when FGPID produce 0.02m shorter compared to PID controller reading.

For better performance results the performances are also evaluated in terms of Root-Mean-Square (RMS) value as listed in Table 4.1. The table shows that the FGPID system has significantly reduced the RMS values of relative velocity (Δv) and stopping distance (sd) compared with its counterparts.

Table 4.1 Output characteristics performances of sudden braking test at 40kmh

Criteria	RMS Value		
	PID	FGPID	% Improvement
Comparison speed (Δv)	1.059m/s	0.2127m/s	79.9
Stopping distance (sd)	61.9m	61.88m	0.02

4.4.2 Sudden Braking Test at Constant Speed of 60 km/h

During sudden braking test at constant speed of 60kmh,better performance achieve when FGPID record faster slip tracking in the first 0.01 after braking compare to PID performance. FGPID also produce faster rise time at 0.01 second. These parameters can be observed in Figure 4.10.through results, FGPID only create 4.7% overshoot compare to PID(13%).PID controller create consequential a high overshoot and eventually reduce the settling time as compared to FGPID

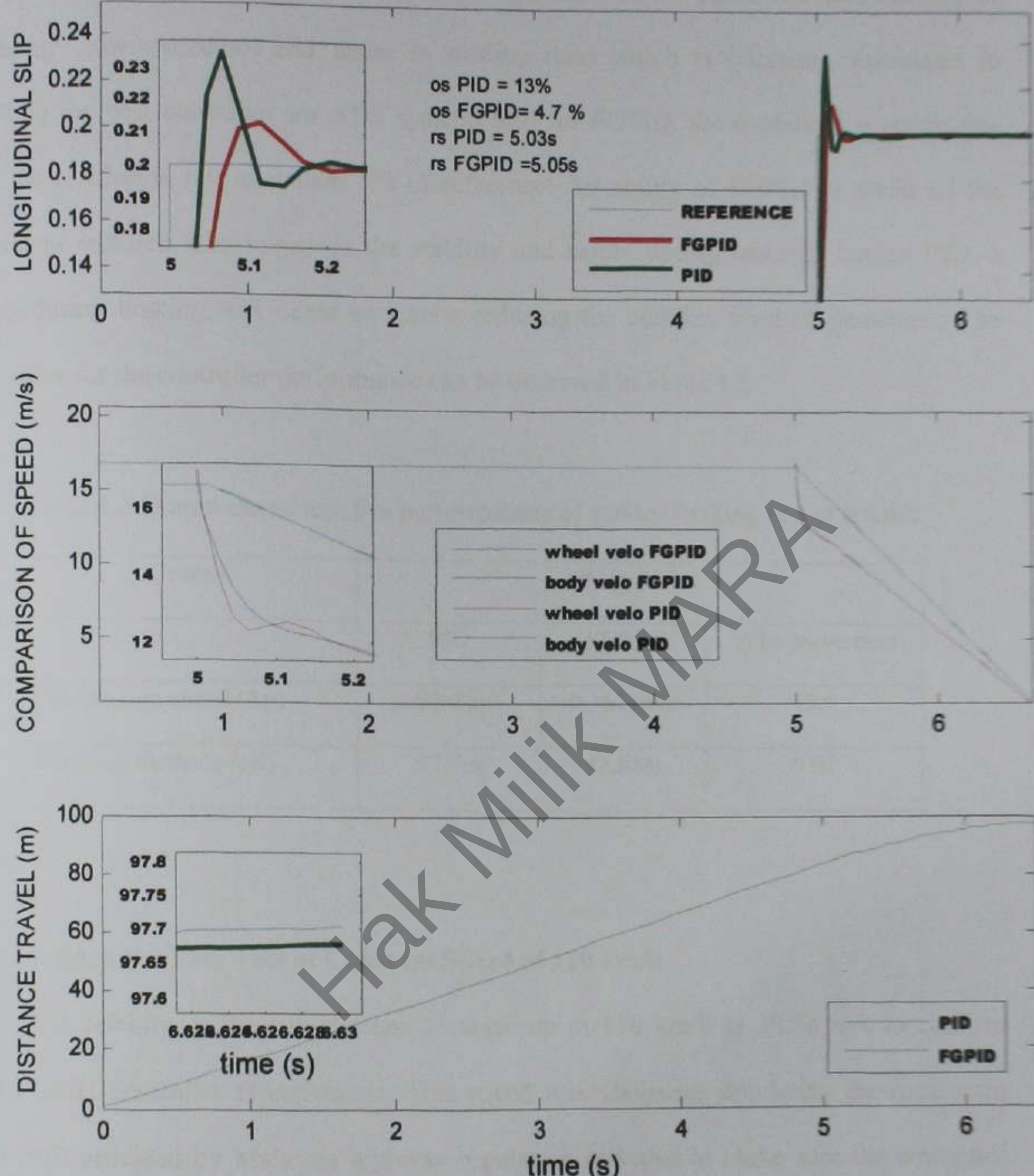

Figure 4.10: Responses of the proposed controller on sudden braking test at 60kmh for PID and FGPID controller

By referring to figure 4.10,PID controllers seems to dominating the performance especially during parameter of fast rise time, but the FGPID put a constant reading of producing low overshoot and faster in settling time which is necessary parameter in providing the best controller for ABS system. Still for FGPID, the overshoot is acceptable since the reading is not over than 5% of reference. An ability of FGPID to attain all the parameters required also improves the stability and safety during braking. Unlike PID, a jerking during braking will occur as results reducing the comfort level of passenger. The RMS value for the controller performance can be observed in Table 4.2.

Table 4.2 Output characteristics performances of sudden braking test at 60kmh

Criteria	RMS Value		
	PID	FGPID	% Improvement
Comparison speed (Δv)	0.8068m/s	0.1621m/s	79.9
Stopping distance (sd)	97.7m	97.68m	0.02

4.4.3 Sudden Braking Test at Constant Speed of 110 km/h

The velocity of the vehicle then increase up to 110 km/h ≅ 30.56 m/s to confirm about FGPID controller effectiveness. This speed was choosing simulating the maximum speed limit provided by Malaysia highway regulation and also to make sure the controller produce good tracking slip. From the simulation results found that the controller accomplish to any constant speed in test. Graphically presented in figure 4.11, as the vehicle speed changes from 40kmh up to 110kmh the FGPID still perform remarkably following the target slip with a minimum overshoot and minimum settling time as compared to PID controller. Significance of this, resulting on stability of vehicle during maneuvering as well as during braking.

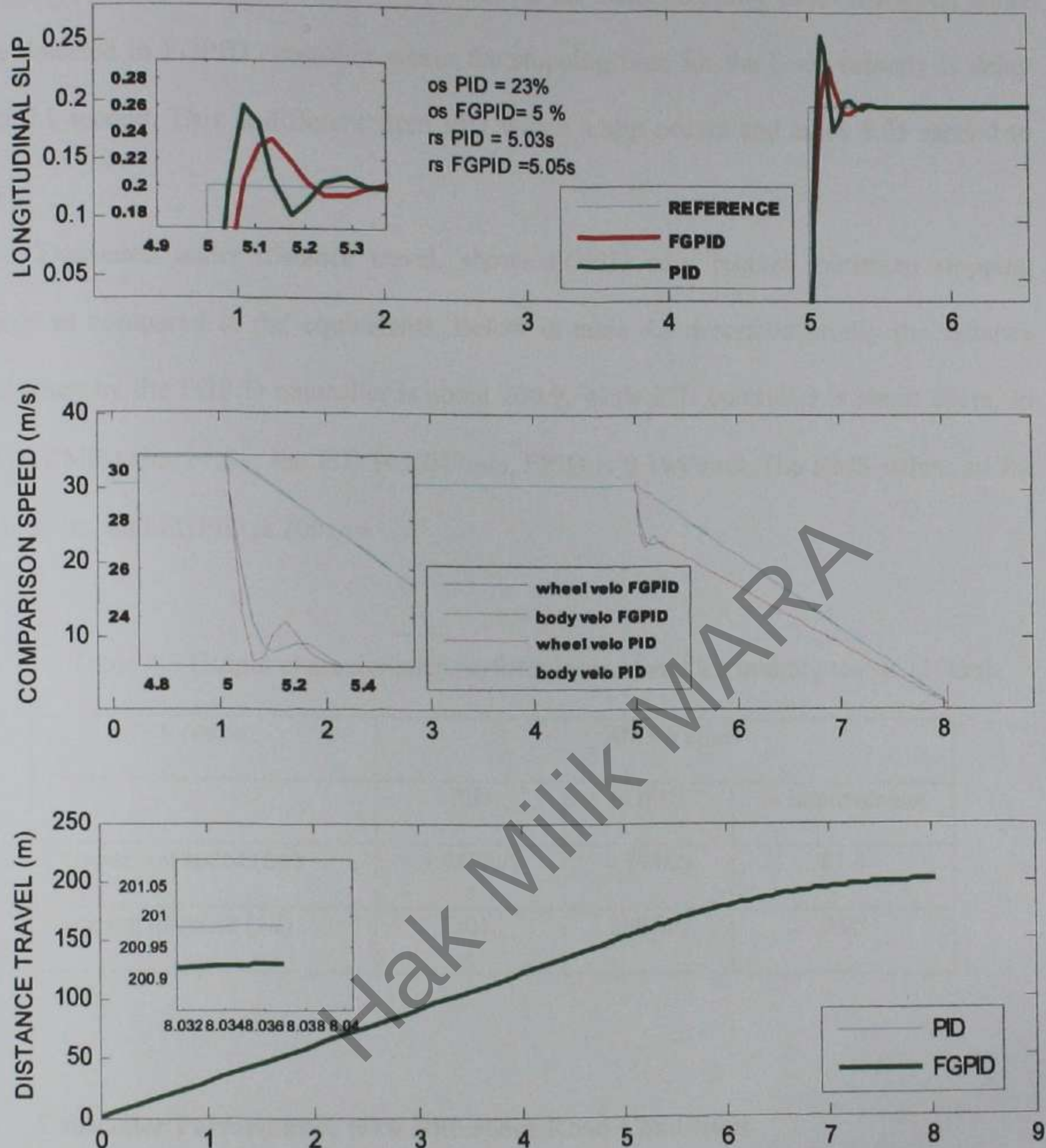

Figure 4.11: Responses of the proposed controller on sudden braking test at 110kmh for PID and FGPID controller

By inspecting speed comparison, it is obvious that velocity of the body attempt to converge with the wheel velocity and producing the same stopping time. However, some delay detected in FGPID controller where the stopping time for the body velocity is delay about 0.1 second. This is different from PID which a slip occurs and takes 8.05 second to stop.

Translated under distance travel, shows FGPID only require minimum stopping distance as compared to the equivalents. Below in table 4.3 described briefly the distance travel taken by the FGPID controller is about 200.9, while PID controller is about 201m. In term of RMS value of Δv, the PID is 1.047m/s, FPID is 0.1946m/s .The RMS value sd for PID is 201m, and FGPID is 200.9m.

Table 4.3 Output characteristics performances of sudden braking test at 110kmh

Criteria	RMS Value		
	PID	FGPID	% Improvement
Comparison speed (Δv)	1.047m/s	0.1946/s	81.4
Stopping distance (sd)	201	200.9m	0.05

4.5 Controller Performance with Difference Road Conditions

As conclusion from this chapter, by evaluating the performance of FGPID throughout all tests, particularly the capability of this proposed controller, it is proved that it is meet the necessity to be used with ABS system. Minimum overshoot, minimum rise time and the shortest settling time are successfully accomplished under FGPID controller.

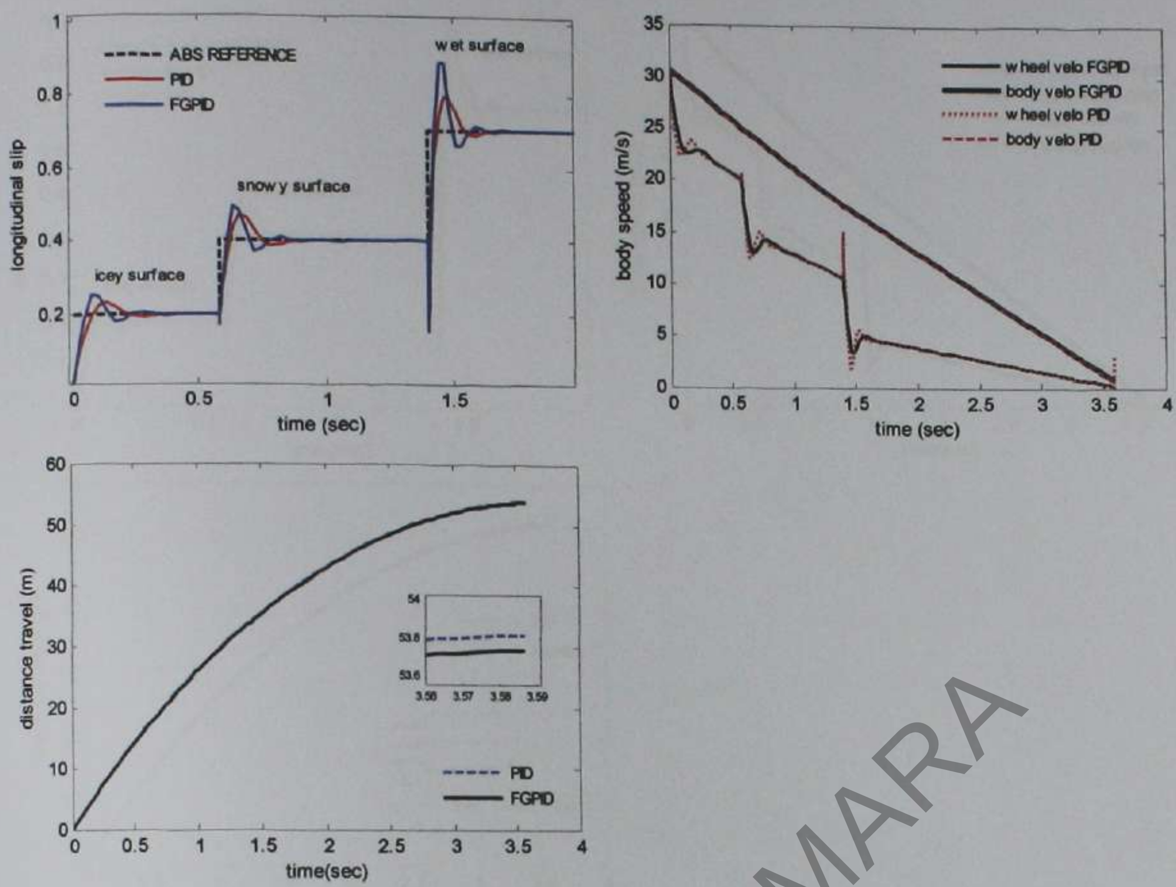

Figure 4.12: Controller performance with difference road conditions at 40kmh

Extensions from the results gathered, the FGPID controller than simulate under the various type of road conditions. Regularly the road condition can be divided by a few circumstances for example a 'normal' road condition, a 'wet' road condition and a 'snowy/icy' road condition. Compilation of graph in figure 4.12 and figure 4.13 shows the status of FGPID under difference road condition prioritize at 40kmh and 60kmh.

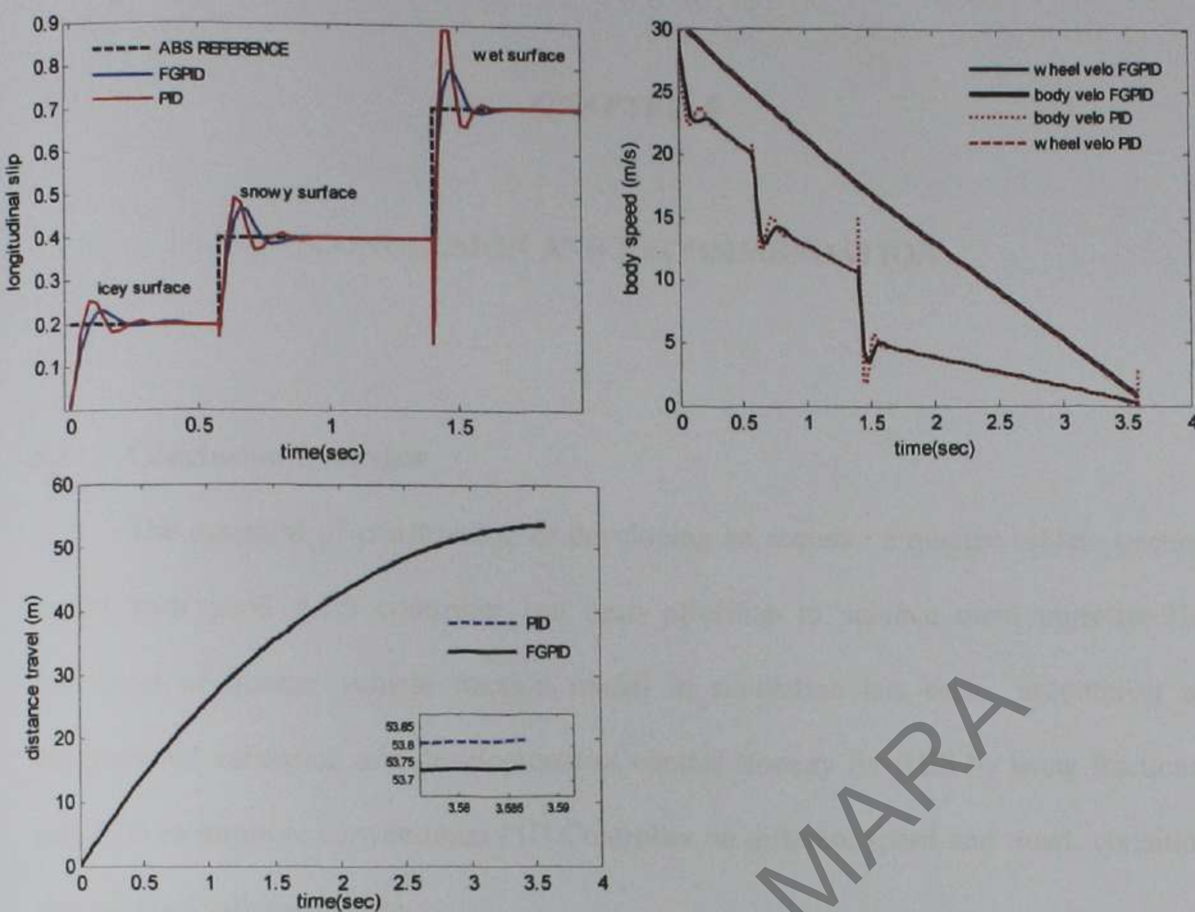

Figure 4.13: Controller performance with difference road conditions at 60 kmh

Overall result based on tire friction (0.2, 0.4 and 0.7) reference still shows the dominance of FGPID on ABS system. Since the model is test (simulation) under maximum tractions conditions (icy surface 0.2), the result of FGPID always better from PID. However on certain conditions like (0.7) wet surfaces, the overshoot for FGPID seems over the value of 5% from reference. This condition might be occurring from simplification make or tuning capability. As the FGPID controlled variable is on the wheel slip, the performance of stopping distance also improves. Though, both of PID and FGPID, slip still occur at the end of the dynamic. Hence, as the purpose of this project to improve stability during braking, it can be determine that this controller is most efficient for ABS controller.

fastest in the stopping time. Noted that vehicle dynamic test which is sudden braking test was used in simulating the ABS on the speed of 60 km/h at icy road situation and the speed were increased up to 110kmh to ensure the performance of FGPID during critical or extreme circumstances.

5.2 Recommendation

The performance of controller is compared with passive and PID. By these characters, it is assumed that the vehicle will be more stable and safety during braking as well as during the emergency braking taken by the driver. As a result, a skidding during braking could be overcome and the risk of accidents can be reduced significantly.

By comparing the responses of the proposed controller structure with the fractional gain PID, conventional PID controller and passive system, the results verified that the proposed control technique proved to be effective in controlling the ABS system. Besides that, this controller technique also can propose as an effective tool in future to be use with an anti-lock braking system.

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APPENDICES

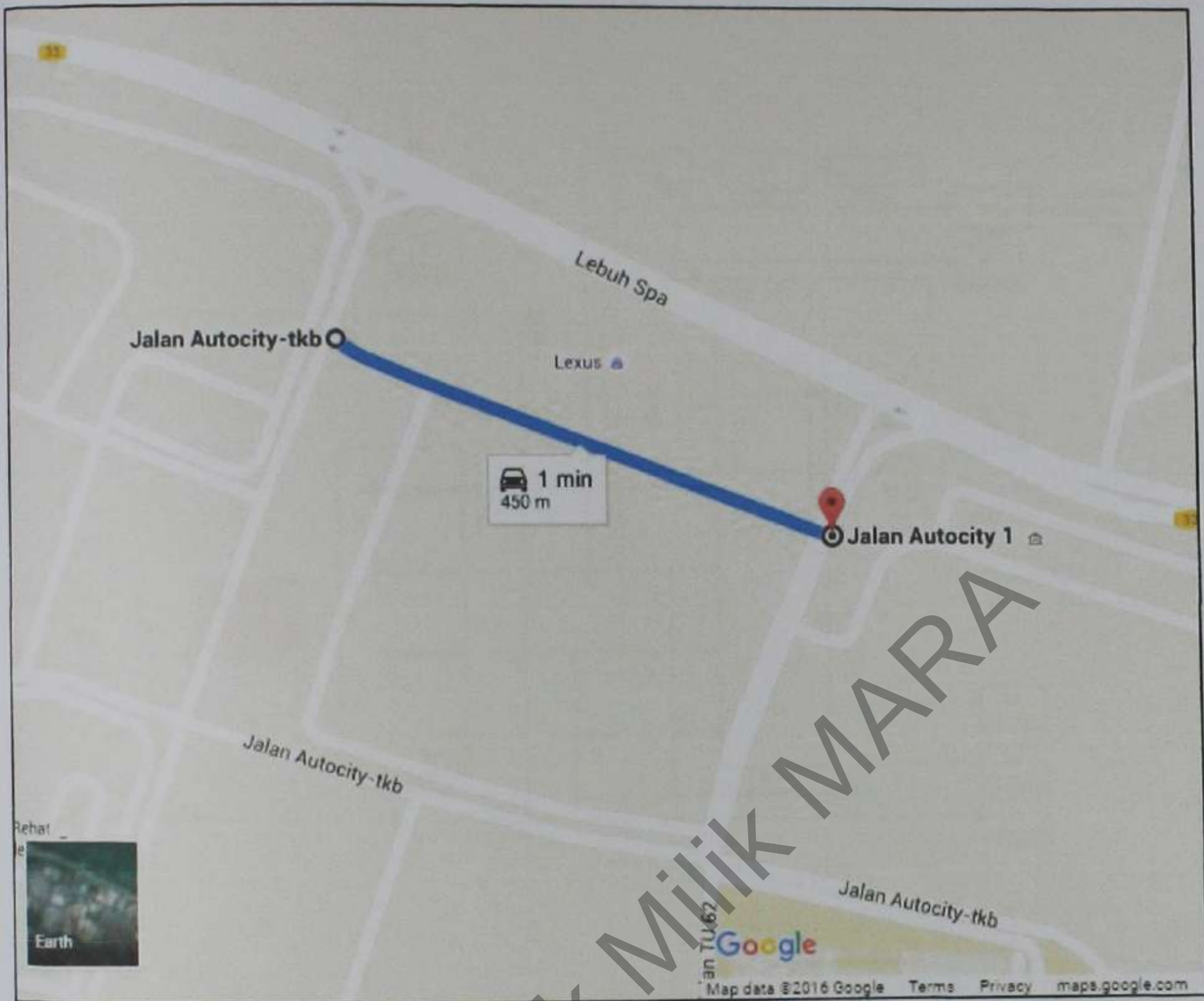
APPENDIX A

Technical Specification Of The Vehicle

PROTON SAGA ISWARA 1.3 MANUAL TRANSMISSION MANUAL (75 BHP)		
Dimensions		 
Body:	Sedan	
Doors:	4	
Seats:	5	
Length:	4280 mm	
Width:	1655 mm	
Height:	1360 mm	
Trunk Size:	315 litres	
Wheel Base:	2380 mm	
Front Track:	1390 mm	
Back Track:	1340 mm	
Clearance:	150 mm	
Engine details		
Engine Type:	Gasoline	
Engine Size:	1298 cc	
Power:	75 bhp	
Power @:	6000 rpm	
Torque:	108	
Fuel Distribution:	OHC	
Cylinders model:	Straight	
Cylinders #:	4	
Valves Per Cylinder:	3	
Cylinders Diameter:	71 mm	

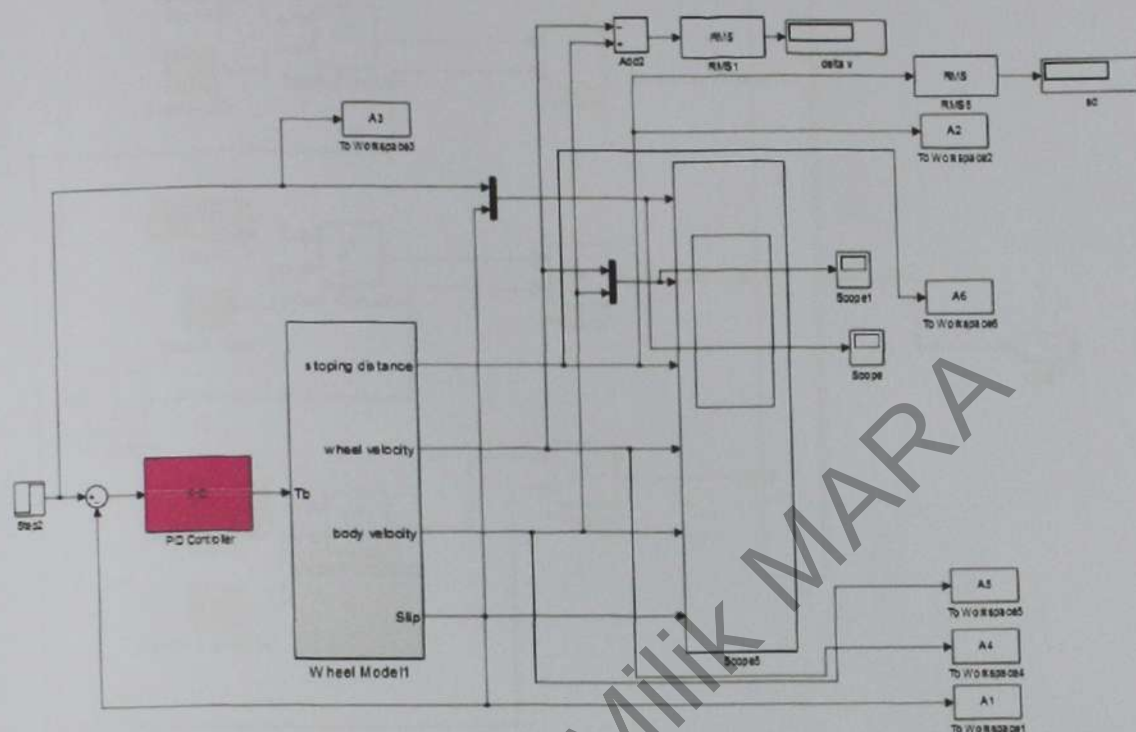
APPENDIX B

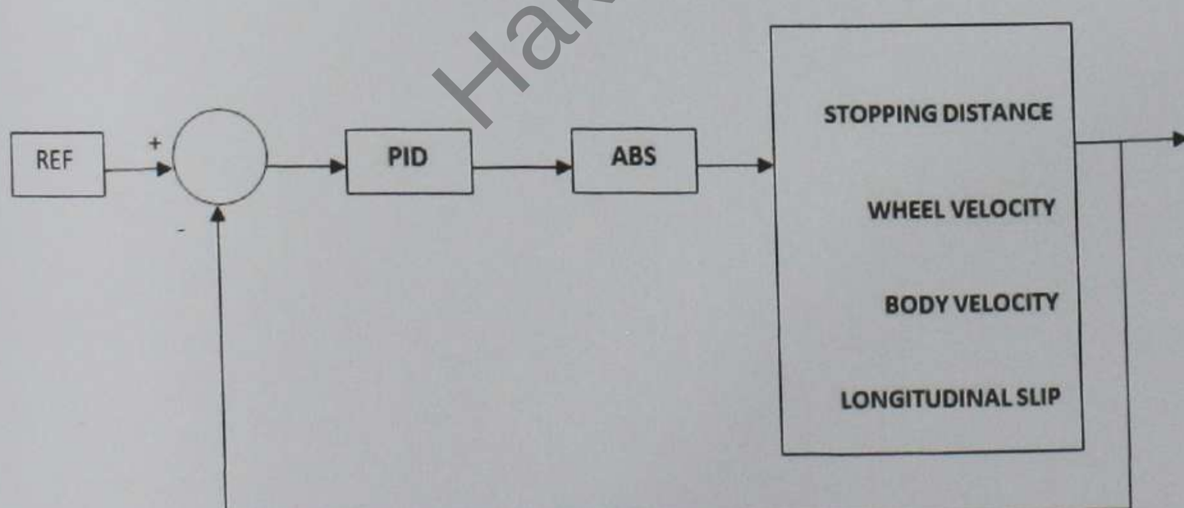
Experiment Track Location



APPENDIX C

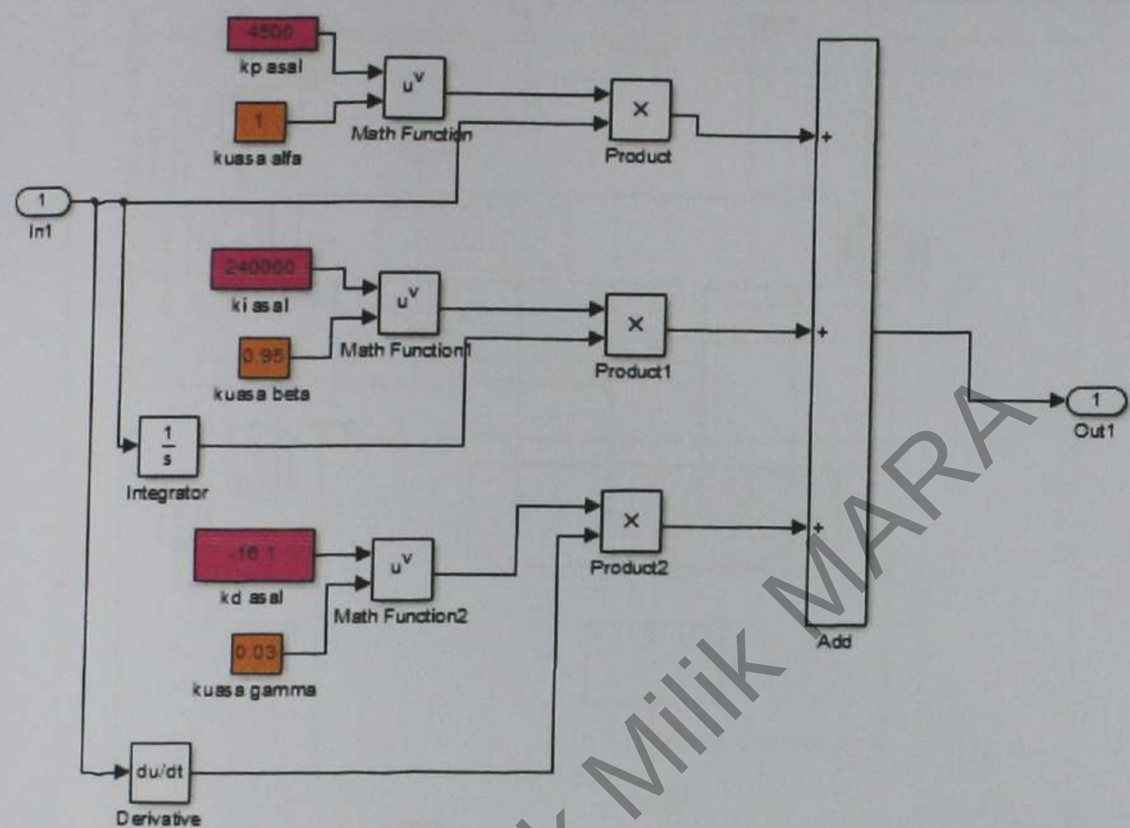
PID Structure





APPENDIX D

FGPID Structure



APPENDIX E

FGPID Structure