MODELLING AND SIMULATION OF LANE KEEPING CONTROL SYSTEM

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

I declare that this project report entitled “Modelling and Simulation of Lane Keeping Control System” is the result of my own work except as cited in references.

Signature : ....

Name : Hazwan bin Hussin

Date : ....

PENGAKUAN

Saya akui laporan ini yang bertajuk “Pemodelan dan Simulasi Sistem Kawalan Pengendalian Lorong” adalah hasil kerja saya sendiri kecuali yang dipetik daripada sumber rujukan.

Tandatangan : ....

Nama : Hazwan bin Hussin

Tarikh : ....

APPROVAL

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

Signature	:	…………………………
Supervisor's Name	:	…………………………
Date	:	…………………………

PENGESAHAN PENYELIA

Saya akui bahawa telah membaca laporan ini dan pada pandagan saya laporan ini adalah memdai dari segi skop dan kualiti untuk tujuan penganugerahan Ijazah Sarjana Muda Kejuruteraan Mekanikal.

Tandatangan : ……………………………

Nama penyelia : ……………………………

Tarikh : ……………………………

DEDICATION

To my supervisor Dr. Amrik Singh A/L Phuman Singh,

My beloved father Hussin bin Md. Rusdi,

My beloved mother Zurina binti Zakaria,

My Brother and Sisters,

My supportive fellow friends,

Thank you for continues support and for everything.

ABSTRACT

The automotive sector is one of the world's leading industries. This industry now is toward a revolution from year to year. The automotive industry consists of many companies and organizations engaged in vehicle design, development, distribution, commercialization, and sales. For autonomous vehicles it is beginning to attract many automakers to make changes of technology and to be at a more advanced level. One of the technologies of autonomous vehicle is a lane keeping control system (LKS) which to keep the vehicle from exit the lane of the road. This system helps to prevent a collision or in an emergency situation. For the objective of this study is to create a mathematical model for the vehicle handling dynamics and to design the lane keeping control system by using PID controller. The scope of this study is to develop a non-linear vehicle handling dynamic model by using MATLAB and Simulink as well as to design the control strategy for lane keeping system. This study is uses two degree of freedom (2DOF) of bicycle model and nonlinear tire model as its vehicle system model to analyze the behavior of vehicle system. The simulation takes place in the MATLAB and Simulink constructs the mathematical model. In this contribution the mathematical modeling of a vehicle equipped with a lane keeping control system is considered. Therefore, the modeling considers the steering model of the vehicle and the vehicle itself as a bicycle model. In this study there are three major components need to be conducted to verify the vehicle system. The first one is the equation of vehicle model which is in this project its use the bicycle model. In the vehicle model there are two parameters need to consider which is the side slip angle and yaw rate. Second is the tire model itself, by combining the tire model and vehicle model, the performance of the vehicle can be determined for side slip angle and yaw rate. Third, is the controller that are using in this study which is the PID controller. The controller take place in the vehicle system is to tune up the control structure of the vehicle and to find a good model structure to perform in the simulation. The graph of the vehicle system will show the behavior of the vehicle after running the simulation. This study concludes by summarizing all the results from vehicle model and the controller.

ABSTRAK

Sektor automotif adalah salah satu industri terkemuka di dunia. Industri ini kini menuju revolusi dari tahun ke tahun. Industri automotif terdiri dari banyak syarikat dan organisasi yang terlibat dalam reka bentuk, pengembangan, pengedaran, pengkomersialan, dan penjualan kendaraan. Bagi kenderaan autonomi, ia mula menarik banyak pembuat kenderaan untuk membuat perubahan teknologi dan berada pada tahap yang lebih maju. Salah satu teknologi kenderaan autonomi adalah sistem kawalan pengendalian lorong (LKS) yang menjadikan kenderaan tidak keluar dari lorong atau jalan. Sistem ini membantu mencegah perlanggaran atau dalam keadaan kecemasan. Untuk objektif kajian ini ia bertujuan untuk mengembangkan model matematik untuk dinamika pengendalian kenderaan dan merancang sistem kawalan menjaga lorong dengan menggunakan pengawal PID. Skop kajian ini adalah untuk mengembangkan model dinamik pengendalian kenderaan nonlinear dengan menggunakan MATLAB dan Simulink serta merancang strategi kawalan untuk sistem pengendalian lorong. Kajian ini menggunakan dua darjah kebebasan (2DOF) model basikal dan model tayar bukan linier sebagai model sistem kenderaan untuk menganalisis tingkah laku sistem kenderaan. Simulasi akan dilakukan dalam MATLAB dan Simulink pula akan merangka model matematik. Dalam sumbangan ini, pemodelan matematik kenderaan yang dilengkapi dengan sistem kawalan pengendalian lorong akan dapat dipertimbangkan. Oleh hal demikian, pemodelan akan dapat menganggap model stereng kenderaan dan kenderaan itu sendiri adalah sebagai model basikal. Dalam kajian ini terdapat tiga komponen utama yang perlu dijalankan untuk menentukan sistem kenderaan. Yang pertama adalah persamaan model kenderaan yang dalam kajian ini menggunakan model basikal. Dalam model kenderaan terdapat dua parameter yang perlu dipertimbangkan ia merupakan sudut slip sisi dan kadar yaw. Kedua adalah model tayar itu sendiri, dengan menggabungkan model tayar dan model kenderaan, tingkah laku kenderaan dapat ditentukan untuk sudut slip sisi dan kadar yaw. Ketiga, adalah pengawal yang digunakan dalam kajian ini, ia merupakan pengawal PID. Pengawal yang berlaku dalam sistem kenderaan adalah untuk menyesuaikan struktur kawalan kenderaan dan mencari struktur model yang baik untuk dilakukan dalam simulasi. Grafik sistem kenderaan akan menunjukkan tingkah laku kenderaan setelah menjalankan simulasi. Kajian ini diakhiri dengan meringkaskan semua hasil dari model kenderaan dan pengawal.

ACKNOWLEDGEMENT

I would like to convey grateful to Allah AWT, who with His willingly offer me the chance to realize my final year project with title "Modelling and Simulation of Lane Keeping Control System".

Special thanks to my supervisor Dr. Amrik Singh A/L Phuman Singh, who had guided me a lot of a tasks through the past one year. He always provides guidance, support and technical expertise enthusiastically and patiently whenever I encounter any issue regarding my final year project and including academic and career aspects.

My completion of this project could not have been accomplished without the support of my friends, Anwar, Rohayu, and Luqman. Thank you for allowing your time to give an idea for my final project. Million thanks to my lovely family, my mother, father, and my siblings for always give an encouragement during my journey to complete this degree. Finally, thanks to everyone who was directly and indirectly involved in helping me to finish this project.

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LIST OF SYMBOLS

α	-	Sideslip of tire
α_f	-	Slip angle of front tire
α_r	-	Slip angle of rear tire
β	-	Sideslip angle
C	-	Lateral axle cornering stiffness
C_a	-	Lateral stiffness of the tires
$C_{\alpha o}$	-	Tire sideslip coefficient.
C_s	-	Longitudinal stiffness of the tires
$C_{\lambda o}$	-	Tire slip coefficient
e_{la}	-	Lookahead error
F_f	-	Cornering force of front tires
F_r	-	Cornering force of rear tires
F_x	-	Longitudinal tire force
F_y	-	Lateral tire force
F_z	-	Vertical load forces of the tires
F_{yf}	-	Front tire front
F_{yr}	-	Rear tire force
g	-	Gravitational
I_z	-	Yaw moment of inertia
K	-	Vehicle understeer gradient
l_f	-	Front axle length

l_r	-	Rear axle length
m	-	Mass
r	-	Yaw velocity
S	-	Longitudinal slip ratio of tires
V_x	-	Vehicle speed
W_f	-	Normal load front axle
W_r	-	Normal load rear axle
$\dot{y}_c$	-	Lateral direction
y_c	-	Lateral displacement
δ_f	-	Angles the front wheel
δ_r	-	Angles the rear wheel
$\dot{\varnothing}$	-	Yaw rate
$\varnothing$	-	Yaw angle
λ	-	Tire slip
δ	-	Steering angle
μ_{max}	-	Maximum friction coefficient

LIST OF ABBREVIATION

ABS	-	Antilock braking system
ACC	-	Adaptive cruise control
AFS	-	Active front steering
ASEAN	-	Association of South East Asian Nations
C.G	-	Centre of gravity
DYC	-	Direct yaw-moment control
ESC	-	Electronic stability control
FLC	-	Fuzzy logic control
JPJ	-	Jabatan pengankutan jalan
LDW	-	Lane departure warning
LKAS	-	Lane keeping assistance system
LKS	-	Lane keeping system
LQR	-	Linear Quadratic Regulator
MATLAB	-	MATrix LABoratory
MIROS	-	Malaysia Institution of Road Safety Research
PID	-	Proportional-Integral-Derivative
SISO	-	Single input and single output plant
TCS	-	Traction control system
2 DOF	-	Two Degree of Freedom
3 DOF	-	Three degree of freedom
4WS	-	Four-wheel steering

CHAPTER 1

INTRODUCTION

1.1 Motivation

Almost daily news of tragic accidents resulting in serious injuries, loss of life and loss of property published in the mass media. This situation shows that accidents are a serious problem that is difficult to overcome. The most factor that leads to road fatalities, human negligence is the main factor. Many drivers like to drive recklessly, they also do not comply with the rules and regulations of the road. In addition, the condition of the car is also the cause of the accident. Many vehicle owners do not maintain their vehicles properly. This situation causes vehicle components such as brakes and tires to fail to function properly. This causes the vehicle to get out of control and can easily break out while driving.

Every year, large numbers of casualties occur around the world. Over 1.25 million people die every year from road fatalities, an average of 3,297 fatalities a day. An addition of about 20 to 50 million are wounded or disabled. For low and middle-income countries with less than semi of the world’s vehicles over 90 percent of all road fatalities happen. Meanwhile, the ninth-most serious cause of death is traffic accidents, accounting for 2.2 percent of all fatalities worldwide (Global status report on road safety, 2018). For the analysis and comparison, Table 1.1 shows road safety ranking status among ASEAN country year 2013 (Global Status Report on Road Safety, 2015). According to this data, Malaysia ranks fourth for the highest number of deaths among ASEAN countries. Based on the road accident data in Malaysia 2011, factors that lead to the accident are assumed to be at 80.6 percent due to human carelessness, 13.2 percent caused by road condition while 6.2 percent of accidents caused by vehicle condition reference by MIROS (2011). In fact, every year we can see the increase of accidents and the statistic of the accident very worrying for all the agencies. Based on source from Traffic Investigation and Enforcement Department, Bukit Aman, JPJ and MIROS, road and index accident development for 9-year (2011- Jun 2019) shown in Table 1.2. The highest number of deaths was in 2016 which 7,152 cases happened, 4,506 got major injuries while 7,415 suffered minor injuries. With these worrying statistics, responsible agencies need to take proactive action to ensure that the road accident is minimized.

Table 1.1: Road safety ranking status among ASEAN country year 2013 (Global Status Report on Road Safety, 2015)

ANALYSIS AND COMPARISON					
Status Ranking Road Safety for ASEAN Country Year 2013					
Country	Approximate Death	Approximate Index WHO/ 100,000 Population	Approximate Index/ 10,000 Registered Vehicle	Ranking Index/ 100,000 Population	Ranking Index / 10,000 Registered Vehicle
Cambodia	1,950	17.4	7.93	5	8
Indonesia	26,416	15.3	2.53	4	4
Laos	910	14.3	6.32	3	7
Malaysia	6,915	24.0	2.90	7	5
Myanmar	3,612	20.3	8.38	6	9
Philippine	1,513	10.5	1.97	2	2
Singapore	159	3.6	1.63	1	1
Thailand	14,059	36.2	4.33	9	6
Vietnam	9,156	24.5	2.24	8	3

Table 1.2: Road and index accident development for 9-year 2011-Jun 2019. (Road Safety Department of Malaysia, 2019)

ROAD AND INDEX ACCIDENT DEVELOPMENT FOR 9-YEAR (2011 - Jun 2019)			
Years	**Death**	**Major injuries**	**Minor injuries**
2011	6877	6328	12365
2012	6917	5868	11654
2013	6915	4597	8388
2014	6674	4432	8598
2015	6706	4120	7432
2016	7152	4506	7415
2017	6740	3310	6539
2018	6284	4895	3446
Jan-Jun 2019	3071	1591	2881

In the automotive industry, improvements in this technology have benefited drivers in terms of safety and saved many lives as a result of technical problems on a vehicle's system. The technology of driver assistance already improves safety. In vehicle handling it explains how the wheeled vehicle responds and reacts to a driver's inputs, it is generally evaluated how the vehicle performs especially when it is cornering, accelerated, and braking. Recently there are many technologies that can increase the safety of the vehicle. One of the improvements is applying the active front steering. Active Front Steering (AFS) systems are used to upsurge lateral and yaw stability of front steering systems. The steering control can also be used to dismiss outer destabilization forces from Mu-split, asymmetrical braking or wind. Falcone *et al.* (2008).

Furthermore, in lane keeping technology there is four-wheel steering (4WS). Much attention was recently given to the design of four-wheel steering systems (4WS) for passenger cars, to improve their handling characteristics. Active four-wheel steering (4WS) device improves the potential of vehicle cornering by adjusting the vehicle state of the front and rear wheels. This means that the lateral stability and handling quality can be improved in a range in which the dynamics of vehicles can be represented by linear models. Nevertheless, as tires reach the limits of adhesion and exhibit nonlinear characteristics on the side force, four-wheel steering systems become less available (Gooch, 2011).

Besides that, Raksincharoensak *et al.,* (2006) found, lane keeping by Direct Yaw-Moment Control (DYC) system is the other technology used in automotive. By controlling the slip side motion, this method will improve the handling and constancy of the car. However, Direct Yaw-Moment Control (DYC) have being practically used to directly control yaw motion by using tire-longitudinal forces, so that it is better to control the yaw rate than the lateral speed.

1.2 Background

The steering control problem has drawn broad attention in recent years. The lane keeping control system serves the driver's side control role of holding the vehicle along the correct lane and is also known as the automatic steering system. With these features, it can potentially decrease workload and tiredness on a long journey such as while driving on the highway. As follows, the fundamental design requirement of the lane control system is the automated control must carry out the lane maintenance task without maneuvering the driver. The steering actuator also smoothly provides the appropriate torque for lane keeping tasks. If necessary, the driver can easily override the steering system. Nagai *et al.* (2003) and Vadeby *et al.,* (2011) found that there are many sensors mounted on modern vehicles in this modern world to avoid a collision like electronic stability control (ESC) system. The major intention of an (ESC) system is to support the driver maintain the balance of the course to avoid over or under the vehicle's steering. When stability is lost, the (ESC) system slows individual wheels, and many systems also minimize engine power and disengage cruise control.

Furthermore, the adaptive cruise control (ACC) is a longitudinal vehicle control system available for commercial use. The ACC system monitors the velocity of the car and be able to be interpreted as a double-mode hybrid system, the throttle control method, measures the throttle speed, and the brake control approach, where the brake pressure is defined (Dai & Koutsoukos, 2020). Besides that, one of the advanced vehicle functions that assist the driver's lane-keeping and offers the LDW (Lane Departure Warning) for comfortable driving circumstances is the Lane Keeping Assistance System (LKAS). By adjusting the angle of the steering wheel of the vehicle or by producing the torque on the steering wheel these systems can keep the lane. But various LKAS controllers examined the subjective view of the driver, showing that the superior performance does not certainly meet the receptivity of the driver. The unnecessary control input may affect an overload of the lateral position of the vehicle in the operation of the LKAS system. Hwang *et al.* (2008). In other to enhance the vehicle performance the, implementation of Antilock Braking System (ABS) and a Traction Control System (TCS) will assist the vehicle traction control when acceleration. Based on Burg *et al.*, (1998), the purpose of this regulation is to improve tire grip, while maintaining enough vehicle stabilization and balance by avoiding the locking of wheels during breaking or rolling during speeding up.

For lane keeping system application of four-wheel steering and two-wheel steering is related to the system. Four-wheel steering (4WS) is a state-of-the-art technology control system that can improve steering functionality. When cornering, four-wheel steering systems are applied to guide the front wheels and the rear wheels independently, according to vehicle motion conditions. Speed, yaw speed and side acceleration compartmental to conventional two-wheel steering (Schein, 2016). Figure 1.1 shows the difference between four-wheel steering and two-wheel steering. So, the system for four-wheel steering (4WS) is better than two-wheel steering (2WS). The vehicle is modeled as a bicycle model, which is enough for a lane keeping assist task. In this project focus will be given on lane keeping control system.

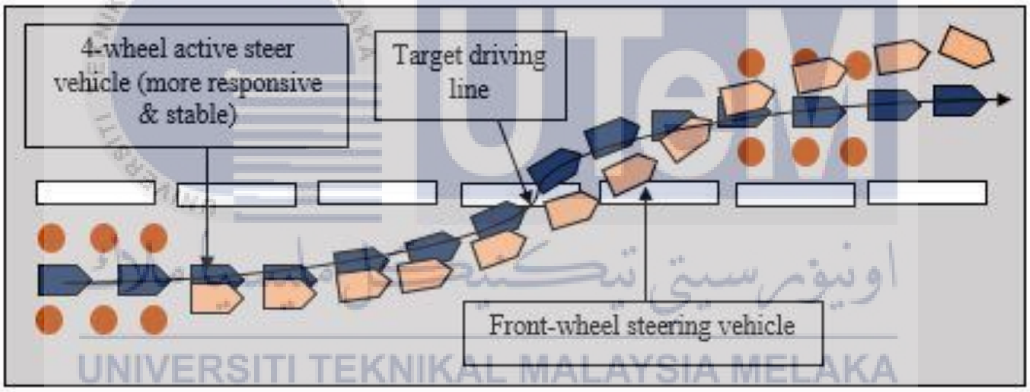

Figure 1.1: Different between four-wheel steering and two-wheel steering

1.3 Objective

The study of this research focused on the simulation of lane keeping control system. The objectives of this project are as follows:

1. To develop a mathematical model for vehicle handling dynamics.
2. To design lane keeping control system by using PID controller.

1.4 Scope

The scopes of this project are:

1. Development of non-linear vehicle handling dynamic model.
2. Design of control strategy for lane keeping system.

1.5 General methodology

In this project, the steps required to achieve the objective are stated below.

1. Literature review

   The main subject matter is learned by reading the journal articles website or any other source related to the subject of the project.

2. Development bicycle modeling model

   The bicycle model with nonlinear tire model will be developed for the lane keeping control system.

3. Building Simulink diagram for tire model

   Build a block diagram of the tire model by using Simulink based on the equation for the tire model.

4. Building Simulink diagram for bicycle model

   Build a block diagram of the bicycle model by using Simulink based on the equations for the bicycle model.

5. Design of lane keeping control system

   Design the lane keeping control system and simulation using MATLAB.

6. Report writing

   All the details and findings of this project will be written.

The Gantt chart of the study for PSM 1 is presented in Table 1.3

Table 1.3: Gantt chart PSM 1

Activities	Week														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Brainstorming and select the title															
Meeting with supervisor															
Submission of the logbook to supervisor															
Report writing															
Literature review															
Derivation of mathematical equation for non-linear vehicle handling dynamic model															
Building Simulink vehicle model non-linear vehicle handling dynamic model															
Generate mathematical equation for lane keeping control system															
Submission of PSM 1 reports to the supervisor															
Preparation of slide presentation															
Presentation PSM 1															

The Gantt chart of the study for PSM 2 is presented in Table 1.4

Table 1.4: Gantt chart PSM 2

Activities	**Week**														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Preparation of PSM II report															
Revision of PSM 1															
Develop the simulation of vehicle model															
Design the controller of lane keeping control system															
Building a control structure for MATLAB															
Generate the results from MATLAB Simulink															
Submission of PSM I1 progress reports to the supervisor															
Preparation of slide presentation															
Presentation PSM II															

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A road accidents involving vehicles result in significant fatalities, injury and financial losses for both society and people affected. This is a crucial issue as it involves the safety of drivers and passengers on the road. Lane keeping assistance system researches for example ware conducted to reduce working loads for drivers in such a hazardous situations and in turn reduce the possibility of road crashes (Yoshida *et al.*, 2008). In this chapter, several topics related to the lane keeping control system will discuss. Among them is the lateral vehicle dynamic model. This analysis is basically to find the model that are used in the vehicle system. There are some topics will be discussing that related to this study which are the development of two degrees of freedom (2 DOF) bicycle model and three degrees of freedom (3 DOF) bicycle model. In other to get the variation between the bicycle model, the four-wheel vehicle model also will be discussing in this chapter. The selection of the tire models is an important criterion to get a good combination between the tire and vehicle. The main forces are produced by tires as a purpose of the driver input in lateral manoeuvring, acceleration and breaking. In other to get the driver assistance system better, the desired path generation method is required. Moreover, in the automotive industry, two types of lateral system in the lane keeping assist system have been built which is lane departure warning (LDW) and lane keeping system (LKS) to increase the safety execution of the vehicle.

2.2 Lateral Vehicle Dynamic Model

The dynamic model of lateral vehicle is an analysis of the vehicle model to determine the detail of the vehicle's crucial components that affecting the lateral vehicle dynamics of the vehicle. There is a certain aspect that needs to be a focus on doing the analysis. Based on (Rajamani, 2011), a vehicle may produce a lateral movement by the kinematic model. This model offers a numerical explanation of the motion of the vehicle, with no pondering its forces that affect the motion.

Figure 2.1 shows a kinematic vehicle model. Point A represents the centre of front wheel. Besides that, the central rear wheel at point B represents the rear wheels and for steering angles, the front wheel is represented by δ_f and the rear wheel is representing by δ_r. The design is derived provided that front and rear wheels can be monitored. The rear steering angle δ_r can be determined as nil for front wheel only steering. For centre of gravity (C.G) is placed at point C meanwhile the wheelbase of the vehicle determines by $L = l_f + l_r$ and the distance of points A and B from the centre of gravity are represented by l_f and l_r respectively (Rajamani, 2011).

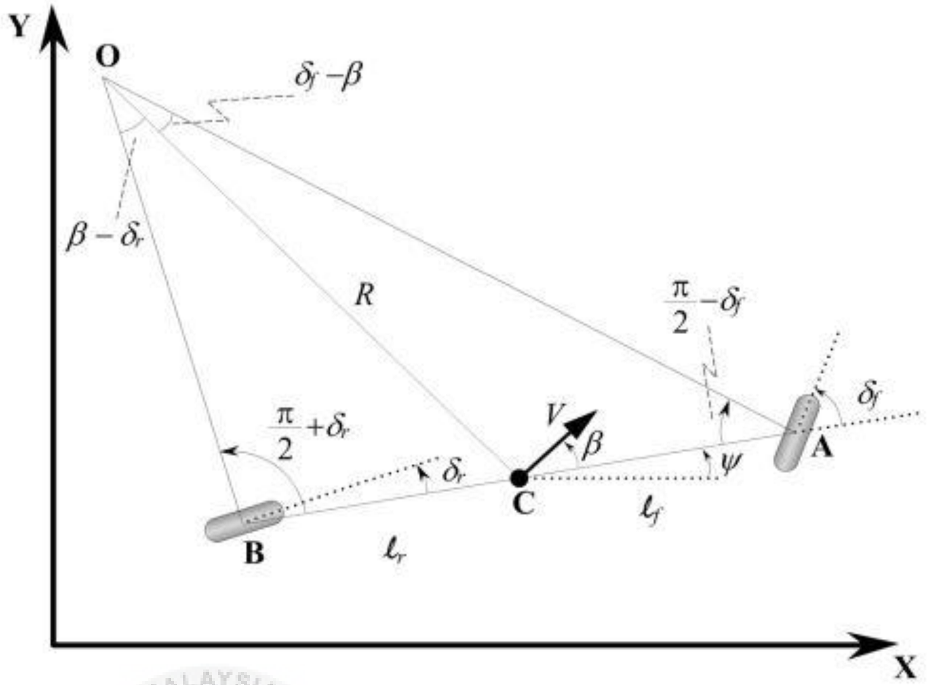

Figure: 2.1 Kinematics of lateral vehicle dynamic (Rajamani, 2011)

For vehicle handling, there are important factors in road traffic safety. To analysis the handling performance, there are various methods of that. Among them is a measurement during driving manoeuvre or evaluation of vehicle behaviour. These approaches are highly effective in demonstrating an existing vehicle, but at the same time, they are simply not acceptable at the early design stage when no real vehicle is worked (Hejtmanek *et al.*, 2013).

In the vehicle system, the number degree of freedom shows a crucial role to get the good estimation and to determine the effectiveness of vehicle handling performance. The amount of data required to explain a system can be defined as a degree of freedom. In this chapter, there are two types of degrees of freedom that are discussed. The first one is two degrees of freedom in the bicycle model and three degrees of freedom in the bicycle model.

2.2.1 Two Degree of Freedom (2 DOF) Bicycle Model

Vehicles handling is one of the major factors of roads safety. There are various methods to do the review of the vehicle performance. The mathematical method and analysis are important because it measures the behaviour of the vehicle while driving. To demonstrating the existing vehicle analysis performance all these methods are important. In order to the define the effects of the vehicle performance, it uses some analysis based on the number of degrees of freedom. The basic variable that uses in two degree of freedom (2 DOF) is yaw rate $\dot{ø}$, yaw angle ø, velocity of lateral direction $\dot{y}_c$ and lateral displacement y_c. Figure 2.2 shows the two degree of freedom bicycle model (Nagai *et al.*, 2002).

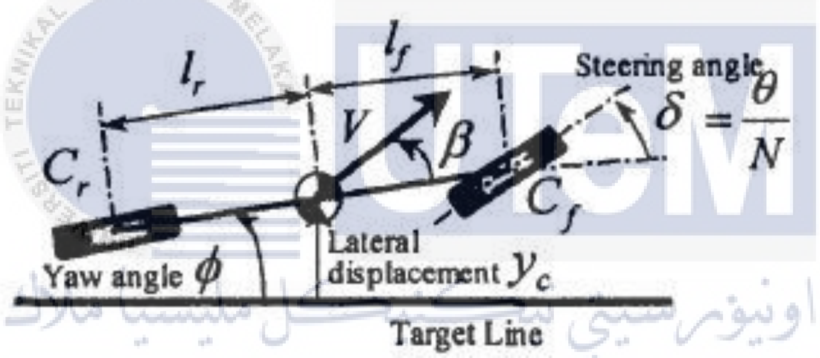

Figure: 2.2 Simplified two degree of freedom bicycle model (Nagai *et al.*, 2002)

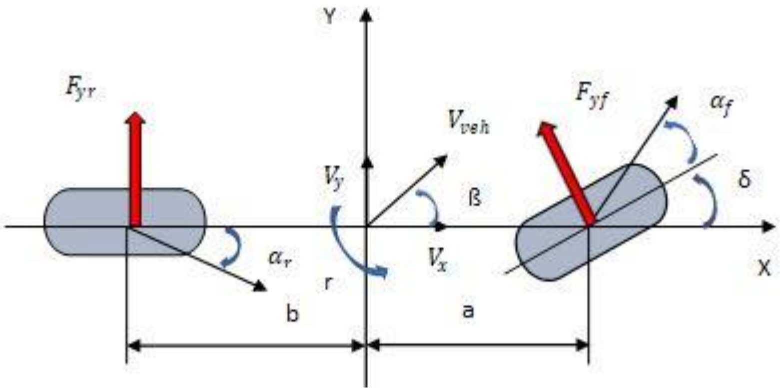

Figure: 2.3 Two degrees of freedom single track model

According to Figure 2.3, two degrees of freedom single track model, the motion of a vehicle can only be defined in the lateral direction (y-axis) by utilizing of the balance of the forces and the balance of the centre of gravity (C.G.). The basic differential equations of this 2 DOF system can be expressed as:

$$\sum F_y : m \cdot a_y = F_{yr} + F_{yf} \cdot \cos(\delta) \quad (2.1)$$

$$\sum M_z : I_z \cdot \dot{r} = a \cdot F_{yf} \cdot \cos(\delta) - b \cdot F_{yr} \quad (2.2)$$

According to the Equations (2.1) and (2.2) above, the mathematical vehicle modelling equation can determine the effectiveness and performance of two degrees of freedom (2 DOF) model.

2.2.2 Three Degree of Freedom (3 DOF) Bicycle Model

The three degrees of freedom (3 DOF) was applied to the model bicycle to increase the exact roll-over estimate, and a neural back-up network was built to monitor the roll-over by taking multi-state vehicle parameters into account. It also to determines the effectiveness of the vehicle when manoeuvring and to get the good combination of the vehicle. It can be quite difficult to capture all movements of a vehicle in mathematical formulas. Even if it can develop the accuracy of the model by including a higher number of elements, the time for computation increases significantly. The three degree of freedom of bicycle model is the design used in this analysis were derived in this section.

In this section, the controller that is develop for three degree of freedom (3 DOF) bicycle model has shown in Figure 2.4 (Rossetter & Christian, 2006).

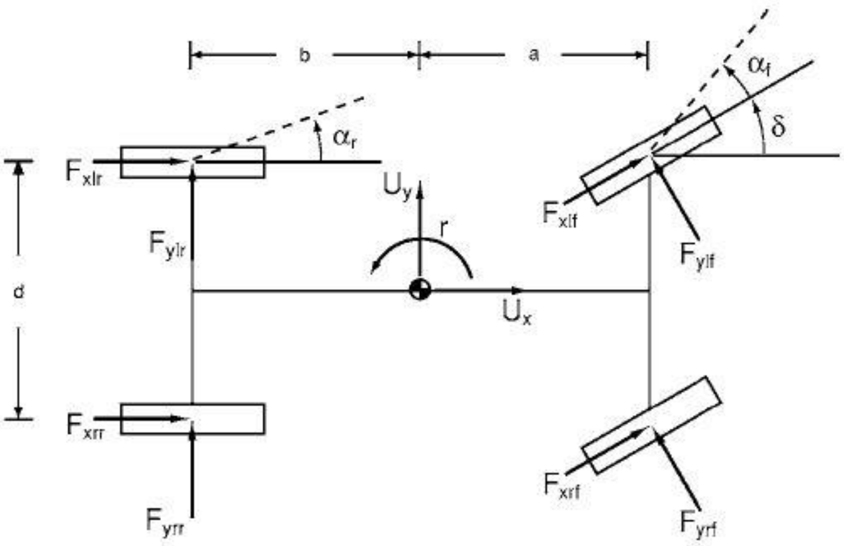

Figure 2.4: Three degree of freedom (3 DOF) bicycle model (Rossetter & Christian, 2006)

Based on (Rossetter & Christian, 2006) there are given that mass m and yaw moment of inertia is I_z. The equations of the system have provided below:

$$m\dot{U}_x = F_{xr} + F_{xf}\cos\delta - F_{yf}\sin\delta + mrU_y \tag{2.3}$$

$$m\dot{U}_y = F_{yr} + F_{xf}\sin\delta + F_{yf}\cos\delta - mrU_x \tag{2.4}$$

$$I_z\dot{r} = aF_{xf}\, sin\,\delta + aF_{yf}cos\,\delta - bF_{yr} \tag{2.5}$$

where,

$$F_{xf} = F_{xrf} + F_{xlf} \tag{2.6a}$$

$$F_{xr} = F_{xrr} + F_{xlr} \tag{2.6b}$$

$$F_{yf} = F_{yrf} + F_{ylf} \tag{2.6c}$$

$$F_{yr} = F_{yrr} + F_{ylr} \tag{2.6d}$$

From the equations above, mathematical modelling can be made and verify the effectiveness of three degree of freedom (3 DOF) model.

2.2.3 Four-Wheel Vehicle Model

The four-wheel vehicle model is a practical driving method nowadays compare with the two-wheel vehicle model. It provides good in terms of vehicle handling due to driving. The resulting controller requires a simple and physically insightful form of steering and throttle coordination. When the direction monitoring target needs a steering outward of a curve, the sideslip balancing of control also requires an improvement of the throttle feedback at the same time, but the throttle must also be reduced if it is steering inside a turn.

In this case, a four-wheel vehicle model design similar to overcome drift balances and construct an orientation path of a constant turning radius and different sideslip, while this simple illustration acts as a clear standard for application and evaluation although the control system is extracted from arbitrary quasi-equilibrium trajectories. Figure 2.5 shows the four-wheel configuration forces and geometrical parameters (Goh & Gerdes, 2016).

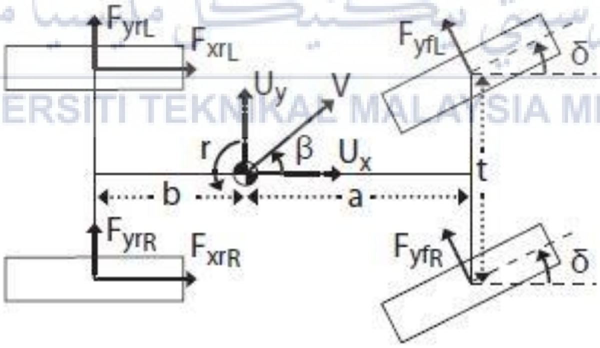

Figure 2.5: Four-wheel configuration forces and geometrical parameters (Goh & Gerdes, 2016)

2.2.4 Tire Model

A tire is considered to have its longitudinal force based on a longitudinal slip ratio, the coefficient of tire-road friction, and standard tyre force. To control the dynamic of the vehicle, the behaviour of the tire plays a significant role. A representation of force and moment of the tire is therefore necessary in vehicle dynamics findings. To determine the behaviour of the tire model, the collected information was defined by a formula based mathematical expressions.

The tire forces do not make contact with the ground at just one level, unlike a rigid undeformed wheel. Rather, due to the vertical load on the vehicle, the tire deforms and interactions with the road over an area identified as the contact patch (Rajamani, 2012). Figure 2.6 shows the tire to the vertical load of the vehicle deforms.

To get more understanding of vehicle tire force Figure 2.7 shows the main forces and moments that perform on the tire. In the middle of the touch patch is the source of the reference axes. The X axis is described as a cross-section between the ground and the wheel's middle plane. For the Z axis, it is perpendicular and above the pitch and for the Y axis, it points to the right to provide a right hand axis (Rajamani, 2012).

The force received by the tire on the road is assumed to be in the centre and can be broken down over three axis. For Fy lateral force is the intensity along the Y-axis. Fx is the longitudinal force along the X-axis and Fz is the force on the Z-axis. Similarly, the tire can be dismantled along the three axes when received by the road. The Mz is the moment at which the Z-axis is in place. The X-axis, Mx moment is known as the turnaround time and the rolling resistance moment is called My. The moment on the X-axis Mx is considered the turning point and the moment on the Y-axis My is defined as a moving resistance moment. (Rajamani, 2012)

Figure 2.6: Tire to the vertical load of the vehicle deforms (Rajamani, 2012)

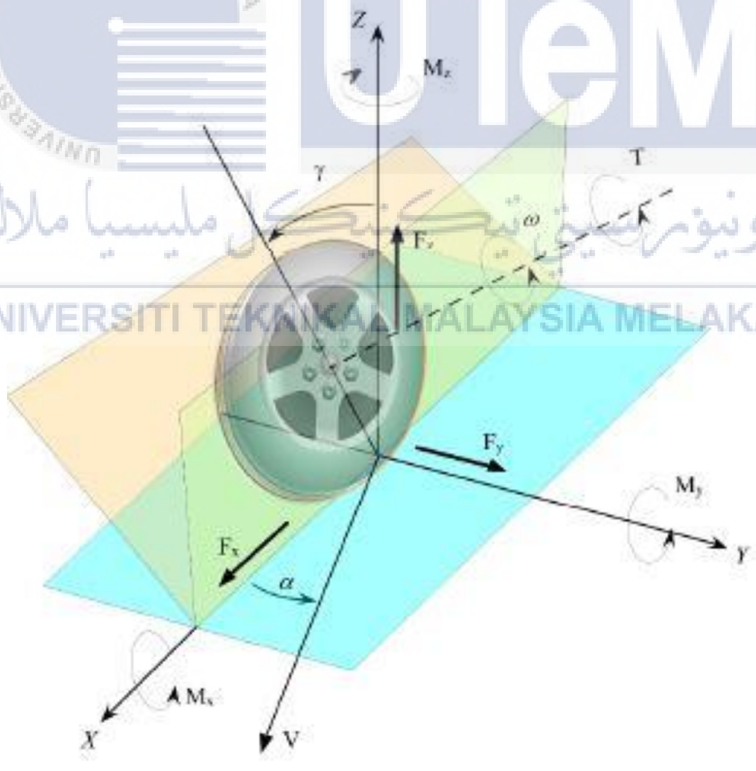

Figure 2.7: Lateral, longitudinal and aligning moments act on the tire (Rajamani, 2012)

2.2.4.1 Linear Tire Model

The linear tire force types are a are great estimations once the slip ratio and slip angle are small singly. For longitudinal tire force, the experiment results from figure 2.8 have found that each tire's longitudinal tire force differs on the slip ratio, vertical tire forces, and the road surface friction coefficient (Rajamani, 2012).

When the tire-road boundary friction coefficient is supposed to be 1 and the usual force is supposed to be steady, the normal difference in the longevity tire force is shown in figure 2.8 as a role of the slip ratio. It is obvious from the figure that, when the longitudinal slip is minimal, the length of the tire is precisely comparative to the slip ratio (Rajamani, 2012).

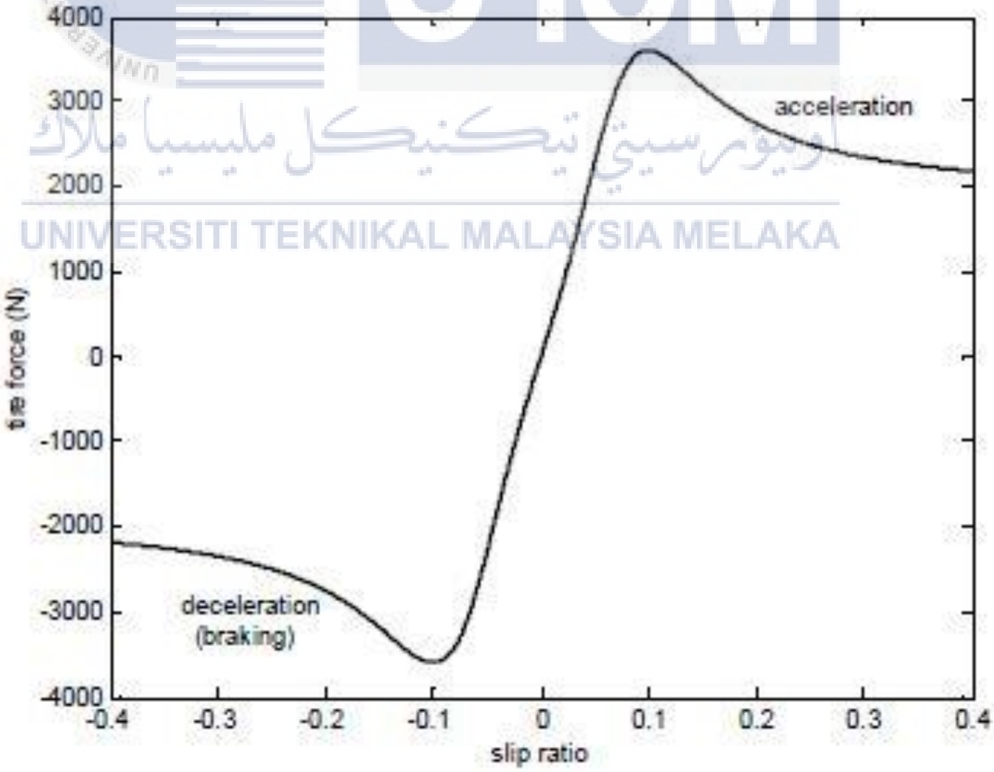

Figure 2.8: Function of slip ratio for the longitudinal tire force (Rajamani, 2012)

For the minor slip angle of the lateral tire force, it is proportional to the slip angle at the tire. From Figure 2.9 a tire's slip angle is determined by the angle from the location of the tire. Tire and the wheel's velocity vector orientation. For the slip angle of the front wheel and rear wheel it can be determined on Equations (2.7) and (2.8) respectively (Rajamani, 2012)

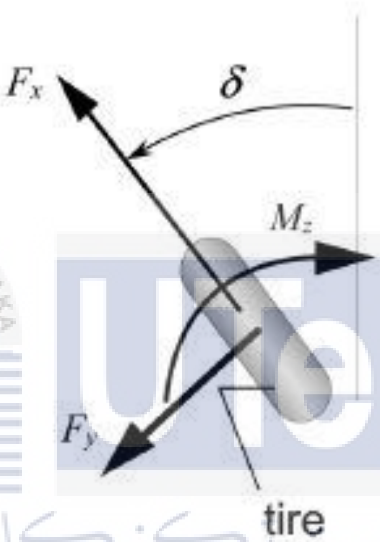

Figure 2.9: Lateral force for tire slip angle at the front wheel (Rajamani, 2012)

$$\alpha_f = \delta - \theta_{vf} \quad (2.7)$$

$$\alpha_r = -\theta_{vr} \quad (2.8)$$

where,

θ_{vf} = Angle velocity vector at the front wheel

θ_{vf} = Angle velocity vector at the rear wheel

δ = Front wheel steering angle

2.2.4.2 Dugoff's Tire Model

Dugoff 's tire model offers an alternative to the Fiala model for analytical foundations for the invention of lateral force built by Fiala (1954), and for combined longitudinal force invention by Pacejka and Sharp (1991). The model from Dugoff provides for forces measurement under the combined generation of lateral and longitudinal tire force. This means that the tire contact patch would have a consistent vertical force distribution. This simplifies the parabolic pressure dissemination adopted by Pacejka and Sharp (1991) compared to more realistic ones. The model, however, provides a major benefit: it permits separate tire rigidity values in the side and longitudinal directions. This is an important improvement because a tire's longitudinal rigidity could be very different from the lateral rigidity (Rajamani, 2012).

For this model, it is precise only when a slide slips angle and it is not far from 0. For the non-linear tire model or existing tire model, there are quite a few types of the tire which include the dugoff tire model and the brush tire model. In the Dugoff model, the vertical load allocation assumptions are different from the brush model. A constant vertical load distribution is assumed by Dugoff (Kissai *et al.*, 2018). The Dugoff tire models can analyze the longitudinal and the lateral tire force. Most researchers used it to achieve better quality in real time. Dugoff tire model can be determined in Equations (2.9) and (2.10) above:

$$F_x = C_s \frac{S}{1+S} \cdot f(\lambda) \tag{2.9}$$

$$F_y = C_a \cdot \frac{\tan(\alpha)}{1+S} \cdot f(\lambda) \tag{2.10}$$

where,

F_x = Longitudinal forces of tires

F_y = Lateral forces of the tires

C_s = Longitudinal stiffness of the tires

C_a = Lateral stiffness of the tires

S = Longitudinal slip ratio of tires

α = Tire sideslip angle

2.2.4.3 Magic Formula Tire Model

An advanced model suits high slip angles and large slip ratios. A tire model is to measure lateral and longitudinal tire forces Fy and Fx, and Mz the alignment moment, the Magic formula tire model (Pacejka and Bakker, 1993) allows for a extensive variety of functional conditions containing big slip angle and slip ratios and shared side and longitudinal force generation. If the intensity Y produced is simply produced by each lateral or longitudinal force, this is stated as a purpose of the input variable X (Rajamani, 2012).

The Magic Formula is commonly used by automakers to model and verify precision-based dynamic performance.

$$F_y(\alpha) = D \cdot \sin(C \cdot \arctan(B\alpha - E(B\alpha - \arctan(B\alpha) \qquad (2.11)$$

where,

B, *C*, *D*, and *E* = The shape of the tire characteristic

F_y = Lateral tire force

α = Side slip angle of the tire

2.3 Desired Path Generation Method Risk Potential Function

The advancement of driver assist systems raises the value of driver models for vehicle control, safety and performance. In order to improve these drivers ' aid systems, driver models must be adept to duplicate human driving habits and differentiate between different drivers. Driver models are enhancing increasingly essential to control safety and execution with the increase in driver support systems. The driver models must be able to reproduce human driving activities and differentiate between various drivers to improve these driver assistance systems (Schnelle *et al.*, 2015).

A method of motion and control based on the risk of accidents that could predict the driver's expertise. The automated braking system in the emerging automotive markets has been introduced recently. But in a crucial case, like a pedestrian abruptly leaving a blind angle of poor visibility, the existing system cannot avoid accidents. The preferred yaw rate and the required longitudinal deceleration are tentatively determined by enhancing the potential field function in the context of the ideal control system. Ultimately, by comparison of the simulation findings with current operating data of knowledgeable drivers, the legality of the planned movement planning and control system is validated (Raksincharoensak *et al.*, 2014).

Body structure absorbing crash energy was developed to mitigate pedestrian injury and has been used for practical purposes so far. Nonetheless, this passive safety system exceeds its limits to extend lower the amount of walker fatalities. Consequently, effective safety technologies for instance autonomous braking structures have recently been created onto the markets to achieve zero fatalities. But In some situations, warning devices are not successful long enough because the response time to the alert devices is too slow to deal with accident prevention for time (Raksincharoensak *et al.*, 2014).

The required longitudinal and lateral motions were generally estimated using traditional motion planning systems in the constant setting using potential region technique. In the case of the same potential field function, for example, vehicle speed and yaw rate. The possible hazard tasks in terms of road boundaries and obstacles are described in the lateral movement control at first. In the longitudinal control of the spring model, the risk potential for the occluded path is defined. The exponential function defines the risk potential used for lateral motion control systems (Raksincharoensak *et al.*, 2014).

The path of the vehicle is defined by the two elements that describe the road borders and the static obstacle. The best route for actual drivers reduces the possibility of accident with the static barrier and the distance from the lane. The structure of the repulsive potential area of road frontiers is shown in Figure 2.10. The possible area has maximum value for convey risk of lane departure at the location of the road confines. The outline of the repulsive potential obstacle field is shown in Figure 2.11. This theoretical area has the maximum value in place of the barrier to reflect the risk of collision (Raksincharoensak *et al.*, 2014).

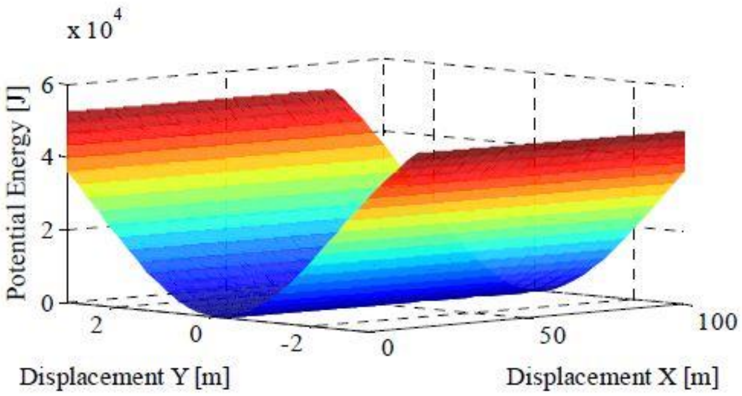

Figure 2.10: Repulsive potential field of the road boundaries (Raksincharoensak *et al.,* 2014)

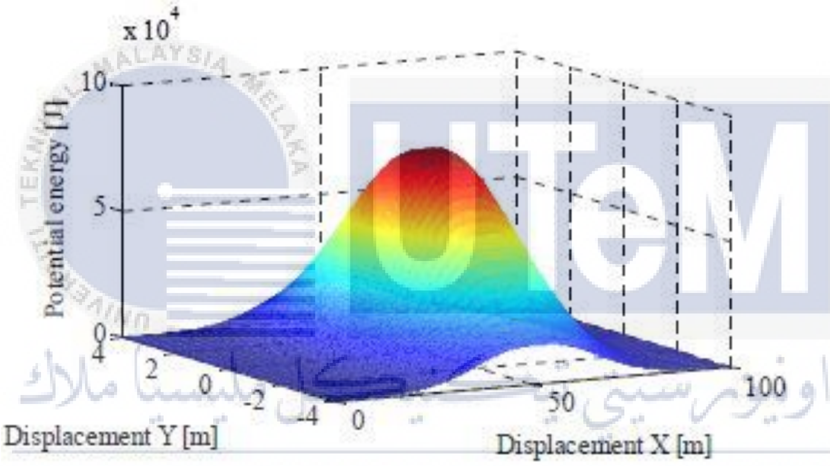

Figure 2.11: Repulsive potential field of the static obstacle (Raksincharoensak *et al.*, 2014)

The parameters of the potential risk function, including weighting and variance of the exponential function, will be calculated by the experienced driver from the collected driving data. The outline of gradient values along the road must be minimized if the experienced driver selects a path through the minimal risk of collision points on the hazard potential map. Figure 2.12 shows the driving situation and the combined potential hazard counter map is express in Figure 2.13 (Raksincharoensak *et al.*, 2014).

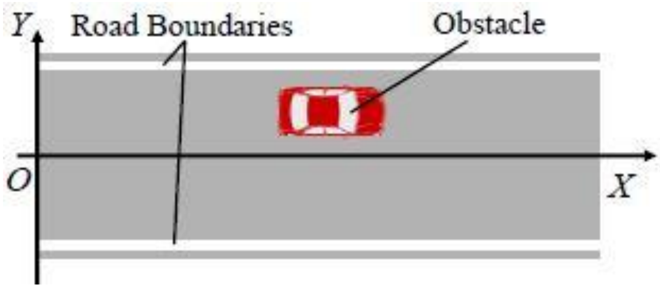

Figure 2.12: Scenario for risk potential computation (Raksincharoensak *et al.*, 2014).

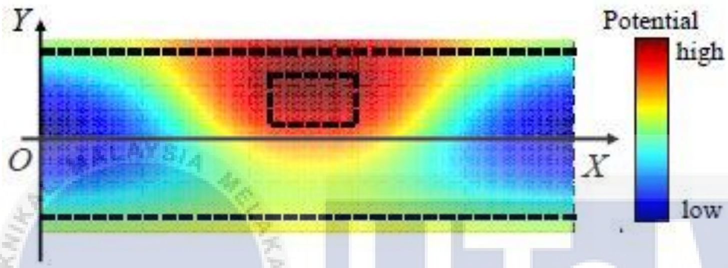

Figure 2.13: Combined potential field hazard map contour (Raksincharoensak *et al.*, 2014).

2.4 Lane Keeping Assist

In the automotive sector, three types of lateral systems, Lane Departure Warning Systems (LDWS), Lane Keeping Systems (LKS) and Yaw Stability Control System, have been developed to address lane departure crashes. (Rajamani, 2011). The system of LKA only function and determine the information and send warning or notification to the driver if needed. The second category was developed for guidance and with the intention of having an impact on driver behaviour, such as LKA systems, which use such methods to control the vehicle to avoid potential departures or crashes. It is important to note that the second category in hardware is more complex than the first and takes more time (Mammeri *et al.*, 2015).

2.4.1 Lane Departure Warning (LDW)

A lane departure warning system (LDW) is a device that tracks the vehicle's lane place and alerts if the vehicle is about to exit the lane. To acknowledge the distinction between road and lane markers, the system of lane departure warning is programmed. The camera of the unit monitors clear lane patterns and serves the data into the software of the unit, integrating this data with the speed of the vehicle. The computer can expect when a vehicle starts drifting in the direction of unplanned lane change using image detection software and patented algorithms. The system automatically produces the generally known rumble strip sound when this happens and notifying the driver to make an adjustment (Rajamani, 2011).

The LDW system is used to warn an unintended departure of the lane driver. Such systems are highly sensitive to road conditions as they rely only on the ability of the vision sensor to detect lane markings on the road. If the LDW system of a vehicle fails to detect road markers, it loses its ability to notify the driver of an unintentional lane departure. Figure 2.14 shows the lane departure warning based on lane marking.

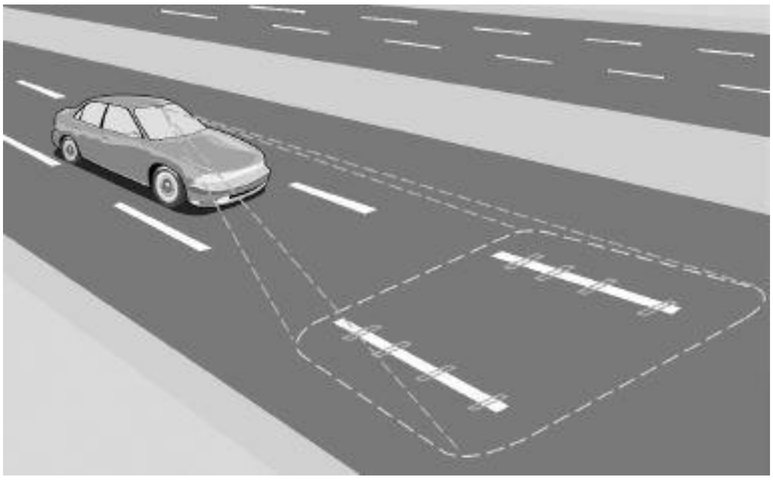

Figure 2.14: Lane departure warning system based on lane marking (Rajamani, 2011)

2.4.2 Lane Keeping System (LKS)

For lane keeping system (LKS) it instinctively monitors the handling to keep the vehicle is on the required lane and the curves around as well (Rajamani, 2011). It means the car driver does not take the hard act to control the steering wheel while the vehicle is having a sudden lane change. In order to balance the difficulty of the arrangement with the responsibility of the drivers, the system attempts at 'monotonous driving'. Which is the system only works on straightest routes and above a certain set speed. For example, drivers will feel tired after a long journey of driving and it will result in the driver having a constantly steer their vehicle and with the LKS it will keep the vehicle in their lane. With this system, it will reduce fatal caused by human error by improving the straight highway road. The system works by using the single charge-coupled device (CCD) camera to identify the lane direction. Besides that, it also used the steering actuator to navigate the front wheel and an electric power unit.

The method uses a CCD camera to identify the lane demarcation, a steering actuator to guide the front wheels, and an electric power unit. By using these mechanisms, the camera will measure the configuration of the road and the location of the host vehicle in the lane. Based on this data, the control unit computes the steering torque required in the lane laterally with the vehicle speed and steering wheel angle.

The LKS system produces a torque that improves the driver to control the present vehicle in the centre of its lane when it travels directly along an expressway. The major component of the system includes the CCD camera which acts to identify the white lane markers and analyse the current torque to support the driver to keep the vehicle stay in the centre of its lane. Based on the approximate position forward of the vehicle, the speed of a steering angle calculated from the steering wheel angle sensor output and the host vehicle speed. For the generation of an assist force, a steering actuator fitted on a steering shaft and a buzzer to inform the driver whether the system is working. The LKS system similarly provides an alert feature for the lane departure driver (Kawazoe *et al.*, 2001). Figure 2.15 shows the basic LKS system configuration.

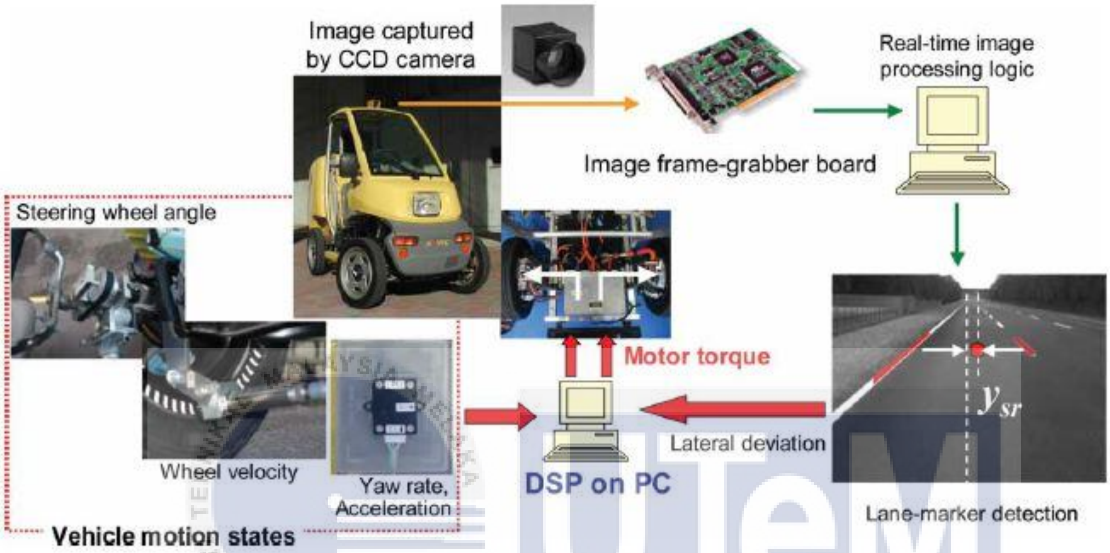

Figure 2.15: Basic LKS system configuration (Raksincharoensak *et al.*, 2006)

2.5 Control System in Automotive Application

For the past years, the control system in the automotive industry is widely used in the world. There are a few types of famous control structures that use a type of feedback controller. Among them is the fuzzy logic controller and Linear Quadratic Regulation (LQR).

2.5.2 Control System for Lane Keeping

The fuzzy logic controller is also used for manufacturing purposes such as the cement kiln control and the Servo hydraulic cylinder position control as well as in the laboratory workplace. A set of empirical decision rules from the skilled operator can also be considered as a controller (Chen *et al.*, 1993). There are several advantages by using the fuzzy controller such as no mathematical framework formulation is necessary and its help to describe inaccurate objects and achieve multinational control, semantic variables, and imprecise reasoning are used. A complicated plant can be invented as a fuzzy model by using of a set of input data by using fugitive recognition methods such as the inequality standard and the weighted recursive lowest square algorithm (Tanaka & Sugeno, 1992).

Among the benefit of using a fuzzy control system is, it able to create linguistic lines by the usage of rules based on experience. It also allows a better execution than the conventional Proportional-Integral-Derivative (PID) controller and it simple to design. To design the fuzzy logic controller. There are basic components that need to know. Figure 2.16 shows the basic components of fuzzy logic controller.

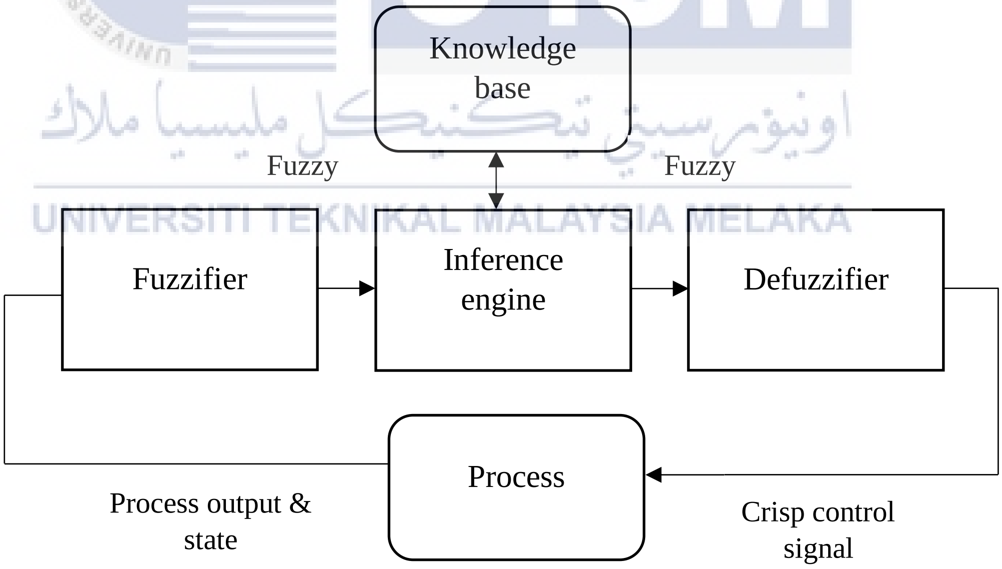

Figure 2.16: Basic components of the fuzzy logic controller

The Linear Quadratic Regulator (LQR) is a well-known method for the second control system that provides optimum regulated feedback gains to ensure stable closed-loop, high-performance systems design. The controller will locate the state feedback control gains vector K. An additional alternative is to use the LQR order which gives the optimum control gain assuming a linear, quadratic cost and zero references.

The first step is to verify that the system can be controlled before designing the controller. Satisfaction means that it can move the system anywhere under the real limitations of the system, as infinite time. The controllability matrix must level n where the rank of a matrix is the number of linear, separate rows or columns for the entire controlled state method. Number n is the amount of variable process condition. The addition of extra conditions to the controllability matrix with greater matrix A, power does not raise the rank of the matrix control because these additional terms are just the linear combinations of previous terms. Specifically, the linear quadratic regulation technique will use for verifying the state-feedback control gain matrix K. (Michigan, 2020)

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this study, the general approach of creating the controller for the lane keeping control system by using the PID controller will be clarified. The general methodology of this study is reviewed in the flow chart as shown in Figure 3.1. Firstly, the explanation of the fundamentals on the lateral vehicle dynamic model on how the execution of the vehicle and it important to define the performance in terms of handling the vehicle. In this study, it explained the basic about two degrees of freedom (2 DOF) of the bicycle model. Besides that, the fundamental of the tire model also is explained. It includes the non-linear tire model and the equation of the tire model. Besides that, the derivation of the mathematical equation for the bicycle model is important to build a vehicle handling dynamic model. The structure of the controller also needs to be established to produce the feedback controller of the vehicle model. Both mechanism vehicle dynamic model and the structure of the controller will be done by MATLAB Simulink. After building the Simulink diagram for the bicycle tire model are discovered, the diagram of the bicycle model is built by using a MATLAB Simulink based on the equations for bicycle model. By comparing with all method, the layout of lane keeping control system can be generated by using the MATLAB simulation. The simulation will be obtained, and the performance evaluation will be analysed.

3.2 Project Framework

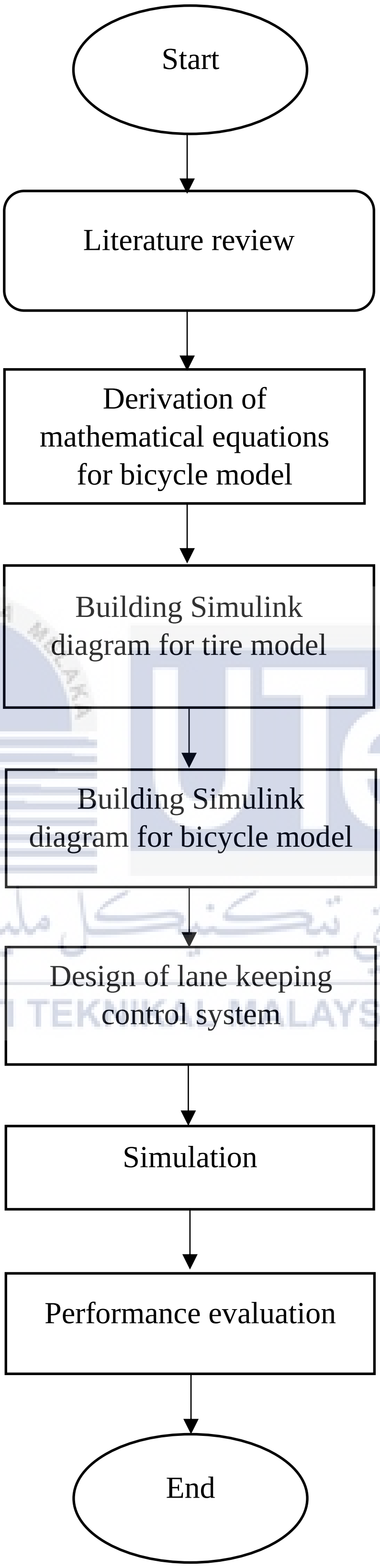

Figure 3.1: Flow chart of the methodology

For the first Projek Sarjana Muda 1 (PSM 1) is start form week 1 until week 14 for this first semester 2019/2020. For PSM 1, the project is consisting of the generation of the mathematical equation for a non-linear vehicle handling dynamic models. After that, the building Simulink diagram for vehicle modelling for non-linear tire model and the design of the bicycle model. For second semester for PSM 2, this project will include the simulation and execution valuation of the lane keeping control system will be made. Figure 3.1 shows the flow chart of the methodology.

3.3 Modelling Vehicle Dynamic

In this chapter, the introduction of the autonomous vehicle control system in the bicycle model was explained including the equation of motion on the lateral, and yaw damping. This model thoroughly explains the actual vehicle dynamics and provided appropriate predictions for real vehicle manoeuvres as part of vehicle handling. To get the model of the lane control system of this vehicle model, the Simulink by MATLAB is an approach to get the vehicle feedback in different driving styles. It is crucial to understand the situation of the vehicle in relation to the desired lane when designing the lane control system, so it is further appropriate to exhibit the movement of the vehicle with the earth-fixed coordination system (Nagai and Raksincharoensak, 2002). Figure 3.2 shows the bicycle model on earth fixed coordinate.

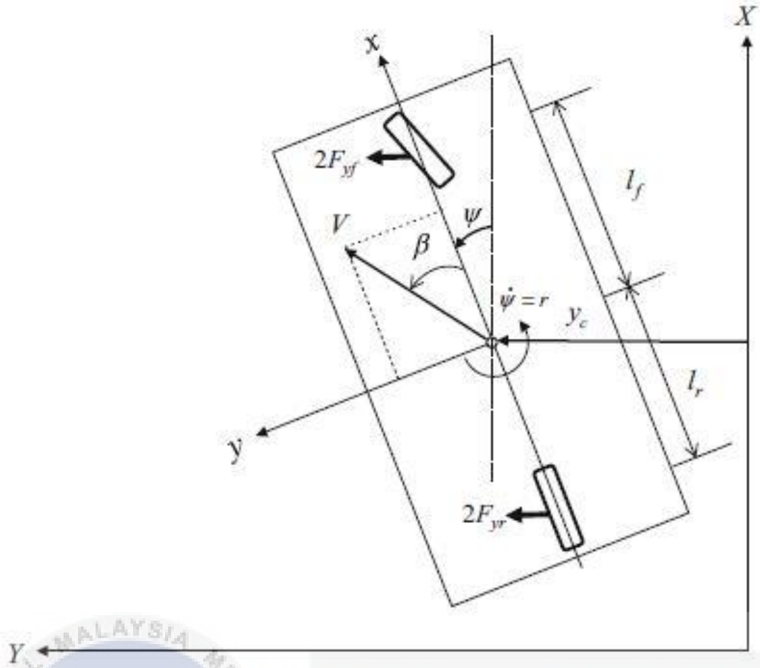

Figure 3.2: Bicycle model on the earth fixed coordinate (Nagai and Raksincharoensak, 2002)

3.3.1 Design of Lane Keeping Control Structure

For derivation of the equation of the vehicle handling model. There are several equations that be made. It can be quite difficult to capture all the movements of a vehicle in analytical equations. While the model can increase accuracy by including a larger number of elements, it significantly increases calculation time (Martino, 2005). In this study, the element needs to describe are the derivation of the non-linear handling vehicle dynamic model. The generation of equations are including the equation of motion by determining the lateral motion and yaw motion. It also includes the control structure controller equation that needs to determine which are the slip angle equation, lane keeping feedback equation and yaw damping equation.

For the bicycle model in Figure 3.2, it displays the tire forces, the status variables, and some simple automobile parameters are used for the equation of motion that measure vehicle dynamics. As the amount of the intensity acting along (x-axis) is equal to zero, the model takes constant car speed, since friction forces account for the rotating opposition and the displacement of the lateral front force into the longitudinal direction. Because of this simplification, the rotation of a vehicle can be defined using an only stability of forces on the side (y-axis) and balance of moments around the centre of gravity (C.G.) (Hejtmanek, 2013).

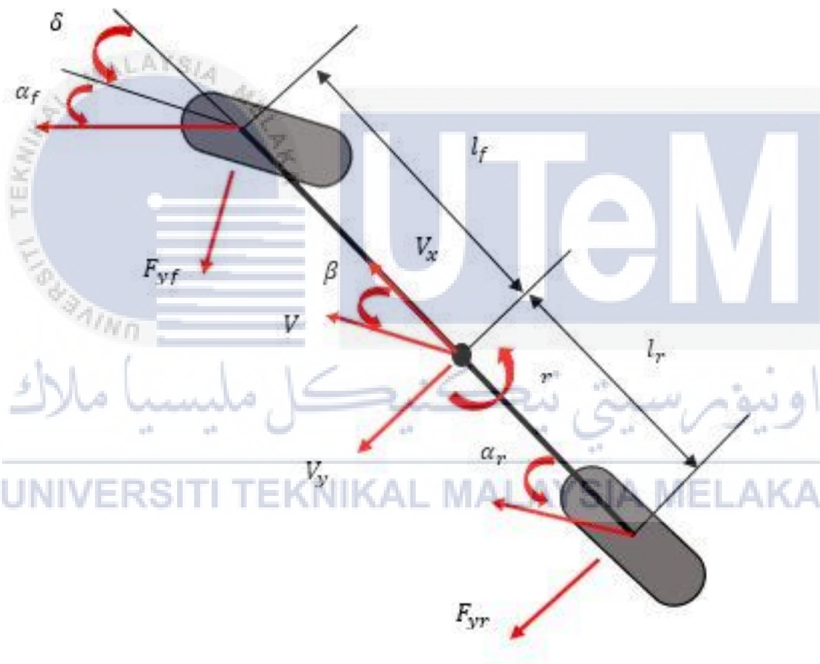

Figure 3.3: Bicycle model

Figure 3.3 shows the parameter of the model can be determined by δ is a steering angle, l_f and l_r length of the front axle and rear axle to the center of gravity (C.G.) respectively, r is the vehicle yaw rate, sideslip angle is β, the vehicle speed is V_x, F_{yf} and F_{yr} is the front and rear tire forces respectively. The vehicle mass is assuming by m and I_z is yaw inertia. After all the parameter is formed, the derivation equation of motion can be express as Equations (3.1) and (3.2) below (Ono *et al.*, 1998**)**

Yaw rate:

$$\dot{r} = \frac{\left(lfF_f - lrF_r\right).\cos\beta}{I_z} \tag{3.1}$$

Side slip angle:

$$\dot{\beta} = \left(\frac{F_f + F_r}{mv}\right) - r \tag{3.2}$$

The parameter of the vehicle model on the figure are shown Table 3.1 below (Ono *et al.*, 1998**).**

Table 3.1: Parameter of the vehicle model (Ono *et al.*,1998).

Parameters	**Values**
Length of front axle to the COG (l_f)	1.2 m
Length of rear axle to the COG (l_r)	1.3 m
Yaw moment of inertia (l_z)	3000 kgm^2
Mass of vehicle (m)	1500 kg
Velocity of vehicle (v)	20 m/s

3.3.2 Equations for Tire Model

The control strategy for developing a control system for cars is proposed for safety and enhanced cornering efficiency of the vehicle against spins. The control strategy. A saddle-node bifurcation, which heavily varies on the saturation of a rear tire side force, has shown the vehicle stabilization. On this basis, the rear tires have a linear function with indecision terms modelling their saturation qualities of a structure. In recent years, steering control of the vehicle has received significant interest, and an integrated four-wheel steering system has been introduced onto the market with feedback control.

This regulation is applied to maximize vehicle stability and manoeuvrability under all conditions of driving. In particular, in crucial cornering motions in an emergency, the vehicle management control will improve safety. However, due to the limitation of theory development in nonlinear systems experiments, most of this design had to be carried out in moderate cornering movements, formed on a linearized model of vehicle dynamics. If the vehicle has constant velocity, the differential equations will describe a double-dimension model of non-linear tire force behaviour.

The following basic mathematical model is used in this analysis in order to prevent complications in control design. Next, the curving forces are based on tire slip angle functions. The mathematical Equations (3.3) to (3.6) are determined below (Ono *et al.*, 1998).

$$F_f = D_f \, sin[C_f \tan^{-1}\{B_f \, (1 - E_f) l_f + E_f \tan^{-1}(B_f l_f)\}] \tag{3.3}$$

$$F_r = D_r \, sin[C_r \tan^{-1}\{B_r \, (1 - E_r) l_r + E_r \tan^{-1}(B_r l_r)\}] \tag{3.4}$$

$$\alpha_f = \beta + \tan^{-1}\left(\frac{l_f}{v} \cdot r \cos\beta\right) - \delta_f \tag{3.5}$$

$$\alpha_r = \beta + \tan^{-1}\left(\frac{l_r}{v} \cdot r \cos\beta\right) \tag{3.6}$$

where,

β = Sideslip angle

r = Yaw velocity

F_f = Cornering force of front tires

F_r = Cornering force of rear tires

l_f = Distance of front axle to the COG

l_r = Distance of rear axle to the COG

α_f = Slip angle of front tire

α_r = Slip angle of rear tire

The low friction roads have coefficients chosen in order for the vehicle to spin quickly, which is similar to the driving conditions on a downhill path at a steady speed with an equal braking effect during throttling. The parameter of the tire model is shown in Table 3.2 below (Ono *et al.*, 1998).

Table 3.2: Parameter of the tire model (Ono *et al.*, 1998)

		B_f, B_r	C_f, C_r	D_f, D_r	E_f, E_r
High friction road	Front	6.7651	1.3000	-6436.8	-1.9990
	Rear	9.0051	1.3000	-5430.0	-1.7908
Low friction road	Front	11.275	1.5600	-2574.7	-1.9990
	Rear	18.631	1.5600	-1749.7	-1.7908

3.4 Time Response Performance

In the industry, PID controllers are widely used. The PID control has a simple structure and its parameters of control are easy for practical engineers to understand. The PID algorithm or controller is the most popular feedback controller used within the process in industries. It is a robust and well understood algorithm, which despite various dynamic process features and offers an excellent control performance.

3.4.1 Effect Control Parameters

The PID algorithm, as its name suggests, consists of three simple gains. The gains include Proportional, Derivative and Integral gains. By using the controller, these autonomous vehicles can follow their desired trajectories.

The effect of the increasing proportional gain Kp is that the control signal is proportionally increased at the same point of error. The reality that the controller is boosts for a given degree of error appears to lead to a faster response but also to a further overreaction of the closed loop method. Another consequence of increasing Kp is, it helps to reduce the permanent state defect but does not eliminate it (Michigan, 2020).

By adding up a derivative term to the controller Kd, it will increase the controller's ability to predict errors. If Kp is constant, the only way to improve the output is by using simple proportional control and the value of Kp will increase if the error rises. The control signal may grow into high with derivative control as the error starts to fall even when the magnitude of the error is comparatively low. Such expectation helps to increase the system's damping, thus reducing the overload. However, creating a derivative term does not effect on the steady-state error (Michigan, 2020).

An integral term is applied to the controller Ki to minimize steady-state errors. If a constant, continuous error is found, the integrator builds and constructs the control signal and slows down the error. However, an integral term is disadvantageous in its ability to render it slower and oscillatory as it may take a while for an integration to "unwind" when an error signal is changed (Michigan, 2020).

In Table 3.3 below, the common effects for the closed loop system of each parameter (Kp, Kd, Ki) are summarized.

Table 3.3: Comparison the Effect of Control Parameter PID Controller (Michigan, 2020).

Gain / Effect	Rise time	Overshoot	Settling time	Steady state error
Proportional, K_p	Decrease	Increase	Small change	Decrease
Integral, K_i	Decrease	Increase	Increase	Decrease
Derivative, K_d	Small change	Decrease	Decrease	No change

3.5 Control Structure of Lane Keeping Control System

The control structure of the Lane Keeping Control System is shown in Figure 3.4. This control system consists of a PID controller, sideslip angle, yaw rate and the steering angle. In this project, the PID controller is used on the state deviation of the sideslip angle and yaw rate. In other to increase vehicle constancy, the main propose of this controller is to tune the value of proportional gain k_p, integral gain k_i and derivative gain k_d.

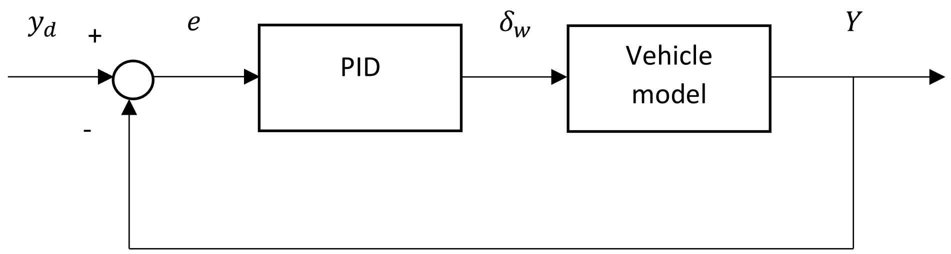

Figure 3.4: Structure of lane keeping control system with a PID controller

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter will explain more about the results and discussion of the data that used to assess the lateral displacement, yaw rate, yaw angle, sideslip angle and lateral acceleration of the vehicle. There are also include the results of the tire model. The tire model that use in this project is the magic formula tire model. To determine the effectiveness of the vehicle behaviour, controller and control structure of the vehicle also need to be determined to find good data. For this project, the controller that is used is the PID controller. It means that the variation of the parameters can show the feedback gain of the vehicle which is lateral displacement. The desired trajectory, magnitude, sideslip angle, yaw angle and yaw rate of the vehicle also can be determining. For a better understanding, the graphical solution is an important example to show the effect of the vehicle.

4.2 Vehicle Model and Tire Model Analysis

For the first data are used to estimate the vehicle model. The equation that generates as in Equations (3.1) and (3.2) above. This equation with the vehicle model parameter is used to assess the sideslip angle and yaw rate. This parameter is shown in Table 3.1 above. This equation was generated as a linear model to get the sideslip and yaw rate of the vehicle. The combination parameter with the tire model also determines the data of the vehicle. This parameter used high friction road for the front and rear tire. The parameter is shown in Table 4.1 below.

Table 4.1: Parameter of High Friction Road for Front and Rear (Ono *et al.*, 1998)

		B_f, B_r	C_f, C_r	D_f, D_r	E_f, E_r
High friction road	Front	6.7651	1.3000	-6436.8	-1.9990
	Rear	9.0051	1.3000	-5430.0	-1.7908

From Table 4.1, it shows the parameter for the high friction road for front and rear tire model. The parameter is used in the vehicle model to get the result of the sideslip angle Figure 4.1 and yaw rate angle Figure 4.2.

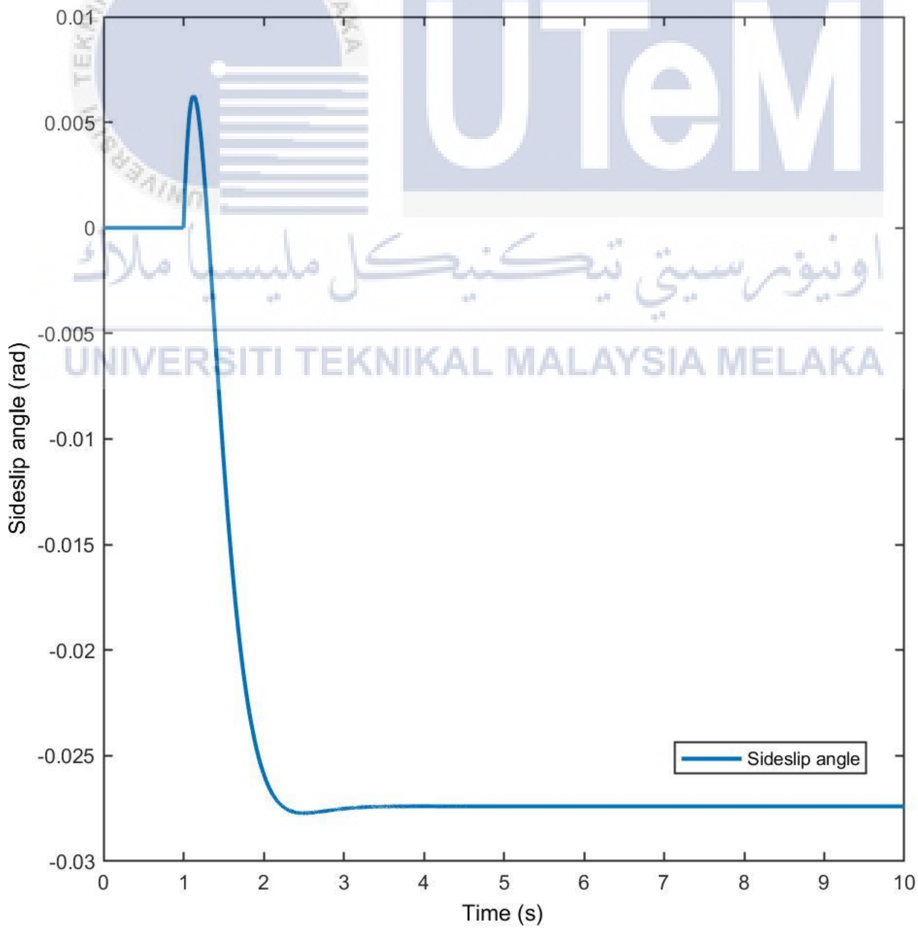

Figure 4.1: Plot of sideslip angle versus time

Figure 4.1 shows the graph of the sideslip angle, which is a sideslip angle against time. Meanwhile, Figure 4.2 shows the value of yaw angle against time.

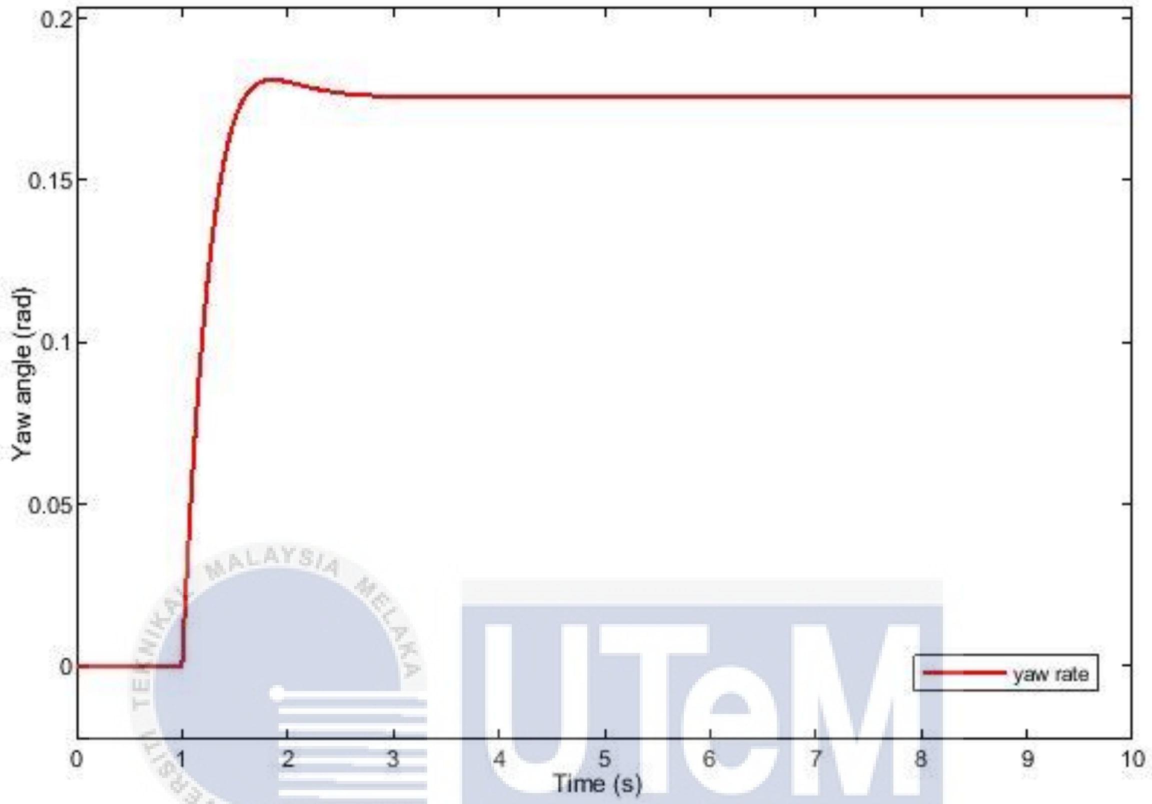

Figure 4.2: Plot of yaw rate versus time

4.3 Effect of Road Friction on Cornering Force

Cornering force of the tire occurs when the vehicle takes a corner at some velocity. The angular force is a lateral tire force produced during the cornering process and produced by the tire slip. The tire slip is equal to the angle of the slip angle. For the slip point, the pad contact patch is deformed. In order to assume the cornering characteristics, the simulation has been done to show the cornering characteristic between high friction road and low friction road for front and rear tire of the vehicle. For easy to understand, the high friction road is for the dry road surface and wet road surface for low friction road. The parameter of the vehicle model and the tire model is taken from Table 3.1 and 3.2 above. Figure 4.3 shows the cornering characteristic for the high friction road of front and rear tire. The significant negative of the cornering force axis is due to the path of the vehicle. According to the results, for comparison of the graph, it shows the front wheel has taken a high cornering force compare to the rear tire.

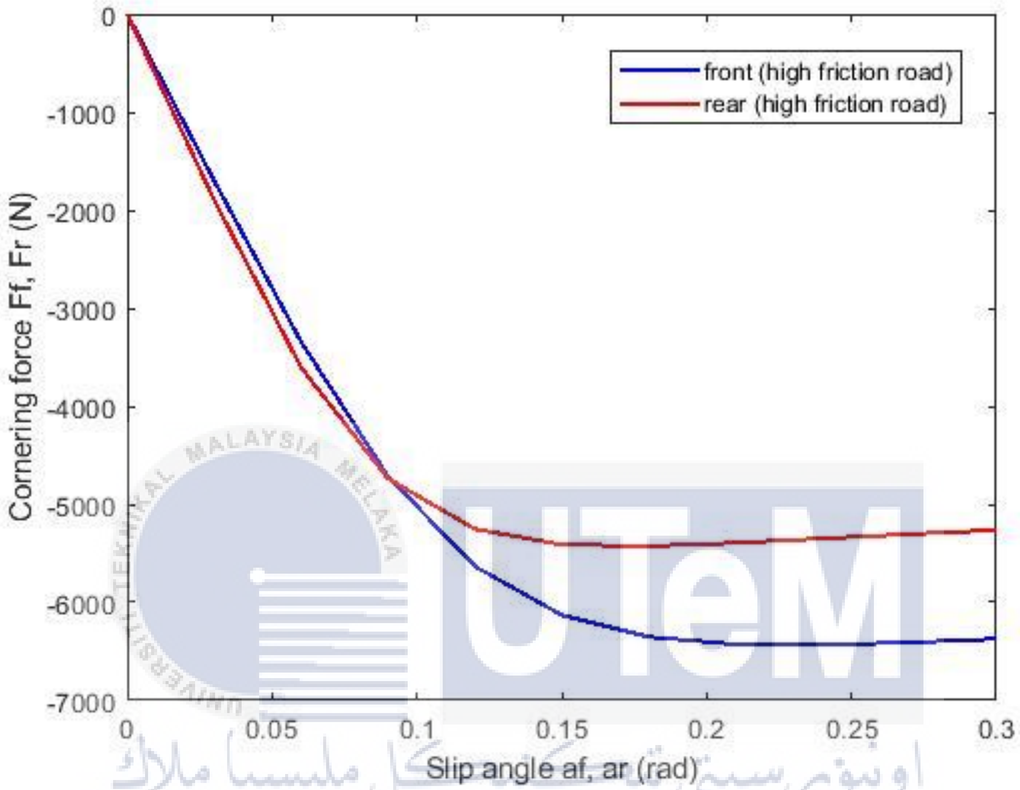

Figure 4.3: Plot of cornering force versus slip angle for high friction road

Figure 4.4 shows the cornering characteristic of low friction road conditions. The value of the cornering force in the front tire is higher than the value at the rear tire. For the effect of the comparison between the high road friction and low road friction, the value of the cornering force of the dry road is higher compare to the wet road condition. It is because the tire contact patch at the high friction road is more than the low friction road. Figure 4.5 shows the comparison of cornering force against the slip angle for high road friction and low road friction.

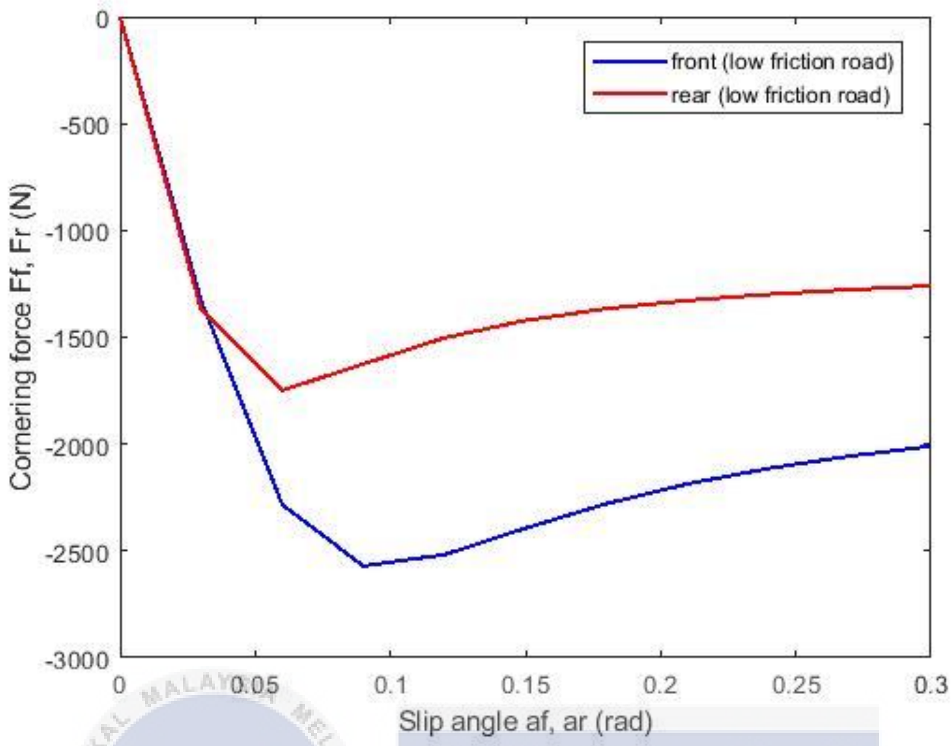

Figure 4.4: Plot of cornering force versus slip angle for low friction road

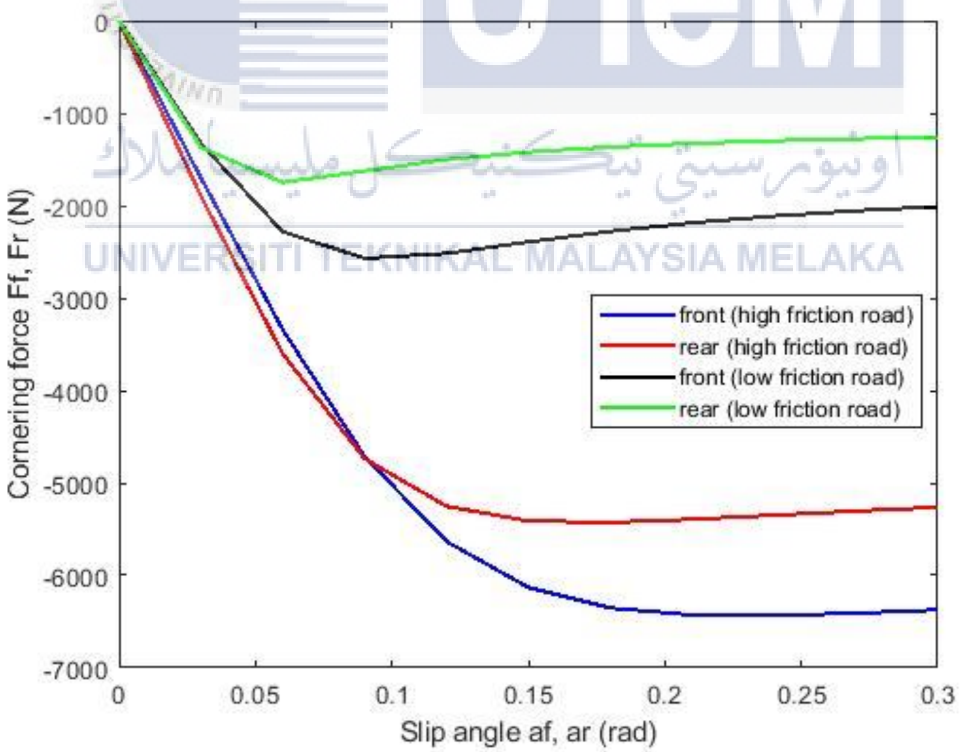

Figure 4.5: Plot of cornering force versus slip angle for high friction road and low friction road

4.4 Lane Keeping System Using PID controller

In order to observe the trends of the lane keeping controls system, the generation of the controller is the important element to get the good effect of the vehicle. In this project, the vehicle model consist of vehicle and tire model are used as a model. For the tire model, it uses a high friction road coefficient as shown in Table 4.1 above. The controller that uses is a PID controller. In order to get the desired value, the PID controller needs to tune and the good result is be taken. The different parameters such as vehicle speed and mass of vehicle also is done by using MATLAB Simulink software to get the variation of the results. The different velocity use in this simulation is 20 m/s, 25 m/s and 30 m/s. For a mass of the vehicle that use is 1500 kg, 2000 kg and 2500 kg.

4.5 Development of Feedback Gain

The feedback for the gain is the lateral displacement. The PID controller had been used in order to tune the output and to get the desired value. Other outputs that are found is including a sideslip angle of the vehicle, yaw rate, yaw angle and lateral acceleration.

4.5.1 Effect of Velocity and Mass on Lateral Displacement

For the result of velocity, the variation speed of the vehicle does not disturb the feedback of the lateral displacement. Based on the result shown in Figure 4.6 plot of lateral displacement versus time for difference velocity, the effect of the velocity on the vehicle, shows no different on lateral displacement. As the velocity of the vehicle increase from 20, 25 and 30 m/s respectively, the lateral displacement remains at the same line for three different velocities. Figure 4.7 shows the plot of lateral displacement versus time for different mass. The results show, there are a different values of lateral displacement. As the value mass of vehicle increases at 1500, 2000 and 2500 kg respectively, the lateral displacement of the vehicle becomes larger with a low mass and smaller with a high mass.

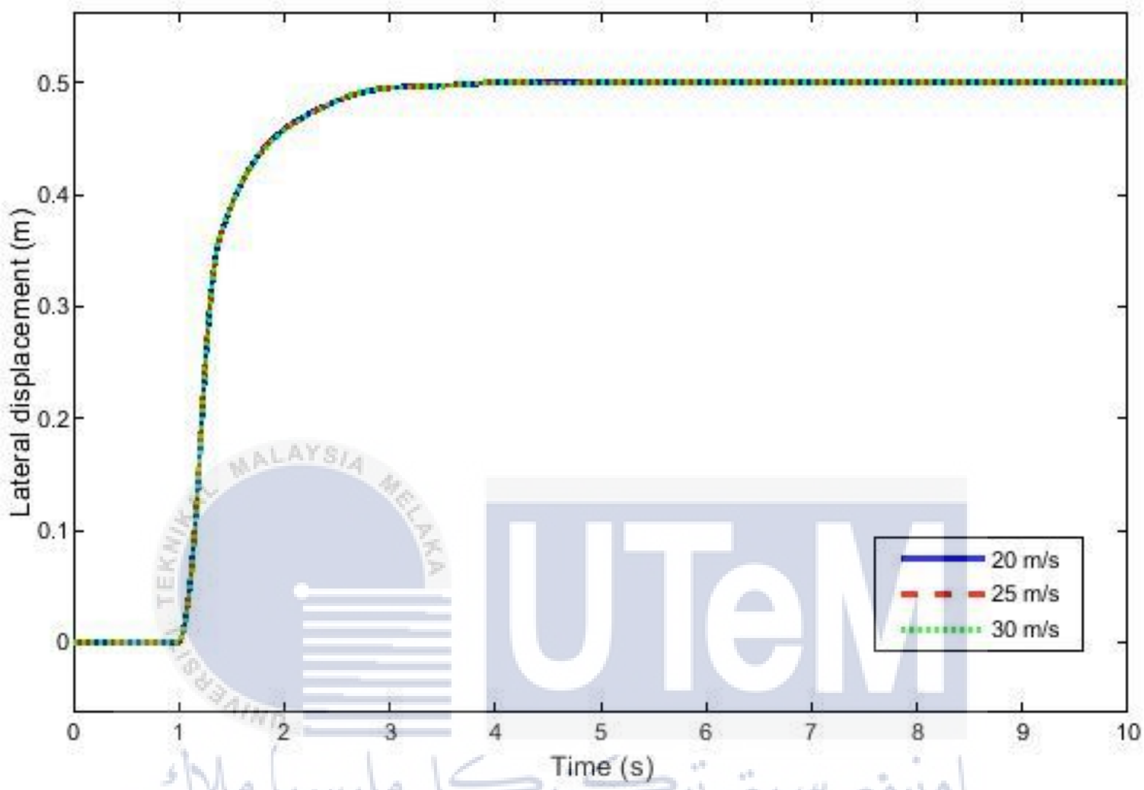

Figure 4.6: Plot of lateral displacement versus time for different velocity

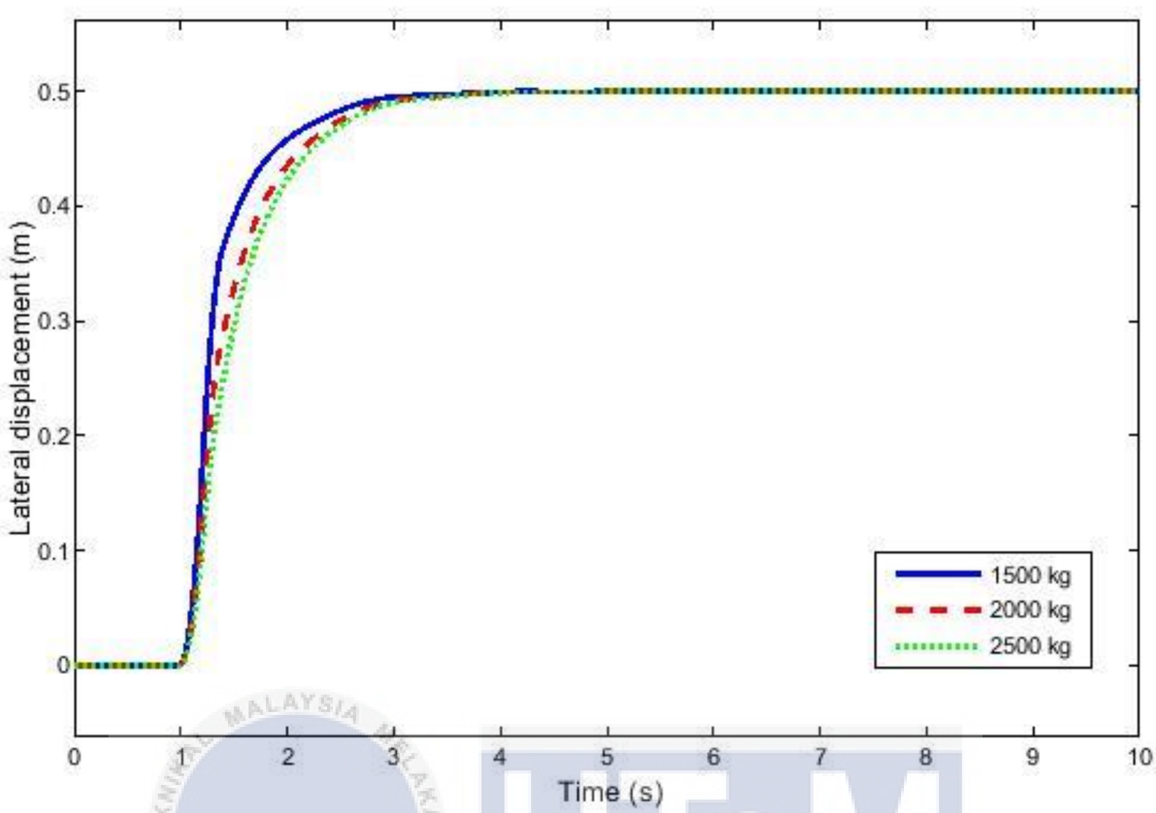

Figure 4.7: Plot of lateral displacement versus time for different mass

4.5.2 Effect of Velocity and Mass on Yaw Rate

Finding the value of the yaw rate is important to determine the heading angle of the vehicle when the vehicle at horizontal. Figure 4.8 shows the plot of yaw rate versus time with a different velocity. For the velocity at 20 m/s, the value of the yaw rate is larger compare to the velocity at 25 m/s and 30 m/s at the first peak. But for the greater value of velocity, it will give more time to the yaw rate to back constant. Figure 4.9 shows the plot of yaw rate versus time with a different mass. To compare the value, a mass of 1500 kg give a high value of yaw rate compare to 2000 kg and 2500 kg. As an increase of the mass, the value of the yaw rate will be lower compared to the low value of mass it will give a high value of yaw rate.

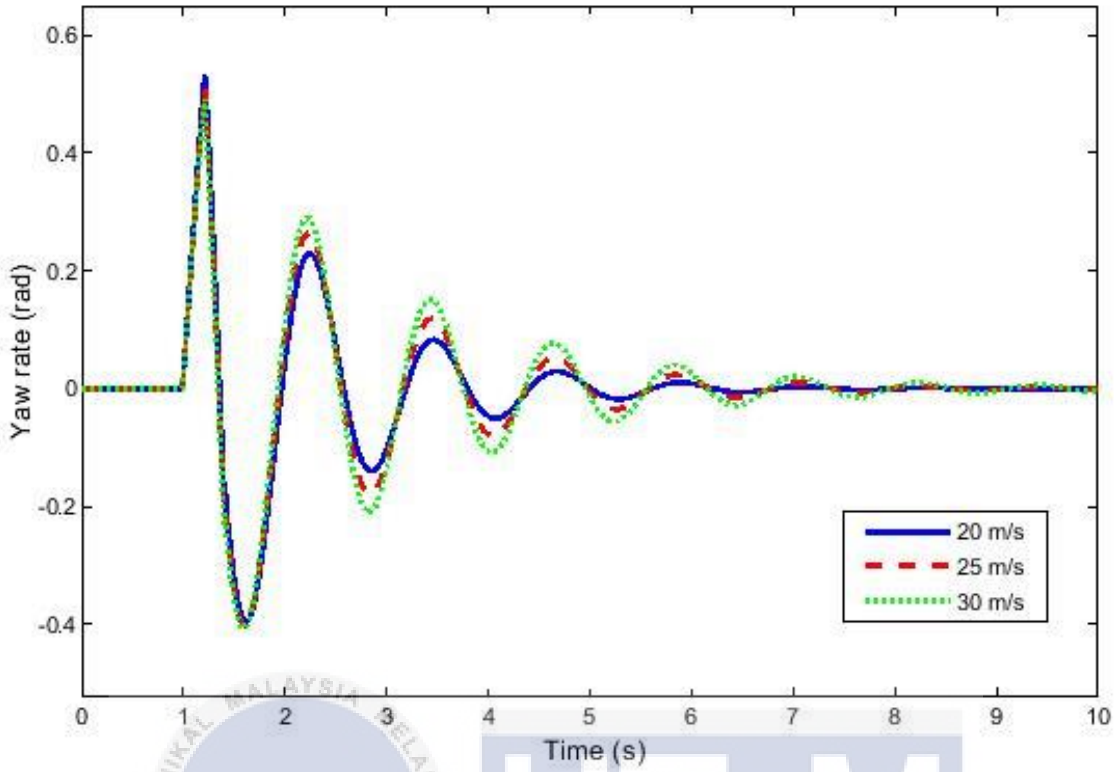

Figure 4.8: Plot of yaw rate versus time for different velocity

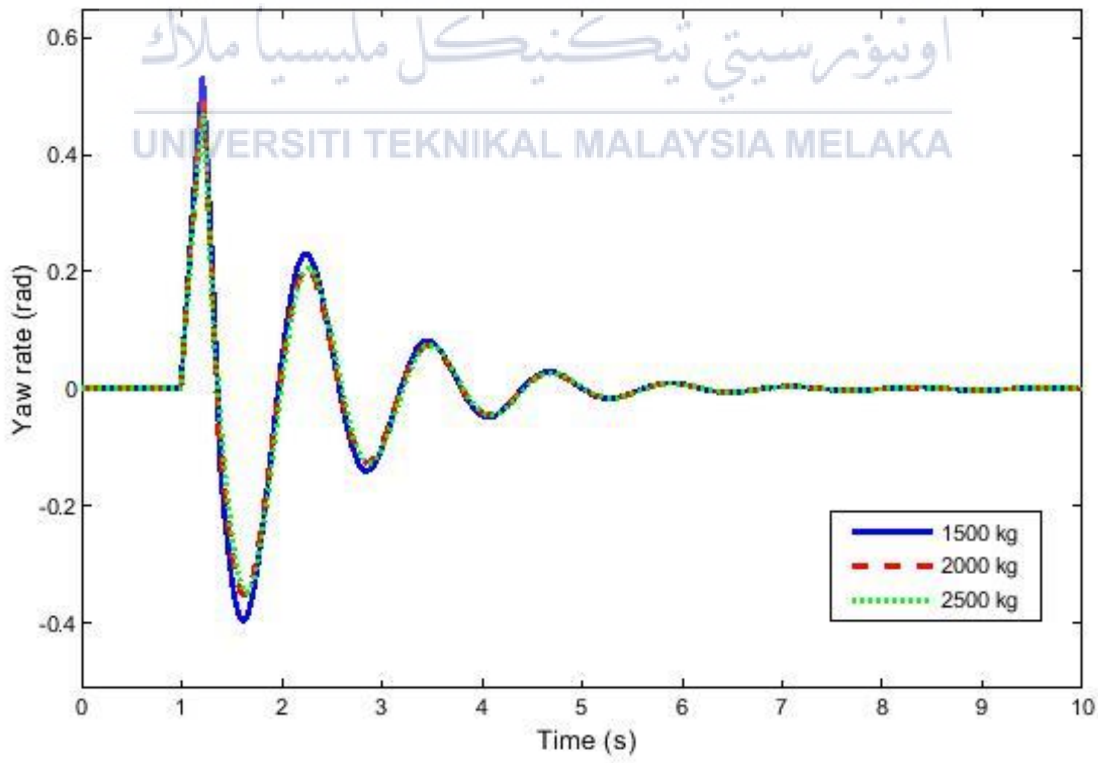

Figure 4.9: Plot of yaw rate versus time for different mass

4.5.3 Effect of Velocity and Mass on Yaw angle

Figure 4.10 shows the plot of the yaw angle versus time with a different velocity. For the velocity at 20 m/s at the first peak, the value of yaw angle is larger compare to the velocity at 25 m/s and 30 m/s but settling time for velocity 20 m/s is faster compare to other velocities. The greater value will give more time to the yaw angle to back constant. Figure 4.11 shows the plot of the yaw angle versus time with a different mass. To compare the value of yaw angle, a mass of 1500 kg give a high value of yaw angle at a peak compare to a value of 2000 kg and 2500 kg. As an increasing the value of mass, the value of the yaw angle will be lower.

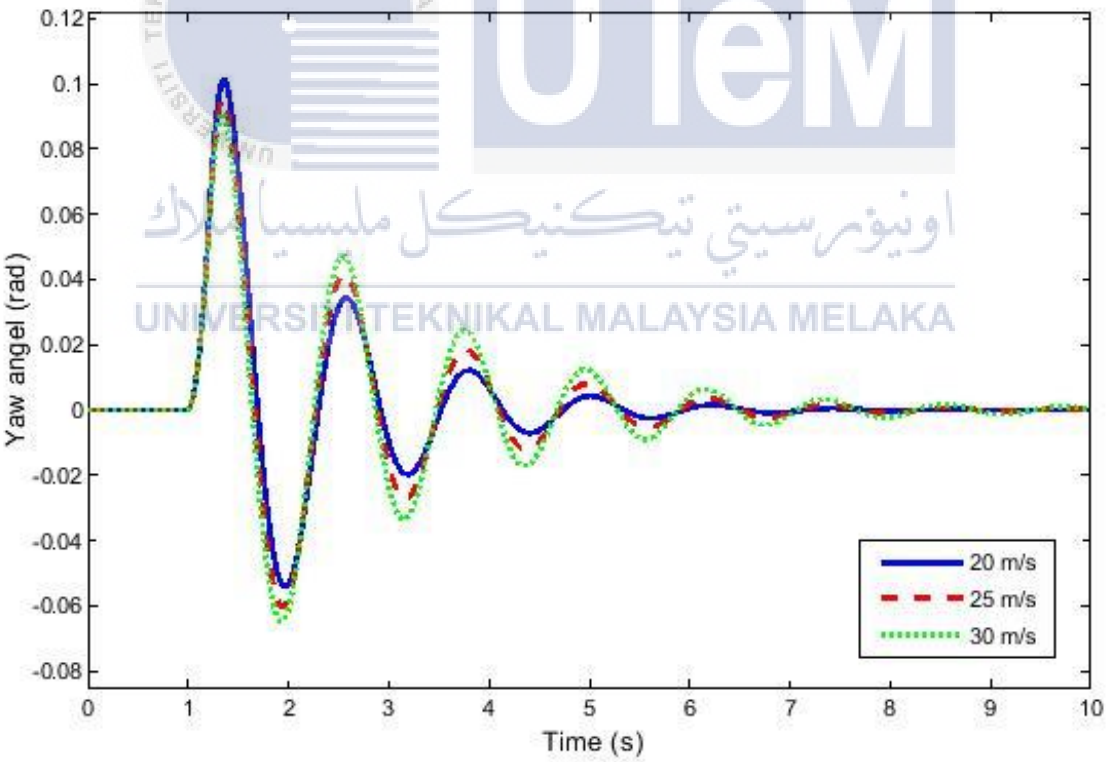

Figure 4.10: Plot of yaw angle versus time for different velocity

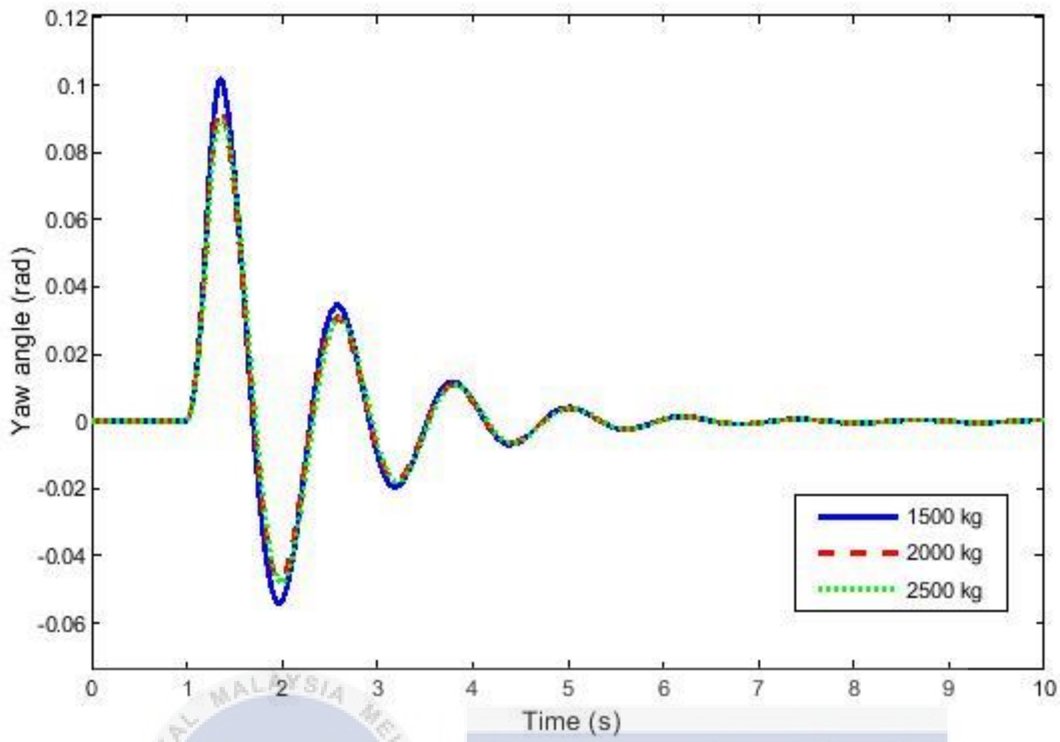

Figure 4.11: Plot of yaw angle versus time for different mass

4.5.4 Effect of Velocity and Mass on Lateral Acceleration

Figure 4.12 shows the plot of lateral acceleration versus time with a different velocity. For the effect of the velocity on lateral acceleration, it shows no different changes. As the velocity of the vehicle increase from 20, 25 and 30 m/s respectively, the lateral acceleration remains at the same line for three different velocities. Figure 4.13 shows the plot of lateral acceleration versus time with a different mass. The results show, there are a different values of lateral acceleration. The value 1500 kg of mass gives a high value of lateral acceleration and it will drop faster compare to the other value of mass. As a decreasing value of mass, the value of lateral acceleration will become higher and will drop faster to be at a constant line.

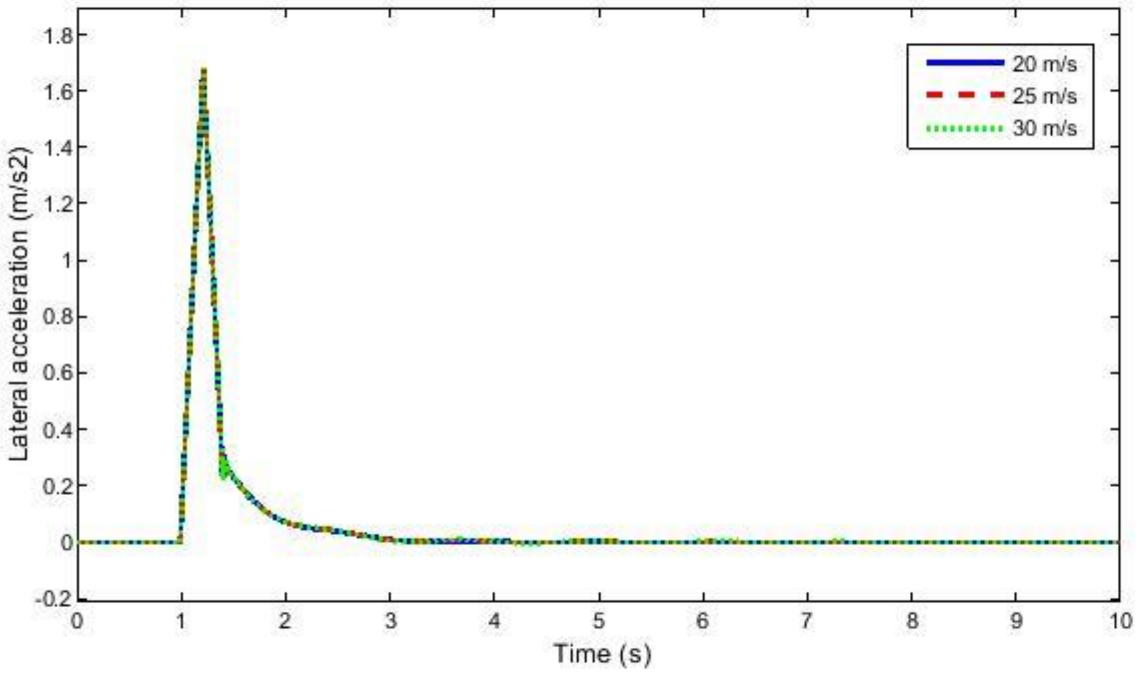

Figure 4.12: Plot of lateral acceleration versus time for different velocity

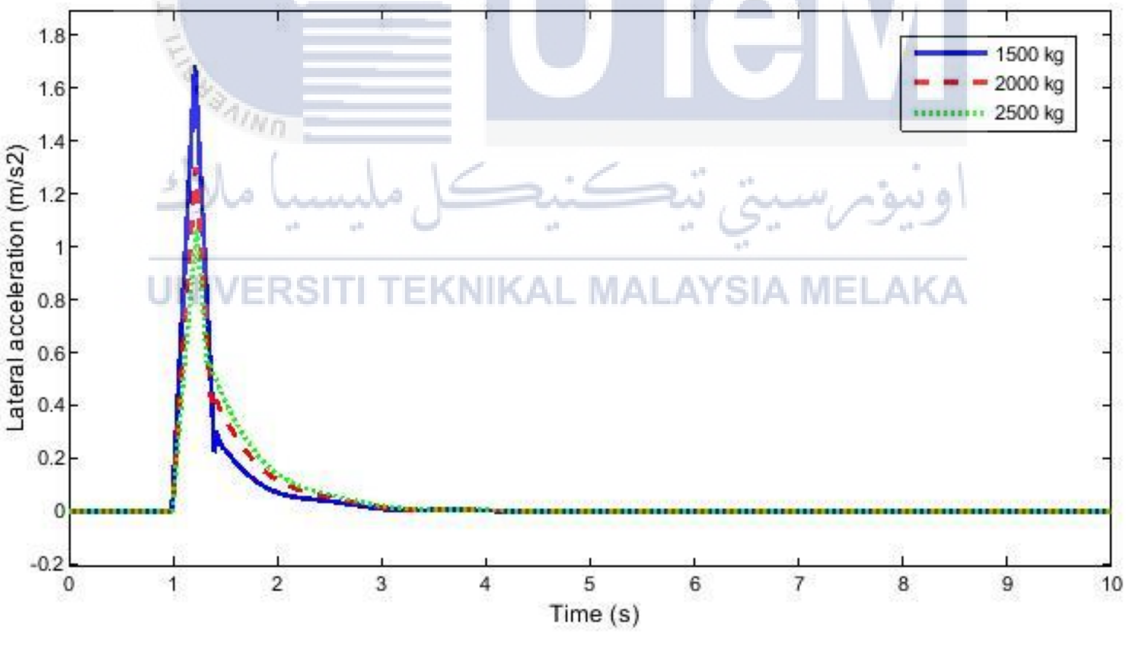

Figure 4.13: Plot of lateral acceleration versus time for different mass

4.6 Discussion on Lane Keeping Control System

Based on results obtained in this thesis. The relation for the lane keeping control system has shown a great performance of the vehicle. For lateral displacement, it shows a good trend that only about 0.5 m to take a displacement and not too much overshoot occurs. The setting time for lateral displacement also is good. For the sideslip angle, the results show a small value of angle which is about 0.08 rad. The small value of the angle does not affect the performance of the vehicle. For the yaw rate, the results show the maximum value is about 0.6 rad/s and there is a small value of angular velocity and it still on the desired angle. The value of the yaw angle shows a small angle that only 0.1 rad for a maximum angle. The trend does not greatly affect the performance of the vehicle because of a small value of angle. The lateral acceleration shows the value of at the peak is about 1.7 m/s^2 which is not too large. The trend value of lateral acceleration after that decrease and back to constant at 0 m/s^2. Based on all the data obtained, the effect on the vehicle in lane keeping control system shows a better performance. To take a vehicle back on the desired lane, it can be performed based on this data.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

To sum up this thesis, it issues the problem of the increasing road accident for vehicles over the year. The discussion is addressed in chapter 1. For this thesis, it proposed the method of the vehicle to overcome the lane change of the vehicle that will cause the accident. The method is generated in this thesis is the lane keeping control system by applying MATLAB simulation. The system will give feedback to the vehicle to perform the lane change maneuver to keep the vehicle follow the desired lane.

The lane keeping control system is generated from the combination of the vehicle model and the tire model. The mathematical model of each model is derived to get the equations. The basic 2DOF bicycle model is taking as an allusion for the vehicle. For the tire model, it is applying the magic formula tire model. The different road conditions of the Magic Formula tire model for high friction and low friction are also determined to get the result. By combination both models, it will form the structure of the vehicle model.

The outputs of the vehicle system are determined by adding a controller. The controller that is using is a PID controller. To get a better execution of the vehicle system, the controller needs to be a tune. Among the outputs of the vehicles system that need to be analyzed are a lateral displacement, sideslip angle, yaw angle, yaw rate and lateral acceleration. All these outputs need to be well tune to get the good performance of the vehicle. For the tire model that use in this case, the different road conditions are applied to get a slip angle of the tire and cornering force of the front and rear tire of the vehicle.

In this case, the different speed and mass of the vehicle also applied to verify the performance of the vehicle system. For example, based on the results, the overshoot and steady state error for lateral displacement of the vehicle can be decreased and it will take a short time to settle. The good results can be done by tuning a PID controller correctly.

The suggested simulation of lane keeping control system shows the possibility of improving vehicle safety. The accident of the vehicle may be avoided, and the life of driver or passenger could be safe with this further development of these lane keeping control systems, which can improve vehicle performance and capability.

5.2 Recommendation

This study involves several limitations to simplify the work. The development of the vehicle and tire model can be done with variables characteristics. For example, there are a few tire models can be applied. Such as the brush tire model, calspan's tire model and dugoff's tire model. Since this thesis of the lane keeping control system is focusing on the PID controller only, thus for future study, the design of the controller can be done for variables characteristic for example by using a fuzzy logic controller to get the better and different performance of the vehicle.

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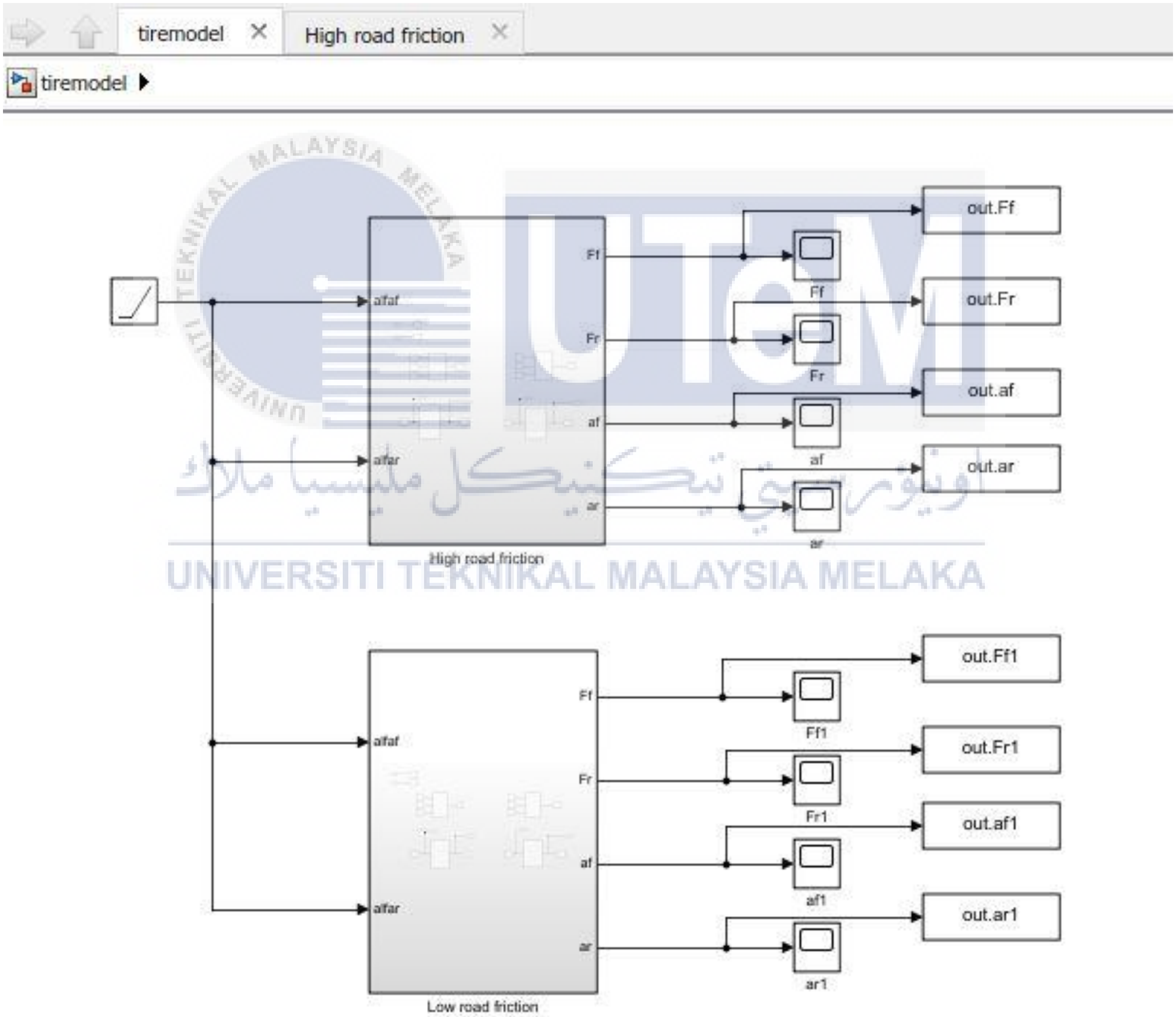
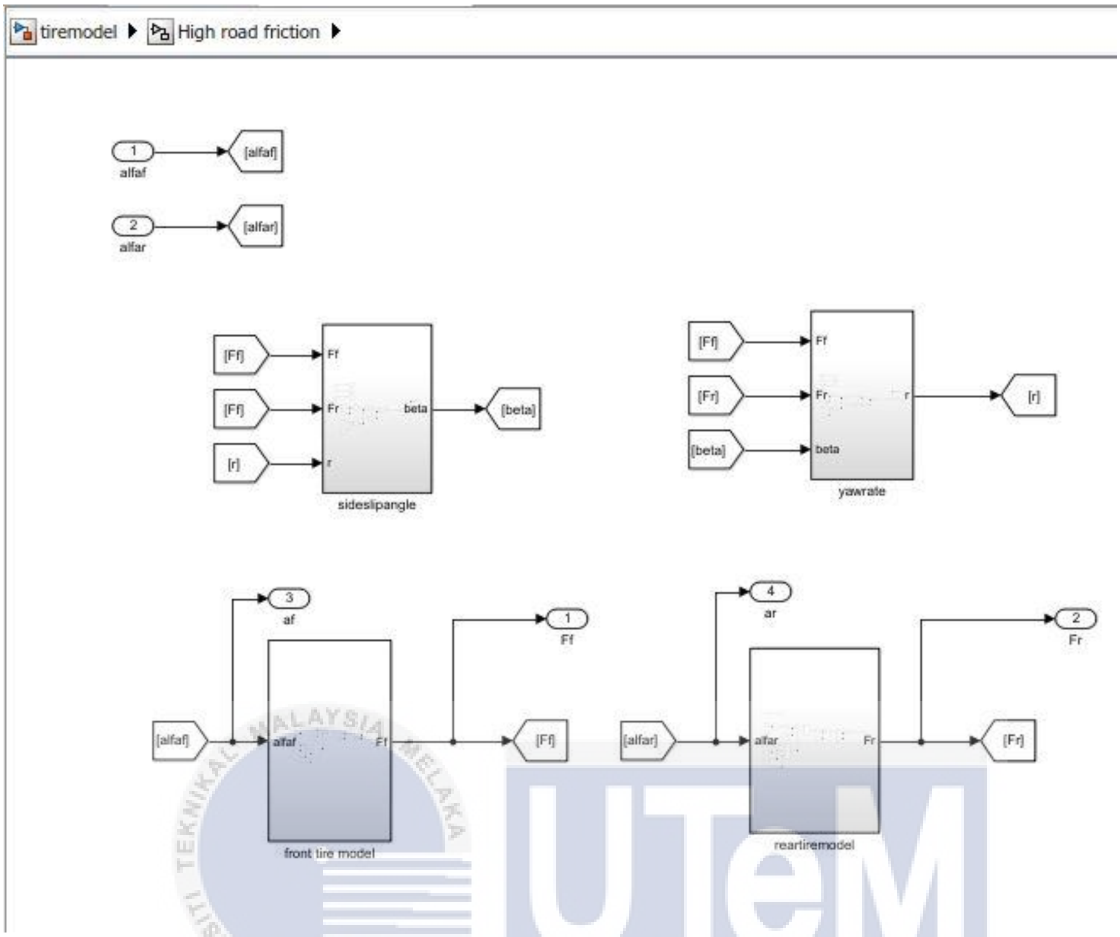
LIST OF APPENDICES

Simulink Block Diagram

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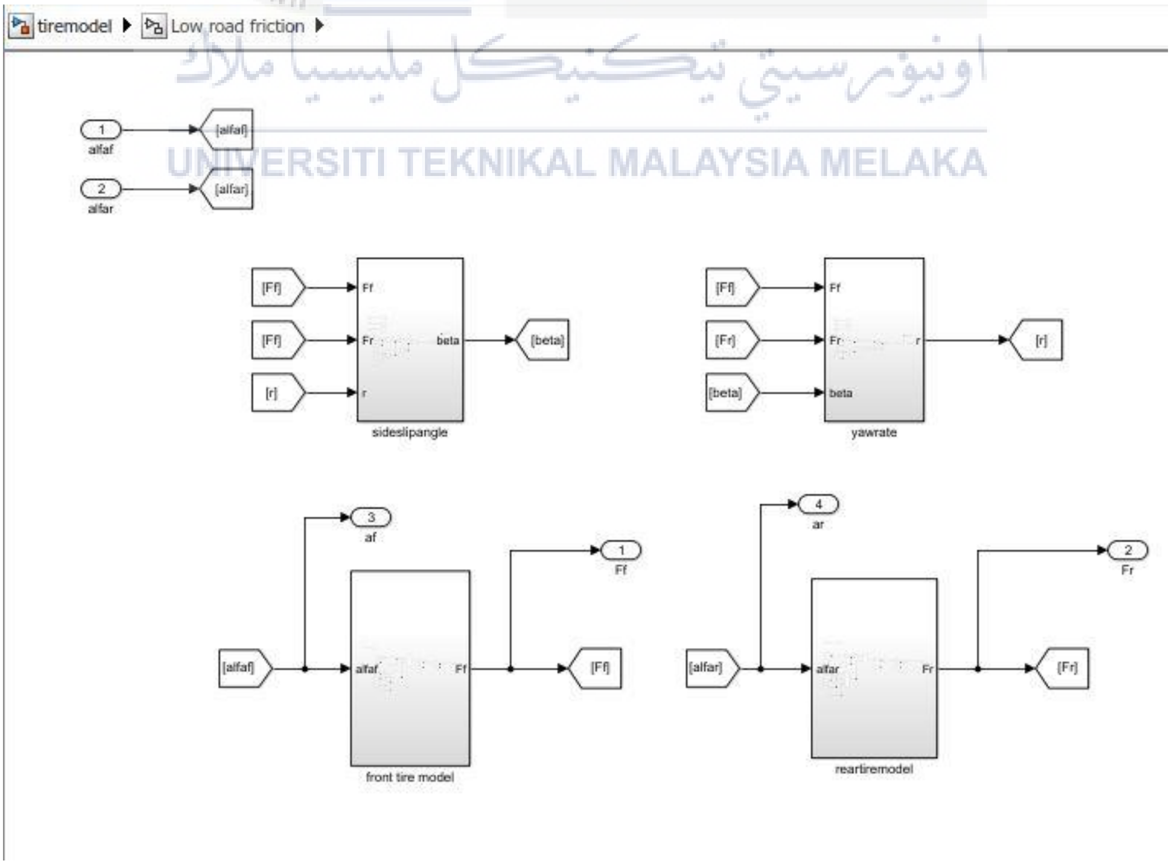
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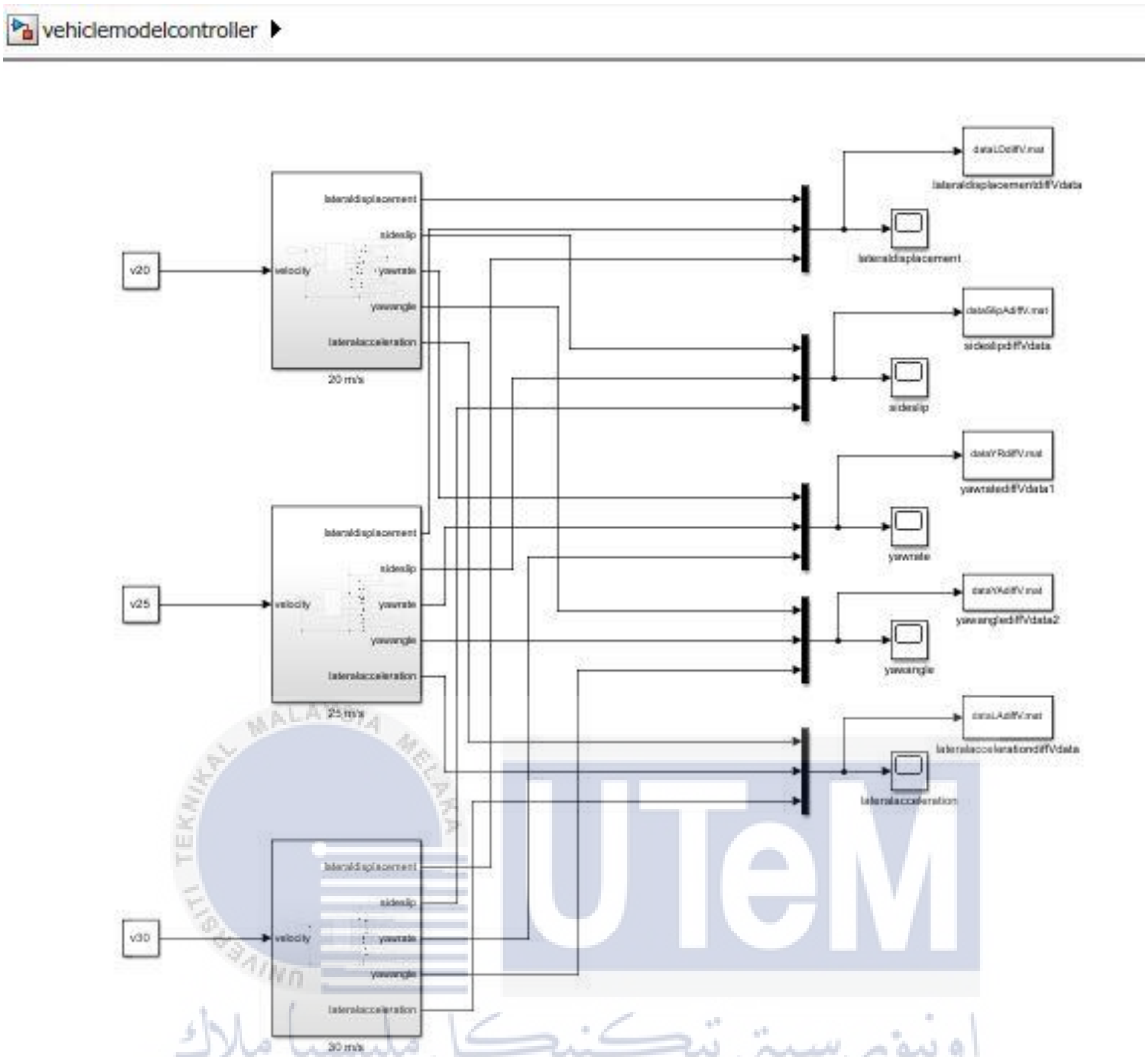
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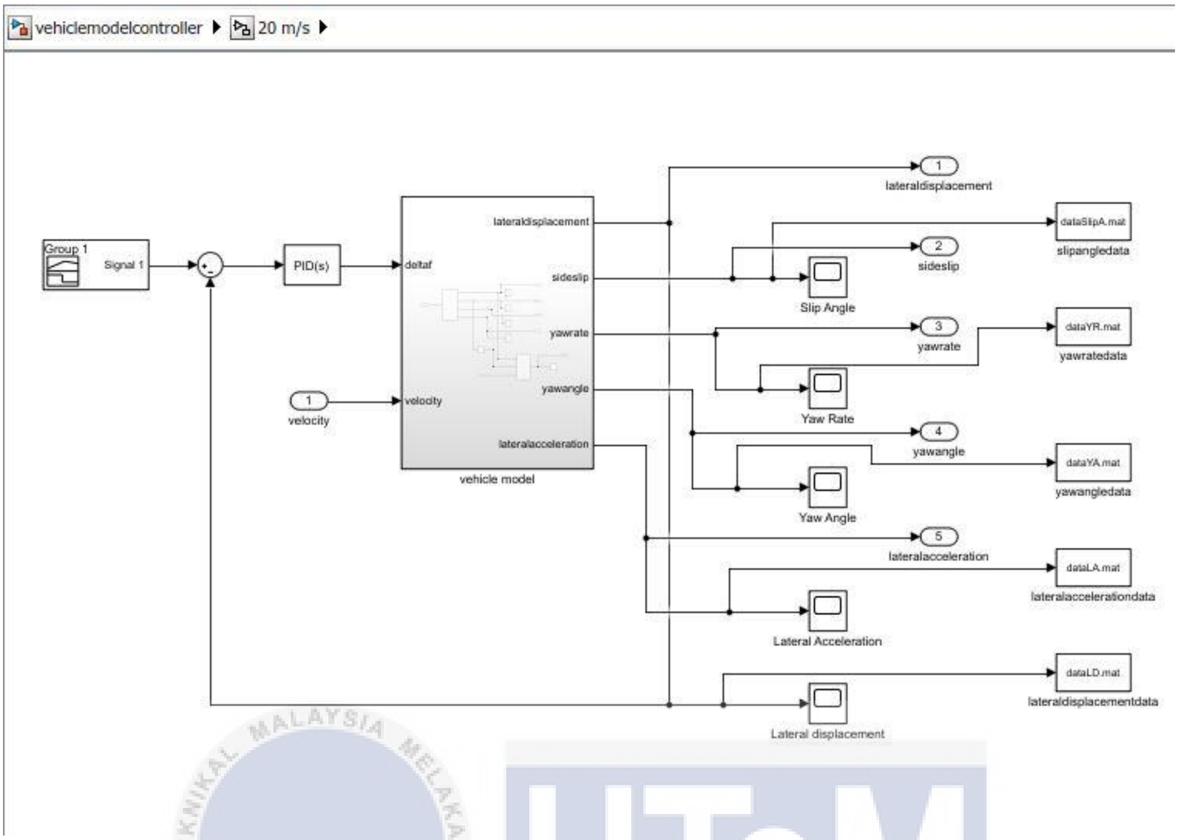
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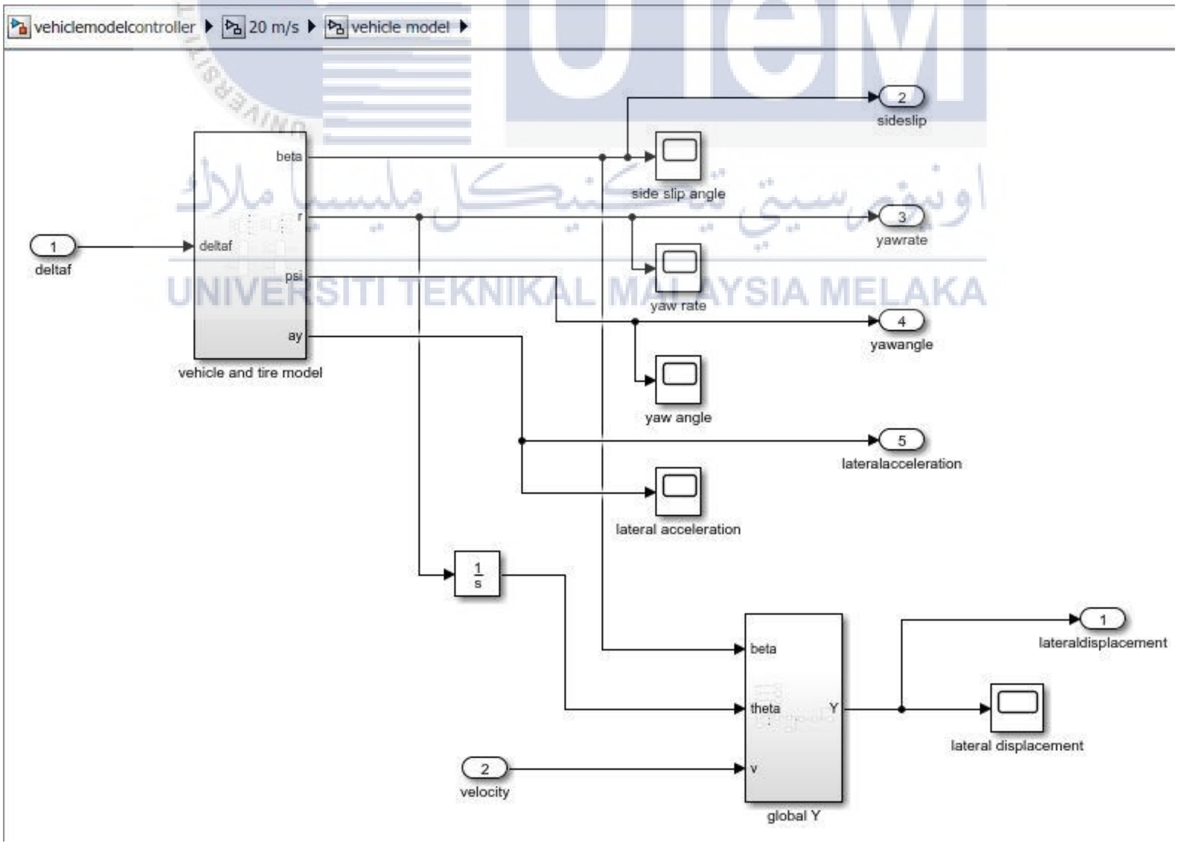
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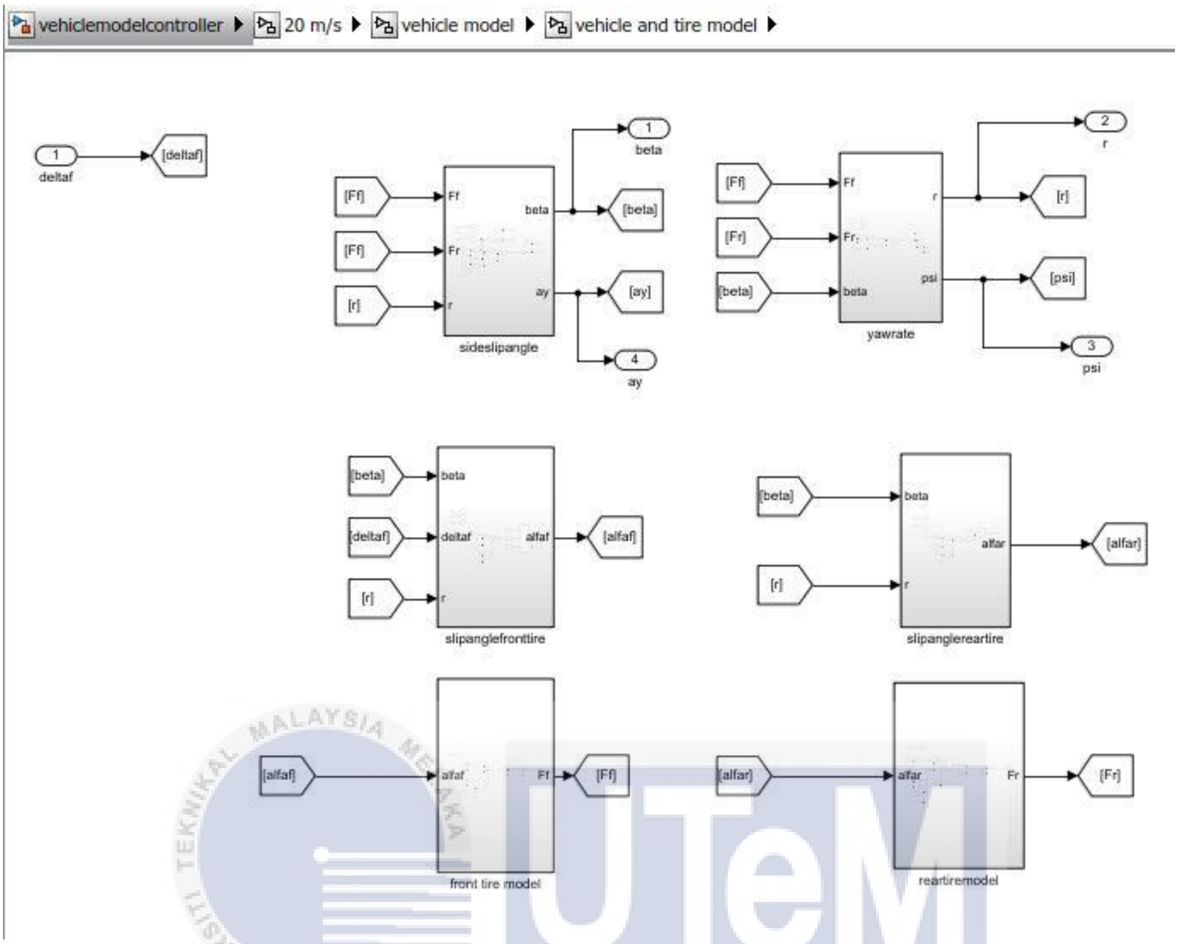
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