

SIMULATION OF AUTONOMOUS DRIVING IN FOLLOWING HIGHWAY LANE



BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (AUTOMOTIVE) WITH HONOURS



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Bachelor of Mechanical Engineering Technology (Automotive) with Honours

SIMULATION OF AUTONOMOUS DRIVING IN FOLLOWING HIGHWAY LANE

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DECLARATION

I declare that this thesis entitled "Simulation Of Autonomous Driving In Following Highway Lane" 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 of any other degree.



APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Automotive) with Honours.

Signature : Supervisor Name Nur Rashid Bin Mat Nuri Date)/22 **UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

DEDICATION

To my beloved mom and dad, Puan Yuslaini binti Yusof and Encik Hairizal, my younger sister and younger brother who encouraged me to make a great thesis based on my topic. I had spent about one year to finish this thesis report.

To my bestfriends, Nur Syahmi and As-Shakirin and also friends from my class as well as from different courses and programmes, who always support and have my back whenever I felt down to earth. Thank you for the inspiration and kind words.

To Universiti Teknikal Malaysia Melaka (UTeM), thank you for giving me opportunity to continue my study in my favourite programme which is the Automotive Technology programme.

Last but not least, the most person who always help me with my thesis, my awesome supervisor, Ts. Dr. Nur Rashid. Thank you for always giving me the opportunities to fix all my mistake from when I was your student until now.

ABSTRACT

An autonomous vehicles are the future smart car that created to be driverless, efficient, and also crash avoiding ideal urban car of the future. Many studies have been made to realize the dream of an autonomous driving with many test of system. Solving the defect during the test run for the autonomous driving simulation will be difficult challenges. As many as the challenges appeared, the first challenge would be to design and customize the system and how the system is needed to be put on the appropriate location. Visible technologies that help an autonomous driving to be more effective are important components of Intelligent Transportation Systems. Many researcher, technologist, engineers, and commercial systems have been proposed in the literature. The derivation about the equation for the vehicle dynamics will help to give more exposure about how the vehicle can turns when reaching the curved road in theory as well as in calculation research. In this paper, the system for an autonomous will be discussed especially about how the system will help driver to reduce accident happened by avoiding collision and impact from possible angle to the vehicle. The lane detection and tracking and lane departure warning both have its own function. Other than that, this paper will also discuss how an autonomous driving vehicle system more advanced system such as lane keeping assist system performs in road lane. This study's objective is to develop lane keeping assist (LKA) system to observe the behavior of the vehicle in highway lane. MATLAB Simulink software will be the platform for developing the system. Many block diagram from the library are used to develop the LKA system in the software such as lane keeping controller which link to the vehicle block diagram to synchronize the lane detection with the movement of the vehicle. The lane also developed in the software for curve road type. Furthermore, that simulation can be observed more clearly with highway speed of 100 km/h. The results present about the difference between the performance of the vehicle without enable the system and with enable the system according to safe lateral distance values. Safe lateral distance that is set from the controller in MATLAB Simulink software is 0.5 m until 2.0 m with interval of 0.5 m. The behavior of the vehicle includes the lateral deviation, relative yaw angle, and steering angle. These three behaviors show how the vehicle perform in highway lane and the comparison for each value of safe lateral distance.

ABSTRAK

Kenderaan berautonomi adalah kereta pintar masa hadapan yang diciptakan untuk dijadikan sebagai kenderaan yang tidak memerlukan pemandu, effisien, dan kenderaan yang dapat mengelakkan rempuhan. Pelbagai penyelidikan telah dilaksanakan bagi merealisasikan impian pemanduan berautonomi dengan pelbagai cubaan sistem. Penyelesaian terhadap kecacatan yang berlaku semasa ujian simulasi pemanduan autonomi menjadi cabaran yang sukar. Dalam pelbagai cabaran yang mendatang, cabaran pertama adalah merancang dan menyesuaikan sistem dan bagaimana sistem perlu ditempatkan di lokasi kenderaan yang sesuai. Teknologi berupa penglihatan pada kenderaan berautonomi yang membantu pemanduan autonomi menjadi lebih berkesan adalah komponen penting Sistem Cerdas Transportasi. Ramai penyelidik, teknologi, jurutera dan sistem komersial telah dicadangkan di dalam kajian perpustakaan. Terbitan tentang persamaan untuk dinamik kenderaan akan membantu untuk mendapatkan lebih banyak pencerahan tentang bagaimana sistem ini dapat membantu pemandu untuk membelok apabila sampai pada selekoh jalan berdasarkan kajian teori dan juga dalam penyelidikan pengiraan. Dalam tulisan ini, sistem untuk autonomi akan dibincangkan terutama mengenai bagaimana sistem akan membantu pemandu untuk mengurangkan kemalangan yang berlaku dengan mengelakkan perlanggaran dan impak dari sudut yang bermungkinan akan berlakunya hentaman. Objektif kajian ini adalah untuk mencipta system lane keeping assist (LKA) bagi permerhatian terhadap tingkah laku kenderaan di lebuh raya. Perisian MATLAB Simulink akan menjadi platfom untuk mencipta sistem. Pelbagai blok gambar digunakan bagi menghasilkan sistem LKA seperti blok gambar lane keeping vang menghubung dengan blok gambar kenderaan bagi menyatukan pengesanan lorong. Selanjutnya, simulasi yang dilakukan dapat diperhatikan dengan lebih jelas dengan kelajuan lebuh raya 100 km/j. Hasil simulasi akan menunjukkan perbezaan antara prestasi kenderaan tanpa mengaktifkan sistem dan system setelah diaktifkan berdasarkan nilai 'safe lateral distance'. 'Safe lateral distance' tersebut menggunakan nilai 0.5 m sehingga 2.0 m dengan selanga nilai 0.5 m. Tingkah laku kenderaan merangkumi 'lateral deviation', 'relative yaw angle', dan sudut stereng. Ketiga-tiga tingkah laku ini akan dibincangkan untuk menyelesaikan bagaimana sistem akan dilakukan di lebuhraya dan perbandingan antara semua nilai 'safe lateral distance'.

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In the Name of Allah, the Most Gracious, the Most Merciful

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LIST OF SYMBOLS AND ABBREVIATIONS

v_x	-	Vehicle speed
β	-	Sideslip angle
r	-	Yaw rate
f_{ω}	-	Lateral wind force
C_r	-	Center of gravity of rear tire
C_f	-	Center of gravity of front tire
т	-	Mass of vehicle
${\mathcal Y}_L$	-	Lateral deviation error
ψ_L	- 1	Heading error
r		Radius
$ ho_r$	- LEK	Road curvature
R_r	E	Curvature radius
T_d	-23A)	Driver torque
T_a	14	Assistance torque
T_s	ملاك	Self aligning torque
x_v	UNIV	Vehicle state
W	-	Disturbance vector
u_v	-	Control input
η_t	-	Torque efficiency
LKA	-	Lane Keeping Assist
LDW	-	Lane Departure Warning
LDT	-	Lane Departure and Tracking

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CHAPTER 1

INTRODUCTION

1.1 Background

Autonomous driving is a method where people can drive their vehicle without controlling the vehicle such as step on the accelerator pedal, brake pedal, and control the steering of the car. The system was set up in the vehicle to give command to the vehicle so that the vehicle will detect surrounding and follow the command that was set up by the driver. Plus, autonomous vehicles are vehicles that are able to detect their surrounding and environment and to move without any intervention of a human driver. It also are known as driverless, self-driving, unmanned or robotic vehicle.

Vehicle automation was first proposed in 1918 (Pendleton et al., 2017), and General Motors demonstrated the first autonomous vehicle concept in 1939. (Shladover, 2018). In the 1950s, General Motors and the Radio Corporation of America Sarnoff Laboratory collaborated on the first steps of research and development (R&D) (Shladover, 2018). Several other R&D programmes were active in the United States, Europe, and Japan from 1964 to 2003, under the individual and joint initiatives of various government institutes and academia to develop automated bus and truck platoons, supersmart vehicle systems, and video image processing for driving scene recognition (Shladover, 2018).

The Defense Advanced Research Projects Agency's (DARPA) Grand Challenges Program in the United States expanded AV research in 2004. In 2005 and 2007, AVs capable of traversing desert terrain were developed as a result of the challenges. Via DARPA's Urban Challenge Program, researchers were also able to position AVs on city roads (Pendleton et al., 2017). R&D has progressed at a rapid pace in both academia and industry since then (Shladover, 2018).

There are variety of system for autonomous driving to be used as a system to detect surrounding of the location so that the autonomous driving can be more effective. For example, the implementation of Lane Keeping Assist (LKA) system for the autonomous driving. LKA system is a pro-active system that is able to alerts the driver, either with an audio/visual prompt or haptic feedback through the steering wheel, and also able to intervene and manipulates the steering to prevent the driver from the case of understeer or oversteer when driving.

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1.2 Problem Statement

Statistics of accident are increasing years by years. There are many types of causes that related to this problem. One of type causes is human factor such as driver's careless and fatigue when driving their vehicle. It shows that the driver can not focus when driving the car and causes accident by changing lane without the driver knowing. The cause inattention when driving also can affect other driver safety. Next, driver tend to oversteer and understeer when they are not focusing on the road which also can cause accident. Oversteer or understeer were also caused by inattention driver. This is because when they are not aware of the lane to control the steering wheel, accident could happened. This is why many researchers, technologists, and engineers were proposing system that could help driver as well as passenger to autonomously control the vehicle whenever required. By developing an autonomous driving system, the results of how the autonomous driving can be obtained to help reduce the accident to occur in highway. The autonomous driving alone will not enough to help to avoid a car accident. So, verifying an assist system for the autonomous driving by using MATLAB Simulink Software can help to investigate the safe lateral distance especially in highway road. Using Simulink also can investigate how the vehicle will perform in respective highway lane with the most accurate calculation of distance and speed. Simulink also will help to reduce the time used to test the safe distance between the car and the highway lane.

1.3 Research Objective

The objectives of the project are:

- To model an autonomous driving block diagram using Lane Keeping Assist system in MATLAB Simulink software.
- b) To investigate the effectiveness of safe lateral distance between vehicle and highway marking lane.
- c) To verify the behavior of the vehicle by following the highway lane.

1.4 Scope of Study

Based on the objectives, the scopes of study are highlighted as follows:

- a) Lane keeping assist (LKA) system is developed in the MATLAB Simulink
 Software.
- b) The safe lateral distance will be set from 0.5m until 2.0m with an interval of 0.5m.
- c) The velocity of the vehicle is set based on highway speed of 100 km/h.

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1.5 Research Flowchart

Figure 1.1 below present the flow of process for this reseach. Process flow for research acts as a map with a brainstorming idea to get a researcher from the beginning of inquiry to the end of a conclusive understanding.





Figure 1.1 Process Flowchart

1.6 Summary

An autonomous driving have been developed since 1980 and further study in 1984 and 1987 for Mercedes-Benz project. The study then spread to a new technology for accomplishment of fully autonomous vehicle. Chapter 2 will continue on how the system is reviewed based on previous study for further planning. Then, Chapter 3 presents the method about how the system is developed using the idea planned while Chapter 4 shows the simulation result test from MATLAB Simulink software with details of discussion. Lastly, Chapter 5 contains conclusion for the whole project.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

To make the explanation simple, literature review is a research about any topic in every particular where it is being described, evaluated, and summarized. It also shows at how the knowledge has developed in the field with the point what was already done, what is generally known, what emerges, and how the topic is currently is being considered. The literary review is to identifies the research gap to understand and explain how the gap is addressed in a specific research project. This section will be describing about type of vehicle, system used for the autonomous driving to work effectively and also the explanation of road lane especially in highway lane.

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2.2 Types of vehicle

Throughout the year, there are two types of vehicle. One is heavy vehicle and another one is light vehicle. The two type of vehicles give differences in specifications as well as its affecting factor. For example, the different between sedan car and heavy truck as for its blind spot, the area of the heavy truck is different from sedan car. This is because the position of side mirror of the heavy truck is higher from the road surface and mostly heavy truck can not see other car driver of motorcyclist below its side mirror compared to sedan car, the blind spot area is smaller.

2.2.1 Heavy vehicle

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Heavy vehicle is a vehicle that has a gross vehicle mass (GVM) or aggregate trailer mass (ATM) of more than 4.5 tons. The GVM of a vehicle is the maximum it can weigh when fully loaded, as specified by the manufacturer. For example, heavy vehicle includes semi-trailers, B-double freight trucks, road trains, passenger buses, vehicle carriers, agricultural vehicles, and special purpose vehicles such as mobile cranes.

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2.2.2 Light vehicle

Light vehicle is vice versa to heavy vehicle because these vehicles has gross vehicle mass (GVM) or aggregate trailer mass (ATM) less than 4.5 tonnes. Light vehicle also defined as a vehicle to carry loads or a small number of passengers up to an officially determined weight. In this case, the vehicle that will be using is car. Car can be classified to few types which is sedan, SUV, MPV, hatchback and many more. The car has different size and dimension of the car. For example, sedan car has bigger dimension than hatchback car dimension, MPV has bigger dimension than SUV car.

2.3 Road lane

A lane is a section of a carriageway reserved for use by a single line of vehicles to regulate and direct drivers and minimise traffic disputes in road transport. Most of public roads (highways) will have at least two lanes, one in either direction, with lane markings separating them. Lanes are marked with road surface markings on multilane highways and busier two-lane roads. Two multi-lane highways are often divided by a median on major highways. Some roads and bridges with low traffic volumes are just a single lane wide and less than 4.6 metres (15 feet) wide. In order to reach each other, vehicles travelling in opposite directions must slow down or stop. Road lane also has their own class and type such as single-lane road, multi-lane road and highway lane. But, for this project, we will be focusing on highway lane.

Each road were named. This will help driver or motocyclist to know which road that they need to take to go to their destination. For example, Table 2.1 below show the name and label of the road in Malaysia which was categorized with several information according to the label of the road. There are different label of road in the table below to differentiate between the main federal route in Semenanjung, Sarawak, Sabah, Labuan FELDA/FELCRA, industrial federal route, institutional facilities federal roads, and the federal road exit where driver will go to the desired federal route.

Examples	Information	Number digits
5 24 247	Main federal route numbers	001–249
276 345	Institutional facilities federal roads	250-479
EXIT 1 EXIT 226	Federal road exit numbers	EXIT 1-EXIT 99 EXIT 201-EXIT 299
1 1-15 3-1	Main federal route numbers (Sarawak)	1-1–1-59 3-1–3-99
A1 A6	Main federal route numbers (Sabah; old numbering system)	A01–A99
700 701 704	Main federal route numbers (Labuan)	700–799
1123 2485	FELDA/FELCRA federal route numbers	1000–1999 2000–2999
3218 3219	Industrial federal route numbers	3000–3999
r,	able 2.1 Federal Route in Ma	alaysia



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2.3.1 Highway Lane

A highway is a public road, especially one that connects two or more locations. Highway land also can be categorised as multi-lane road. A multi-lane highway is described as a highway with at least two lanes for the exclusive use of traffic in each direction, with no or partial access control, but with intermittent flow interruptions at signalised intersections not closer than 3.0 km. They are usually found in suburban areas leading to central cities or along high-volume rural corridors connecting two cities or major activity centres that produce a large number of daily trips.

Multi-lane highway road usually have four or six lanes with the speed limits ranging from 80 km/h to 110 km/h in Malaysia. The daily traffic volume ranges between 15,000 to 40,000 vehicles. With grade separations and no cross-median entry, it could handle up to 100,000 vehicles a day. For multilane highways, traffic signals at major intersections are possible, allowing for partial access control.

Highway lane also can be differ in its lane width according to location and surrounding of the location. The minimum lane width for highway lane is 3.5 m and the max speed limit is 110 km/h. There also two different design of road in Malaysia to differentiate the road type, rural road design and also urban road design. These road design gives different definition. Rural road defined as low traffic volume roads that connects state in a country with a higher speed limits while urban road defined as roadways that characterized by low to moderate traffic volume roads that connects cities in a country. This type of road usually will have lower speed limits compared to rural road design.

Standard	Max design speed limit (km/h)	Minimum lane width (m)	Access control	Application
JKR R6	110	3.5	Full	$\label{eq:expressways} \text{ under the administration of Malaysian Highway Authority (MHA)}$
JKR R5	100	3.5	Partial	Primary roads and partial access highways for the Federal JKR
JKR R4	90	3.25	Partial	Main / secondary roads
JKR R3	70	3.0	Partial	Secondary roads
JKR R2	60	2.75	None	Minor roads Note: JKR R2 is the minimum geometrical standard for 2-lane roads
JKR R1	40	(5.0)*	None	Single-lane minor roads (country lane)
JKR R1a	40	(4.5)*	None	Single-lane roads (roads to restricted areas such as quarries)

Table 2.2 Rural Road Design

Standard	Max design speed limit	Minimum lane width	Access control	Application
	(KIII/II)	think	014	
JKR U6	90	3.5	Full	Expressways under the administration of Malaysian Highway Authority (MHA)
JKR U5	80	3.5	Partial	Arterial roads and partial access municipal highways
JKR U4	70	3.25	Partial	Arterial / collector roads
JKR U3	60	3.0	Partial	Collector roads / Local streets
	E.			Local streets
JKR U2	50	2.75	None	
		Aiwn .		Note: JKR U2 is the minimum geometrical standard for 2-lane roads
JKR U1	40	(5.0)*	None	Single-lane street (in towns)
JKR U1a	40	(4.5)*	None	Single-lane street (as in low-cost housing areas)

UNIVERSIT Table 2.3 Urban Road Design MELAKA

2.3.2 Vehicle Lateral Dynamics

Vehicle lateral dynamics is shown using the well-known bicycle model (Chouki Sentouh, 2016) as shown in Figure 2.2. This model is derived from the nonlinear four-wheel vehicle system as in Figure 2.1 (Weichao Sun, 2019) assuming:

a) The dynamics of the vehicle speed, v_x , and aerodynamic forces are ignored;

b) The lateral tyre forces are proportional to the slip angles of each axle; and

c) The small angle assumption is taken into account.

It should be noted that these assumptions are suitable for highway driving under moderate acceleration conditions and have been commonly adopted for lateral control and mutual lateral control.



Figure 2.1 Vehicle Model



Figure 2.2 Bicycle Model

The vehicle dynamics is given by

$$\begin{bmatrix} \beta^{\cdot} \\ r^{\cdot} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} \beta \\ r \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} \delta + \begin{bmatrix} e_1 \\ e_2 \end{bmatrix} f_w$$
(2.1)

where β is the sideslip angle at the center of gravity (CG), r is the yaw rate, and f_{ω} denotes the lateral wind force.RSITI TEKNIKAL MALAYSIA MELAKA

$$a_{11} = \frac{2(C_r + C_f)}{mv_x}$$
(2.2)

$$a_{12} = \frac{2(I_r C_r - I_r C_f)}{m v_x^2}$$
(2.3)

$$a_{21} = \frac{2(I_r C_r - I_r C_f)}{I_z}$$
(2.4)

$$a_{12} = \frac{2(I_r^2 C_r - I_r^2 C_f)}{I_z v_x}$$
(2.5)

$$b_1 = \frac{2C_f}{mv_x} \tag{2.6}$$

$$b_1 = \frac{2I_f C_f}{I_z} \tag{2.7}$$

$$e_1 = \frac{1}{mv_x} \tag{2.8}$$

$$e_2 = \frac{I_w}{I_z} \tag{2.9}$$



For the lane keeping control, the vehicle positioning on the road must be studied. To the end, the following dynamics of two supplementary variables provided by the vehicle vision system, namely lateral deviation error y_L and heading error ψ_L , from Figure 2.5 and incorporated into Equation 2.10.

$$\dot{y_L} = \beta v_x + L_p r + \psi_L v_x \tag{2.10}$$

$$\psi_L = r - \rho_r v_x \tag{2.11}$$

where ρ_r is the road curvature and it is defined as $\rho_r = 1/R_r$, with R_r the curvature radius. Dynamics of y_L and ψ_L have been considered in various control contexts of intelligent vehicles with experimental validations.

To quantify the driver's feeling with respect to the feedback torque provided by the LKA system, the following steering system is also integrated into vehicle system.

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$$J_s \delta^{"}_d + B_u \delta^{'}_d + K_s \delta_d = T_d + T_a - T_s$$



(2.12)

Where the expression of the self-aligning torque is given by

$$T_s = -\frac{2C_f \eta_t}{R_s} \beta - \frac{2I_f C_f \eta_t}{R_s v_x} r + \frac{2C_f \eta_t}{R_s^2} \delta_d$$
(2.13)

The road-vehicle model used purposes can be represented in the following form

$$x_{v} = A_{v}x_{v} + B_{vu}u_{v} + B_{uw}w$$
(2.14)

Where $x_v = [\beta \ r \ \psi_L \ y_L \ \delta_d \ \delta_d]$ is the vehicle state, $w = [f_w \ \rho_r]$ is the disturbance vector, and the control input u_v is composed by the assistance and driver torques $u_v = T_a + T_d$. The system matrices from Equation 2.14 are given by

$$A_{v} = \begin{bmatrix} a_{11} & a_{12} & 0 & 0 & b_{1}/R_{s} & 0 \\ a_{21} & a_{22} & 0 & 0 & b_{2}/R_{s} & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ v_{x} & l_{p} & v_{x} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ a_{61} & a_{62} & 0 & 0 & a_{65} & a_{66} \end{bmatrix}$$

$$B_{vu} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1/J_{s} \end{bmatrix}$$

$$B_{vw} = \begin{bmatrix} e_{1} & e_{2} & 0 & 0 & 0 & 0 \\ 0 & -v_{x} & 0 & 0 & 0 \end{bmatrix}$$

$$(2.16)$$

$$B_{vw} = \begin{bmatrix} e_{1} & e_{2} & 0 & 0 & 0 & 0 \\ 0 & -v_{x} & 0 & 0 & 0 \end{bmatrix}$$

$$(2.17)$$

$$a_{62} = \frac{2C_{f} l_{f} \eta_{t}}{R_{s} v_{s} J_{s}}$$

$$(2.18)$$

$$a_{65} = \frac{-2C_{f} \eta_{t}}{R_{s}^{2} J_{s}}$$

$$(2.19)$$

$$a_{66} = \frac{J_u}{J_s}$$
(2.20)

2.4 Development of autonomous driving system in MATLAB Simulink

In this project, autonomous driving will be using vision system to detect the road marking in highway to assist the autonomous driving process. Thus, Lane Keeping Assist (LKA) system is one of the suitable system that can be used to assist the autonomous driving process in highway.

LKA system is a system that built in the car so that it can detect surrounding and track the road marking for the car to follow the lane properly in autonomous driving mode. It can track the road marking and estimate the vehicle lateral location with respect to the road centerline and at the same time, it can continuously communicate with the drivers for driving automation. The idea of driver-automation shared control implies that both driving actors should have vehicle control through the steering wheel at the same time, allowing the human driver to convey control intentions that either circumvent or adhere to the automation.

2.4.1 Lane Keeping Assist (LKA) system

In order to understand how the autonomous driving perform in highway lane, first UNIVERSITI TEKNIKAL MALAYSIA MELAKA the simulation of the LKA system in MATLAB software using Simulink tool is carried out. Safe lateral distance in the MATLAB Simulink Software will be the main component and it is the variable for this project to observe the different vehicle behavior in the simulation.

LKA system consists of camera that can detect road marker, an Electronic Control Unit (ECU) and Electric Power Assist Steering system (EPAS). The ECU then will calculate and reposition the vehicle in highway lane or to the desired road lane (Richard Romano, 2019). The position of LKA system will be anywhere on the vehicle such as at the windshield as long as it can detect the visible road marker on highway. LKA system can be classify as two group of controller which is the first one is Lane Departure Warning (LDW) controller that only detect information and sends warning to the ECU if necessary. Other than that, LDW also generate alarm to give warning to the driver about their vehicle position in road lane depends on the lane detection and tracking algorithm (A. Kamble, Prof. S. Potadar, 2018). Next, the controller is also can detect information but it is designed with feedback, which is Lane Detection and Tracking (LDT) controller (Abdelhamid Mammeri, 2015). Lane line detection is an important from the traditional assisted driving era until modern technology era (Xianwen Wei, 2018). Moreover, LDT also provides basic information to the driver such as the lane structure and the positions of other vehicle in the lanes (Chanho Lee, 2018). This two groups or categories are combined into one system called LKA controller to make the feedback of the autonomous more effective system which have the potential to control the vehicle and simultenously avoiding collision or impact to the vehicle (Abdelhamid Mammeri, 2015).

By monitoring the vehicles' position on the road lane, the LDW will give warning if the vehicle is not on the lane or about to depart outside the lane (Rajamani R, 2011). From the component consists of a camera, onboard computer and the software that can be put or attached on the dashboard or windshield, the camera can directly tracks the visible road lane marking in order to give information to the ECU of the vehicle. The lane detection and tracking will be using features such as a colored lane detection, line clustering, and scan line test to obtained the information before warning the drivers (Chanho Lee, 2018).
2.4.2 LiDAR

Detecting objects from camera imagery requires both classification and localization of each object of interest. There are so many objects that cannot be expected ahead of time to be found in each image, so each input image has a different number of outputs. There also no knowing about whereabout these objects might appear in the image or how big the sizes might be (Pan Wei, 2018).

Lidar is a technique for determining ranges (variable distance) by aiming a laser at an object and measuring the time it takes for the reflected light to return to the receiver. Due to differences in laser return times and laser wavelengths, lidar can also be used to create digital 3-D representations of areas on the earth's surface and ocean bottom. It has applications on the ground, in the air, and on mobile devices. Figure 2.4 show the example of Lidar detection for single object that present in the single camera image. There also show the angle for every beam from the camera to the object in front of the Lidar.



Figure 2.4 LiDAR beam detection

2.4.3 Safe Lateral Distance

Lateral position is a position of a vehicle at which the distance is being measured from the center of the vehicle to the right or left of the road lane marker as shown in Figure 2.3. But, for the safe lateral distance, it is defined as safe position of the vehicle to the object on the side of the vehicle. In this context, the road marker will be the object that is need to be avoid in highway lane. It also shows that the bigger the value of lateral distance or the far the distance from the vehicles center line, the safer the driver and the passenger in the vehicle. As well as the bigger the safe lateral distance value, the smoother the autonomous driving process as it will help to maintain the vehicle position inside the road marking.



Figure 2.5 Road and Vehicle Geometry

2.5 Summary

Literature review defined as reviewing previous researcher about the specific topic to get more information. This review will help to gain more information to proceed with the project theory such as the vehicle dynamics, safe lateral distance, lateral position, LDT system, LDW system and also LKA system. Plus, it is important to get more information from previous studies as it will help current study to may be getting new idea.



CHAPTER 3

METHODOLOGY

3.1 Introduction

In general, this chapter will present the method approached used in carrying out the project. This chapter will show the flow of the project from the beginning until the end of the project. In this chapter, it consists of the project planning process flow chart, project research, development of the autonomous driving model, lane keeping assist model, vehicle and environment model.

This chapter also will be explained the detail process of the project since it started. The block diagram for the Lane Keeping Assist (LKA) system is an important component for this project to work out and effectively make the simulation works. The accuracy of the system where it detects that road lane marking and how it reacts when the collision is about to happen.

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3.2 Process Flow Chart

Figure 3.1 presents the process flow of the whole project starting with the project's title identification, followed by some researches about the title chosen. The problem was then indentified and analyzed. The system were then developed through Simulink in MATLAB Software.





Figure 3.1 Process Flowchart

3.3 Methodology

For this project, there will be a software to do the simulation of the movement of vehicle in highway lane. The simulation for this project will be using Simulink MATLAB Software.

Simulink software provides a graphical user interface (GUI) for building and modelling the system as block diagram. In this project, the simulation also will be using LKA block diagram from the Automated Driving Toolbox. Moreover, Simulink in MATLAB Software also can help user to observe the simulation alongside with the data from the simulation.

3.4 Road Lane Setting

Lane setting is a setting for the lane that will be used for the vehicle to move to simulate the movement according to the setting of the lateral safe distance of the Lane Keeping Assist (LKA) system.

Lane section also are important as the simulation can show how the vehicle performs for the lane deviation. There are 3 lanes on the simulation which includes the road lane to simulate the road lane detection from the system.





Figure 3.3 Road Lane Shape

3.5 Development of Lane Keeping Assist (LKA) system complete model

The development of Lane Keeping Assist (LKA) system consists of the main system which is lane keeping assist controller in the lane keeping assist subsystem and the driver and environment subsystem. There is also user control whereby the lateral distance can be change to observe different results of how the steering angle performed during the simulation. Every important subsystems are merged and connected to form a full system model of LKA system.



Figure 3.4 Lane Keeping Assist (LKA) System (complete model)

3.6 Lane Keeping Assist (LKA) Subsystem

LKA system should be consist of system that can use the surrounding of the vehicle to send the information such as road marking so that the vehicle can keep drive autonomously in desired lane. The first subsystem that need to be in the Lane Keeping Assist system is the Detect Lane Departure subsystem which is needed to detect and analyze the road marking on highway. Then, second subsystem is Estimate Lane Center subsystem to give the information about center of the lane in highway. The, Lane Keeping Controller is the important subsystem that will make the system effectively working. This subsystem also will be includes the lane assist offset, driver steering angle, longitudinal velocity, and also



Figure 3.5 Lane Keeping Assist subsystem with controller block diagram

Lane assist is a system that will give warns to the driver and helps to keep the vehicle in its lane without driver input. Plus, it will also help the driver to avoid any accident from happened.

3.6.2 Lane Sensor

Different from lane assist, lane sensor is a component in the LKA system to sense and observe the visible road marking in highway lane. It connected with Lane Assist to help do the task.

3.6.3 Longitudinal Velocity

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Velocity can be vary, either longitudinal which is forward and backward, or lateral which is right or left. But, in the lane keeping assist system, the path that will be used for the simulation is forward. Thus the longitudinal velocity is set to 100 km/h for the simulation. This is because the simulation will be based on the highway speed.

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Block Paramet	ters: Ego Velocity	×
Constant		
Output the const 'Constant value treat the consta the same dimen	stant specified by the 'Constant value' parameter. If ' is a vector and 'Interpret vector parameters as 1-D ant value as a 1-D array. Otherwise, output a matrix nsions as the constant value.	' is on, with
Main Signa	l Attributes	
Constant value:		
v0_ego		:
🗹 🛐 Data prop	perties: v0_ego	×
Sa Value:	27.777777777778	
Data Type:	double	!!
Dimensions:	[1 1]	
Complexity:	real	/
ALA	YSIL	

Figure 3.6 Vehicle Velocity

The velocity of the vehicle is important. This is because there is different type of road lane, and it will also make the speed limit different to the other type of road lane. For this simulation, the longitudinal velocity of the vehicle will be based on the highway road speed limit. Unit of velocity parameter used in the MATLAB Simulink is meter per second (m/s). So, the velocity used is 100 km/h or to be exact value used in the Simulink Software is 27.7778 m/s as shown in Figure 3.6 above.

3.6.4 Driver Steering Angle

Driver steering angle is important as it is used to control the vehicle direction. The driver needs to control the steering input as the vehicle move forward. This system will be set according to the LKA system. This will help the vehicle to move forward smoothly on the highway lane and the steering angle will be autonomously be controlled through the system based on the lane detection.

3.7 Vehicle and Environment Subsystem

This project requires vehicle and environment subsystem because the simulation will not be completed. The vehicle and environment subsystem consist of other subsystem which is vehicle dynamic model, driver model, and these models are connected to pack ego actor and scenerio reader.

3.7.1 Vehicle Dynamics Model

Vehicle dynamic is the important part the is needed to make the LKA system works effectively. The subsystem will be under subsystem of vehicle and environment.



Figure 3.7 Vehicle Dynamics Model

3.7.2 Driver Model

Driver model subsystem also important to the system as it should be the model of a driver who drive the vehicle in the simulation.



3.8 Summary

Methodology is important to this project because the result and data that is need to be observed will be based on the methodology. If the procedure when developing the system is wrong, it will affect the project because it will make the simulation failed. The data can not be obtained from a failed simulation.

This chapter presents the proposed methodology in order to observe how the vehicle with autonomous driving using Lane Keeping Assist (LKA) system will perform in highway lane in simulation. It also shows that how the subsystem or component that is important to be put together to develop the system that help most of people who used to avoid collision and avoid accident especially is highway lane.



CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and observation on the simulation that has been developed in the MATLAB Simulink software. Furthermore, the discussion about the results also will be presented including the discussion about difference between the performance of the vehicle without enable the system and with enable the system.

4.2 Simulation Results of Autonomous Driving

The simulation results show when the LKA system is not enable and enabled. Then, data collected from the simulation are using different value of safe lateral distance which are 0.5m, 1.0m, 1.5m and 2.0m.

4.2.1 Lane Keeping Assist system (LKA) is not enabled

The car will still move in forward direction with the autonomous driving mode. But it will be not as accurate as when the vehicle drives by the help from Lane Keeping Assist (LKA) system as shown in Figure 4.4.



From the collected data, the plotted line of lateral deviation went from the middle to point -0.5 m and 0.5 m approximately less than 2 s. This means when the vehicle is moving, the vehicle is moving with no lane marking detection and not in a stable position across the lane. It also will cause the vehicle to change the lane. The next graph is relative yaw angle versus time. From the graph, the data shows that the relative yaw angle for the vehicle is also not stable. The last graph shows how the steer in the vehicle is being steered to control the lateral motion when the vehicle is moving forward. The data also is not a stable data where there is too little angle used for the steer that make the vehicle to move not in a stable movement.

These three graphs show that the vehicle is still moving according to the lane prepared, but the movement of the vehicle is not in a proper movement. This is because there is no assist system even though the autonomous driving is enabled.

4.2.2 Lane Keeping Assist (LKA) system is enabled

When the LKA system is enabled, the car motion will be assisted, and the movement of the vehicle towards the lane will be more accurate. The accuracy also will be based on the safe lateral distance. In this section, there will be three types of graphs of car performance according to the value of safe lateral distance used which is 0.5 m, 1.0 m, 1.5 m, and 2.0 m as shown in Figure 4.2 until Figure 4.5, respectively.



Figure 4.2 Safe lateral distance (0.5m)

The first data collected is when the safe lateral distance is 0.5 m. Figure 4.2 above shows the lateral deviation of how the system detects the length between the right and left side of the vehicle and the line of the road lane when the car is moving. It is still not in stable position, but the data show that the vehicle is still on the same lane when the car is steered.

The relative yaw angle showing that the car travels in good position. But, with the high velocity, the simulation shows the vehicle experience understeer that causes it to change its lane. The data of steering angle also show that the vehicle cannot control properly because the high speed when turning the vehicle to the right or to the left that cause understeer.





Based on Figure 4.3, there is no obvious change since the safe lateral distance were increased only 0.5 m from the previous data. The simulation is improved in the terms of wider safe lateral distance as but the vehicle is still not perfectly driven through the lane. The vehicle started to maintain it movement and position on the middle lane.



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Regarding results of safe lateral distance, 1.5 m as shown in Figure 4.4, the safe lateral distance is improved from the previous data. So, it started to show a stable movement of the vehicle motion. From the data, the simulation show the movement of the vehicle is move without changing lane even with high velocity of 100 km/h. It still appear that the movement is still non stable such as understeer that cause the vehicle to almost change its lane but it still can maintain the position on the middle lane.



before the simulation. The data collected is different to the data of simulation when the safe lateral distance is 0.5 m.

For this simulation, the vehicle movement is at perfect movement. It can be proved as the graph of lateral deviation vs time which shows that the vehicle move in only middle lane and not changing the lane even the with the velocity of 100 km/h. Data from relative yaw angle vs time shows that the car is not moving away from the lane as it follow perfectly through the lane of the road in simulation. Lastly, the steering angle shows perfectly hot the vehicle steer the vehicle to get into the lane provided with the autonomous drving and the assist from Lane Keeping Assist (LKA) system.

4.3 Discussion

Control performance of the vehicle is performance of how the vehicle is perform when the LKA system is enabled. It will show how the difference between 0.5 m and 2.0 m of safe lateral distance controlling performance with 0.5 m interval. Plus, by using the speed according to highway lane which is 100 km/h, the data will be shown is lateral deviation, relative yaw angle and steering angle of the vehicle. These three variable is against time as it simulate based on time and the data collected is in graph format.

Next, lateral deviation is defined as the distance between the center of mass of the vehicle and the closest point on the desired path. In this project, lateral deviation is referred to the lateral movement whenever the vehicle reaches the curved road. Furthermore, the simulation displayed that when the safe lateral distance is small, 0.5 m, the vehicle changed its lane.

Next is the relative yaw angle is a data for the vehicle when it rotate the vehicle in yaw rotation or in left and right position when the vehicle is steer to the right or to the left. Moreover, yaw angle is dependent to the steering angle because when the vehicle is steered, which produced steering angle and by making the vehicle to move towards the steered position, yaw angle will also be produced. According to the collected result shown in Figure 4.5, if the system can detect the lane marking, the vehicle can be steered smoothly.

Steering angle will be explained about the angle of the steer when the simulation is run and the vehicle is at the curved road position. For example, safe lateral distance of 2.0 m give more effectiveness in lane marking detection from the LKA system that will help the vehicle to steer better. This is because the bigger the number of safe lateral distance, the better the performance of the controlling of the vehicle

4.4 Summary

As for conclusion, the performance of the movement of the vehicle is based on how the safe lateral distance is being set. This is because the bigger value of the safe lateral distance set, the better the road lane marking or border detection. Thus, it can improve the performance of the vehicle movement when it is autonomously driving the vehicle. For example, the data for 0.5 m of safe lateral distance show that how the vehicle is not properly driven even the Lane Keeping Assist (LKA) system is enable compared to the 2.0 m of safe lateral distance that show the vehicle is perfectly driven which is not changing its lane and steered properly because of the detection of the road line on the lane in being improved. Other than that, vehicle velocity also give effect to the car performance when autonomously driven. This is because the vehicle can experience understeer or oversteer when then vehicle is too fast, and it cannot perform a fast response when the vehicle face curve lane whether it is right or left. The value of safe lateral distance is crucial for the LKA system to perform better in autonomous driving.



CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The autonomous driving can help to achieve many objectives such as assisting user to drive the car while the driver resting in the car without needing to stop the vehicle. The autonomous system also is great for those who really want to save their time when working out from their home range as they need to get a rest while going for work. In addition, the autonomous driving will be more effective when there is an assist for the autonomous driving such as Lane Keeping Assist (LKA) system. This is because the system used for the autonomous driving can detect information and send if nessecary using Lane Departure Warning (LDW) controller and Lane Detection and Tracking (LDT) controller that detect the information but with feedback. These two controller then was combined to form a system called Lane Keeping Assist (LKA) system that was used for autonomous driving.

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Simulink in MATLAB Software is the platform used for developing the system as well as collection the data from the simulation. By using the proper block diagram in the library browser such as the lane keeping assists controller block diagram and vehicle dynamics block diagram, the full model of the Lane Keeping Assist (LKA) system is developed. Next, the result shows how the vehicle will move in longitudinal movement with different value of lateral distance set in the user control. The result from the simulation will give different data according to the value of safe lateral distance set in the user control. The bigger the value of safe lateral distance set, the wider the system to detect the road line so it can give accurate information to the controller to assit the autonomous driving. For example, 2.0 m of safe lateral distance give more accurate data and give better simulation for the autonomous driving compared to 0.5 m of safe lateral distance that shows unstable movement of vehicle movement in simulation

5.2 **Recommendation**

Recommendation is one of the important key so any product can be improved soon or later near future. Autonomous driving have been a great assist for those people who really need and using it to its full potential include people who need to be multitasker as they need to do task even when they were driving the car. Due to all its greatness, there is still limitation to its technology because there are so many moving paramaters in the driving function that need to be handled and controlled simultinouesly. With just one failure, it could a highly catastrophic. The first and foremost, road condition can be highly unpredictable because in some cases, there are smooth and marked broad highways. But other cases, the road is in bad condition for examples, no lane marking and potholes. So, because of LKA system detects lane marking, the proposed recommendation for the problem is person in charge for drawing the lane marking need to always make a check up in every month to make sure that there are lane marking on the road and it is not disappear. Therefore, the vehicle can move on the lane properly. Next, LKA system also need to improve the vehicle speed setting. Since there are unpredictable road condition, the speed setting will help to decelerate when approaching road bump and whenever there are requirement for the vehicle to slow down.

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APPENDICES

Appendix 1 Gantt Chart

SEMESTER 6 (PSM 1)																		
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