PATH TRACKING FOR UNINTENDED ROADWAY DEPARTURE

KELVIN LOI HUI KOK

**This report is submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering**

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

AUGUST 2021

DECLARATION

I declare that this project report entitled “Path Tracking for Unintended Roadway Departure” is the result of my work except as cited in the references

Signature : ....

Name : Kelvin Loi Hui Kok

Date : 14/9/21

APPROVAL

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

Signature : ....

Name of Supervisor : Dr. Amrik singh a/l Phuman singh

Date : 17/09/2021

DEDICATION

To my beloved mother and father

ABSTRACT

Unintended roadway departure (URD) has been one of the main causes of traffic fatalities. New technologies such as autonomous steering that automatically detect departure from the lane and provide interventions could help prevent unintended roadway departure. This study is aimed at developing and evaluating the effectiveness of a path tracking controller for unintended road departure. To achieve this, a path tracking controller is designed which comprises feedforward, feedback, and yaw controllers. A 2-DOF vehicle model with a Brush tire model is implemented as the control system plant. The lane-keeping controller is built and simulated using MATLAB Simulink. From the result, the cornering force increases with increasing friction coefficient due to the increased contact stresses because of tire deformation. The controller's performance is evaluated using various velocities. The result shows that the controllers can track the desired path with relatively small lateral error with an increasing velocity. As velocity increases, the maximum absolute tire force usage increases due to the higher centrifugal force. Maximum absolute lateral error, heading error, and yaw rate error also increases with increasing velocity. We can conclude that as velocity increase, the ability for the controller to track the path decrease.

ABSTRAK

Permegian jalan raya yang tidak disengajakan merupakan salah satu penyebab utama kemalangan jalan raya. Teknologi baru seperti stereng autonomi yang dapat mengesan keberangkatan dari lorong secara automatik serta memberikan campur tangan dapat membantu mencegah keberangkatan jalan raya yang tidak diingini. Tujuan kajian ini adalah untuk membina dan menilai keberkesanan pengawal penjejakan laluan untuk keberangkatan jalan yang tidak disenjagakan. Untuk mencapai tujuan ini, pengawal penjejakan laluan yang terdiri daripada feedforward, maklum balas, dan menguap telah dirancangkan. Model kenderaan 2-DOF dengan model tayar Brush diimplementasikan sebagai loji untuk system kawalan. Pengawal penjejakan laluan dibina dan disimulasikan menggunakan MATLAB Simulink. Dari hasil keputusan, daya penjuru meningkat dengan peningkatan pekali geseran disebabkan oleh peningkatan tegangan senthuan menegak dan melintang akibat ubah bentuk tayar. Halaju yang berbeza telah digunakan untuk menilai prestasi pengawal. Hasilnya menunjukkan bahawa pengawal dapat mengesan jalan yang diinginkan dengan kesilapan lateral yang agak kecil dengan halaju yang semakin meningkat. Penggunaan daya tayar mutlak maksimum meningkat dengan halaju kerana daya sentrifugal yang lebih tinggi. Apabila halaju meningkat, kesilapan lateral mutlak maksimum, ralat arah, dan ralat kadar menguap juga meningkat. Kita dapat menyimpulkan bahawa apabila halaju meningkat, kemampuan pengawal untuk mengesan jalan menurun.

ACKNOWLEDGEMENT

I would like to give thanks to Dr. Amrik Singh, my supervisor, for guiding me through the final year project. His enthusiasm, patience, and advice have helped me tremendously in my final year of study. He always provides guidance and expertise whenever I face any issues regarding the project. He always finds time to conduct weekly meetings to make sure that our works are progressing smoothly despite his busy schedule.

Secondly, I'd like to express my gratitude to University Teknikal Malaysia Melaka for accepting me into the graduate program. I'd also like to show my appreciation to the Faculty of Mechanical Engineering for teaching me knowledge of engineering.

I'd like to thank my friends for their encouragement, patience, and support. Lastly, I'd want to thank my family for their unwavering support.

CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ARE	Algebraic Ricatti Equation
DYC	Direct Yaw-Moment Control
LDW	Lane Departure Warning Systems
LKA	Lane Keeping Assist
LQG	Linear Quadratic Gaussian
LQR	Linear Quadratic Regulator
MPC	Model Predictive Control
NHTSA	National Highway Traffic Safety Administration
PID	Proportional, Integral, and Derivative
SMC	Sliding Mode Control
URD	Unintended Roadway Departure
2-DOF	2 Degree of Freedom
3-DOF	3 Degree of Freedom
7-DOF	7 Degree of Freedom

14-DOF	14 Degree of Freedom
2WS	Two Wheel Steering
4WS	Four Wheel Steering

LIST OF SYMBOLS

a_y	-	Vehicle's lateral acceleration
c	-	Lateral axle cornering stiffness
c_α	-	Tire cornering stiffness
c_f	-	Cornering stiffness of front axle
c_r	-	Cornering stiffness of rear axle
e	-	Distance between desired path and center of gravity
e_{la}	-	Lookahead error
f_r	-	Rolling resistance coefficient
F_{xi}	-	Longitudinal tire force
F_{yf}	-	Front lateral tire force
F_{yi}	-	Lateral tire force
F_{yr}	-	Rear lateral tire force
F_{zf}	-	Front axle normal load

F_{zr}	-	Rear axle normal load
g	-	Gravitational acceleration
J_i	-	Wheel moment of inertia
J_z	-	Yaw moment of Inertia
k_p	-	Lanekeeping potential field gain
K_{US}	-	Understeer gradient
$k_{\Delta\psi}$	-	Yaw damping gain
l	-	Length of the vehicle
l_f	-	Distance between center of gravity and front axle
l_r	-	Distance between center of gravity and rear axle
m	-	Mass of the vehicle
R_w	-	Wheel's effective radius
T_{bi}	-	Wheel braking torque
T_f	-	Front track
T_i	-	Wheel traction torque
T_{Roll}	-	Rolling resistance torque
v	-	Velocity
v_x	-	Longitudinal velocity

v_y	-	Lateral velocity
x_{la}	-	Lookahead distance
α_f	-	Slip angle of the front tire
α_r	-	Slip angle of the rear tire
β	-	Vehicle sideslip angle
γ	-	Yaw rate
δ	-	Steering angle
$\delta_{control}$	-	Feedback steering angle
δ_f	-	Front steering angle
δ_{ff}	-	Feedforward steering angle
δ_{yaw}	-	Yaw control steering angle
κ	-	Path curvature
μ	-	Surface coefficient of friction
$\Delta\psi$	-	Heading error
ψ_{CG}	-	Vehicle's heading angle relative to the earth frame
ψ_r	-	Path's heading angle relative to the earth frame

CHAPTER 1

INTRODUCTION

1.1 Motivation

Traffic accidents and related deaths have been increasing in Malaysia due to the growing population and vehicles on the roads. The number of accidents had increased from 148,801 accidents to 326,817 accidents as the population of Malaysia grows from 19,494,000 in 1994 to 25,600,000 in 2004 (Umar, 2005). This unnerving situation needs to be restrained to save lives and reduce economic loss. According to data from the Malaysian Ministry of Transport, the overall number of road accidents grew by 41% from 2007 to 2016, from 369,319 to 521,466. (Ministry of Transport, 2016). The total number of deaths was increased from 6282 to 7152. The total number of vehicles involved in road accidents rises by almost 44%, from 666,027 to 960,569 in the same period. Figure 1.1 shows Malaysia's total road and motor vehicle accidents from 2007-2016 (Ministry of Transport, 2016).

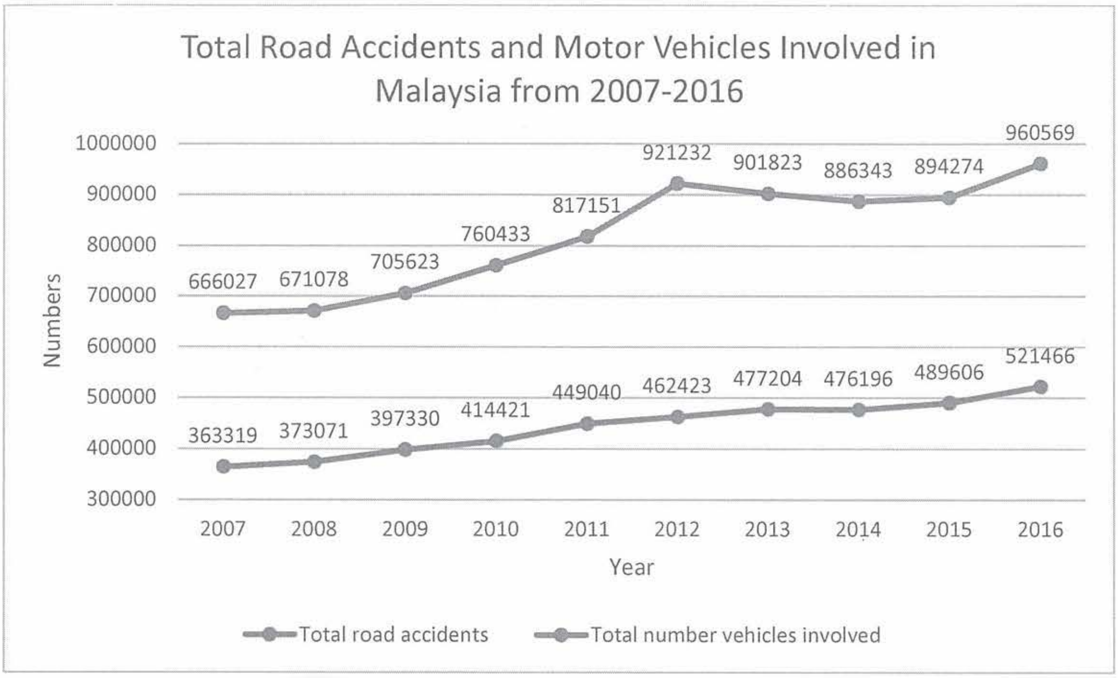

Figure 1.1: Malaysia's total road and motor vehicle accidents from 2007-2016 (Ministry of Transport, 2016)

Road safety monitoring remains inadequate in contempt with the extensive financing of the Malaysian Government. Road safety aspects are detrimentally impacted by the escalating mobility of modern society. Dangerous turning, speeding, and other offenses are the most reported causes of accidents in Malaysia, which occupy 28.8%, 16.1%, and 15.8%, respectively. (Abdelfatah, 2016).

One of the main causes of traffic fatalities is Unintended Roadway Departures (URD). (Alleyne, 1997). A URD happens when the vehicle swerves away from its intended path without the driver's control (Alleyne, 1997). Unintended Roadway Departure (URD) is often caused by distraction, fatigue, and other acts of negligence and failure to command the path of the vehicle track to coincide with the road direction. Human error is responsible for 94% to 96% of vehicle crashes as stated by the 2016 fatality report (Bruce, 2017).

Implementation of intelligent road systems makes roads safer and minimizes the accidents occurring. New technologies such as autonomous steering that automatically detect departure from the lane and provide interventions could help prevent unintended roadway departure as driver error is eliminated from the equation.

1.2 Background

An autonomous vehicle is a vehicle that operates itself by sensing its environment and operating without human intervention. Autonomous automotive systems are growing at a remarkable pace. Self-driving technologies are developed by major automakers such as Tesla, Uber, Google, and Nissan. Autonomous vehicles map and interpret their surroundings by using a wide array of sensors. The software then processes the information and commands vehicle's the 'actuator' to make an intervention, which can be steering, braking, and acceleration. These autonomous technologies could assist the driver during emergencies to prevent unintended roadway departure.

Lane departure systems like the Lane Departure Warner System (LDW) detect and alert the driver when the vehicle leaves its intended path with sound, visual, or vibration alerts. However, an appropriate response is required from the driver, which they may be unable to perform. The response of these systems if the driver does not take control after the system has intervened determines whether or not they can avert a crash. That said, a driverless lane-keeping assist needs to take over during emergencies to prevent crashes. Several automakers have built their LKA (Lane Keeping Assist) systems in many variants to improve lane assist and decrease the number of accidents caused by unintended roadway departures (Kang, 2017). Lane Keeping Assist (LKA) is a technology that warns the driver if the vehicle is straying out of its lane. and, with no response, automatically make interventions to correct the vehicle's path. These systems improve lane control via torque created on the steering wheel or controlling of rotation of the steering wheel is turned. These systems are able to maintain lane-keeping by controlling the steering wheel angle or through torque generation on the steering wheel (Hwang, 2008).

This study is aimed at developing and evaluating the effectiveness of a path tracking controller for unintended road departure. To achieve this, a path tracking controller is designed which comprises feedforward, feedback, and yaw controllers. The control system uses a 2-DOF vehicle handling model as its plant. To assure the vehicle's tracking ability, various vehicle feedback states are used. This control is proposed so that under all conditions, the vehicle is able to maintain its stability and maneuverability (Ono et. al., 1998). Most modern vehicles steer by only turning the front wheels. This means that the driver uses only one input, the front steering angle, to regulate the vehicle's lateral acceleration and yaw rate.

Different techniques, such as linear quadratic Gaussian (LQG), sliding mode, adaptive, and nonlinear control were used for designing vehicle control systems. To design the path tracking control system, MATLAB Simulink is used. The control system performance is assessed by utilizing a 2-DOF vehicle handling model.

1.3 Objectives

The objectives of this project are as following:

1. To develop a path tracking controller for unintended road departure.

2. To evaluate the effectiveness of the path tracking controller.

1.4 Scope

The scope of this project includes the following:

1. Development of the nonlinear vehicle handling model.
2. Design of the path tracking control system in Simulink.
3. Performance evaluation of the path tracking controller.

1.5 General Methodology

In this project, the following are the steps required to establish the objectives :

1. Literature review

   Journal, articles, websites, or other sources related to the topic of the project will be reviewed to understand the fundamental of the topic.

2. Derivation of the vehicle dynamics model

   The mathematical model of each segment will be developed for path tracking by using a 2-DOF bicycle model with a Brush tire model and the equations of motion of the bicycle model will be derived.

3. Design of a path tracking controller

   Path tracking controller operates by using an autonomous steering input. The steering controller comprises feedforward, feedback, and yaw components. A bicycle model is used to predict the steering input to track the path. A lane-keeping steering feedback system is used to reduce errors induced by disturbances or modeling errors. A yaw control system is used to minimize yaw errors.

4. Building MATLAB Simulink diagram for path tracking control system.

   The vehicle dynamics model and control system are constructed by using MATLAB SIMULINK.