SIMULATION OF ADAPTIVE CRUISE CONTROL USING PID AND MODEL PREDICTIVE CONTROLLERS

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DECLARATION

I hereby, declared this report entitled Adaptive Cruise Control Using Model Predictive and Proportional integral and derivative controllers is the results of my own research except as cited in references.

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Signature :

Name : Hilal Hazman Bin Hazli

Date : 27 January 2022

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 : Ts. Dr. Nur Rashid bin Mat Nuri @ Md Din

Date : 28 Janurary 2022

DEDICATION

I dedicate this report to my parents Encik Hazli Bin Abu and Puan Kalshom Binti Sutaji and my beloved supervisor Dr Nur Rashid Bin Mat Nuri @ Md because self-efforts for the challenging work need from the elders. Not forget to my friends who have lending their hand to help me.

ABSTRACT

The research on Autonomous vehicles was started nearly a century ago, but significant parts of significant advancements have been done over the past few decades. One of the significant advancements have been done is Advance Driver Assistance System (ADAS). The role of ADAS is to prevent death and injuries by reducing the number of accidents. Unfortunately, most favourite assistance system, traditional cruise control, was not one of ADAS. there are several disadvantages to the conventional cruise control system. For example, when the car in front is travelling less than the desired speed, the driver must engage with the brake pedal at any stage to prevent a collision. The best solution is Adaptive cruise control where this advance cruise control can avoid collision by automatically adjusts the vehicle speed to maintaining the safe distance between two vehicles. In addition, this technology is in level 1 automated vehicles 13 state by SAE International's standard J3016. In this thesis, a Model Predictive Controller (MPC) and the Proportional integrated derivative (PID) controller are compared using the Adaptive Cruise Control (ACC) systems. The goal of the control system is to maintain a safe distance between the lead vehicle and the Adaptive cruise control vehicle. The ACC system automatically adjusts the vehicle speed to maintain a safe distance from vehicles ahead. The frontal or rear-end collisions and traffic congestions can be reduced by maintaining the safe distance using the spacing control by the Adaptive Cruise Control system. Two scenarios are considered MATLAB/Simulink to analyse the performances of the system. In Scenario 1 the simulation run in low traffic density and in scenario 2 the simulation run in high traffic density. These two simulations was shown to be effective way to observe the performances between two different controller of adaptive cruise control system. Acceleration, velocity, and distance between two cars is the important result in this research. The acceleration of ACC car indicates the comfortability driving, where the result show that Adaptive Cruise Control using MPC have better acceleration response. While the velocity result shows capable of ACC car the car-following capability and regulates velocity to achieve velocity set. Each controller achieves the car-following capability however the velocity response of Adaptive Cruise Control with MPC show fast response significantly in scenario 2 by 1.2% better than Adaptive Cruise Control using PID. Then, Distance between ACC car and lead car shows the capability of ACC system to maintain the safe distance as well as avoid frontal collision. The result shows that the PID controller did not achieve the safety driving capability where the relative distance exceed the safe distance repeatedly. However, the MPC controller have excellent response when it able to maintain the relative distance above safe distance. The RMS difference of velocity and distance is also important result for the simulation. The velocity in two scenarios show different result of percentage difference between both of controller, 0.01% and 1.2% for scenario 1 and scenario 2. The percentage difference of relative distance and safe distance for adaptive cruise control using MPC are 6.12 % for scenario 1 and 2.69 % for scenario 2 compared to the percentage difference of adaptive cruise control using PID, 8.13% and 5.21%.

ABSTRAK

Penyelidikan mengenai kenderaan Autonomi telah dimulakan hampir satu abad yang lalu, tetapi bahagian penting kemajuan penting telah dilakukan sejak beberapa dekad yang lalu. Salah satu kemajuan penting yang telah dilakukan ialah Advance Driver Assistance System (ADAS). Peranan ADAS adalah untuk mencegah kematian dan kecederaan dengan mengurangkan jumlah kemalangan. Malangnya, kebanyakan sistem bantuan kegemaran, kawalan pelayaran tradisional, bukanlah salah satu daripada ADAS. terdapat beberapa kelemahan pada sistem kawalan pelayaran konvensional. Sebagai contoh, apabila kereta di hadapan bergerak kurang daripada kelajuan yang diingini, pemandu mesti menggunakan pedal brek pada mana-mana peringkat untuk mengelakkan perlanggaran. Penyelesaian terbaik ialah Kawalan pelayaran adaptif di mana kawalan pelayaran maju ini boleh mengelakkan perlanggaran dengan melaraskan kelajuan kenderaan secara automatik untuk mengekalkan jarak selamat antara dua kenderaan. Selain itu, teknologi ini berada dalam keadaan kenderaan automatik tahap 1 piawaian SAE International J3016. Dalam tesis ini, Pengawal Ramalan Model (PRM) dan pengawal terbitan bersepadu berkadar (TBB) dibandingkan menggunakan sistem Kawalan Pelayaran Adaptif (KPA). Matlamat sistem kawalan adalah untuk mengekalkan jarak selamat antara kenderaan utama dan kenderaan kawalan persiaran Adaptive. Sistem ACC melaraskan kelajuan kenderaan secara automatik untuk mengekalkan jarak selamat dari kenderaan di hadapan. Perlanggaran depan atau belakang boleh dikurangkan dengan mengekalkan jarak selamat menggunakan kawalan jarak oleh sistem Kawalan Pelayaran Adaptif. Dua senario dianggap MATLAB/Simulink untuk menganalisis prestasi sistem. Dalam Senario 1 simulasi dijalankan dalam kepadatan trafik rendah dan dalam senario 2 simulasi berjalan dalam kepadatan trafik yang tinggi. Kedua-dua simulasi ini telah ditunjukkan sebagai cara yang berkesan untuk memerhatikan prestasi antara dua pengawal berbeza sistem kawalan pelayaran adaptif. Pecutan, halaju, dan jarak antara dua kereta adalah hasil penting dalam penyelidikan ini. Pecutan kereta KPA menunjukkan keselesaan pemanduan, di mana keputusan menunjukkan Kawalan Pelayaran Adaptif menggunakan PRM mempunyai tindak balas pecutan yang lebih baik. Manakala keputusan halaju menunjukkan keupayaan kereta KPA keupayaan mengikut kereta dan mengawal halaju untuk mencapai set halaju. Setiap pengawal mencapai keupayaan mengikut kereta namun tindak balas halaju Adaptive Cruise Control dengan PRM menunjukkan tindak balas pantas dengan ketara dalam senario 2 sebanyak 1.2% lebih baik daripada Adaptive Cruise Control menggunakan TBB . Kemudian, Jarak antara kereta ACC dan kereta utama menunjukkan keupayaan sistem KPA untuk mengekalkan jarak selamat serta mengelakkan perlanggaran hadapan. Keputusan menunjukkan bahawa pengawal TBB tidak mencapai keupayaan pemanduan keselamatan di mana jarak relatif melebihi jarak selamat berulang kali. Walau bagaimanapun, pengawal PRM mempunyai tindak balas yang sangat baik apabila ia dapat mengekalkan jarak relatif melebihi jarak selamat. Perbezaan RMS halaju dan jarak juga merupakan hasil penting untuk simulasi. Halaju dalam dua senario menunjukkan hasil perbezaan peratusan perbezaan antara kedua-dua pengawal, 0.01% dan 1.2% untuk senario 1 dan senario 2. Perbezaan peratusan jarak relatif dan jarak selamat untuk kawalan pelayaran adaptif menggunakan PRM ialah 6.12 % untuk senario 1 dan 2.69 % untuk senario 2 berbanding perbezaan peratusan kawalan pelayaran adaptif menggunakan TBB, 8.13% dan 5.21%.

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LIST OF SYMBOLS AND ABBREVIATIONS

D,d	-	Diameter
ACC	-	Adaptive Cruise Control
MPC	-	Model Predictive Control
ADAS	-	Advance Driver Assistance System
LKA	-	Lane Keeping Assist
PID	-	Proportional Integral Derivative
MPR	-	Market Penetration Rate
PID-based ACC	-	Adaptive Cruise Control using PID controller
MPC-based ACC	-	Adaptive Cruise Control using MPC controller
m/s	-	Metre per second
s	-	second

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CHAPTER 1

INTRODUCTION

1.1 Background

Conventional cruise control systems for passenger cars are becoming less and less effective as traffic congestion increases, making it difficult to travel at a pre-set speed. As a result, vehicle automation in the longitudinal direction is needed to because it is able to control traffic flow while increasing highway capacity, so adaptive Cruise Control (ACC) seems to be an alternative in this condition. ACC automatically adjusts a vehicle's velocity to achieve the desired distance to the preceding vehicle or the desired velocity in the absence of either. however, this ACC technology has already well-equipped in modern car with various brand names; Super Cruise, Smart Cruise Control, Active distance Assist Distronic, Intelligent Cruise control and Dynamic cruise control.

In this study, for adaptive cruise control design a Upper controller from hierarchical control structure has been used to analysed the major functioning of the ACC system. First-order vehicle model has chosen as vehicle modelling because it much simpler due to the reduction, and many complicated and time-consuming equations have been eliminated, including the calculations including masses, springs, dampers, and other similar materials can be denied. This vehicle model will be installed to ego vehicle and lead vehicle to perform two vehicle system.

The purpose of this thesis is to study the performance of controllers in the adaptive cruise control system. MPC and PID are the controller options in this thesis. Those controllers have been proposed in many studies for various system, and the performance given is impressive. The model predictive control (MPC) can obtain eco-driving, driving safety, comfortability, and tracking capability. The performances of the MPC-based ACC system are evaluated and compared with the proportional-integral-derivative (PID) controller-based ACC system. The PID based controller has been utilised widely in Adaptive Cruise Control. A PID control approach has been improving driving stability and comfort. Finally, a comparative assessment of the impact of each controller on the system performance in two scenarios is presented and discussed.

1.2 Problem statement

Nowadays, an advanced driver assistance system (ADAS) is the most crucial part of a modern car. The role of ADAS is to prevent death and injuries by reducing the number of accidents. Unfortunately, most favourite assistance system, traditional cruise control, was not one of ADAS. In a traditional cruise control system, the driver can set the desired speed. The car will maintain that speed once established; this is done independently of the environment and other vehicles on the road. When the vehicle ahead is travelling slower than the desired velocity, the driver must intervene with the brake pedal at some point to avoid a collision. However, there are several disadvantages to the conventional cruise control system. For example, when the car in front is travelling less than the desired speed, the driver must engage with the brake pedal at any stage to prevent a collision. Furthermore, if the driver is in less alert on driving this can lead frontal collision. Therefore, due to the disadvantages of conventional cruise control, it is crucial to provide a solution. The best solution is Adaptive cruise control where this advance cruise control can avoid collision by automatically adjusts the vehicle speed to maintaining the safe distance between two vehicles. In addition, this technology is in level 1 automated vehicles 13 state by SAE International's standard J3016. To design the

ACC system, a simple model of ego and the lead vehicle is created to simulate the basic ACC system by adjusting the speed of the ego vehicle following the processing data from the sensor while maintaining safe distance from the lead vehicle. Two different controllers have been adopted to realise this major functioning of the adaptive cruise control system: MPC and PID controller.

1.3 Research objective

The main aim of this research is to design the adaptive cruise control system in MATLAB/Simulink. Specifically, the objectives are as follows:

a) To design vehicle model in MATLAB/Simulink.

b) To design adaptive cruise control system using Model Predictive and Proportional integrated derivative controllers.

c) Compare the performance of Adaptive Cruise Control system with MPC controller and PID controller in terms of safety driving, driving comfortability, car-following and regulates the velocity into set velocity.

1.4 Scope of research

To achieve the objective of this project, several scopes have been planned:

a) Modelling the vehicle model in MATLAB/Simulink.

b) Use two different controllers to the adaptive cruise control system which are Model Predictive and proportional integral derivative controllers.

c) The comparative assessment applies in two scenarios which are in high traffic density scenario and low traffic density scenario.

1.5 Methodology

Below is a flowchart methodology for this project, starting with a literature review followed by developing a vehicle model, then implementing two controllers into the ACC system and making a comparison in terms of performance regulates the velocity of vehicle to maintain the safe distance between the lead vehicle and ACC vehicle. After the comparison can be detected continue with the discussion and recorded in the report.

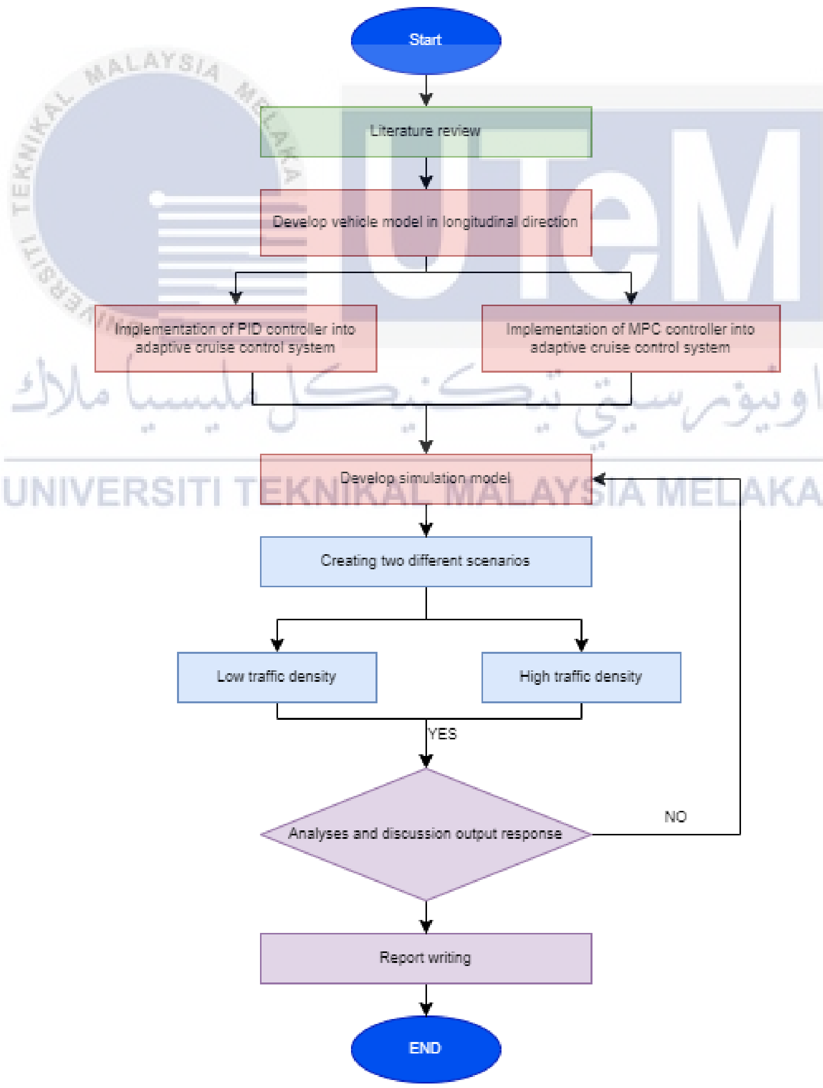

Figure 1.1 Process Flowchart methodology

1.6 Summary

The first chapter of this thesis opens with background of the study and further describes about the development adaptive cruise control. This is followed by the Problem statement, research objective, scope of study and Flowchart methodology. The chapter concludes with process flowchart methodology to complete this thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Advance driver assistance system (ADAS) such as Lane Keep Assist (LKA), Adaptive Cruise Control (ACC), and Autonomous Emergency Brake are a crucial component in today's modern civilization. As a key component of ADAS, ACC systems performance has a vital influence in driver driving experience, as recorded in numerous linked studies. This chapter is about submission previous research of the respective literature in this field of study, including review of literature in research of adaptive cruise control, adaptive cruise control design, modelling of the vehicle, MPC-based adaptive cruise control system and PID-based adaptive control system.

2.2 Conventional cruise control and Adaptive cruise cntrol

The cruise control can automatically regulate the speed of a vehicle on the road. The concept was initially applied in the Chrysler 1958 Imperial, based on a 1948 mechanical engineer Ralph Teeter. This technology is merely acting as a speed limiter. It is up to the driver to select the desired speed or limit speed and govern the forward range. ACC, by default, uses sensor and involves both relative distance and speed control. ACC is an advanced cruise control system that automatically adjusts the vehicle speed to keep a safe distance from the front vehicle (Chamraz et al., 2018). Today's ACC systems are primarily concerned with tracking a specified distance from a preceding vehicle or tracking the desired speed. The ACC system has other benefits: improving driving comfort, decreasing driving errors, enhancing safety, improve traffic flows, and and eco-driving (Lu and Aakre, 2018).

ACC now is a crucial advanced driver assistant system for all car manufacturers to supply in modern automobiles (Alomari et al., 2020). Alomari et al.(2020) state that the ACC was introduced as an intelligent driving assistance technology to increase driver preference and save workload dramatically. This device can assist prevent accidents and reduce the impacts when a safety gap and speed should occur in the targeted drive range. ACC system can automatically adjust the speed of the vehicle to follow the preceding vehicle safely. Suppose the car in front travels at speed (Luu & Lupu, 2019).

2.3 Modern car with Adaptive cruise control

Many car manufacturers believe the Adaptive cruise control technology is the basis of fully autonomous driving. Most automakers give the system brand names more marketable and fashionable. Some brand names are Super Cruise, Smart Cruise Control, Active distance Assist Distronic, Intelligent Cruise control and Dynamic cruise control. These brand names showed that the adaptive cruise control system was already installed in modern cars (Edelstein, 2021).

Cadillac introduces supercruise and claims that drivers can take their hands off the wheel. The Super Cruise mapped 200,000 miles of highway and was well equipped with cameras, radar, and lidar. This technology also has a system to maintain the level of driver alertness via a driver-facing camera. However, the system is not widely availed only available in CT6 sedan. Mercedes-benz have one of the most comprehensive adaptive cruise control. The latest one called “Distronic Plus System”. In the case of stop-and-go circumstances, the Distronic Plus System may keep traffic up and able to fully stop during Subaru's Eyesight is a compilation of adaptive cruise control with lane-keeping assist. This technology equipped with a "pre-collision throttle management" feature, which reduces the throttle before a predicted crash and automated low-speed emergency braking.

Mercedes-Benz has one of the most comprehensive adaptive cruise control. The latest one called the "Distronic Plus System". In the case of stop-and-go circumstances, the Distronic Plus System may keep traffic up and able to fully stop during stop and go scenario. The driver must tap the "resume" button of the cruise control to resume driving for longer stops, but below 3 seconds, the system will automatically resume driving.

2020 BMW 3 series offers the best combination of sensory technology. The cameras is addition technology uses beside ultrasonic and radar sensors to receive data from surrounding vehicle while driving. "stop-and-go "brake is well equipped great for occupants who spend a long time in standstill traffic as it alleviates the tiredness on the driver's legs and feet. Moreover, the camera installed will able to detect the speed limit sign and send information to the system to reduce or increase speed to match the recommended rate of speed (Abhey dhange, 2019)

Perodua Ativa Top-spec AV well equipped with several Advance Safety Assist included lane keeping control (LKC) , Vehicle stability Control (VSC) , Adaptive cruise control(ACC) and more.

2.4 Time Gap of Manual Car-following vs Time Gap of ACC

Nowadays, the ADAS system represented by ACC system enters the market quickly. This article (Q. Wang, 2018) is about setting essential parameters of the ACC system, proposes a viable plan based on human conduct analysis and corresponding technological standards. According to a technical standard, the minimum time gap is below