LANE KEEPING CONTROL ALGORITHM USING IMAGE PROCESSING

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DEDICATION

This thesis is dedicated to my families, my parents' brothers and sisters back home for their unending support all through my studies. To my beloved wife and two sons, for their understanding of the many nights, I was away thanks!

To God be all the glory.

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ABSTRACT

Motivated by the ideas of an autonomously driven vehicle and driving safety issues, driver assistance systems such as active braking, cruise control and lane departure warning lane-keeping, become a very active research area. Over the years, studies have shown that several control strategies have been developed and tested with the use of sensor like LIDAR with very little accuracy. The use of LIDAR sensor could not accurately detect the lanes especially in bad weather conditions like rain and snow. Image processing technique has a great potential of solving this issue, however, very little research has been done with a camera to detect the road lane. The aim of this thesis was to develop a controller algorithm for lane keeping using image processing methods. Both simulation and experimental studies were carried out using a vehicle model based on a single-track bicycle model. An image processing algorithm was developed for lane detection using various edge detection techniques. The results show that Roberts edge detector performed better compared to other edge detectors with detection time of 0.4 sec and lane detection of 0.8 sec. A Proportional Derivative (PD) controller was simulated by manually tuning its parameters to keep the vehicle in its desired track. The model was further validated by an experimental PD study, where the PD parameters were also tuned manually. In the simulation studies, the image processing algorithm process the image by identifying the error signal, which was sent to the controller that generates the steering control command to drive the vehicle toward the desired reference track. This same method was also used in the experimental studies. The results showed that the control strategy for the PD control achieved the objective of steering the vehicle towards the reference trajectory by reducing the lateral deviation error to zero at a much lower longitudinal velocity of 1m/s and a K_p gain of 0.004 and K_d gain of 0.001 and the experimental results showed a similarity with simulations results. Further analysis found that PD controller was not robust in maintaining its performance under various conditions as a result of changing parameters. Using the same system setup, model predictive control (MPC), Fuzzy logic and Fuzzy-proportion, integral derivative (PID) control algorithms were simulated to improve lane-keeping system performance. Fuzzy-proportion integral derivative showed the best performance with less overshoot, a maximum lateral deviation of 2 cm and settling time of 12 sec, K_p of 0.01, K_i of 0.01 and K_d of 0.06. Better and faster response control of the vehicle was achieved using Fuzzy-proportional integral derivative (PID) controller.

ABSTRAK

Didorong oleh idea-idea kenderaan yang digerakkan secara automatik dan masalah keselamatan pemanduan, sistem bantuan pemandu seperti brek aktif, kawalan pelayaran dan penyimpanan lorong peringatan laluan keluar, telah menjadi bidang penyelidikan yang sangat aktif. Selama bertahun-tahun, kajian menunjukkan bahawa beberapa strategi kawalan telah dikembangkan dan diuji dengan penggunaan sensor seperti LIDAR dengan ketepatan yang sangat sedikit. Penggunaan sensor LIDAR tidak dapat mengesan lorong dengan tepat terutamanya dalam keadaan cuaca buruk seperti hujan dan salji. Teknik pemerosesan gambar mempunyai keupayaan yang tinggi untuk mengatasi isu ini, namun, sangat sedikit penyelidikan yang dilakukan dengan kamera untuk mengesan jalan raya. Tujuan tesis ini adalah untuk mengemukakan pengembangan algoritma pengawal untuk menjaga lorong menggunakan kaedah pemprosesan gambar. Kedua-dua kajian simulasi dan eksperimen dilakukan dengan menggunakan model kenderaan berdasarkan model basikal laluan tunggal. Algoritma pemprosesan gambar dibangunkan untuk pengesanan jalur menggunakan pelbagai teknik pengesanan tepi. Hasil yang diperolehi menunjukkan bahawa pengesan tepi Roberts bekerja lebih baik dibandingkan dengan pengesan tepi lain dengan masa pengesanan 0.4 saat dan pengesanan lorong 0.8 saat. Pengawal *Proportional Derivative* (PD) disimulasikan terlebih dahulu dengan menyesuaikan parameternya secara manual untuk memastikan kenderaan berada di laluan yang diinginkan. Model ini selanjutnya disahkan dengan kajian PD secara eksperimental, yang mana parameter PD juga ditala secara manual. Dalam kajian simulasi, algoritma pemprosesan gambar memproses gambar dengan mengenal pasti ralat isyarat, yang dihantar ke pengawal untuk menghasilkan arahan kawalan stereng untuk menggerakkan kenderaan ke arah laluan rujukan yang diinginkan. Kaedah yang sama juga digunakan dalam kajian eksperimen. Hasil kajian menunjukkan bahawa strategi kawalan untuk kawalan PD mencapai objektif mengarahkan kenderaan ke arah laluan rujukan dengan mengurangkan ralat sisihan lateral menjadi sifar pada kelajuan longitudinal yang jauh lebih rendah 1 m/s dan gandaan K_p 0.004 dan K_d sebanyak 0.001 dan hasil eksperimen menunjukkan kesamaan dengan hasil simulasi. Analisis lanjut mendapati bahawa pengawal PD tidak cekap dalam mempertahankan prestasi dalam pelbagai keadaan akibat perubahan parameter. Menggunakan penyediaan sistem yang sama, model kawalan prediksi (MPC), logik *Fuzzy* dan algoritma kawalan *Fuzzy-proportional integral derivative* (PID) disimulasikan untuk meningkatkan prestasi sistem menjaga lorong. *Fuzzy*-PID menunjukkan prestasi terbaik dengan sedikit lebihan, sisihan lateral maksimum 2 cm, waktu penyelesaian 12 saat K_p 0.01, K_i 0.01 dan K_d 0.06. Tindak balas dan kawalan kenderaan yang lebih baik dan pantas dicapai dengan menggunakan pengawal *Fuzzy-PID*.

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LIST OF ABBREVIATIONS

LIDAR	-	Light Detection and Ranging
LKA	-	Lane-keeping Algorithm
LKAS	-	Relative Leader-Member Exchange
LTA	-	Leader-Member Exchange
LCA	-	Statistical Package for Social Science for Window
LDW	-	Lane Departure Warning
VBLR	-	Vision-based lane-recognition
ADAS	-	Advanced Driver Assistant System
GPS	-	Global Positioning System

LIST OF SYMBOLS

Sign	Unit	Description
δ	degree	front steer angle of the vehicle
M_z	Nm	yaw moment at c.g
e_1	radian	the lateral distance of c.g from the centreline
e_2	radian	orientation error of vehicle yaw angle from lane
R	cm	radius of road
τ	Degree	yaw angle of the vehicle
ψ	Degree/Sec	yaw rate of vehicle
V	m/s	velocity of vehicle
V_x	m/s	the longitudinal velocity of the vehicle
m	Kg	vehicle mass
l_f	Cm	distance from c.g. to the front axle
l_r	Cm	distance from c.g. to the rear axle
C_{af}	N/rad	cornering stiffness of the front tire
C_{ar}	N/rad	cornering stiffness of the rear tire
F_{yf}	N	lateral force of the front tire
F_{yr}	N	lateral force of the rear tire
I_z	kgm^2	yaw inertia of the vehicle

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CHAPTER 1

INTRODUCTION

1.1 Research Background

With the current rate at which civilisation and technological advancement are growing at a rapid pace, especially in the automotive sector in areas like development of auto-electronics technology, active vehicular safety has become one of the most researched topics and has attracted more attention in recent years.

The automotive industry worldwide is enthusiastic about developing an advance driver assistance system (Muhammad, 2015). Advanced Driver Assistance System (ADAS) is a name for a group of features added to the vehicle to aid the driver while driving. The highlights were developed to automate, adapt and enhance vehicle systems for safety and better driving. Figure 1.1 shows the standard features that are incorporated into ADAS. The most common element in ADAS is Adaptive cruise control and park assist.

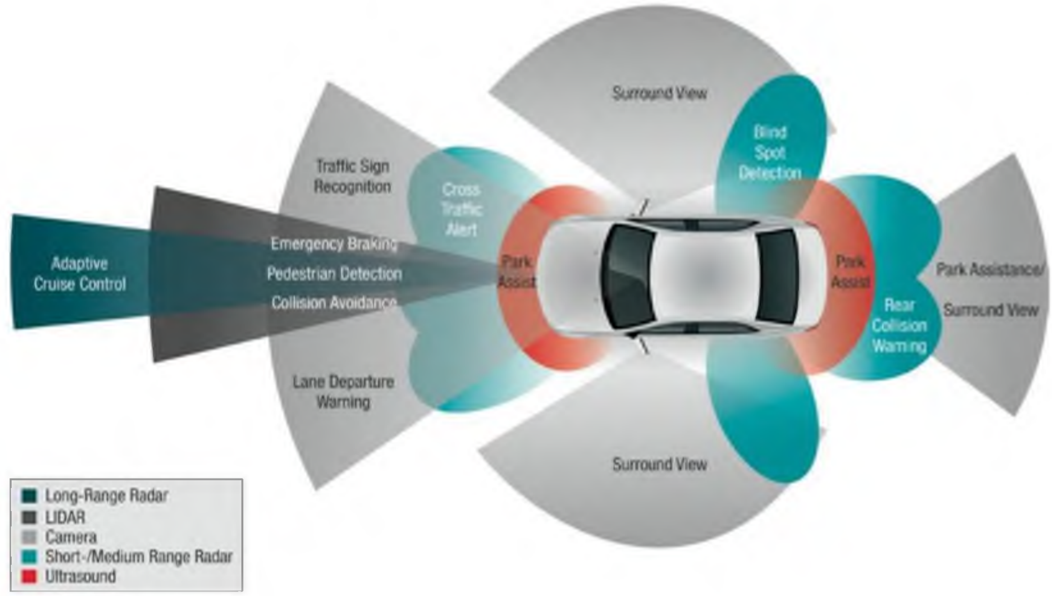

Figure 1. 1 Features of Advanced Driver Assistance System ADAS, (source: https://www.eletimes.com)

With sensor technology and control algorithms, the advance driver assistant system ADAS helps to increase safety, adapt to surrounding and automate the car. ADAS technology arguably has its roots in features that started showing up more than a decade ago, like adaptive cruise control, or perhaps even further back to the introduction of simple driver warning systems, such as emergency brake lights.

Some of the most common features that are incorporated into the ADAS system includes: collision avoidance system, adaptive cruise control, automated braking, automate lighting, parking assist system, lane departure warning system and a lane-keeping system.

There are different names given to this system, either lane keeping assist (LKA) or lane departure warning (LDW). Based on the manufacturers this system may have a different name. This system is responsible for making drivers aware of an immediate or an unintended lane departure. They were initially designed as a means of alerting a driver who is sleeping while driving, to enable the driver to regain control of the vehicle. Hence this system is called LDW. However, on the other hand, LKA is more or less a modification or an advancement in LDW that not only warns the driver of an unintended lane departure but also takes control of the vehicle, by keeping it in its lane until the driver regains full consciousness.

The sensing element in the system systems varies. Some use some sort of infrared sensors such as Light Detection and Ranging (LIDAR) sensors, but these days there is an increased rate of vehicles equipped with vision sensors installed on their windshield rear-view mirrors. These sensors detect the lane and when there is a sudden lane departure, an alert is sent to either the driver or lane-keeping controller. These alerts could be either vibration of the seat or steering or an audible sound just to get the attention of the driver to steer the vehicle back to its lane or automatically steering the vehicle back to its lane before giving control back to the driver.

In the automated driving mode of the autonomous car, the vehicle's lateral movement is controlled by a lateral control algorithm. The objective of this algorithm is to keep the vehicle in the centre of its lane. Position and orientation of the vehicle can be determined by the use of sensors such as the camera used in identifying the white middle marker and left and right boundaries on the road and also by the use of sensors like Lidar for path tracking techniques both by explicitly or implicitly means. Regardless of the apparent simplicity of discovering white lane marks on the road, it can be extremely hard to find white lane marks on different kinds of road. These problems could be attributed to either of the following; shadows, occlusion by other vehicles, changes in the road surface itself, and different types of lane markings. A good lane detection algorithm should be capable of detecting all kinds of lane marks from roadways and filter them to estimate an accurate estimate of the vehicle position relative to the lane.

Lane detection is a major aspect of developing an autonomous vehicle and is a complex and challenging task. It involves the localization of the road and the determination of the relative position between vehicle and road. In recent years, several lane detection techniques have been proposed by researchers under two broad classifications such as framework-based and vision-based technique. Framework-based techniques are mostly robust and have a high development cost in setting up (Yaghoobi et al, 2018). Vision-based strategy with a camera mounted on a vehicle has a more prominent favourable position of using already existing lane markers on the road and to locate a road curvature in its front view.

Under the vision-based approach, a lot of studies in lane detection have been carried out in detecting lane boundaries. Most of the algorithms for lane detection are edge-based where it involves processing an image to find potential lane edges to detect the lane mark of the road. Various edge detection techniques have been evaluated and tested by various researchers such as canny edge detection (Chan et al, 2018), sobel edge detection (Cao et al, 2019). After edge detection, a lane detection algorithm is ran to detect road lane markers A suitable lane detection algorithm has to be robust in detecting different kinds of road lane which is used in deteriming vehicle position. In detecting lane boundaries, various techniques have been used such as Hough Transform, Canny edge detection algorithm, bilateral filter etc (Cao et al, 2019).

1.2 Problem Statement

Since the cause of most traffic accidents are human error or omission (Adanu et al, 2018), it is anticipated that the emergence of autonomous technologies will reduce the number of car accidents. Although there is not enough statistical data to sustain this statement yet (Bimbraw, 2015). However, there have been an increasing trend of automatization in cars of today. Although much progress in enhancing comfort and safety has been achieved, autonomous cars for the public are not a reality yet because there are different issues to be solved. Tasks, such as parking assistance or keeping a safe distance from other vehicles, have been implemented in commercial vehicles during the last years. Most of these advances focus on improving the passengers and pedestrians safety in the surrounding area.

However, human failures keep being the main cause of serious accidents. Up to now, advanced driver assistance systems (ADAS) have been developed to aid drivers in highways as adaptive cruise control (ACC) systems. Hence, urban environments deserve more attention since traffic accidents mainly occur in populated areas. From the ADAS development point of view, the main problem is due to the fact vehicle's behaviors can somehow be unpredictable. Nevertheless, from the safety point of view, autonomous systems capable of aiding the driver in case of an unpresidented situations can help in controlling the vehicle, hence averting any possible accident.

Over the years serveral control strategies have been tested with the use of sensor like LIDAR and cameras. Although much progress has being achieved in semi autonomous cars. However, studies on suitable controller for fully autonomous vehicle are still being tested. This studies is one of many such studies on the development of a suitable control structure for a fully autonomous vehicle.

In recent years basic Advanced Driver Assistance Systems (ADAS) functions such as Lane Keeping and Adaptive Cruise Control became common in lower middle class cars, making vehicle automation available to a wider public Active safety systems must operate consistently and must perform robustly in unpredictable environments. This study focus on the investigation of suitable controllers to help improve lane-keeping system. Studies have shown the use of sensors, controllers and advanced software together with other custom-made hardware to assemble autonomous cars. Although the prototypes seem to be close to successful, a fully autonomous car that is reliable enough to be on the streets has not been constructed yet (Rosique et al, 2019)..

In summary investigations on a suitable control structure for the development of lane keeping algorithms have been the topic of researchers over the years. There is, therefore, the need to study further ways in the control of autonomous vehicle using sensors like camera and controllers. Its was said by Pendleton et al, (2017): Zhao et al, (2018) that better control of autonomous vehicle is achieved when using computer vision image techniques, since it is close to the human drive vision experience. Therefore, this study aims at gaining knowledge that would be helpful in the design of better control strategies for Autonomous vehicles.

1.3 Objectives

The aim of this study is to develop a lane keeping algorithm using image processing.

The specific objectives of this research are:

(i) To develop and validate 4 edge detection techniques

(ii) To develop a controller algorithm for lane keeping system

(iii) To compare the lane-keeping performance using PID, MPC Fuzzy Logic and Fuzzy-PID controller.

1.4 Research Question

(i) What are the various edge detection techniques used for lane detection using image processing?

(ii) How can the design of lane keeping controllers using image processing be done?

(iii) What are the similarities between the performances of the lane keeping PD, MPC, Fuzzy Logic and Fuzzy-PID controllers?

1.5 Scope of the Study

The scope of this entire research was limited to the following;

(a) The scope of this study was a simulation and experimental studies of lane-keeping algorithms using image processing techniques at constant velocity.

(b) The simulation studies were done for a single circular lane track for all controllers.

(c) Experimental studies was also done on a single circular lane track in a closed environmental setting.

(d) The experimental study was done to validate the simulation model used.

1.6 Research Flow

This section presents the research flowchart for the entire study. Figure 1.2 presents the research flow taken to achive the studies objectives. The study began with review of literature to identify the techniques used in lane detection and lane keeping. Current issues faced by lane detection and lane keeping system were reviewed to establish the research gap and problems associated with lane detection and lane keeping.

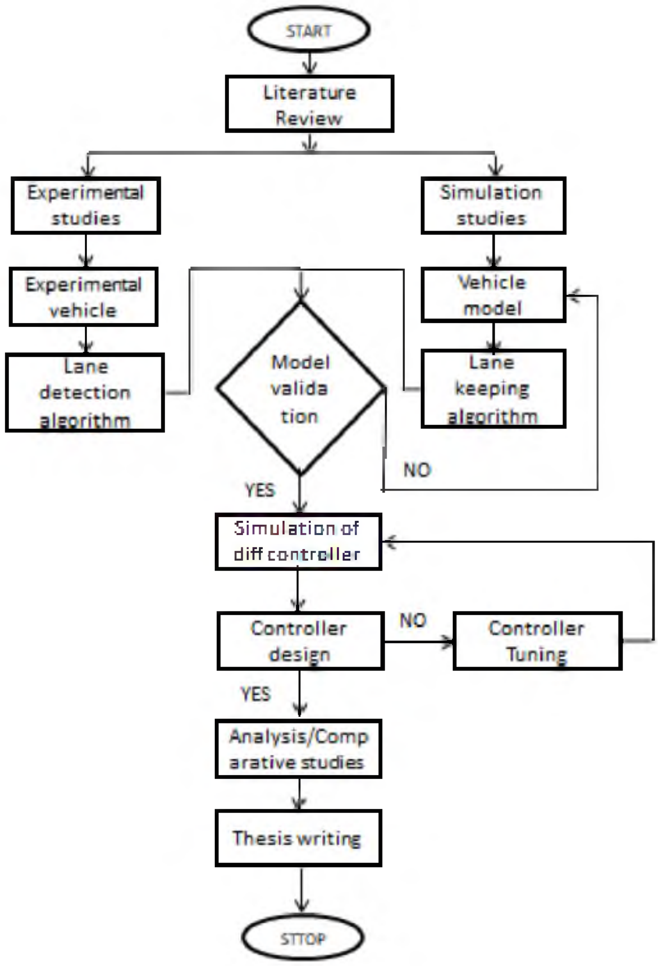

Figure 1. 2 Research Flow

From Figure 1.2, the study proceeded with literature review for both simulation and experimental studies, where vehicle model was mathematically derived and an experimental vehicle was also coupled. A lane detection algorithm was also developed. Using the derived vehicle model a simulation of lane keeping was done. The same model used for the simulation studies was adopted and used for the experimental vehicle lane keeping control. This was done to validate the model adopted. After validating the model, simulations were carried out before proceeding to the controller design and further analysis of the controllers. A detailed comparative study was carried out for all the controllers. The final stage in the flowchat is writing of the thesis.

1.7 Thesis Contribution

This study contributes to the body of knowledge in the following ways;

(i) Four different edge detection techniques were proposed, evaluated and tested. And it was discovered from the result obtained that interms of image processing time, Roberts edge detector performed better than canny, prewits and sobel with an edge detection time of 0.4sec and lane detection of 0.8sec as compared to other techniques. Therefore, this studies showed that Robert edge detector is more suitable when faster image processing time is required in the development of lane detection algorithm

(ii) A PD control algorithm for lane-keeping was simulated for a single circular lane track using image processing as the main feedback control. Findings from the simulation studies of PD revealed that the image processing feedback system was fast (0.8sec) enough to process the lane markings within a reasonable time 0.8sec before feeding the control signal to steer the vehicle to its appropriate trajectory. Other controllers like MPC and Fuzzy logic were further simulated and their results also showed to be similar to the of PD control. Similarly an experimental vehicle was developed to validate the simulation study findings. PD lane keeping algorithm with same vehicle model and parameters was tested on the experimental vehicle and the result proved suitable by providing almost similar result with the simulation studies.

(iii) From the simulation studies a Fuzzy-PID controller using fuzzy gain scheduling scheme was developed, since according to literature no study on lane keeping using fuzzy-PID gain scheduling has been done. The fuzzy rule base and reasoning was utilised to determine the PID controller parameters. Results demonstrated a better control with a maximum lateral deviation of 2cm and settling time of 12sec with K_p of 0.01, K_i of 0.01 and K_d of 0.06.for Fuzzy-PID control as compared to PD,MPC and Fuzzy logic.

1.8 Thesis Organization

This thesis is organised into five chapters. A summary of these chapters is highlighted below:

Chapter 1: This chapter presents the introduction and general background to the study. It highlights the studies problem statement and the set objectives for the study. The study scope and detail reseach flow of the processes taken for the study are also presented in this chapter.

Chapter 2: This chapter gives a detailed overview of the study of lane detection and lane-keeping and identifies current areas of research and research gap. It also gives background information on various techniques of lane detections and highlights some of their major setbacks. Furthermore, the chapter explain the basic in the development of vehicle dynamic models for both lateral and longitudinal motion. And finally, the chapter looks into the design of controllers for lateral vehicle dynamics.

Chapter 3: This chapter explains the methodology of the entire research. Materials/Tools and equipment used were also highlighted in this chapter. The lane detection technique used were explained well. Also, lateral dynamics for the steering angle control was discussed and the vehicle model used was discussed too. The experimental vehicle was also discussed from the modification to the implementation stage.

Chapter 4: This chapter highlights the lane detection performance analysis of the various edge detection techniques and also the various simulations studies that were carried out for PD, MPC and Fuzzy logic control. This chapter also presents the performance and robustness analysis results for all the controllers and experimental mobile robots. The chapter also presents a detailed comparison of the performance analysis of PD, MPC and Fuzzy Logic controllers. Also, the performance of the experimental vehicle was compared with the simulation results and the results were discussed.

Chapter 5: This chapter presents the conclusion and recommendation part of this study. It summaries the findings and concludes with some very important recommendations for future study.

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