VISION-BASED AUTONOMOUS VEHICLE DRIVING CONTROL SYSTEM

By

KHALID BIN ISA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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To my mother, my late father, my brothers, my sisters-in-law, my lecturers, my friends and my love you are the rhythm in my tune, you are the sun and my moon, you are the beach and my wave, you are the glove and I am the hand, you are the station and I am the train, you are the teacher and I am the pupil, you are the suture to my wound, you are the magnet to my pole, you are the sum to my equations and you are the answer to my question. I dedicate this thesis to you.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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April 2005

Chairman : Associate Professor Adznan Bin Jantan, PhD

Faculty : Engineering

In recent years, extensive research has been carried out on autonomous vehicle system. A completely autonomous vehicle is one in which a computer performs all the tasks that the human driver normally would. However, this study only focuses on driving control system that based on vision sensor. Therefore, this study presents a simulation system with Graphical User Interface (GUI) to simulate and analyse the driving control for autonomous vehicle that based on video taken from the vehicle during driving on highway, by using MATLAB programming. The GUI gives easy access to analyse video, image and vehicle dynamics. Once the GUI application for simulation is launched, user can enter input parameters value (number of frames, canny edge detection value, vehicle speed, and braking time) in text control to simulate and analyse video images and vehicle driving control.

In this study, there are four subsystems in the system development process. The first subsystem is sensor. This study was used a single GrandVision Mini Digital Video as sensor. This video camera provides the information of Selangor's highway environment by recording highway scene in front of the vehicle during driving.

Then, the recorded video is process in second subsystem or named as image-processing subsystem. In this subsystem, image-capturing techniques capture the video images frame by frame. After that, lane detection process extracts the information about vehicle position with respect to the highway lane. The results are angle between the road tangent and orientation of the vehicle at some look-ahead distance. Driving controller in the controller subsystem that is the third subsystem used the resulted angle from lane detection process along with vehicle dynamics parameters to determine the vehicle-driving angle and vehicle dynamics performance. In this study, designing a vehicle controller requires a model of vehicle's behaviour whether dynamics or kinematics. Therefore, in vehicle subsystem that is the fourth subsystem, this study used vehicle's dynamics behaviour as the vehicle model. The model has six degrees of freedom (DOF) and several factors such as the vehicle weight, centre of gravity, and cornering stiffness were taken into account of dynamics modelling.

The important contribution of this study is the development of vehicle lane detection and tracking algorithm based on colour cue segmentation, Canny edge detection and Hough transform. The algorithm gave good result in detecting straight and smooth curvature lane on highway even when the lane was affected by shadow. In this study, all the methods have been tested on video data and the experimental results have demonstrated a fast and robust system.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SISTEM KAWALAN PEMANDUAN KENDERAAN BERAUTONOMI BERASASKAN PENGLIHATAN

Oleh

KHALID BIN ISA

April 2005

Pengerusi : Profesor Madya Adznan Bin Jantan, PhD

Fakulti : Kejuruteraan

Sejak kebelakangan ini, kajian mendalam telah lakukan ke atas sistem kenderaan berautonomi. Kenderaan berautonomi yang lengkap merupakan satu kenderaan yang dikendalikan oleh komputer dalam melaksanakan semua tugas sebagaimana manusia lakukan. Walaubagaimanapun, pengajian ini hanya menfokuskan pada sistem kawalan pemanduan yang berasaskan pengesan penglihatan. Oleh yang demikian, pengajian ini mempersembahkan satu sistem simulasi dengan Antaramuka Pengguna Bergrafik (GUI) untuk melakukan simulasi dan menganalisa kawalan pemanduan kenderaan berautonomi yang berdasarkan pada video yang diambil daripada kenderaan semasa pemanduan di lebuhraya, dengan menggunakan pengaturcaraan MATLAB. GUI memudahkan capaian untuk menganalisa video, imej dan dinamik kenderaan. Apabila aplikasi GUI untuk simulasi dilancarkan, pengguna boleh memasukkan nilai parameter kemasukan (bilangan bingkai, nilai pengesanan sisi Canny, kelajuan kenderaan, dan masa membrek) ke dalam kotak kawalan bagi melakukan simulasi dan menganalisa imej-imej video dan kawalan pemanduan kenderaan.

Dalam pengajian ini, terdapat empat subsistem di dalam proses pembangunan sistem. Subsistem pertama adalah pengesan. Pengajian ini telah mengguna satu Mini Digital Video GrandVision sebagai pengesan. Kamera video ini memberikan maklumat berkaitan persekitaran lebuhraya di Selangor dengan merakamkan keadaan lebuhraya di hadapan kenderaan semasa pemanduan. Kemudian, video yang telah dirakam, diproses di dalam subsistem yang kedua atau dinamakan sebagai subsistem pemprosesan imej. Di dalam subsistem ini, teknik penangkapan imej menangkap imej-imej video secara bingkai demi bingkai. Selepas itu, proses pengesanan laluan mengasingkan maklumat berkenaan posisi kenderaan seiring dengan laluan di lebuhraya. Keputusannya adalah sudut diantara garis sentuh jalanraya dan juga orientasi kenderaan pada suatu jarak penglihatan. Pengawal pemanduan di dalam subsistem pengawal iaitu subsistem yang ketiga, telah menggunakan sudut yang telah dihasilkan daripada proses pengesanan laluan bersama dengan parameter dinamik kenderaan, untuk menentukan sudut pemanduan dan pencapaian dinamik kenderaan. Di dalam pengajian ini, merekabentuk pengawal kenderaan memerlukan model ciri-ciri kenderaan sama ada dinamik atau kinematik. Oleh yang demikian, di dalam subsistem kenderaan iaitu subsistem keempat, pengajian ini telah menggunakan ciri-ciri dinamik kenderaan sebagai model kenderaan. Model ini mempunyai enam darjah kebebasan dan faktor-faktor seperti berat kenderaan, pusat graviti, dan kekuatan lencongan juga telah diambil kira bagi pemodelan dinamik.

Sumbangan penting pengajian ini adalah pembangunan algoritma bagi pengesanan dan penjejakan laluan kenderaan yang berasaskan segmentasi tanda warna, pengesanan sisi Canny, dan transformasi Hough. Algoritma ini telah memberikan keputusan yang baik bagi mengesan laluan lebuhraya yang lurus dan yang mempunyai kelengkungan yang kecil walaupun terdapat bayang-bayang pada laluan tersebut. Dalam pengajian ini, semua kaedah-kaedah telah diuji pada data video dan keputusan eksperimen membuktikan bahawa sistem ini adalah pantas dan tegap.

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My deepest and utmost gratitude to my family; they have stood by me and witnessed my study and career evolves for the better. They have also been my definite source of constant support and encouragement. Last but not least, to my dear friends; thank you for your support. I love you all very much.

I certify that an Examination Committee met on 9th April 2005 to conduct the final examination of Khalid bin Isa on his Master of Science thesis entitled "Vision-based Autonomous Vehicle Driving Control System" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Mohammad Hamiruce Marhaban, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Adzir Mahdi, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Sabira Khatun, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Che Mat Hadzer Mahmud, PhD
Associate Professor
School of Electrical and Electronic Engineering
Universiti Sains Malaysia
(External Examiner)

GULAM RUSUL RAHMAT ALI, PhD
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 20 JUN 2005

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master. The members of the Supervisory Committee are as follows:

Adznan Bin Jantan, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Abd. Rahman Bin Ramli, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Khairi Bin Yusuf, PhD
Faculty of Engineering
Universiti Putra Malaysia
(Member)

AINI IDERIS, PhD
Professor/Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 14 JUL 2005

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

KHALID BIN ISA

Date: 10 Jun 2005

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LIST OF ABBREVIATION

DOF	-	Degree of Freedom
LED	-	Light Emitted Diode
RF	-	Radio Frequency
LOIS	-	Likelihood of Image Shape
GOLD	-	Generic Obstacle and Lane Detection
PID	-	Proportional, Integral, Derivative
FLASH	-	Flexible Low-cost Automated Scaled Highway
VVTI	-	Virginia Tech Transportation Institute
ITS	-	Intelligent Transportation System
AVI	-	Audio Video Interleave
RGB	-	Red, Green, Blue
HSV	-	Hue, Saturation, Value
RMS	-	Root Mean Square
CG	-	Centre Gravity
2WS	-	Two Wheels Steering
DYC	-	Direct Yaw Control
MATLAB	-	Matrix Laboratory
GUI	-	Graphical User Interface

CHAPTER 1

INTRODUCTION

Automobile manufacturers have developed and are continuing to develop systems for cars that extenuate the driver's burden to monitor and control all aspects of the vehicle. In the last decades in the field of transportation systems a large emphasis has been given to issues such as improving safety conditions, optimising the exploitation of transport network, reduce energy consumption and preserving the environment from pollution. The endeavours in solving these problems have triggered the interest towards a new field of research and application such as autonomous vehicle driving, in which new techniques are investigated for the entire or partial automation of driving tasks. These tasks include: following the road and keeping within the correct lane, maintaining a safe distance among vehicles, regulating the vehicle's speed according to traffic conditions and road characteristics, moving across lanes in order to overtake vehicles and avoid obstacles, finding the shortest route to a destination, and moving within urban environments.

A completely autonomous vehicle is one in which a computer performs all the tasks that the human driver normally would. Ultimately, this would mean getting a car, entering the destination into a computer, and enabling the system. From there, the car would take over and drive to destination with no human input. The car would be able to sense its environment and make steering and speed changes as necessary. So, to develop an autonomous vehicle it will involve automated driving, navigating and monitoring systems.

This scenario would require all of the automotive technologies such as lane detection to aid in passing slower vehicles or exiting a highway, obstacle detection to locate other cars, pedestrian, animals, etc., cruise control to maintain a safe speed, collision avoidance to avoid hitting obstacles in the roadway, and lateral control to maintain the car's position on the roadway. So, sensors will be a major component to develop these technologies.

Completely automating the car is a challenging task and is along way off. However, advances have been made in the individual systems. Cruise control is common in cars today. Adaptive cruise control, in which the car slows if it detects a slower moving vehicle in front of it, is starting to become available on higher-end models. In addition, some cars come equipped with sensors to determine if an obstacle is near and sounds an audible warning to the driver when it is too close.

1.1 Motivation

One of the major reasons of automating the driving task is safety. Human errors are the main cause of many accidents these days. Human driving error may be caused by a number of factors including fatigue and distraction. The driver must constantly monitor the road conditions and react to them over an extended period of time during long drives on the highway. This constant attentiveness is tiring and the resulting fatigue may reduce the driver's reaction time. Additionally, the driver may be distracted from the task of driving by conversations with other passengers, tuning the radio and using a cell phone. Therefore, to reduce the number of injuries and fatalities on the roadways these errors must be eliminated. However, viewed from another perspective, a car capable of driving itself can allow the driver to perform non-driving tasks safely while travelling to their destination.

1.2 Problems Statement

The invention of cruise control decreased the burden of driving for anyone driving on highway. Besides, power steering, anti-lock braking and traction control were created to further alleviate stress from the driver. Therefore, the next step is to completely automate the driving experience. This leads many researchers to do research about autonomous vehicle driving system. There are many problems that needed to be understood, analysed and solved:

1. Forward vision sensor and data acquisition; it provides information of the road.
2. Lane detection and tracking on highway; it provides the input of the vehicle steering command.
3. Kinematics and dynamics model of vehicle; it shows the behaviour of the vehicle.
4. Vehicle control systems and algorithms; it controls the movement of the vehicle.

Looking on previous researches, some of them just focused only on lane detection for autonomous vehicle driving system without discussing driving system [1]. The problem with this is that the big picture of vehicle following the road is not presented. On the other hand, for researches that focused on vision-based driving control system, majority of control algorithms for such a vehicle only use the kinematics model [2], and [3]. The advantage of the kinematics model is that it keeps the steering and velocity of the vehicle completely decoupled. The problem with this is that, in the process, the dynamics of the vehicle are ignored. Therefore, this thesis focused on vision-based autonomous vehicle driving control system, where the control algorithms for the vehicle used the dynamics model.

1.3 Goal

The goal of this research is to develop a simulation of vision-based autonomous vehicle driving control system. In the feature, this system can be realised for commercial implementation. The implementation of this system in commercial and passenger vehicle can be used as a driver assistant when the driver is tired or suffers from fatigue.

1.4 Objectives

Autonomous vehicle driving control system carries a large number of benefits especially for automotive industry. The general objectives of this research are:

1. To improve the vehicle driving control system by detect the driving lane using computer system.
2. To make driving on today's highway safer and easier.
3. To reduce the driver's burden during driving in relation to the fact that human errors are the main cause of many accidents these days.
4. To assists human driver, therefore the driver can perform non-driving tasks while travelling.

The specific objectives of this research are:

1. To prove that by using HSV colour space the shadow in the image can be removed.
2. To prove that by processing and analysing the images during driving, a vehicle can determine the steering command for the vehicle lateral control.
3. To prove that the vehicle's dynamic performance can be determined by combining the steering command and others vehicle dynamics parameters. Therefore, the mathematical operations, implementation methods, techniques and approaches to develop a simulation of the system must be implemented.

1.5 Research Scopes

This system used a single video camera as an input sensor for the vehicle, so it not doing all the tasks of autonomous vehicle driving system. Therefore, the scopes of this research are:

1. Analyse video data and capture the video image frame by frame.
2. Detect and track the desired lane of straight or smooth curvature highway using image processing and analysis methods.
3. Determine and analyse the dynamic model of the vehicle.
4. Determine and analyse vehicle lateral and longitudinal control.
5. Determine and analyse the performance of the vehicle.

CHAPTER 2

LITERATURE REVIEW

Autonomous driving functionalities can be achieved acting on infrastructures and vehicles. Enhancing road infrastructures may yield benefits to those kinds of transportation, which are based on repetitive and prescheduled routes, such as public transportation and industrial robotics. On the other hand, it requires a complex and extensive organization and maintenance, which can become extremely expensive in case of extended road networks for private vehicles use. For this reason, the system that is expected to be achieved on a short-term basis can only be vehicle-autonomous. In this review, only selected components of autonomous vehicle driving control system are considered, while road infrastructure, inter-vehicle communication, satellite communications and route planning issues are not covered.

2.1 Sensors

The key element in autonomous vehicle driving system is sensor, which provides information to the electronic control unit. The sensor gave information to the controller and then the controller will determine where the path is located with respect to the vehicle. Each sensor available to perform this task has different level accuracy and ease of implementation. In addition, some sensors require changes to the roads themselves while others can be used on existing roads.

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