DEVELOPMENT OF A VEHICLE ROBOTIC DRIVER WITH INTELLIGENT CONTROL SYSTEM MODELLING FOR AUTOMATED STANDARD DRIVING-CYCLE TESTS

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Specially dedicated to my great supervisor

To my beloved mother and father for their prayers and love during all my life

To my wife for her love and support

To my siblings for their support

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ABSTRACT

New road vehicles are required to undergo several specific tests to meet the requirement set by governing bodies in various markets. These tests are often carried out over specific driving-cycles. To carry out lab-based driving-cycle tests, a typical vehicle manufacturer will employ a trained driver to follow driving profiles on a chassis dynamometer. This project involves development of a robotic driver controller for the automation of dynamometer-based vehicle testing according to industry standard driving cycle tests and produce repeatable results by replacing the traditional method of employing a human driver with a robot driver. The throttle and brake pedals control systems modelling and design for automatic transmission vehicle are implemented, with Fuzzy model reference adaptive control (Fuzzy MRAC) as the main controller. The vehicle model was developed using black-box modelling approach where simulations are performed based on real-time data and processed using Matlab System Identification tool. The Fuzzy MRAC was then designed within the simulations to attain the driving performance. The vehicle model response was sent as feedback to the robotic DC linear actuator motor which was modelled based on DC linear actuator motor design specification. The results obtained from simulation and modelling experiment were discussed and compared. The performed work concludes that system identification modelling with best fit accuracy of 79.93% can be applied in Fuzzy MRAC to ensure smooth and accurate vehicle driving pattern behavior even when the leading vehicle exhibits highly dynamic speed behavior during driving-cycle test. The performance of the vehicle model has shown an average 0.07 MSE for the throttle system and 0.008 MSE for the brake system of the vehicle model.

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ABSTRAK

Kenderaan jalan raya yang baru perlu melalui beberapa ujian spesifik untuk memenuhi syarat-syarat yang ditetapkan oleh perbagai badan pentadbiran dalam pasaran. Ujian-ujian ini biasaannya dilaksanakan berdasarkan kitaran memandu tertentu. Untuk menjalani uiian kitaran memandu di makmal, pengilang kenderaan biasanya melantik pemandu terlatih untuk mengikuti profil pemanduan di atas dinamometer cesi. Projek ini melibatkan pembangunan pengawal pemandu robotik untuk automasi ujian kenderaan di atas dinomometer mengikut ujian kitaran pemanduan piawaian industri yang berupaya menghasilkan keberulangan keputusan yang baik dengan menggantikan kaedah tradisional, iaitu dari pemandu manusia kepada pemandu robotik. Rekabentuk dan pemodelan pengawal pedal pendikit dan pendal brek untuk kenderaan bertransimisi automatik dilaksanakan melalui kaedah Kawalan Rujukan Model Suai Fuzzy (Fuzzy MRAC) sebagai pengawal utama. Model kenderaan dihasilkan menggunakan pendekatan permodelan kotak hitam yang mana simulasinya dilakukan berdasarkan data masa nyata dan telah diproses menggunakan alat identifikasi sistem Matlab. Fuzzy MRAC kemudiannya direkabentuk dalam persekitaran simulasi untuk mendapatkan prestasi pemanduan. Tindak balas model kenderaan dihantar sebagai maklum balas kepada motor penggerak lelurus DC robotik yang telah dimodelkan berdasarkan spesifikasi rekabentuk motor penggerak lelurus DC. Dapatan keputusan daripada simulasi ujikaji permodelan telah dibincangkan dan dibandingkan. Hasil kerja yang telah dijalankan menyimpulkan bahawa permodelan identifikasi sistem dengan ketepatan penyuaian terbaik 79.93% boleh digunakan dalam Fuzzy MRAC untuk memastikan corak tingkahlaku pemanduan kenderaan yang tepat dan lancar walaupun ketika kenderaan yang diuji menunjukkan tingkahlaku kelajuan yang dinamik semasa ujian kitaran pemanduan. Prestasi kenderaan telah menunjukkan purata 0.07 MSE untuk system pendikit dan 0.008 MSE untuk system brek model kenderaan.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

TABLE OF CONTENTS

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 3 METHODOLOGY

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 4 RESULTS AND DISCUSSION

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 5 CONCLUSIONS AND FUTURE RECOMMENDATIONS

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF TABLES

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF FIGURES

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

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PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF SYMBOLS

e	Error between the system and model outputs
$\frac{\delta e}{\delta \theta}$	Sensitivity derivative of the system
$-\gamma'$	Adaption gain
μ_A	Membership function of A
μ_B	Membership function of B
U_i	Centre of the output membership function
Tr	Settling time
Ts	Rise time
$\%OS$	Percentage overshoot
w_n	Natural frequency
ζ	Damping ratio
T	Time
y_1	Actual value
$y^{\sim}{}_1$	Predicted value

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LIST OF ABBREVIATIONS

MRAC	Model Reference Adaptive Controller
Fuzzy MRAC	Fuzzy Model Reference Adaptive Controller
Fuzzy 3MRAC	Fuzzy Model Reference Adaptive Controller With Three Membership Function
Fuzzy 7MRAC	Fuzzy Model Reference Adaptive Controller With Seven Membership Function
FLC	Fuzzy Logic Controller
MSE	Mean Square Error
RMSE	Root Mean Square Error
COG	Centre of Gravity
E	Error
CE	Change of Error
NEDC	New European Driving Cycle
ARX	Auto-Regressive with exogenous input
ARMAX	Autoregressive Moving Average with Exogenous Inputs
NB	Means Negative
NM	Means Negative Medium
NS	Means Negative Small
ZE	Means Zero Error

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PS	Means Positive Small
PM	Means Positive Medium
PB	Means Positive Big

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF APPENDICES

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces the study by giving a general overview of research background, problem statement, research objectives, scopes and outline of the thesis.

1.2 Research Background

The demand for transportation is expected to increase along with the increase in population and global economy. According to International Organization of Motor Vehicle Manufacturers (OICA) the world motor vehicle sales has increased to ninety seven millions vehicles in 2017 compared to ninety four millions vehicles in 2016, as can be observed in Figure 1.1.

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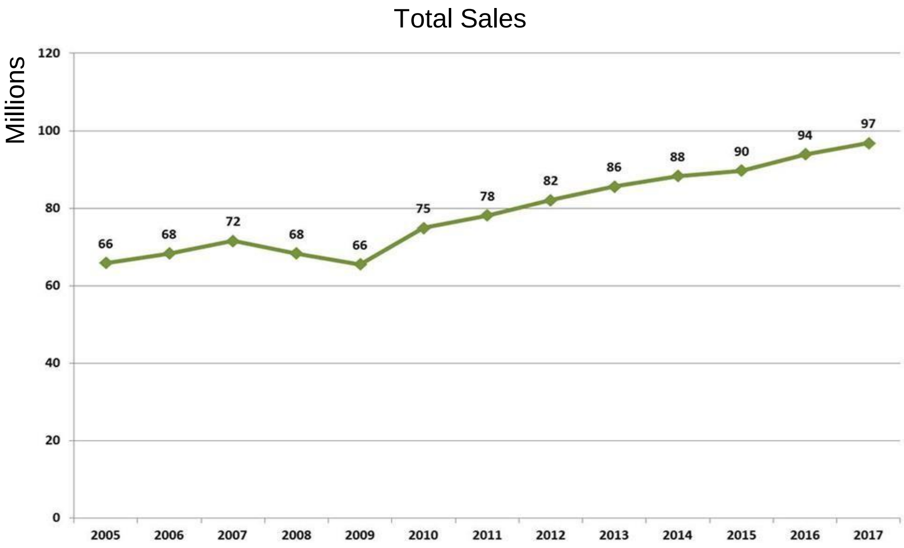

Figure 1.1 : World Motor Vehicle Sales according to (OICA) [1]

This rise of vehicles production will greatly impact the environment through three major areas, namely resource depletion, greenhouse emission and the local pollution. These are caused by the fuel combustion and emissions from cars, trucks, buses and other vehicle. The five major emissions produced by internal combustion engines are hydrocarbons (HC), Carbon Monoxide (CO), oxides of nitrogen (NOx), Carbon Dioxide (CO_2) and solid particulates [2].

The vehicle-related emissions are dangerous and hazardous to the human health and the environment. CO_2 emission relates directly to fuel consumption and can be reduced by increasing engine efficiency and electrification/hybridization of powertrains. The concentration of NOx, HC and CO in the exhaust gas can be reduced through fine-tuning of the engine operation and with advancement in modern powertrain technology [3]. Authorities worldwide are imposing strict regulations on CO_2 emission from road vehicles. Emissions from vehicles are measured over specific driving pattern called driving cycles which vary according to countries and regions [4]. Some examples of such driving cycles include Environmental Protection Agency: Federal Test Procedure (EPA: FTP-75) that is use in United States of America and the World Harmonized Light Vehicle Test Procedure (WLTP) driving cycle, and the outgoing New Europe Driving Cycle that is used in the Europe. Japan also has its own driving cycle which are the 10 modes, 10-15 modes and 11 modes test programs [5].

As the use of vehicles rapidly increase, the amount of pollution from the vehicle exhaust gas entering the atmosphere increases. To reduce this impact, stricter vehicle emissions and more stringent environmental protection laws are imposed on manufacturers. Today’s automobile industry places improvement on energy consumption and emission levels as the primary areas for progress [6,7]. In order to launch a new car model, an automobile manufacturer has to ensure that it follows the applicable regulations and standards. With concern for the welfare of the environment, emission standards impose maximum allowable amount of pollutants a car can emit. In order to assess the pollutant emission rate of the certifiable vehicle, it has to perform a type-approval test cycle on a chassis dynamometer, where tailpipe gases are collected and analysed over standard driving cycles. To carry out emission tests, the automobile industry will employ dedicated drivers to drive their vehicle according to standard driving cycle on a chassis dynamometer. A driving cycle is a

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fixed schedule of vehicle operation which allows an emission test to be conducted under reproducible conditions. Driving cycles are usually defined in terms of vehicle speed and gear selection as a function of time. Emission levels are dependent upon many parameters, including vehicle-related factors such as model, size, fuel type, technology level and mileage, and operational factors such as speed, acceleration, gear selection and road gradient. Not surprisingly, therefore, different driving cycles have been developed for different types of vehicle such as cars, vans, trucks, buses and motorcycles [5].

1.3 Problem Statement

To carry out an emission test, a typical manufacturer will employ a trained driver to follow the driving cycle on a chassis dynamometer. Current vehicle dynamometer emission test methods require trained and qualified personnel to perform repeated test cycles for long periods of time and a ‘driver’s aid’ is provided to ensure that the driven cycle is as close as possible (e.g. within stated tolerances) to the defined standard driving cycle [5]. Having a driver conduct this test will subject the test to errors and even manipulation of test procedure besides inconsistent measurements which will require averaging of results over multiple tests. Thorough comparisons between robotic drivers and human drivers have shown that over-predict emission levels by 10-20% compared to human driver [8]. This can be attributed to differences in driving style. Human drivers tend to reduce the variation in acceleration by looking ahead of the current speed, hence obtaining smoother transitions between speed changes. This assists the comfort of the passengers. A robotic driver tends to closely follow the exact speed of the drive cycle, resulting in more frequent acceleration changes. In addition, experienced test-drivers acquire the skills to be able to drive closes to the minimum speed tolerance set by standard procedures thereby achieving lower emission levels. This manipulation and exploitation of test tolerance can be eliminated by having an automated system to conduct the driving cycles test.

This research is carried out to develop a robotic driver that is able to drive the vehicle based on standard driving cycles and replace the on-board human driver. The robotic driver is a combination of motors, hydraulic pumps, and actuators which are controlled via an advanced artificial intelligence control system with a closed loop

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controller. Existing controllers in this application are based on traditional PID system which has displayed several disadvantages and exhibit varying degree of success in term of controller output accuracy. A simple conventional controller is not sufficient to deliver the required precision needed in driving cycle tests. This can be overcome by introducing a level of intelligence in the controller system. Therefore a control method that adapts the vehicle model and robotic driver to various driving pattern behaviours while maintaining system performance without parameter resets is needed. The Fuzzy Model Reference Adaptive controller (Fuzzy MRAC) is proposed in this study because the reference for the controller, which is the driving cycle is known input. In model reference adaptive control (MRAC) the system performance is given by the reference model and the tuning of controller parameters is based on the error, defined as the difference between reference model and real process responses. The main weakness of the standard MRAC is due to the presence of pure integral inside the adaptation law that will bring oscillation and instability in the Model Reference Adaptive Control controller output. To overcome this problem, the fuzzy logic controller is introduced in this study to replace the standard adaptive control in Model Reference Adaptive Controller. The fuzzy logic system obtains the desired output of the controlled object by regulating the adjustable parameters so that the output of the system under certain conditions can track the reference model output precisely [9,10]. Therefore, Fuzzy MRAC is suitable for applications in dynamic industrial control systems, where the influence of internal and external disturbances is high. As such, the Fuzzy MRAC has been selected as the controller of a robotic driver where the system can easily follow the reference standard driving cycle to achieve better accuracy and efficiency of standard driving cycle tests.

The automated vehicle driving system proposed in this study is used to drive the vehicle following the speed and time specified by the operator [7,11]. The idea is to replace the human driver with a robotic driver to carry out the driving cycle test. The purpose on eliminating human driver as a medium to drive the car is to reduce the error and inconsistencies that occur during driving cycle test [12,13]. This way, the drive cycle test can be carried out more efficiently. There are several disadvantages having a human as a driver to run the drive cycle test. The disadvantages include:

- vulnerability to human error.
- different reaction time.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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