ROBUST ELECTRONIC BRAKE FORCE DISTRIBUTION IN HYBRID ELECTRIC VEHICLES

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ROBUST ELECTRONIC BRAKE FORCE DISTRIBUTION IN HYBRID ELECTRIC VEHICLES

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I wish to dedicate this dissertation to my beloved people. To my precious parents who have helped me find my way and a big part of my success in life. They always respire me to try for bright future. I am really honored to have them. Everything that I am now is because of them.

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ABSTRACT

The vehicle braking system is one of the crucial issues in the vehicle dynamics and automotive safety control. This research focuses on the implementation of a control scheme for allocation of the brake force for the Through-the-Road (TtR) four-wheel-drive (4WD) Hybrid Electric Vehicle (HEV) to investigate the vehicle yaw stability control. The development of the mathematical models of the vehicle dynamic that comprised of rigid body dynamics, tire dynamics, longitudinal force and lateral force from the literature review are one of the most crucial steps to make sure the result obtained is closed as possible to the actual system. Robust controller is designed to control the vehicle yaw stability based on the electronic brake force distribution (EBD) braking system. By applying the robust control scheme, the vehicle yaw stability can be enhanced against the external disturbances. The performance of the proposed controller is compared based on the transient response's specifications to the reference signal response for the effectiveness analysis through simulation in the MATLAB/SIMULINK environment.

ABSTRAK

Sistem brek kenderaan adalah salah satu isu yang amat penting dalam dinamik kenderaan dan kawalan keselamatan automotif. Kajian ini memberikan tumpuan dalam perlaksanaan sistem kawalan untuk pengagihan tekanan brek dalam Through-the-Road (TtR) pacuan empat roda (4WD) kenderaan elektrik hibrid (HEV) untuk mengawal kestabilan kawalan rewang kenderaan. Pembinaan model matematik dinamik kenderaan adalah terdiri daripada badan kenderaan dinamik, tayar dinamik, tenaga membujur dan daya sisi yang dapat diperolehi daripada kajian maklumat merupakan salah satu pendekatan yang paling penting untuk memastikan keputusan yang diperolehi adalah sama dengan sistem sebenar. Pengawal teguh direka untuk mengawal kestabilan rewang kenderaan dengan berdasarkan pengagihan tekanan brek elektronik (EBD). Dengan menggunakan sistem kawalan yang kukuh, kestabilan rewang kenderaan boleh dipertingkatkan terhadap masalah. Prestasi pengawal yang direkakan akan dibandingkan dengan berdasarkan spesifikasi sambutan fana sebagai rujukan respons isyarat untuk analisis keberkesanan dengan melalui simulasi dalam persekitaran MATLAB/SIMULINK.

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LIST OF SYMBOLS

$\propto_i$	-	Tyre slip angle
β	-	Side-slip angle
μ	-	Road friction coefficient
M	-	Direct yaw moment
δ	-	Steering angle
δ_{sw}	-	Steering wheel angle
γ	-	Yaw rate
γ_d	-	Desired yaw rate
β_d	-	Desired side-slip angle
A	-	Steering stability factor
N	-	Static load transfer
ΔN	-	Dynamic load transfer
I_z	-	Vehicle moment of inertia
f	-	Front wheel
r	-	Rear wheel
fr	-	Front right wheel
fl	-	Front rear wheel
rr	-	Rear right wheel
rl	-	Rear left wheel
m	-	Vehicle mass
g	-	Gravitational acceleration
A	-	Vehicle projection area
d	-	Vehicle tread
h	-	Height of centre of gravity
f_r	-	Rolling coefficient

R_t	-	Tire radius
ρ	-	Air density
V	-	Vehicle velocity
i_{CVT}	-	CVT gear ratio
F_{EHB}	-	EHB force
K_{xi}	-	Coefficient for braking force to lateral force
v_x	-	Longitudinal velocity
a_x	-	Longitudinal acceleration
a_y	-	Lateral acceleration
L_f	-	Distance from centre of gravity to front axle
L_r	-	Distance from centre of gravity to rear axle
T_e	-	Engine torque
T_{mf}	-	Front motor torque
T_{mr}	-	Rear motor torque
C_d	-	Air drag coefficient
C_i	-	Tire cornering stiffness
C_f	-	Front tire cornering stiffness
C_r	-	Rear tire cornering stiffness
N_d	-	Final reduction gear ratio
N_{mf}	-	Front motor reduction gear ratio
Subscript x	-	Longitudinal direction
Subscript y	-	Lateral direction

LIST OF ABBREVIATIONS

HEV	-	Hybrid Electric Vehicle
EV	-	Electric Vehicle
4WD	-	Four-Wheel-Drive
TtR	-	Through-the-Road
EBD	-	Electronic Brake Force Distribution
DOF	-	Degree-of-Freedom
GA	-	Genetic Algorithm
PID	-	Proportional Integral Derivative
SMC	-	Sliding Mode Control
FL	-	Fuzzy Logic
RFLC	-	Robust Fuzzy Logic Controller
ABS	-	Antilock Braking System
IWM	-	In-Wheel-Motor
LQR	-	Linear Quadratic Regulator
LQ	-	Linear Quadratic
EHB	-	Electro-Hydraulic Brake
SWIFT	-	Short Wavelength Intermediate Frequency Tire Model
ICE	-	Internal Combustion Engine
S-HEV	-	Series Hybrid Electric Vehicle

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Hybridization of the four-wheel-drive (4WD) vehicle is able to provide numerous of the advantages to mankind. Almost half of the energy is dissipated during the braking process for the conventional vehicle which compares to the HEV [1], [2]. The HEV is adopted by separating the motors at the front wheel and the rear wheel [3], [4]. Firstly, the HEV is developed to achieve the improvement in fuel economy or better performance in which is collated to the conventional vehicle [3], [4], [5]. Secondly, the additional mechanical device such as the propeller shaft and the transfer case that are needed for transferring the engine power to the wheels, can eliminated by adopting separate motors at the front wheel and the rear wheels [3], [4]. Last but not least, vehicle stability control improved by obtaining the adequate control of the EBD braking system [6].

Electronic brake force distribution (EBD) which is also known as electronic brake-force limitation is one of the most successful and advance new refinements to the Antilock Braking System (ABS). It is a subsystem of the ABS and based on the principle that a car can be stopped down without necessary of every wheel needs to put forth the same effort. The EBD system is important in forbidding the rear wheels from locking prior to front wheels by adjusting the brake force distribution scale among the front and the rear automatically [7]. This is due to some wheels are carrying a heavier load than others and it will require more brake force to stop down the vehicle or without making the vehicle lost control. With the EBD system, it will compare the data from the yaw sensor to the steering wheel angle sensor to observe it if the vehicle is in two common situations during unstable condition that called over-steering or under-steering. After that, the data will processed by a computer which is called as an electronic control unit (ECU) will determine the load on each wheel and the slip ratio of each of the tires individually. Once it is noticing that the rear wheels are in the danger of slipping, it will apply less force towards them while increasing or maintain the force to the front wheels. The EBD components consist of speed sensors, brake force modulators, ECU, yaw sensor and also steering wheel angle sensor.

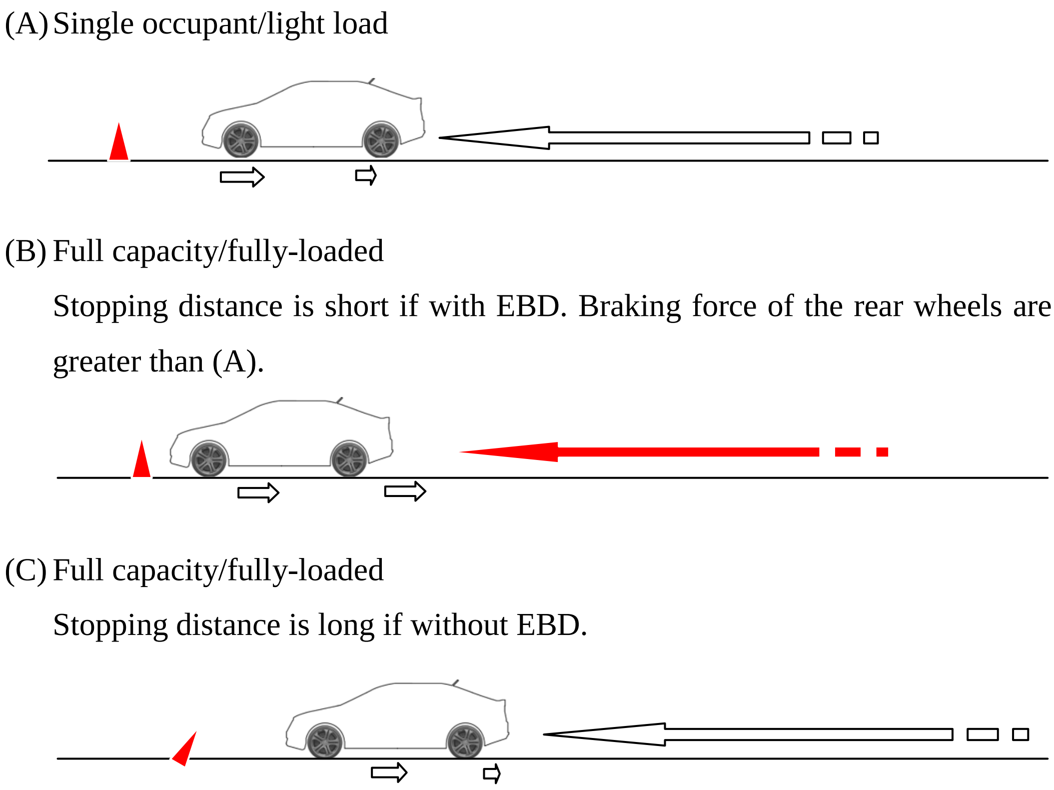

Figure 1.1 How Electronic Brake Force Distribution Functions

1.2 Problem Statement

The development of the control schemes in the EBD are performed using many different types of the controllers. Nevertheless, among these controllers, the development of the robust controller is still has not been developed to enhance the robustness against the side wind disturbance and the performance of the EBD braking system. Thus, the vehicle yaw stability control of a TtR-4WD-HEV is investigated by using the robust control scheme and the classical control scheme to overcome the external disturbance. MATLAB/SIMULINK models have been done to simulate the dynamic behavior of the vehicle system.

1.3 Objectives of Project

There are total of two objectives to be achieved upon the completion of this project. The objectives of this study are:-

(i) To establish a mathematical model of four-wheel-drive (4WD) hybrid electric vehicle (HEV) with electronic brake-force-distribution (EBD).

(ii) To apply a robust control scheme for vehicle yaw stability system based on electronic brake-force-distribution (EBD).

1.4 Scope and Limitations of Project

The research works carried out in this project are concentrated and limited to following aspects:-

(i) Study the working principle of the 4WD HEV.
(ii) Vehicle specifications: 4WD, HEV, 4 in-wheel-motors (IWMs)
(iii) A Mathematical model of a 4WD HEV that consists of rigid body dynamics, tire dynamics, longitudinal force and lateral force model are collected from literature review.
(iv) A linear 2-DOF vehicle model is considered as a desired vehicle model.
(v) Development of a simulation model by using MATLAB/SIMULINK.
(vi) Performance of the vehicle stability is analyzed with a J-turn and a single lane change simulation results.

1.5 Thesis Outline

The thesis is organized as follows: -

In Chapter 1, broad review or background of the project, problem statement, target extraction or objectives and scope and limitations are presented.

In Chapter 2, a detailed review of the published papers and journals relating to the control scheme of the TtR-4WD-HEV is presented. The review examines numerous control systems and optimizations that have been studied for enhancing the vehicle yaw stability.

In Chapter 3, step by step of the methodology used throughout the process for completing this project is presented. The steps that involve throughout the project development will be explained in detail according to the respective sections. Flow chart of the overview methodology will be also presented in this chapter.

In Chapter 4, the system dynamic model of the TtR-4WD-HEV will be presented. This chapter includes the equation of the rigid body dynamics, load transfer, tire dynamics, longitudinal force, lateral force and equations of the motion to form a non-linear mathematical model of the TtR-4WD-HEV.

In Chapter 5, non-linear HEV simulation model for the controller design and controllers are presented. Results and discussions for each work done throughout the project will also be described. All the results presented for the response of the controllers are only based on simulation in the MATLAB/SIMULINK environment.

In Chapter 6, highlights some key conclusions of the thesis and recommendations for further research based on the outcomes of the thesis.

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