MODELLING AND CONTROL OF AN INTELLIGENT ANTILOCK BRAKING SYSTEM

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

DECEMBER 2005

To my beloved Mother, Father (Allahyarham), Wife and my cheerful son

ACKNOWLEDGEMENTS

I am greatly indebted to Allah SWT on his blessing for making this study successful.

I would like to express my thanks and gratitude to Assoc. Prof. Pakharuddin Mohd. Samin and Assoc. Prof. Dr. Musa Mailah, my supervisors, for their guidance, support and advice throughout my study. I am very thankful to Dr. Khisbullah Hudha for his assistance and ideas.

Thank you to my colleagues at the Faculty of Mechanical Engineering, UTM, Dr. Dody Prayitno for his advice, Pak Gigih Priyandoko for his control tutorial, Pak Sugeng Ariyono, Ahmad Nasirudin, Doni Setiawan, Ahmad Fitriadi etc. for providing an enjoyable study environment. Thanks also to my colleagues at the Faculty of Electrical Engineering, UTM, Pak Wahyu Kusuma for his mechatronics tutorial, Pak Ustadz Andi Ardiansyah, Pak Reza Firsandaya Malik, Rudi Harun etc. for sharing the electrical knowledge.

My sincere appreciation extends to my mother, father, sister and brother for their moral support.

Finally, special thank to my beloved wife for her encouragement, support and patience.

ABSTRAK

Tesis ini menerangkan satu pendekatan bijak untuk mengawal Sistem Brek Anti-kekunci *(ABS)* yang menggunakan kaedah *Gradient Descent* untuk penyesuaian secara terus bagi *Fuzzy-Sliding Mode Controller (on-line FSMC).* Ini merupakan suatu kaedah baru yang diaplikasikan dalam ABS dan ia merangkumi pembelajaran parameter untuk meminimumkan ralat jangkaan di antara input kehendak dengan output sebenar dalam *loop* kawalan suapbalik. Sistem *fuzzy* terjana melalui *Adaptive Neuro-Fuzzy Inference System (ANFIS)* dengan melatihkan data input-output *Sliding Mode Control (SMC)* yang berpandukan ABS. Penyelidikan ini juga memperihalkan satu pendekatan baru bagi pengawal boleh-sesuai untuk ABS di bawah skema *Active Force Control (AFC)* yang telah mempamerkan kebolehsesuaian dan kecekapan dalam mengawal sistem dinamik. Objektif utama strategi kawalan adalah untuk mengawal nilai optimum gelincir roda *(optimum wheel slip value)* sistem tersebut, termasuk ketidaklinearan, ketidakpastian parameter dan gangguan demi menghalang roda daripada menjadi terkunci sepenuhnya. Pengajian permodalan *(modelling)* dan simulasi telahpun dijalankan dengan bersungguh-sungguh ke atas satu model brek kereta (suku) yang disimplifikasikan, pada halaju terus dengan mengambil kira skema kawalan gunaan *(applied control scheme).* Pengajian secara bandingan di antara berbagia kaedah kawalan terus juga dijalankan untuk menunjukkann perbezaan dari segi prestasi. Keputusan simulasi menunjukkan strategi *on-line FSMC* lebih baik dalam mengawal sistem ABS daripada strategi SMC. Keputusan simulasi juga menunjukkan bahwa strategi AFC memiliki ketahanan lasak walaupun ada kehadiran gangguan.

ABSTRACT

This thesis describes an intelligent approach to control an Antilock Braking System (ABS) employing a Gradient Descent Method for on-line adaptation of Fuzzy-Sliding Mode Controller (on-line FSMC). This is a new method that is applied into the ABS which includes the estimation of learning parameters to minimize the prediction error between the desired input and the actual output in the feedback control loop. The fuzzy system is developed using Adaptive Neuro-Fuzzy Inference System (ANFIS) by training the input-output data of the ABS based on Sliding Mode Control (SMC). This study also describes another new approach to robust control ABS employing Active Force Control (AFC) scheme. The main objective of the proposed control strategies is to control the optimum wheel slip value of the ABS that include nonlinearities, parametric uncertainties and disturbances in order to prevent the controlled wheel from becoming fully locked.. A modelling and simulation study was rigorously carried-out on a simplified quarter car braking model in the straightforward speed (straight line braking) with the applied control schemes taken into account. A comparative study between a number of control strategies was also performed to demonstrate the differences in performance. The simulation result showed that the on-line FSMC strategy demonstrated its superiority in controlling the ABS than the SMC strategy. The simulation results showed also that the AFC scheme demonstrated its robustness even in the presence of disturbance.

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LIST OF SYMBOLS

A_1	-	Effective orifice area of the build valve
A_2	-	Effective orifice area of the dump valve
A_f	-	Frontal area of the vehicle
b_i	-	Output membership function centers
C_d	-	Aerodynamic drag coefficient
c^i_j	-	Input membership functions centers
$\boldsymbol{e}_1$	-	Prediction error that denoted
F_a	-	Aerodynamic drag force
F_t	-	Tractive force
F_w	-	Wheel viscous friction force
g	-	Gravitational constant
h_{cg}	-	Center of gravity height
IN	-	Estimated mass
J	-	Moment of inertia of wheel
K_b	-	Gain between T_b and P_i
L	-	Wheel base
m_t	-	Mass of quarter vehicle
M_v	-	Mass of vehicle
N_v	-	Normal load
N_w	-	Number of wheels
P_i	-	Hydraulic pressure at the valves
P_{low}	-	Constant reservoir pressure
P_p	-	Constant pump pressure
Q'	-	Estimated disturbance torque
R_w	-	Wheel radius
S_{slide}	-	Sliding surface

T_b	-	Brake torque
T_{di}	-	Engine torque
$u(t)$	-	Control input
V	-	Vehicle speed
$\dot{V}$	-	Vehicle acceleration
$\dot{\omega}$	-	Wheel angular acceleration
$\boldsymbol{x}(t)$	-	State vector
ρ	-	Air density
λ_d	-	Desired slip
μ	-	Friction coefficient
μH	-	Maximum friction between tire and road
σ^i_j	-	Input membership functions spread

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CHAPTER 1

INTRODUCTION

1.1 Introduction

An Antilock Brake System (ABS) is a closed loop control system that modulates the brake torque that is applied to the wheel in order to prevent the controlled wheel from becoming fully locked.

ABS is among the most important safety systems in a vehicle. In automatic highway system, automatic brake actuation is a very important part of the overall vehicle control system. It prevents the wheel lock-up under critical braking conditions, such as those encountered with wet or slippery road surfaces and driver panic reaction (Bosch, 1995). By preventing the wheel lock-up, ABS ensures that the vehicle remains responsive to steering wheel inputs. Reduced stopping distance on account of ABS is more evident on wet or slippery road surfaces (Garrick *et al*., 1998).

1.2 Objectives of Study

The objectives of this study can be stated as follows:

i. To study an Antilock Brake System (ABS) including the non-linear characteristics and the time-varying nature of the system components

ii. To propose a new method of the intelligent ABS based on on-line Fuzzy-Sliding Mode Control (on-line FSMC) approach
iii. To introduce a new robust control employing Active Force Controller (AFC) which implemented to the ABS system
iv. To study the performance of the proposed controller

1.3 Scope of Study

The scopes of this study can be stated as follows,

i. Modelling of brake system dynamics
The mathematical model of the system is developed from a quarter car model by considering the straight line braking with zero steering wheel input.
ii. Modelling of hydraulic actuator system
A nonlinear actuator employing hydraulic valve control was used as the controller element in the ABS system
iii. Development of a nonlinear approach for controlling the ABS system based on Sliding Mode Controller (SMC)
iv. Generation of fuzzy rules based on SMC-ABS using Adaptive Neuro-Fuzzy Inference System (ANFIS)
v. Development of an intelligent control approach for the ABS system based on on-line Fuzzy-Sliding Mode Control (on-line FSMC) using gradient descent method
vi. Development of a robust control approach for the ABS system based AFC scheme (SMC-AFC, FSMC-AFC, and Online FSMC-AFC)
vii. Comparative study and performance analysis of the proposed control strategy

1.4 Problem Statement

ABS is one of the automotive industry's most recent attempts in enhancing passenger safety specifically related to accident avoidance. However, designing an ABS is a challenging task considering the fact that it is highly non-linear and a time varying system. The interaction between the tires and the road surface, the dynamics of the whole vehicle and the characteristics of key components in ABS (such as valves, brake chambers and brake pads) are all non-linear and time varying. Although a linear model can be derived through simplification, it is less accurate thus impedes the use of some advanced control strategy.

Due to the nonlinearities of the brake actuation system, an intelligent and robust braking control system with a faster response is required to handle even sudden, extreme variations in driving conditions with little loss of traction and steering ability. The vehicle could stop optimally regardless of spilt surface condition while directional stability and control is maintained. Many different robust and intelligent controls have been developed and research on improved control methods is continuing. Algorithms such as sliding mode control, fuzzy logic control, adaptive control, neural network control, fuzzy-sliding mode, fuzzy-neural, etc. have been successfully presented. In this study, a number of advanced control methods applied to ABS is proposed and evaluated.

1.5 Research Methodology

The modelling and control of an Antilock Braking System is mainly done through a simulation. The Simulation study is performed using MATLAB /Simulink version 6.5. Prior to simulation, the vehicle brake dynamic system, hydraulic actuator and the controller methods were first modelled. The next step is the simulation for wheel slip control of ABS considering a straight line braking which consist of slip trajectory. The Sliding Mode Control (SMC) approach was first implemented as the main control strategy of the ABS system. Later, an intelligent control method employing an on-line learning using gradient descent method was then investigated in the ABS based on SMC (SMC-ABS) system. This intelligent control requires an Adaptive Neuro-Fuzzy Inference System (ANFIS) tool to execute an off-line training procedure that produce the initial parameter and obtains the fuzzy rule. The Active Force Control (AFC) is also introduced and implemented into the ABS system at a later stage. The results were analyzed for each performance. Finally, a comparative study of the controllers was conducted. The methodology of executing this project is illustrated using a flow-chart diagram as shown in Figure 1.1.

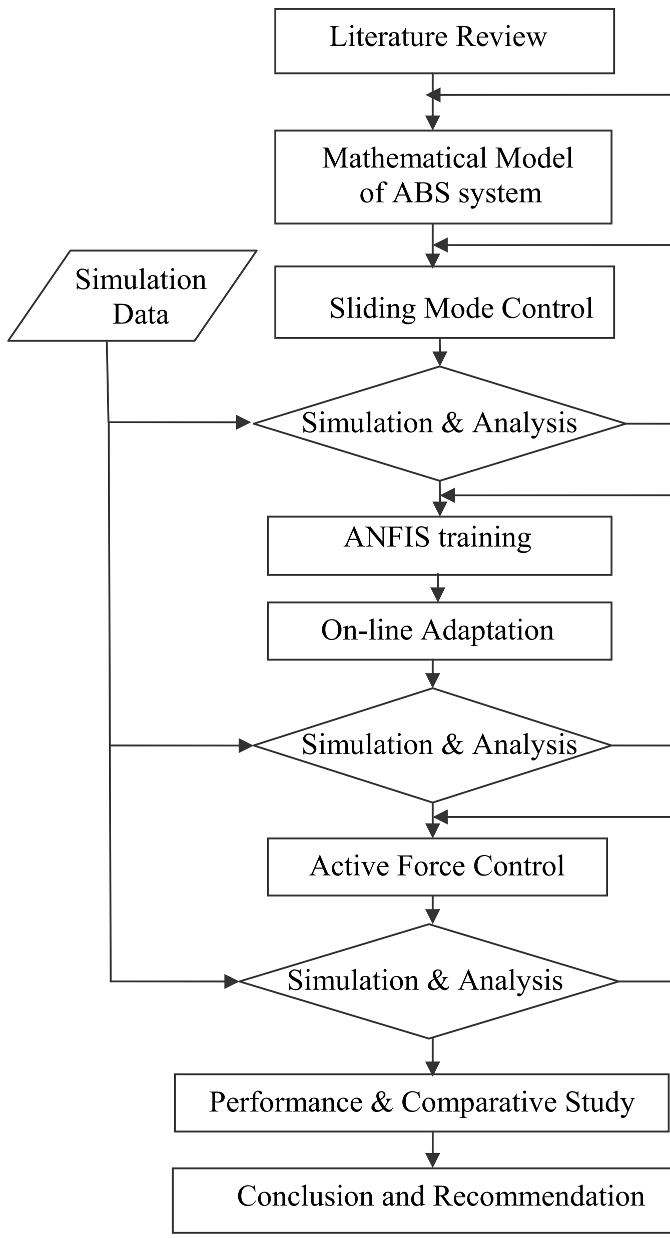

Figure 1.1 Flow-chart of the project implementation

1.6 Organization of the Thesis

This thesis is organized into five chapters. Chapter 1 presents an overview of the project, objective and scope of the study and the methodology of carrying out the project.

Chapter 2 provides an overview of an Antilock Braking System (the history and its function), followed by a theoretical background of ABS control system. It is also described the concept of ABS and some control strategies which have been implemented in the ABS system. Potential of the proposed controller is discussed in this chapter.

Chapter 3 discusses the mathematical model of the vehicle braking system and hydraulic actuator system. The sliding mode control approach is modeled and simulated for ABS using MATLAB/Simulink. The parameters used to run the simulation are shown in this chapter.

Chapter 4 deals with an intelligent control approach proposed for ABS. The discussion starts with the training of ANFIS in sliding mode ABS system. The intelligent control employing online learning using gradient descent method is then simulated and evaluated. This chapter also introduces the implementation of Active Force Controller on the ABS system. The performance of the proposed controller is evaluated based on the stopping distance achieved by each type of ABS control strategy.

Chapter 5 gives the overall conclusion on the study that has been done and the recommendations for future study are suggested.

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