SIMULATION AND EXPERIMENTAL ANALYSIS OF AN ACTIVE VEHICLE SUSPENSION SYSTEM

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Dedicated with love to my wife,

Norhaliza Binti Ali

and to my sons,

Muhammad Akmal Adlan and

Muhammad Zawir Zakwan.

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ABSTRACT

This project was carried out to study the performance of a two degree-of-freedom (DOF) active vehicle suspension system with active force control (AFC) as the main proposed control technique. The overall control system essentially comprises two feedback control loops. First is intermediate AFC control loop for the compensation of the disturbances and second is the outermost Proportional-Integral-Derivative (PID) control loop for the computation of the optimum commanded force. Iterative learning method (ILM) and crude approximation (CA) were used as methods to approximate the estimated mass in the AFC loop. Both simulation and experimental studies were applied in this project. A quarter car model consists of sprung and unsprung masses is considered in developing of the computer simulation model in Simulink and also in the experimental set-up. Both simulation and experimental work were carried out and the results between the two of them are compared. The results of the simulation study show that active suspension system using AFC with CA and ILM gives better performance compared to PID controller and passive suspension system. Experimental results obtained in the study further verified the potential and superiority of the performance of the active suspension system with AFC strategy compared to the PID control.

ABSTRAK

Projek ini dilaksanakan bagi mengkaji prestasi sistem gantungan aktif kenderaan sambutan dua darjah dengan dicadangkan kawalan daya aktif (AFC) sebagai teknik kawalan utama. Sistem kawalan keseluruhan pada dasarnya mempunyai dua gelung kawasan suapbalik. Pertama, kawalan gelung pertengahan AFC untuk mengimbangi gangguan dan yang kedua adalah kawalan gelung paling luar PID untuk mengira daya optimum yang dikehendaki. Kaedah pembelajaran lelaran (ILM) dan anggaran kasar (CA) digunakan untuk menganggarkan jisim anggaran di dalam gelung AFC. Kedua-dua kaedah iaitu kajian simulasi dan eksperimen dilaksanakan di dalam projek ini. Model suku kenderaan yang terdiri daripada 'sprung mass' dan 'unsprung mass' dipertimbangkan dalam membangunkan model simulasi di dalam Simulink dan juga susun atur eksperimen. Simulasi dan eksperimen dilakukan dan keputusan kedua-duanya dibandingkan. Keputusan kajian simulasi menunjukkan bahawa sistem gantungan aktif menggunakan AFC dengan kaedah pembelajaran lelaran (ILM) dan anggaran kasar (CA) memberikan prestasi yang baik berbanding kawalan PID dan sistem gantungan pasif. Keputusan eksperimen yang diperolehi dalam kajian mengesahkan potensi dan keunggulan prestasi sistem gantungan aktif dengan strategi AFC berbanding kawalan PID.

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LIST OF SYMBOLS

a	-	Acceleration of the body
A	-	Proportional learning parameter
B	-	Derivative learning parameter
b_s	-	Damping coefficient
D	-	Derivative
$e(t)$	-	Error (output – input)
$\dot{e}(t)$	-	Derivative error
f_a	-	Actuator force
F_a	-	Actuated force
F^*	-	Estimated force
I	-	Integral
K_d	-	Derivative controller gain
K_i	-	Integral controller gain
K_p	-	Proportional controller gain
k_s	-	Spring stiffness
k_t	-	Tyre stiffness
$m(t)$	-	Control signal
m_s	-	Sprung mass
m_u	-	Unsprung mass
M^*	-	Estimated mass of the body
P	-	Proportional
TE_k	-	Error value/current root of sum squared position track error

u_k	-	Current estimate value
u_{k+1}	-	Next estimated value
z_r	-	Displacement of road
z_s	-	Displacement of sprung mass
z_u	-	Displacement of unsprung mass
$\dot{z}_s$	-	Velocity of sprung mass
$\dot{z}_u$	-	Velocity of unsprung mass
$\ddot{z}_s$	-	Acceleration of sprung mass
$\ddot{z}_u$	-	Acceleration of unsprung mass
$z_s - z_u$	-	Deflection of suspension
$z_u - z_r$	-	Deflection of tyre

LIST OF ABBREVIATIONS

ADC	-	Analoque-to-digital converter
AF-AFC	-	Adaptive fuzzy active force control
AFC	-	Active force control
AFC-CA	-	Active force control with crude approximation
AFC-ILM	-	Active force control with iterative learning method
CA	-	Crude approximation
DAS	-	Data acquisition system
DCA	-	Digital-to-analoque converter
DOF	-	Degree of freedom
FLC	-	Fuzzy logic control
I/O	-	Input/output
IAFCRG	-	Intelligent Active Force Control Research Group
ILM	-	Iterative learning method
LVDT	-	Linear variable differential transformer
PC	-	Personal computer
PD	-	Proportional-Derivative
PID	-	Proportional-Integral-Derivative
PLC	-	programmable logic control
RTW	-	Real-Time Workshop
SANAFC	-	Skyhook and adaptive neuro active force control

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Traditionally, automotive suspension designs have been a compromise between three conflicting criteria of road holding, load carrying and passenger comfort. The suspension system must support the vehicle, provide directional control during handling manouevres and provide effective isolation of passenger payload from road disturbances [1]. Good ride comfort requires a soft suspension wheras insentivity to applied load requires stiff suspension. Good handling requires a suspension setting somewhere between the two.

Due to these conflicting demands, suspension design has had to be something of a compromise, largely determined by the type of use for which the vehicle was designed. Active suspensions are considered to be a way of increasing the freedom one has to specify independently the characteristics of load carrying, handling and ride quality.

A passive suspension system has the ability to storage energy via a spring and to dissipate it via a damper. Its parameters are generally fixed, being chosen to achive a certain level of compromise between road holding, load carrying and comfort.

An active suspension system has the ability to store, dissipate and to introduce energy to the system. It may vary its parameters depending upon operating conditions and can have knowledge other than the strut deflection the passive system is limited to.

1.2 Objective

The main objective of this project is to study the performance of an active suspension system using active force control (AFC) through simulation and experimental works.

1.3 Scope of work

The scope of this study consists of two major parts. The first is simulation works and the second is experimental works. For the simulation works, the scope involve is as follows:

i) To use an existing mathematical model of an active suspension.

ii) Apply active force control (AFC) with crude approximation (CA) and iterative learning method (ILM) to active suspension system.

iii) Simulate active suspension system with active force control with crude approximation (AFC-CA) and active force control with iterative learning method (AFC-ILM) strategy incorporated with different road profile.

iv) Study the performance of active suspension using AFC-CA and AFC-ILM strategy compare to PID control.

The scopes involved in an experimental works is as follows:

i) Prepare experimental set-up.

ii) Develop Simulink model in Real-Time Workshop (RTW).

iii) Run experiment.

iv) Study the performance of active suspension system using AFC-ILM strategy compare to PID control with the different disturbance.

v) Compare simulation results with the experimental results.

In experimental works, AFC strategy is used with iterative learning method (ILM) is applied to approximate the estimated mass. The study in experimental work will compare the result between PID and AFC-ILM only with different type of disturbance. A quarter car model is considered in both simulation and experimental study.

1.4 Project Implementation

The research is started with deriving the mathematical model of the main dynamic system for the vehicle suspension system using Newton's Second Law. First, dynamic equation for passive suspension system is derived followed by active suspension system. The model used is a two degree of freedom (DOF) system representing a class of passenger car. Disturbances also were modeled mathematically. Then, control scheme was developed and modelled. The schemes include PID and AFC strategy employing both crude estimation and iterative learning method.

Based on the derived models, a simulation study using MATLAB and Simulink was carried out. Started with the passive suspension system with open loop system followed by closed loop system of active suspension system. The results of the simulations were then compared for both passive and active suspension. The simulation results of active suspension system using AFC strategy and PID controller also were compared.

Experimental set-up for the proposed system then was prepared. The work involve during the set-up preparation is to develop experimental modules in the MATLAB which known as Simulink model with Real-Time Workshop (RTW). Then the experiment was carry out and the results obtained are analysed. Then experimental results was compared to simulation results in order to validate the results obtained for both method. This project implementation can be illustrated in a form of a flow chart as shown in **Figure 1.1**. Gantt Chart of the project schedule is shown in **Figure 1.2**.

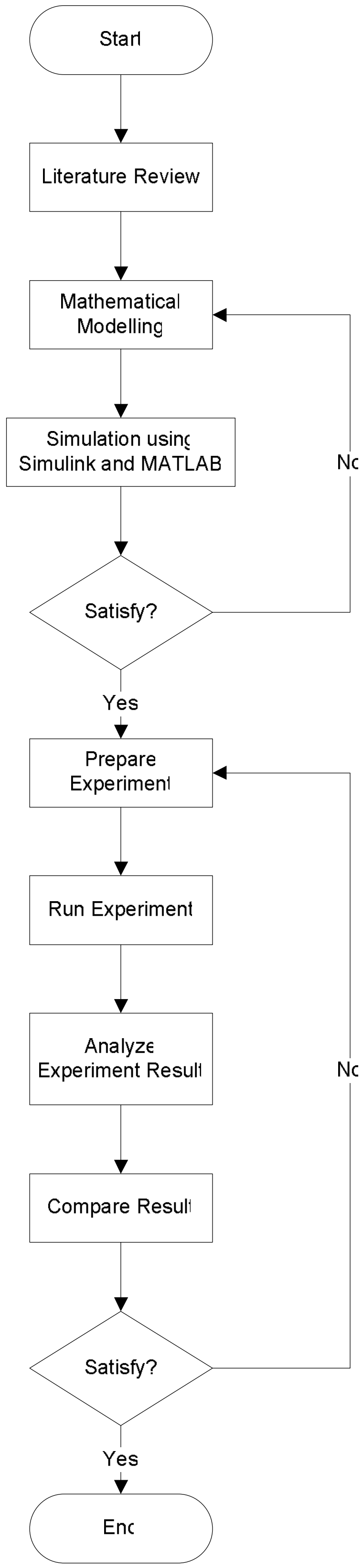

Figure 1.1: Flow chart of the project implementation

SEMESTER 1

No.	Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18
1	Brief idea	*																	
2	Literature review		*	*	*	*	*	*		*	*	*	*						
3	Study dynamic system					*	*	*											
4	Modelling proposed system									*	*	*	*						
5	Simulate proposed system													*	*				
6	Report writing														*	*	*		
7	Presentation																	*	

SEMESTER 2

No.	Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18
1	Prepare experiments	*	*	*	*														
2	Run experiments					*	*	*											
3	Analyze result									*	*								
4	Compare simulation results with experimental results										*	*	*						
5	Report writing													*	*	*	*		
6	Presentation																	*	

Semester break

Figure 1.2: Gantt chart of the project schedule

1.5 Organisation of Thesis

This thesis is organised into seven chapters. General introduction to the suspension system, the objective and the scope of the project and how the project is implemented is presented in Chapter 1. Chapter 2 discussed about theoretical information and literature review related to the project backgraound. This includes the definition of the suspension systems and its function. Explanation of types of suspension system and the concept of proportional-integral-derivative (PID) controller, active force control (AFC) and iterative learning method (ILM) also done in this chapter. A number of related research is reviewed adequately in this chapter.

Mathematical modelling based on quarter car model is presented in Chapter 3. Disturbances model and proposed simulation models also discussed in detail. Parameters used for simulation is highlighted in this chapter. Chapter 4 presents the simulation results for the different types of suspension system with various control strategies.

In chapter 5, experimental set-up for this project is explained in detail. This includes the development of the Simulink model with Real-Time Workshop (RTW) complete with all related subsystems in the model. Hardware components that used in the set-up also described. Then, parameters for experiment is presented.

Chapter 6 presents experimental results. System response with various conditions are presented and disscussed adequately. Chapter 7 gives the overall conclusion on the study that has been done and recommend of future works could be considered as extension to this study.

CHAPTER 2

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

This chapter includes the study of the suspension definition, function of the vehicle suspension and the vehicle dynamics. Three competing types of suspension systems are also described in this chapter which are passive, semi active and active suspension system. PID control, active force control (AFC) strategies and iterative learning method (ILM) are also discussed. Then, the review of the previous research related to the active suspension system is given.

2.2 Definition of Suspension System

Suspension system is a system that supports a load from above and isolates the occupants of a vehicle from the road disturbances. Springs in the suspension system are flexible elements. They able to store the energy applied to them in the form of loads and deflections. They have the ability to absorb energy and bend when

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