FACULTY OF ELECTRICAL ENGINEERING

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

INTELLIGENT CONTROLLER DESIGN FOR A NONLINEAR QUARTER-CAR ACTIVE SUSPENSION WITH ELECTRO-HYDRAULIC ACTUATOR SYSTEM

Maslinda Binti Paharudin

Bachelor of Electrical Engineering (Control, Instrumentation and Automation) with Honours

June 2015

" I hereby declare that I have read through this report entitle "Intelligent Controller Design for A Nonlinear Quarter-Car Active Suspension with Electro-hydraulic Actuator System" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation) with Honours "

Signature : ..……

Supervisor's Name : DR. ROZAIMI BIN GHAZALI

Date : ……..

INTELLIGENT CONTROLLER DESIGN FOR A NONLINEAR QUARTER-CAR ACTIVE SUSPENSION WITH ELECTRO-HYDRAULIC ACTUATOR SYSTEM

MASLINDA BINTI PAHARUDIN

A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation) with Honours

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

I declare that this report entitle "*Intelligent Controller Design for A Nonlinear Quarter-Car Active Suspension with Electro-hydraulic Actuator System*" is the result of my own research except as cited in the references. The report has not been accepted submitted in candidature of any other degree.

Signature : …….

Name : MASLINDA BINTI PAHARUDIN

Date : …….

Specially dedicated:

To my beloved father Paharudin Bin Ambran,

To my beloved mother Hamsiah Binti ABD Karim,

My beloved sister and brothers,

My supervisor and all my lecturers,

All my friends.

For their encouragement, support and motivation through my journey of education

ACKNOWLEDGEMENT

Bismillahirrahmanirrahim,

Alhamdulillah. Many grateful and thanks to Allah SWT for His continuous blessing and giving me the consent to complete this Final Year Project. This Final Year Project was organized by Faculty of Electrical Engineering (FKE), Universiti Teknikal Malaysia Melaka (UTeM) for student in final year to complete the undergraduate program in Bachelor of Electrical Engineering Major in Control, Instrumentation and Automation with Honors.

First of all, my sincere gratitude goes to my supervisor, Dr Rozaimi bin Ghazali to give me the opportunity to be under his supervision for Final Year Project. Many thanks for encouragement, suggestions and guidance in achieving the goal and maintain the progress in track. The discussions and the meeting give me a lot of new knowledge to explore regarding to my project. Next, I also want to thanks to all the lecturers of FKE, UTeM for their support and motivation to complete the project.

Many thanks to my friends, Azmiratul Nur Binti Omar, Mohamad Nafis Bin Maznan and Nabil Syafiq Bin Razali who help me and give me the suggestion and motivation to make my best for this project. Not to forget to all my classmates in 4 BEKC and other friends, thank you very much for the support and concern to my final year project directly or indirectly. The four years experience will be remembered as an important memory before enter the new chapter of line as an engineer soon.

Last but not least, deepest thanks and appreciation to my parents for their moral supports, love, sacrifice throughout my life. I am thankful for their sacrifice, patience, and understanding during completing this project. Their sacrifice had inspired me from day I learned to write and read until I am now.

ABSTRACT

Nowadays, active suspension system becomes important to the automotive industries and human life due to its advantages in improving road handling and ride comfort. The aims of this project are developing mathematical modelling and design an intelligent control strategy. The project will begin with a mathematical model development based on the physical principle of the passive and active suspension system. Electro-hydraulic actuator was integrated in order to make the suspension system under the active condition. Then, the model will be analyzed through MATLAB and Simulink software. Finally, the proportional-integral-derivative (PID) controller and an intelligent controller which is Fuzzy Logic are designed in the active suspension system. The results can be obtained after completing the simulation of the quarter-car nonlinear passive and active suspension system. From the simulation made through MATLAB and Simulink, the response of the system will be compared between nonlinear passive and nonlinear active suspension system. Besides that, the comparison has been made between Fuzzy Logic and PID controller through the characteristics of a vehicle body and control force from the suspension system. As a conclusion, developing a nonlinear active suspension system with electro-hydraulic actuator for quarter car model has improved the car performance by using a Fuzzy Logic controller. Otherwise, the suspension control system may serve for ride comfort and to support the body of the vehicle. The improvements in performance will improve road handling and ride comfort performance of both systems.

ABSTRAK

Pada masa kini, sistem suspensi aktif menjadi penting kepada industri automotif dan kehidupan manusia kerana kelebihannya dalam meningkatkan pengendalian jalan dan keselesaan perjalanan. Tujuan projek ini adalah membangun pemodelan matematik dan mereka bentuk strategi kawalan pintar. Projek ini akan bermula dengan pembangunan model matematik berdasarkan prinsip fizikal sistem suspensi pasif dan aktif. Penggerak elektro-hidraulik telah bersepadu untuk menjadikan sistem penggantungan di bawah keadaan aktif. Kemudian, model ini akan dianalisis melalui MATLAB Simulink dan perisian. Akhirnya, berkadar-asasi-derivatif (PID) pengawal dan pengawal pintar yang logik kabur direka dalam sistem suspensi aktif. Keputusan boleh diperolehi selepas menamatkan simulasi tak linear suku kereta pasif dan sistem gantungan aktif. Dari simulasi yang dibuat melalui MATLAB Simulink dan, sambutan daripada sistem akan dibandingkan antara linear sistem suspensi aktif pasif dan tak linear. Selain itu, perbandingan itu dibuat antara Logik Fuzzy dan pengawal PID melalui ciri-ciri tenaga badan kenderaan dan kawalan dari sistem penggantungan. Sebagai kesimpulan, membangunkan sistem gantungan aktif tak linear dengan elektro-hidraulik penggerak untuk model kereta suku telah bertambah baik prestasi kereta dengan menggunakan pengawal Logik Fuzzy. Jika tidak, sistem kawalan penggantungan boleh menyampaikan untuk keselesaan pemanduan dan untuk menyokong badan kenderaan. Peningkatan dalam prestasi akan meningkatkan pengendalian jalan dan menunggang prestasi keselesaan kedua-dua sistem.

TABLE OF CONTENTS

CHAPTER	TITLE		PAGE
	SUPERVISOR DECLARATION		**i**
	TITLE		**ii**
	DECLARATION		**iii**
	DEDICATION		**iv**
	ACKNOWLEDGEMENT		**v**
	ABSTRACT		**vi**
	ABSTRAK		**vii**
	TABLE OF CONTENTS		**viii**
	LIST OF TABLES		**xi**
	LIST OF FIGURES		**xii**
	LIST OF SYMBOLS		**xiv**
	LIST OF APPENDICES		**xv**
1	**INTRODUCTION**		
	1.1	Project Background	1
	1.2	Problem Statements	3
	1.3	Objective	4
	1.4	Scope	5
	1.5	Thesis Outline	6
2	**LITERATURE REVIEW**		
	2.1	Introduction	7
	2.2	Basic Principles of Suspension	8
		2.2.1 Passive Vehicle	8
		2.2.2 Semi-active Vehicle	9
		2.2.3 Active Vehicle	10

	2.3	Purpose of the Suspension System	12
		2.3.1 Main Components	12
	2.4	Mathematical Modelling of Suspension	13
	2.5	Literature Review	
		2.5.1 Backstepping Controller Design	14
		2.5.2 Sliding Mode Controller Design	15
		2.5.3 Fuzzy Logic Controller Design	15
		2.5.4 Proportional-Integral-Derivative (PID) Controller Design	16
	2.6	Conclusion	17
3	**METHODOLOY**		
	3.1	Project Methodology	18
	3.2	Procedure 1: Get Information About Suspension System	20
		3.2.1 Nonlinear Passive Suspension System	20
		3.2.2 Nonlinear Active Suspension System	20
	3.3	Procedure 2: Design the Mathematical Modelling	21
		3.3.1 Suspension System	21
		3.3.1.1 Nonlinear Passive Suspension System	21
		3.3.1.2 Nonlinear Active Suspension System	24
	3.4	Procedure 3: Design the Mathematical Modelling for Electro-hydraulic	26
	3.5	Procedure 4: Design the PID and Fuzzy Logic Controller	27
	3.6	Gantt Chart and Key Milestone	34
4	**RESULTS AND DISCUSSION**		
	4.1	Introduction	35
	4.2	Software Development	35
	4.3	Performance of Nonlinear Passive and Nonlinear Active Suspension	37

		4.3.1 Sprung and Unsprung Mass Acceleration	38
		4.3.2 Suspension Travel and Wheel Deflection	41
		4.3.3 Comparison between Nonlinear Passive and Active	43
	4.4	Nonlinear Active Suspension with Electrohydraulic using PID Controller and Fuzzy Logic Controller	45
		4.4.1 Comparison between PID Controller and Fuzzy Logic Controller	46
5	**CONCLUSION AND RECOMMENDATION**		
	5.1	Conclusion	53
	5.2	Recommendation	54
REFERENCES			55
APPENDICES			58

LIST OF TABLES

TABLE	TITLE	PAGE
1.0	Zeigler-Nicholas tuning rule	17
3.1	Rules base of fuzzy logic model	32
3.5	Project gantt chart	33
4.1	Parameters of quarter car model	35
4.2	Parameters of electro-hydraulic actuator	36
4.3	Nonlinear passive simulation values	44
4.4	Nonlinear active simulation values	44
4.5	Comparison between nonlinear passive and nonlinear active with PID controller and fuzzy logic	51
4.6	Comparison of percentage reduction with both controllers	52

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Passive suspension system	9
2.2	Semi-active suspension system	10
2.3	Active suspension system	11
2.4	Fully active suspension system	11
2.5	Main component of suspension system	13
3.1	Flowchart of project procedure	19
3.2	Nonlinear passive suspension for quarter car model	21
3.3	Nonlinear active suspension for quarter car model	24
3.4	Three-land four-way valve-piston system	26
3.5	Structure of PID controller	28
3.6	Structure of Fuzzy Logic control	29
3.7	Membership function of deflection velocity	30
3.8	Membership function of body velocity	30
3.9	Membership function of body acceleration	31
3.10	Membership function of force	31
4.0	Bump road disturbance input	37

4.1	Block simulink of nonlinear passive and nonlinear active suspension system	38
4.2	Car body acceleration of nonlinear passive suspension system	39
4.3	Car body acceleration of nonlinear active suspension system	39
4.4	Car body acceleration of nonlinear passive suspension system	40
4.5	Car body acceleration of nonlinear active suspension system	40
4.6	Suspension travel of nonlinear passive suspension system	41
4.7	Suspension travel of nonlinear active suspension system	42
4.8	Wheel deflection of nonlinear passive suspension system	42
4.9	Wheel deflection of nonlinear active suspension system	43
4.10	Block simulink of nonlinear quarter-car active suspension with electro-hydraulic actuator	45
4.11	Block simulink of nonlinear quarter-car active suspension with PID controller	45
4.12	Block simulink of nonlinear quarter-car active suspension with Fuzzy Logic controller	46
4.13	Comparison of body acceleration of sprung mass	48
4.14	Comparison suspension travel of sprung mass	48
4.15	Comparison body acceleration of unsprung mass	49
4.16	Comparison wheel deflection of unsprung mass	49

LIST OF SYMBOLS

U	-	Hydraulic actuator
X_1	-	Displacement of body
X_3	-	Displacement of angular version
K_{cr}	-	Critical gain
P_{cr}	-	Critical period
M_1	-	Mass of body
M_2	-	Mass of wheel
K_s	-	Spring of suspension
K_t	-	Spring of tyre
B_s	-	Damping coefficient of suspension
B_t	-	Damping coefficient of tyre
F	-	Force
K_p	-	Proportional gain
K_i	-	Integral gain
K_d	-	Derivative gain

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Block Simulink Open Loop Nonlinear Passive Suspension System	58
B	Block Simulink Open Loop Nonlinear Active Suspension System	59
C	Block Simulink Electro-hydraulic Actuator System	60
D	Toolbox of Fuzzy Logic Controller	61
E	Surface Viewer of Fuzzy Logic	61
F	Rule Viewer	62

CHAPTER 1

INTRODUCTION

1.1 Project Background

The automobile industry has contributed to the growth of the Malaysian automotive industry. Over the years, the industry has successfully developed and improved its technical capabilities, expertise and resources to manufacture a wide range of cars. Today, Malaysian-made cars are exported to a number of countries such as Singapore, United Arab Emirates, Thailand and Indonesia. In 2004, Malaysia's major import sources were Korea, Japan and Thailand, which accounted for 75.4 % of total import for the cars industry [1].

Nowadays, people do not have to be told how important the automobile industry to their lives. The automobile such as car is used to get people to work, deliver food, and other commodities. Without them realizing it, the condition of the car is a major contributor in road accidents. Acting Transport Minister Datuk Seri Hishammuddin Hussein mentioned that the government was taking the matter seriously over the road accidents which were recorded [2]. According the previous research, condition of the car is a big factor that contributes to the accidents. For instance, the accident statistics in Malaysian shows that our roads are dangerous, which is the condition of the road will be affecting the comfort while driving [3].

In line with the government's aim of making Malaysian as a country with a list of accidents by the year 2020, greater emphasis has been placed by the car industry, major players in engineering design as well as establishing strategic to reduce the accident in this country. The intelligent controller design for the car with the active suspension system might be capable to reduce the accident cases due to road handling.

Technically, a car suspension system functions as the mechanism that a part of the car body and the wheels of the car where it will bear the car's weight which to keep the contact between the tires and the road surface. Due to the high performance, increased of the vehicle capabilities has also changed the performance of the suspension system to imitate the same effect [4].

As known, the vehicle is a piece of mechanism equipment used as the medium of transportation. This agent of transmission has a strong nonlinear characteristic which can be uncertain with the dynamic parameters like masses, inertias, suspension springs and tires sides slip coefficients [5]. Under the vehicle, the suspension is more likely as the linkage between unsprung mass and the sprung mass [6].

1.2 Problem Statement

Generally, the main criteria that have deeply taken in vehicle designing are safety and comfort. Suspension system is an important role in completing both requirements in designing, as well continuing the lifetime of other component and give comfort ability during driving. Although, both of events in the system are subjective, the suspension system always gives more safety and comfort factor to the vehicle. As known, passive and active suspension system gives a high performance in the system which is the vibration of the amplitude is high and the time requirement in the system for the vibration in both of suspension is longer.

In order to overcome this condition, the capability of a controller to deal with an uncertainties and highly nonlinear system is analyzed based on quarter-car model. The active electro-hydraulic suspension is introduced in this system. The hydraulically actuated suspension is controlled with the use of hydraulic servomechanism. Other than that, the conventional controller of backstepping, sliding mode, fuzzy logic and PID controller design are always been used to solved a linear system [7-16].

1.3 Objectives of the Project

The objectives of this project are:

a) To develop a nonlinear mathematical modelling for quarter car active suspension with the electro-hydraulic actuator system.
b) To analyze the performance of a passive suspension system for a nonlinear quarter car model.
c) To design and evaluate an intelligent control strategy for an active suspension system based on Fuzzy Logic Controller.

1.4 Scope of Project

The scopes works of this project are as follows:

i. Development of mathematical modeling of a nonlinear quarter car active and passive suspension system.
ii. Design a controller PID and Fuzzy Logic for nonlinear active suspension system.
iii. Perform a simulation result of nonlinear passive and active suspension system in MATLAB/Simulink.
iv. Comparison study for nonlinear active suspension system based on PID and fuzzy logic controller in term of deflection velocity, body velocity and body acceleration.

This project will introduced in four stages of work

i. First Stage : Literature Review
    - All the information about the project can get through internet, journals, magazines, published paper and reference books.
    - Learn about the related software (Simulink, MATLAB)
    - Explaining more about the suspension system.

ii. Second Stage : Design and Simulation

- Mathematical modeling of nonlinear passive and active suspension system will be designed.
- The electro-hydraulic actuator system will be introduced in nonlinear active suspension system.
- Comparison between PID and fuzzy logic controller nonlinear active suspension system.
- MATLAB/Simulink software is used to simulate the performance of nonlinear passive and active suspension system.

iii. Third Stage: Implementation

- The simulation result of nonlinear passive and active suspension system will be analyzed.
- The simulation result with different controller will be analyzed

iv. Fourth Stage: Report Writing

- Write all the information which is related to the project.
- Show all the idea using flowchart to present the implementation of project.
- State the starting condition until the project is done.

1.5 Thesis Outline

In general this thesis is divided into five chapters, where it consists of:

Chapter 1: Introduction

Chapter 2: Literature Review

Chapter 3: Research Methodology

Chapter 4: Results and Discussions

Chapter 5: Conclusion and Recommendation

Chapter 1 is an overview of the research project in whole. For the first chapter is about introduction. In this chapter describe about the background, problem statement, objective and scope of the project.

Chapter 2 presents the literature review and theory background. In this chapter explain about the background of study which is related to the project. This chapter introduced the evidence that use in this project (e.g. books, internet, lecture notes etc) and focusing on the project report, thesis, journal paper etc).

Chapter 3 discusses about the methodology adopted for this research work. It involves the materials, subjects and equipment that are used in this project.

Chapter 4 shows the result obtained from the data presented. Then the related parameters are arranged tidily using the aid of figures and tables. Hence, all the result is explained and compared with another method. Then from the comparison with another method, it will be discussed.

Chapter 5 explains the conclusion achieved in this project and also the some suggestion to future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In general, an active suspension is widely used in automation system as it is an important part for safety purpose. Balancing the tradeoff between ride quality and road handling performance is a purposed of the suspension system [17]. This performance can be achieved by maintaining the relative position and movement between the vehicle body and wheels. Hence, the effects of vibrations will be reduced for particular road profile. The performance of the handling requires a stiff suspension because the system becomes stable when the tire contact keeping with the road. Suspension can be categorized as a dangerous and safe condition. The dangerous suspension is referring the road irregularities which can allow the body, resulting in poor ride comfort performance.

The ride comfort is referring to the vertical acceleration of sprung mass and ability of the tire deflection will be held by the system. The passenger will feel comfort when maintaining the vertical acceleration. Reducing sprung mass acceleration is one of the factors that can give the passenger comfort while adequate suspension deflection will be provided by the system which to maintain the condition tire to the ground contact [18].

Nowadays, the automotive suspension makes a design method based on the optimal control strategies. Sprung mass acceleration, suspension deflection and tire deflection are optimized by the suspension system. the main components use to designing in suspension system is a spring and parallel damper. All the components are placed together between the vehicle body and the wheels. Ride comfort as well as good handling is an important factor in designing the suspension system.

2.2 Basic Principles of Suspension System

Whenever the vehicle passes through bumps or holes in the road, the suspension system will allow moving up and down. As the result, the riding of vehicle becomes smoothly over the various roads. The types of vehicle suspension are available may be categorized as passive vehicle suspension system, semi-active vehicle suspension system and active vehicle suspension system [19].

2.2.1 Passive Vehicle Suspension System

A passive suspension system has the shock absorbers and the conventional springs as shown in Figure 2.1. In a passive system, there are two characteristics, linear and nonlinear characteristics. The linear characteristic of the system is a normal spring and relationship in shock absorbers between force and velocity is a nonlinear characteristics. However, the dynamics in the passive suspension system can fully control in term of vertical motion. The passive suspension system element cannot give the energy to the system. Even though no energy supplied, the relative motion can be controlled by different types of damping to the wheel.