



Faculty of Mechanical Engineering

**CONTROL OF PNEUMATICALLY ACTUATED ACTIVE SUSPENSION
SYSTEM USING MULTIPLE PROPORTIONAL-INTEGRAL WITH
KNOWLEDGE-BASED FUZZY**

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**CONTROL OF PNEUMATICALLY ACTUATED ACTIVE SUSPENSION
SYSTEM USING MULTIPLE PROPORTIONAL-INTEGRAL
WITH KNOWLEDGE-BASED FUZZY**

FITRIAN IMADUDDIN

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in fulfillment of the requirements for the degree of Master of Science
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DECLARATION

I declare that this thesis entitle “Control of Pneumatically Actuated Active Suspension System using Multiple Proportional-Integral with Knowledge-based Fuzzy” is the result of my own research except as cited in the references. This thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : 
Name : FITRIAN IMADUDDIN
Date : 1 October 2019

DEDICATION

To my beloved mother, father, and brothers

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ABSTRACT

This study investigates the use of pneumatically actuated active suspension system to improve ride performance of the vehicle. The main content of this study is the development and application of the Knowledge-Based Fuzzy (KBF) multiple Proportional-Integral (PI) control scheme and the investigation of the force tracking control system that can provide improvement in vehicle ride performance. These two controllers are arranged in a separated control loops called the inner loop controller for force tracking control of the pneumatic actuator and the outer loop controller using KBF multiple PI control to reject the effects of road-induced disturbances. The performance of the proposed controller is compared to the multiple PI controller without KBF scheme and the existing passive suspension system. Simulation studies are presented in time domain simulation while the experimental evaluation is conducted on a full-scale quarter car test rig. In general, it can be reported that the proposed control scheme is able to provide improvement in terms of body states compared to its counterparts. The proposed scheme is also easy to realize in practice due to its simple structure.

ABSTRAK

Penyelidikan ini mengkaji penggunaan sistem suspensi lasak menggunakan pneumatik untuk meningkatkan mutu pemanduan sesebuah kenderaan. Kandungan utama kajian ini adalah pembangunan skim dan aplikasi kawalan fuzzy proportional-integral berperingkat berpandukan pengetahuan (*KBF multiple PI control*) dan kajian mengenai sistem kawalan pengesan daya yang boleh menghasilkan peningkatan kepada mutu pemanduan kenderaan. Kedua-dua alat kawalan ini disusun dalam suatu gelung kawalan berasingan yang dinamakan pengawal gelung dalaman untuk kawalan daya pneumatik dan pengawal gelung luaran yang disebut *KBF multiple PI control* untuk menolak kesan daripada gangguan permukaan jalan. Mutu alat kawalan yang dicadangkan dibandingkan dengan alat pengawal *multiple PI* tanpa skim KBF serta dengan sistem suspensi pasif yang sedia ada. Kajian simulasi ditunjukkan dalam domain masa, manakala penilaian percubaan dijalankan pada *quarter-car-test-rig* skala penuh. Secara amnya, dapat disimpulkan bahawa skim alat kawalan yang dicadangkan berkemampuan untuk menghasilkan peningkatan yang berkesan dari segi kenyamanan apabila dibandingkan dengan sistem kawalan yang lain. Skim yang dicadangkan juga mudah untuk dijelaskan dalam bentuk latihan kerana bentuknya yang ringkas.

TABLE OF CONTENT

	PAGE
TITLE PAGE	i
DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENTS	iv
ABSTRACT	v
ABSTRAK	vi
TABLE OF CONTENTS	vii
LIST OF TABLES	xi
LIST OF FIGURES	xiii
LIST OF SYMBOLS	xxi
CHAPTER	
1. INTRODUCTION	1
1.1. Introduction	1
1.2. Problem Statement	2
1.3. Research Background	3
1.4. Objectives and Scope of Research	4
1.5. Methodology	5
1.6. Thesis Outline	6

2.	LITERATURE REVIEW	9
2.1.	Introduction	9
2.2.	Classification of Vehicle Suspension Systems	10
2.2.1.	Passive Suspension	11
2.2.2.	Semi-Active Suspension	11
2.2.3.	Active Suspension	12
2.3.	Actuator Selection in Active Suspension System	13
2.4.	Active Suspension Control Strategies	15
2.4.1.	PID Controller	15
2.4.2.	Linear Control	16
2.4.3.	Non-linear Control	17
2.4.4.	Intelligent Control	18
2.5.	Summary	19
3.	MODELLING AND VALIDATION OF TWO DEGREES OF FREEDOM QUARTER CAR MODEL	21
3.1.	Introduction	21
3.2.	Quarter Car Modelling	21
3.3.	Quarter Car Validation	23
3.3.1.	Instrumented Quarter Car Test Rig	24
3.3.2.	Validation Procedures	25
3.3.3.	Model Validation Results	26
3.4.	Summary	35
4.	FORCE TRACKING CONTROL OF PNEUMATICALLY ACTUATED ACTIVE SUSPENSION SYSTEM	36

4.1.	Introduction	36
4.2.	Modelling of Pneumatic Actuators	37
4.3.	Controller Structure	40
4.4.	Simulation Study	43
4.4.1.	Simulation Parameters	43
4.4.2.	Performance Evaluation of Force Tracking Controller	44
4.5.	Experimental Evaluation	51
4.5.1.	Instrumented Quarter Car Test Rig	51
4.5.2.	Experimental Results	53
4.6.	Summary	62
5.	MULTIPLE PROPORTIONAL INTEGRAL CONTROL SYSTEM	64
5.1.	Introduction	64
5.2.	Controller Design	64
5.3.	Simulation Study	66
5.3.1.	Simulation Parameters	66
5.3.2.	Frequency Domain Simulation Results	67
5.3.3.	Time Domain Simulation Results	70
5.4.	Experimental Evaluation	75
5.4.1.	Experimental Setup	75
5.4.2.	Experimental Results	75
5.5.	Summary	82
6.	KNOWLEDGE-BASED FUZZY MULTIPLE PROPORTIONAL INTEGRAL CONTROL SYSTEM	84
6.1.	Introduction	84

6.2. Controller Design	85
6.3. Simulation Study	91
6.3.1. Simulation Parameters	91
6.3.2. Simulation Results	92
6.4. Experimental Evaluation	96
6.4.1. Experimental Setup	96
6.4.2. Experimental Results	97
6.5. Summary	111
7. CONCLUSION	112
7.1. Introduction	112
7.2. Conclusions	112
7.3. Summary of Research Contributions	114
7.4. Recommendation for Future Works	115
REFERENCES	116
LIST OF PUBLICATIONS	124

LIST OF TABLES

TABLE	TITLE	PAGE
4.1	Simulation Parameters of the pneumatic model	43
4.2	RMS value of desired and actual force of sinusoid function	56
4.3	RMS value of desired and actual force of square function	59
4.4	RMS value of desired and actual force of saw-tooth function	62
5.1	The parameters of the outer-loop PI controller	67
5.2	Time domain response comparison between various systems for 0.5 Hz	70
5.3	Time domain response comparison between various systems for 5 Hz	71
5.4	Time domain response comparison between various systems for 15 Hz	71
6.1	Input-output characteristics of the ordinary Multiple PI control	85
6.2	Membership function parameters of absolute body displacement error	89
6.3	Membership function parameters of absolute body acceleration error	90
6.4	Prescribed output values of the fuzzy system	90
6.5	RMS comparison between passive, multiple PI active and KBF multiple PI active for 0.5 Hz	92

6.6	RMS comparison between passive, multiple PI active and KBF multiple PI active for 5 Hz	92
6.7	RMS comparison between passive, multiple PI active and KBF multiple PI active for 15 Hz	93
6.8	RMS comparison of body displacement and body acceleration between KBF multiple PI and its counterparts	110
6.9	RMS comparison of suspension deflection and wheel acceleration between KBF multiple PI and its counterparts	111

LIST OF FIGURES

FIGURE	TITLE	PAGE
3.1	Passive Quarter Car Model	22
3.2	Active Quarter Car Model	23
3.3	Instrumented Quarter Car Test Rig	25
3.4	Validation results for body displacement at 0.94 Hz	27
3.5	Validation results for body displacement at 1.18 Hz	27
3.6	Validation results for body displacement at 1.42 Hz	27
3.7	Validation results for body displacement at 1.66 Hz	28
3.8	Validation results for body displacement at 1.89 Hz	28
3.9	Validation results for body acceleration at 0.94 Hz	29
3.10	Validation results for body acceleration at 1.18 Hz	29
3.11	Validation results for body acceleration at 1.42 Hz	29
3.12	Validation results for body acceleration at 1.66 Hz	30
3.13	Validation results for body acceleration at 1.89 Hz	30
3.14	Validation results for suspension deflection at 0.94 Hz	31
3.15	Validation results for suspension deflection at 1.18 Hz	31
3.16	Validation results for suspension deflection at 1.42 Hz	31
3.17	Validation results for suspension deflection at 1.66 Hz	32
3.18	Validation results for suspension deflection at 1.89 Hz	32
3.19	Validation results for wheel acceleration at 0.94 Hz	33

3.20	Validation results for wheel acceleration at 1.18 Hz	33
3.21	Validation results for wheel acceleration at 1.42 Hz	33
3.22	Validation results for wheel acceleration at 1.66 Hz	34
3.23	Validation results for wheel acceleration at 1.89 Hz	34
4.1	Schematic representation of pneumatic actuator with force tracking control	38
4.2	Control structure of force tracking control with PI controller	41
4.3	Control structure of force tracking control with on-off controller	42
4.4	Force tracking performance comparison at 600 N peak forces for sinusoid function; (a) on-off controller, (b) PI controller	45
4.5	Force tracking performance comparison at 600 N peak forces for square function; (a) on-off controller, (b) PI controller	46
4.6	Force tracking performance comparison at 600 N peak forces for saw-tooth function; (a) on-off controller, (b) PI controller	47
4.7	Force tracking performance comparison at 800 N peak forces for sinusoid function; (a) on-off controller, (b) PI controller	48
4.8	Force tracking performance comparison at 800 N peak forces for square function; (a) on-off controller, (b) PI controller	49
4.9	Force tracking performance comparison at 800 N peak forces for saw-tooth function; (a) on-off controller, (b) PI controller	50
4.10	1-DOF Quarter Car Test Rig	52
4.11	Schematic representation of pneumatic actuator with force tracking control using proportional valve	53
4.12	Performance of force tracking control system in 600 N sinusoid functions	54

4.13	Performance of force tracking control system in 800 N sinusoid functions	54
4.14	Performance of force tracking control system in 1000 N sinusoid functions	55
4.15	Performance of force tracking control system in 1200 N sinusoid functions	55
4.16	Performance of force tracking control system in 1400 N sinusoid functions	55
4.17	Performance of force tracking control system in 1600 N sinusoid functions	56
4.18	Performance of force tracking control system in 600 N square functions	57
4.19	Performance of force tracking control system in 800 N square functions	57
4.20	Performance of force tracking control system in 1000 N square functions	57
4.21	Performance of force tracking control system in 1200 N square functions	58
4.22	Performance of force tracking control system in 1400 N square functions	58
4.23	Performance of force tracking control system in 1600 N square functions	58
4.24	Performance of force tracking control system in 600 N saw-tooth functions	60

4.25	Performance of force tracking control system in 800 N saw-tooth functions	60
4.26	Performance of force tracking control system in 1000 N saw-tooth functions	60
4.27	Performance of force tracking control system in 1200 N saw-tooth functions	61
4.28	Performance of force tracking control system in 1400 N saw-tooth functions	61
4.29	Performance of force tracking control system in 1600 N saw-tooth functions	61
5.1	Overall control structure of multiple PI control	65
5.2	Frequency domain response comparison between multi-order active and passive suspension	68
5.3	Frequency domain response comparison between multi-order, passive and zero-order system	69
5.4	Frequency domain response comparison between multi-order, passive and first-order system	69
5.5	Frequency domain response comparison between multi-order, passive and second-order system	70
5.6	Body displacement of 0.5 Hz sinusoid road profile	72
5.7	Body acceleration of 0.5 Hz sinusoid road profile	72
5.8	Body displacement of 5 Hz sinusoid road profile	73
5.9	Body acceleration of 5 Hz sinusoid road profile	73
5.10	Body displacement of 15 Hz sinusoid road profile	74
5.11	Body acceleration of 15 Hz sinusoid road profile	74

5.12	Body displacement of multi-order active and passive suspension at 1.42 Hz	77
5.13	Body acceleration of multi-order active and passive suspension at 1.42 Hz	77
5.14	Suspension deflection of multi-order active and passive suspension at 1.42 Hz	78
5.15	Wheel acceleration of multi-order active and passive suspension at 1.42 Hz	78
5.16	Body displacement of multi-order active and passive suspension at 1.65 Hz	79
5.17	Body acceleration of multi-order active and passive suspension at 1.65 Hz	79
5.18	Suspension deflection of multi-order active and passive suspension at 1.65 Hz	80
5.19	Wheel acceleration of multi-order active and passive suspension at 1.65 Hz	80
5.20	Body displacement of multi-order active and passive suspension at 1.88 Hz	81
5.21	Body acceleration of multi-order active and passive suspension at 1.88 Hz	81
5.22	Suspension deflection of multi-order active and passive suspension at 1.88 Hz	82
5.23	Wheel acceleration of multi-order active and passive suspension at 1.88 Hz	82

6.1	Overall Controller structure of knowledge-based fuzzy multiple PI control	87
6.2	Surface map of proposed fuzzy system	90
6.3	Responses comparison between passive, Multiple PI active, and KBF Multiple PI active of 0,5 Hz sinusoid road profile; (a) body displacement, (b) body acceleration, (c) suspension deflection, and (d) wheel acceleration	94
6.4	Responses comparison between passive, Multiple PI active, and KBF Multiple PI active of 5 Hz sinusoid road profile; (a) body displacement, (b) body acceleration, (c) suspension deflection, and (d) wheel acceleration	95
6.5	Responses comparison between passive, Multiple PI active, and KBF Multiple PI active of 15 Hz sinusoid road profile; (a) body displacement, (b) body acceleration, (c) suspension deflection, and (d) wheel acceleration	96
6.6	Body displacement performances comparison between KBF multiple PI and its counterparts at 0.94 Hz	98
6.7	Body acceleration performances comparison at 0.94 Hz; (a) between multiple PI and passive, (b) between KBF multiple PI and passive	98
6.8	Suspension deflection performances comparison between KBF multiple PI and its counterparts at 0.94 Hz	99
6.9	Wheel acceleration performances comparison at 0.94 Hz; (a) between multiple PI and passive, (b) between KBF multiple PI and passive	99

6.10	Body displacement performances comparison between KBF multiple PI and its counterparts at 1.18 Hz	100
6.11	Body acceleration performances comparison at 1.18 Hz; (a) between multiple PI and passive, (b) between KBF multiple PI and passive	101
6.12	Suspension deflection performances comparison between KBF multiple PI and its counterparts at 1.18 Hz	101
6.13	Wheel acceleration performances comparison at 1.18 Hz; (a) between multiple PI and passive, (b) between KBF multiple PI and passive	102
6.14	Body displacement performances comparison between KBF multiple PI and its counterparts at 1.42 Hz	103
6.15	Body acceleration performances comparison at 1.42 Hz; (a) between multiple PI and passive, (b) between KBF multiple PI and passive	103
6.16	Suspension deflection performances comparison between KBF multiple PI and its counterparts at 1.42 Hz	104
6.17	Wheel acceleration performances comparison at 1.42 Hz; (a) between multiple PI and passive, (b) between KBF multiple PI and passive	104
6.18	Body displacement performances comparison between KBF multiple PI and its counterparts at 1.66 Hz	106
6.19	Body acceleration performances comparison at 1.66 Hz; (a) between multiple PI and passive, (b) between KBF multiple PI and passive	107
6.20	Suspension deflection performances comparison between KBF multiple PI and its counterparts at 1.66 Hz	107

6.21	Wheel acceleration performances comparison at 1.66 Hz; (a) between multiple PI and passive, (b) between KBF multiple PI and passive	108
6.22	Body displacement performances comparison between KBF multiple PI and its counterparts at 1.89 Hz	108
6.23	Body acceleration performances comparison at 1.89 Hz; (a) between multiple PI and passive, (b) between KBF multiple PI and passive	109
6.24	Suspension deflection performances comparison between KBF multiple PI and its counterparts at 1.89 Hz	109
6.25	Wheel acceleration performances comparison at 1.89 Hz; (a) between multiple PI and passive, (b) between KBF multiple PI and passive	110

LIST OF SYMBOLS

- α_{in} - Heat transfer coefficient for compression
- α_{in} - Heat transfer coefficient for expansion
- μ_A - Functional mathematical form of a membership function
- A - Piston effective areas
- $A_{vi,in}$ - Valve areas for input path
- $A_{vi,in}$ - Valve areas for exhaust path
- β - Viscous friction coefficient of the pneumatic cylinder
- c_j^i - Center (mean) of the membership function
- σ_j^i - Spread (deviation) of the membership function
- θ - Representation of fuzzy parameters (center and spread)
- b_i - Output membership function for i -th rule
- C_1 - Coefficient for unchoked flow
- C_2 - Coefficient for choked flow
- C_f - Non-dimensional discharge coefficient
- C_s - Stiffness value of the passive damper
- e - errors

- e_z - body displacement errors
- \dot{e}_z - body velocity errors
- \ddot{e}_z - body acceleration errors
- f - regulated scaling factor of knowledge-based fuzzy scheme
- F - External force against pneumatic actuator
- F_p - Augmented force from the actuator
- F_f - Coulomb friction force of the pneumatic cylinder
- K_I - Integral Constant
- K_P - Proportional Constant
- K_s - Stiffness value of the passive spring
- L - Stroke length of the piston
- M - Mass of the pneumatic piston
- M_u - Mass of the wheel axle (unsprung mass)
- M_s - Mass of the vehicle body (sprung mass)
- \dot{m}_r - Mass flow rate of air
- P_1 - Pressures of the air in the first chamber of pneumatic cylinder
- P_2 - Pressures of the air in the second chamber of pneumatic cylinder
- P_{cr} - Critical pressure ratio
- P_d - Downstream pressures
- P_s - Supply pressure
- P_u - Upstream pressures
- R - Ideal gas constant

RMS - Root Mean Square

V_{01} - Inactive volume at the end of the stroke and admission ports of the pneumatic

V_c - Control Signal

x - Piston position relative to the middle of the stroke

Z_u - Vertical displacement of the wheel axle

Z_s - Vertical displacement of the vehicle body

Z_r - Vertical displacement of road profile

\dot{Z}_u - Vertical velocity of the wheel axle

\dot{Z}_s - Vertical velocity of the vehicle body

\dot{Z}_r - Vertical velocity of road profile

\ddot{Z}_u - Vertical acceleration of the wheel axle

\ddot{Z}_s - Vertical acceleration of the vehicle body