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Modeling And Controller Design For An Active Car Suspension System Using Quarter Car Model

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Date : 8th JUNE 2012

MODELING AND CONTROLLER DESIGN FOR AN ACTIVE CAR SUSPENSION SYSTEM USING QUARTER CAR MODEL

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

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2012

I declare that this report entitle "*Modeling And Controller Design For An Active Car Suspension System Using Quarter Car Model*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : MOHD SYAZWAN NAIM BIN MOHAMAD BASIR

Date : 8th JUNE 2012

To my beloved mother, father, brothers and sister

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ABSTRACT

The suspension system is a system that connects the wheels of an automobile vehicle to its body. It will absorb the energy of the vertically accelerated wheels and allow the car‟s body to ride undisturbed and improve the riding quality and handling of the car when taking the corners or driving on different road conditions. The active suspension system is one of the suspension systems that used by the modern cars nowadays. It has the ability to absorb, store and dissipate energy to the system. In this project, the Fuzzy Logic Controller has been developed to control the active car suspension system for quarter car model and it has been compared with the Linear Quadratic Regulator (LQR). This project compared the active car suspension system with the passive suspension system. The responses of the systems were simulated by using Matlab software. The Simulink in the Matlab was used to write the program for desired controllers. From the simulations that has been done, the Fuzzy Logic Controller give the best results in body acceleration, body velocity and suspension deflection compared to LQR and passive suspension system. This showed the improvement of the car‟s ride comfort and handling.

ABSTRAK

Sistem suspensi adalah sistem yang menghubungkan roda dan badan sebuah kenderaan. Ia akan menyerap tenaga dari pecutan menegak roda dan membuatkan badan kenderaan tidak terganggu sekaligus meningkatkan pengendalian kenderaan apabila melalui selekoh atau permukaan jalan yang tidak rata. Sistem suspensi aktif adalah salah satu system suspensi yang digunakan oleh kereta-kereta moden pada masa kini. Ia mempunyai keupayaan untuk menyerap, menyimpan dan melesapkan tenaga untuk sistem. Dalam projek ini, Pengawal Logik Fuzzy telah dibangunkan untuk mengawal sistem gantungan kereta aktif untuk model kereta suku dan ia telah dibandingkan dengan Pengawal Selia Linear Kuadratik (LQR). Projek ini akan membandingkan sistem gantungan kereta yang aktif dengan sistem gantungan pasif. Simulasi projek ini dijalankan dengan menggunakan perisian Matlab. Simulink dalam Matlab telah digunakan untuk menulis program untuk pengawal yang diingini. Daripada simulasi yang telah dilakukan, Pengawal Logik Fuzzy memberikan hasil yang terbaik dalam pecutan badan, halaju badan dan pesongan penggantungan berbanding dengan LQR dan sistem gantungan pasif. Ini menunjukkan peningkatan dari segi keselesaan pemanduan dan pengendalian kereta.

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LIST OF SYMBOLS

Z_b, Z_w, Z_r	- Body displacement, wheel displacement, road displacement
$\dot{Z}_b, \dot{Z}_w, \dot{Z}_r$	- First order derivative of body displacement, wheel displacement, road displacement
$\ddot{Z}_b, \ddot{Z}_w, \ddot{Z}_r$	- Second order derivative of body displacement, wheel displacement, road displacement
m_b	- Body mass
m_w	- Wheel mass
K_1	- Spring constant of the body
K_2	- Spring constant of the wheel
B_s	- Damping constant of wheel
x	- State vector
$\dot{x}$	- Derivative of state vector respect of time
y	- Output vector
u	- Control vector
w_1	- Input
A	- System matrix
B	- Control input vector
C	- Output matrix
G	- Disturbance matrix

CHAPTER 1

INTRODUCTION

1.1 Project Background

There were many researches that had been done to design the active suspension system by using many types of controller such as Fuzzy Logic, PID, Linear Quadratic Regulator (LQR), and Proportional Integral Sliding Mode Controller (PISMC). The result of the past researches shows that the active suspension system can provide better riding comfort and improve the handling of the car. The purpose of this project is to design a Fuzzy Logic controller for an active car suspension by using the quarter car model. The performance Fuzzy Logic controller then will be compare with the Linear Quadratic Regulator (LQR) and the passive suspension system in term of its body acceleration, body velocity, and suspension deflection.

1.2 Problem Statement

The conventional car suspension which is the passive suspension system cannot give the best comfort ride and handling when driving on the different road quality and driving situation. The passive suspension system has the fixed value of spring stiffness and damping value. The fixed setting of the passive suspension system is always a compromise between comfort and safety of any given input of road condition. To overcome this problem, the active suspension system has been designed. The active suspension system commonly attached with a force actuator that will provide the force to control the movement of the suspension. This force will be controlled by a controller which is the computer or electronic control unit (E.C.U) in the car. The controller of the active car suspension needs to be carefully design in order to get the best performance due to its complexity.

1.3 Objectives

The objectives of this project are as follows:

i. To design a Fuzzy Logic Controller for an active car suspension system using quarter car model.
ii. To design the Linear Quadratic Regulator (LQR) controller and passive suspension system as the comparisons for the Fuzzy Logic Controller.
iii. To analyze the performance of Fuzzy Logic Controller, LQR controller and the passive car suspension system using computer simulation.

1.4 Scopes

To achieve the objectives of the project, there are several scopes that need to be followed:

i. This project will be focus on to design the Fuzzy Logic controller for the quarter active car suspension system.
ii. Analyze the performance of proposed Fuzzy Logic Controller, LQR controller and the passive car suspension system with different road profiles.
iii. The MATLAB-SIMULINK software will be used to stimulate the responses.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter includes the studies and research paper that related to this project. The papers have been referred carefully since there are some knowledge and information from the papers that can be use and apply to complete this project. The literature review was a process that will be ongoing until the end of the project. The sources of the literature review are thesis, journals, reference books and others sources from the internet.

2.2 Literature Research

2.2.1 Type of Car Suspension

2.2.1.1 Passive Suspension System

A passive suspension system consists of the conventional springs and the shock absorbers [1]. The spring is the energy storing elements meanwhile the shock absorber or damper is the energy dissipating element. Both springs and shock absorbers of the passive suspension system have fixed characteristic parameters. So, these two elements can‟t provide any energy or force to the suspension system.

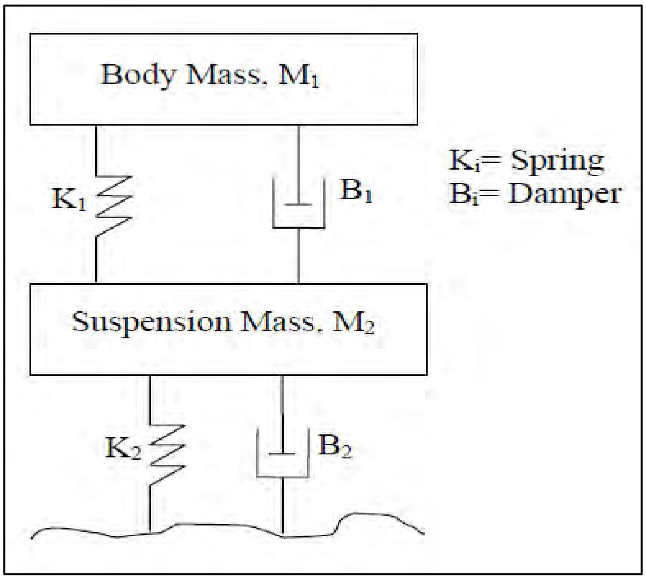

Figure 2.1: Passive Suspension System Model

2.2.1.2 Semi-Active Suspension System

In the semi active suspension system, the conventional spring like the one in the passive suspension system is attached parallel with an active damper. The damping force of the active damper can be adjusted to suit with the operating condition [2].

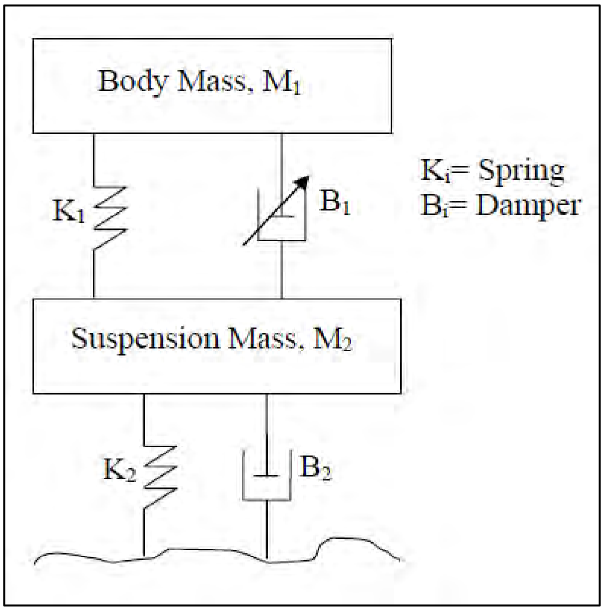

Figure 2.2: Semi Active Suspension System Model

2.2.1.3 Active Suspension System

The active suspension system currently is the most advanced suspension system in the world. This type of suspension has an ability to store, dissipate and provide energy to the system. The active suspension has an active element; a hydraulic or pneumatic actuator that installed parallel with the spring and the shock absorber or damper [1-3]. The active element generates the additional force to the system and suppresses the system responds to the changes of the road surface and condition which in turns increase the performance ride comfortable and handling of the car. To operate, the active suspension system required some sensors, an electronic control unit (ECU) or a controller, and power source to power up the actuator. These additional units had made the design of the active suspension system very complex and increased the cost to develop and build it.

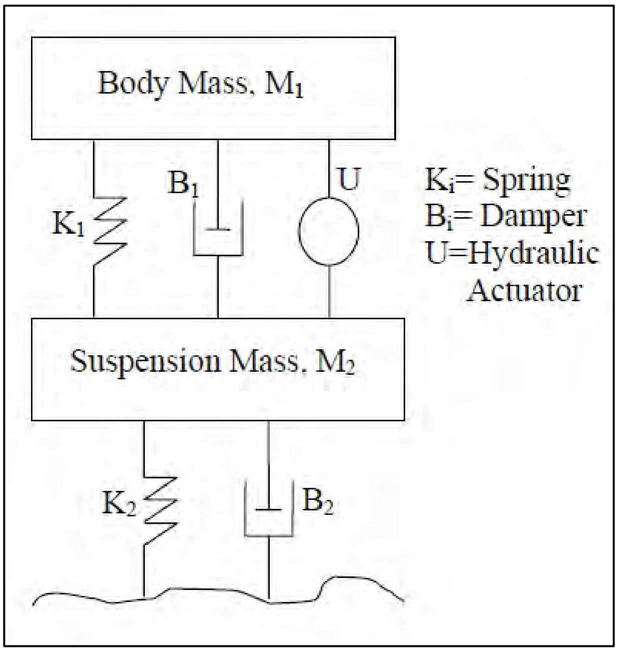

Figure 2.3: Active Suspension System Model

2.2.2 Fuzzy Logic Controller

M.M.M Salem and Ayman A.Aly have described the design of Fuzzy Logic controller for the active car suspension using quarter car model with 2 degree of freedom (D.O.F) [4]. This model uses a unit to create the control force between the body mass and the wheel mass. The Fuzzy Logic controller used in the active suspension system has 3 inputs which are the body acceleration, body velocity, body deflection and one input, which is the desire actuator force. The designed Fuzzy Logic controller had been compared with the PID controller. There were two type road conditions that used as the road disturbance input, the smooth road and the real road roughness. For the smooth road condition, the proposed Fuzzy Logic controller had given the reduction in percentage in body acceleration, suspension working space and dynamic tire load amplitudes less than the PID controller by 65%, 19.35% and 30.43% respectively. For the real road roughness condition, the proposed Fuzzy Logic controller also gives the percentage in the body acceleration, suspension working space and dynamic tire load amplitudes less than the PID controller by 61.3%, 6.9% and 24.24% respectively. Therefore, the proposed Fuzzy Logic controller for the active suspension system had improved the stability of the quarter car model.

In 1996, Andrew J.Barr and Dr.Jeffery L.Ray had designed a Fuzzy Logic controller for an active suspension system [5]. This research used the quarter car suspension model to represent the whole suspension system of a car. The designed Fuzzy Logic controller was compared with the Linear Quadratic Gaussian (LQG) and the passive suspension system. For the Fuzzy Logic controller, the inputs are the body velocity and the body acceleration while the output of the Fuzzy Logic controller was the force of the actuator. There were 9 rules developed for the Fuzzy Logic with the linguistic labels of Negative, Zero and Positive. The performance of the Fuzzy Logic controller and the LQG were evaluated by comparing the responses of its sprung mass acceleration, tire deflection, and suspension deflection. The responses from the simulation showed that the Fuzzy Logic controller had reduced the sprung mass acceleration, tire deflection and the suspension deflection more compared to the LQG. The decreased of the responses showed the improved of the ride and handling performance of the car.

Meanwhile, Thivagaran Gopallah in his research also had design a Fuzzy Logic controller for a quarter car active suspension system [2]. There were 9 rules that developed for the Fuzzy Logic controller. The inputs for the Fuzzy Logic are body velocity and the body acceleration while the output is the control force. The proposed Fuzzy Logic controller then was compared with the optimal controller which is the LQR and also with the passive suspension system. There were three input signal that has been used to simulate the road disturbances; the step input, ramp input and the bump input. From the simulation results, the Fuzzy Logic controller gave the better performance compared to LQR and passive suspension. The Fuzzy Logic controller greatly decreased the responses of suspension deflection, body acceleration and the wheel deflection. The decreased of these three responses mean the increased of the ride comfort and road handling.

2.2.3 Linear Quadratic Controller (LQR)

In the research done by Abu Bakar Adham Bin Hell Mee [1], the Linear Quadratic Regulator (LQR) had been designed for the active suspension system. The system uses the half car model. For the half car model, the interaction is between the car body and the wheels between both ends of the car body. The first interaction caused the vertical motion and the second interaction produced an angular motion. The active suspension system with the LQR controller was compared with the passive suspension system. The performance for both active suspension system and passive suspension system were compared in term of 3 parameters, the vertical body displacement, vertical wheel displacement and the body acceleration. From the simulation, the Fuzzy Logic had decreased the body acceleration and the vertical body displacement. The decreased of the body acceleration and the vertical body displacement will lead to the increased of the driving comfort and handling of the car. Meanwhile, the Fuzzy Logic controller had increased the vertical wheel displacement of the suspension system and this showed the increased of the tire to road contact and reduced the probability for the car to loss of control.

Yahaya Md. Sam, Mohd Rudin Hj. Ab.Ghani and Nasarudin Ahmad also had design a LQR controller for active suspension system in their research [6]. The LQR was compared with the passive suspension system. They had used the step and random input signal in the simulation to simulate the road condition that will faced by the car"s wheel. The simulation results shows that the active suspension system that using the LQR improved the response of suspension deflection, body velocity and the suspension velocity compared to the passive suspension system. This means the active suspension gives a better performance of the comfort ride and good handling of the car.

2.2.4 Proportional Integral Sliding Mode Controller (PISMC)

Yahya Md.Sam and Johari Halim Shah Bin Osman proposed a new method of modeling the active suspension system by using the half car model [7]. The Proportional Integral Sliding Mode Controller (PISMC) was designed to be used in the active car suspension. The proposed PISMC equation is as follow:

$$u(t) = -(CB)^{-1}\,[CAx(t) + \phi\sigma(t)] - k(CB)^{-1}\frac{\sigma(t)}{|\sigma(t)|+\delta} \qquad (2.1)$$

There were two parameters observed in the simulation, the body acceleration and the wheel deflection. The simulation results show that the active suspension system that using the PISMC increased the wheel deflection of the active suspension system; mean that the increased of the tire to road contact. This increased the car handling and will avoid the car from skidding. Besides that, the body acceleration of the half car model was slightly reduced when using the PISMC. So, it improved the ride comfort and retaining the road handling of the car. For overall, the simulation results showed that the PISMC proved to be effective in controlling the vehicle suspension system.

2.3 The Theory of Fuzzy Logic Controller

2.3.1 Introduction

In 1965, the concept of the Fuzzy Logic was introduced by Lofti Zadeh, a professor at University of California [9]. This concept do not applied to the control systems until 1970‟s due to the limitation of the computer capability at that time. Fuzzy Logic is a problem-solving control system that can implement itself in the system like embedded micro-controller, networked and multi-channel PC.

The advantages of Fuzzy Logic Controller are [10]:

i. It can be implement in complex system where mathematical modeling is too difficult.

ii. Fuzzy logic is conceptually easy to understand.
iii. It can be built on top of the experience of experts.
iv. Simple to design.
v. It can be blended with the conventional controller and simplify their implementation.

The Fuzzy Logic Controller consist of four elements; fuzzification interface, fuzzy inference mechanism, rule-based and defuzzification interface [10]. The fuzzification interface is the element that converts the inputs of Fuzzy Logic Controller which are in real number into fuzzy value. The fuzzy inference mechanism is where the input data are process and the outputs are compute. A rule-based holds the knowledge in the form of a set of IF-THEN rules, of how best to control the system. Then, the outputs which are in the fuzzy value are converted into real-number by defuzzification interface. Figure 2.4 shows the elements in the Fuzzy Logic Controller [2].

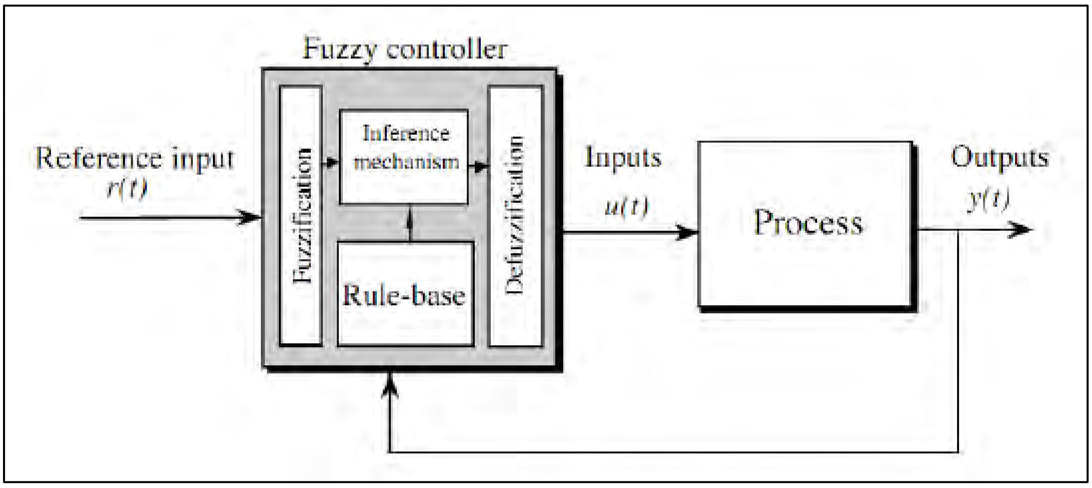

Figure 2.4: Elements in Fuzzy Logic Controller

2.3.2 Rule-Based System

The rule-based system is the heart of the Fuzzy Logic Controller and it consist the collection of fuzzy IF-THEN rules [11]. A rule of Fuzzy Logic Controller can be written as follow: