**SUPERVISOR DECLARATION**

“I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive)”

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Date : …………………………....

# ACTIVE SUSPENSION CONTROL OF GROUND VEHICLE HEAVE AND PITCH MOTION

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**ACTIVE SUSPENSION CONTROL OF GROUND VEHICLE HEAVE AND PITCH MOTION**

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**This report is submitted in partial fulfillment of the requirement for Degree of Bachelor in Mechanical Engineering (Automotive)**

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**DECLARATION**

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

Signature : ……………..…………….
Author : …………………………...
Date : …………………………...

To beloved parents

# ACKNOWLEDGMENT

Praise to God almighty for His grace in providing me the strength and ability in bringing this research to completion.

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# ABSTRACT

Vehicle in motion experience unwanted motion such as heave and pitch motion due to driver input and road irregularities. Heave motion refers to the vehicles vertical displacement and the pitch motion refers the angular moment in the longitudinal direction of the vehicle. Active suspension system uses a feedback control system which reduces the effects of pitch and heave motion of the vehicle by using counterforces of the actuators onto the suspension system. PID controller have been used in previous active suspension system control strategy, and to improve the efficiency and the effectiveness of the control strategy, a new controller is introduced, namely the fuzzy logic controller. The mathematical model for the half car suspension model is developed and modeled in the MATLAB Simulink software. Using the vehicle model, a control strategy is constructed using PID controller and the fuzzy logic controller. The feedback control system includes the decoupling transformation, in which splits the needed forces to the front and rear actuators of the active suspension. To prove the effectiveness of the fuzzy logic controller on the vehicle suspension model, a performance evaluation is performed by comparing the results of the fuzzy logic controller with the result obtained through simulation of the feedback control system using the PID controller. Based from the comparison of the controllers, the fuzzy logic controller is decided as better performing in terms of reducing the vehicle vibrations.

# ABSTRAK

Sebuah kenderaan yang bergerak akan mengalami gerakan kenderaan yang tidak di ingini seperti jonketan dan getaran disebabkan oleh permukaan jalan raya yang tidak sekata dan juga kerana input dari pemandu. Getaran merujuk kepada sesaran badan kenderaan di arah atas dan ke bawah, manakala getaran kenderaan merujuk pada momen sudut kenderaan tersebut. Sistem suspensi aktif mengunakan sistem kawalan berbalik intuk mengurangkan kesan getaran dan jongketan pada kenderaan dengan mengunakan daya dari penggerak pada sistem suspensi. Sebelum ini dalam strategi kawalan untuk sistem suspensi aktif, pengawal PID telah di gunakan, dan untuk menambahbaik prestasi dan kecekapan strategi kawalan, pengawal yang baru diperkenalkan, iaitu pengawal *fuzzy logic*. Model matematik yang mewakili sistem suspensi separuh kenderaan di terbitkan, dan berikutan itu dimodelkan dalam perisian MATLAB Simulin. Dengan menggunakan model kenderaan tersebut, satu strategi kawalan menggunakan pengawal PID dan satu lagi menggunakan pengawal *fuzzy logic* dibina. Sistem kawalan berbalik juga merangkupi transformasi nyahgandingan, dimana membahagikan daya yang diperlukan pada penggerak hadapan dan penggerak belakang pada sistem suspensi aktif. Untuk tujuan membuktikan kecekapan pengawal *fuzzy logic* pada sistem suspensi kenderaan, penilaian prestasi dijalankan dengan membandingkan keputusan daripada pengawal *fuzzy logic* dengan keputusan pengawal PID. Berdasarkan daripada keputusan perbandingan antara pengawal PID dan pengawal *fuzzy logic*, didapati pengawal *fuzzy logic* lebih bagus dalam mengurangkan getaran pada kenderaan.

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| | | |
|---|---|---|
| $a$ | = | Distance if the Front Axle from C.G. |
| $b$ | = | Distance of the Rear Axle from C.G. |
| $C_{dF}$ | = | Front Suspension Damping |
| $C_{dR}$ | = | Rear Suspension Damping |
| $F_{af}$ | = | Front Actuator Force |
| $F_{ar}$ | = | Front Actuator Force |
| $F_{dF}$ | = | Force Exerted by the Front Damper |
| $F_{dR}$ | = | Force Exerted by the Rear Damper |
| $F_{sF}$ | = | Force Exerted by the Front Spring |
| $F_{sR}$ | = | Force Exerted by the Rear Spring |
| $F_{tF}$ | = | Force Exerted by the Front Wheel |
| $F_{tR}$ | = | Force Exerted by the Rear Wheel |
| $F_z$ | = | Vertical Force |
| $h$ | = | Height of C.G. from the Ground |
| $I_p$ | = | Moment of Inertia of Pitch |
| $K_{sF}$ | = | Front Suspension Spring Stiffness |
| $K_{sR}$ | = | Rear Suspension Spring Stiffness |
| $K_{tF}$ | = | Front Tire Spring Stiffness |
| $K_{tR}$ | = | Rear Tire Spring Stiffness |
| $M_b$ | = | Mass of Vehicle Body |
| $M_p$ | = | Pitch Moment |
| $M_{wF}$ | = | Mass of the Front Wheel |
| $M_{wR}$ | = | Mass of the Rear Wheel |
| $N$ | = | Negative |
| $NB$ | = | Negative Big |
| $NS$ | = | Negative Small |

| | | |
|---|---|---|
| $P$ | = | Positive |
| $PB$ | = | Positive Big |
| $PS$ | = | Positive Small |
| $t$ | = | Time |
| $t_s$ | = | Settling Time |
| $\dot{V}$ | = | Longitudinal Acceleration of the Vehicle |
| $Z$ | = | Zero |
| $\ddot{Z}_b$ | = | Body Vertical Acceleration |
| $Z_{bF}$ | = | Front Body Vertical Displacement |
| $Z_{bR}$ | = | Rear Body Vertical Displacement |
| $\dot{Z}_{bF}$ | = | Front Body Vertical Velocity |
| $\dot{Z}_{bR}$ | = | Rear Body Vertical Velocity |
| $Z_{wF}$ | = | Front Wheel Vertical Displacement |
| $Z_{wR}$ | = | Rear Body Vertical Displacement |
| $\dot{Z}_{wF}$ | = | Front Wheel Vertical Velocity |
| $\dot{Z}_{wR}$ | = | Rear Wheel Vertical Velocity |
| $\ddot{Z}_{wF}$ | = | Front Wheel Vertical Acceleration |
| $\ddot{Z}_{wR}$ | = | Rear Wheel Vertical Acceleration |
| $\theta$ | = | Pitch Angle |
| $\ddot{\theta}$ | = | Pitch Acceleration |

## LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

This chapter describes the background of active suspension control of ground vehicle heave and pitch motions. Next, the problem statement of this study and the objective of the project are explained. Following that, the scope of the project is mentioned and finally this chapter is ended with the outline of the Thesis.

## 1.2 BACKGROUND

The heave motion of a vehicle is the vertical displacement of the vehicle body, and the pitch motion of the vehicle is the angular moment in the longitudinal direction of the vehicle. These unwanted motions of the vehicle affect the ride quality and reduces the handling performance. Vertical forces are generated from the suspensions of the vehicle, which in result will cause the vehicle to experience pitch and heave motions. An active suspension control system is applied to reduce the effects of vibration the vehicle experiences. The active suspension system uses a feedback control system which sends signals to the actuators to generate force that will reduce the unwanted motions. Various types of controllers have been proposed to improve the effectiveness of the active suspension system, and for his study, the Fuzzy logic control system is proposed to improve the efficiency of the control system (Campos et al. 1999).

## 1.3 PROBLEM STATEMENT

Vehicle in motion experience unwanted motions such as heave and pitch motion due to the road conditions. The pitch motion also occurs during sudden braking or sudden acceleration of the vehicle. This uncontrollable motion of the vehicle will cause the vehicle to vibrate resulting in driving discomfort and poor vehicle handling.

By applying the active suspension control system, the vibrations and unwanted motions of the vehicle due to road irregularities can be significantly reduced, improving driving comfort.

## 1.4 OBJECTIVE

The objective of this study is to develop a control strategy for vehicles active suspension system control unit by using the fuzzy logic controller.

## 1.5 SCOPE OF PROJECT

The scope of this study is to develop the mathematical equation for the four-degree of freedom (4DOF) half car pitch plane vehicle model. Following that, a MATLAB Simulink model based on the 4 DOF mathematical equations is developed. Finally, a control strategy of active suspension system for the 4 DOF model is developed.

## 1.6 THESIS OUTLINE

Chapter one of this report includes the background of study, problem statement, objective of this study and the scope of project is described. In Chapter two, the description of vehicle suspension system and the active suspension system is presented, following that is the controllers that are used in the control strategy, which includes the PID Controller and the Fuzzy logic controller together with the derivation of the mathematical model for the half car pitch plane model. Chapter three of this report holds the methodology of this project, which includes the procedure, parameters and preliminary results. Chapter four presents the results of the performance evaluation for the control strategy that was developed. In Chapter five, discussion on the conducted method is explained. Finally, the conclusion is presented in Chapter six.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

In this chapter the passive suspension system of a conventional vehicle is discussed together with the active suspension system. In this chapter also discussed the controllers that are used in the active suspension control strategy. The modeling assumptions are discussed and the mathematical model for the half car pitch plane model is derived. The chapter is concluded with the derivation of the equation for the decoupling transformation.

## 2.2 VEHICLE SUSPENSION SYSTEM

Vehicles such as cars and motorcycles are driven in road surfaces that are at most times not smooth and uneven. Due to the road profiles that the vehicle is travelling, the vehicle experiences vibrations and ride discomfort. In order to reduce the effects of vibration on the car, vehicles are designed with a suspension system. The typical suspension system of a car includes a spring and a damper that connects the wheels or the vehicle with the body, as illustrated in Figure 2.1.

The suspension system provides a vertical counterforce to compensate the forces experienced by the wheels due to the uneven road terrain, in order to isolate vibrations the vehicles chassis. The suspension also helps to well maintain the steer and the camber settings of the wheels to the road profile. The suspension responds to the control forces that are produced by the tires longitudinal forces due to acceleration and braking, lateral forces due to cornering and driving torques. The suspension of the vehicle also functions to resist the roll moment of the car due to cornering, and maintaining the wheels contact to the ground at all times (Gillespie 1992).

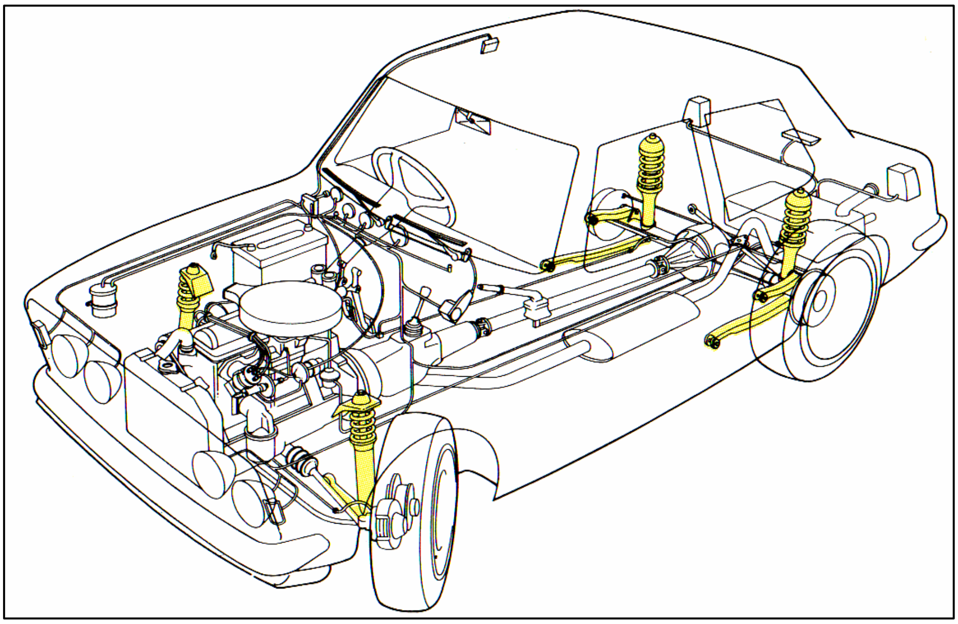

Figure 2.1: Vehicle suspension System

(Source: Wood, 2009)

The performance of a vehicles suspension system is rated based on the vehicles ability to provide better road handling and improved passenger ride comfort. The comfort of the passenger depends mostly on the combination of vehicles vertical motion (heave motion) and the angular motions of the vehicle (pitch and roll motion). Present vehicle suspension system which uses passive components can offer only minimum effects in improving the vehicles handling and ride quality by using spring and dampers coefficient at fixed rates. Sport vehicles are normally fitted with stiffer and harsh suspension to provide good handling to the vehicle, but stiffer suspension reduces the passenger comfort. Luxury cars, in the other hand often uses much softer suspension in order to provide better passenger comfort, but softer suspension reduces the vehicle driving performance. Poor vehicle performance due to road profile and reduced in passenger comfort are caused by the excessive vehicle vibrations which as a consequence results artificial speed limit, decrease in vehicle frame durability, effects the passenger in term of biological and also damages the cargo (Ikenaga et al. 2000).

It has been a major challenge in vehicle design in order to reduce the vehicle vibration caused by uneven road conditions and to improve the vehicles quality in terms of handling and comfort (Lin et al. 1992). Over the years since the start of automotive era, many types of vehicle suspension has been developed, which uses numerous kinds of springs, dampers and linkages with custom made flexibility. The most common and simplest type of suspensions are the passive suspensions, which does not require external energy source, but passive suspension does not control the heave and pitch motions of the vehicle independently (Campos. et al. 1999). Efforts has been taken to conduct research that would improve the vehicle suspension system, and the results show that the only way to improve vehicles performance in providing better handling and drive control is by adding external force which would provide a counter force that compensates to the forces on the wheel.

## 2.3 ACTIVE SUSPENSION SYSTEM

Passive suspension vehicles have limitation due to the fixed spring elasticity and damper characteristics, which causes the vehicle to isolate the vibration up to a certain frequency range. Active suspension system developed to design a suspension system which responses automatically in reducing the vibrations and unwanted motion. An active suspension system uses the data's collected by the sensors, and a central unit computes the information's from the sensor and sends the signal to the suspension system which response accordingly to maintain the vehicles stability (Alexandru and Alexandru 2011).

Active suspension system is a normal suspension system added with independent actuators on each wheel. Actuators are fitted in parallel to the suspension system between the vehicle body and the wheel. The actuators utilize the space between the wheel and the body to pull and push the vehicle body in order to minimize the vibration caused by the road irregularities (Pekgökgöz et al. 2010). These actuators act as to improve the vehicles passive suspension system response towards vibration and handling. Actuators exert force on the suspension system through a feedback control system that interprets the real time information obtained from the sensors (McGinn and Geraghty 2010). Figure 2.2 shows an active suspension vehicle that fitted with sensors that monitor the vehicles body position, and four hydraulic actuators at each strut of the vehicle, controlled by the pressure from the hydraulic pump. The pump increases and decreases the pressure in the strut based on the information fed by the microcomputer.

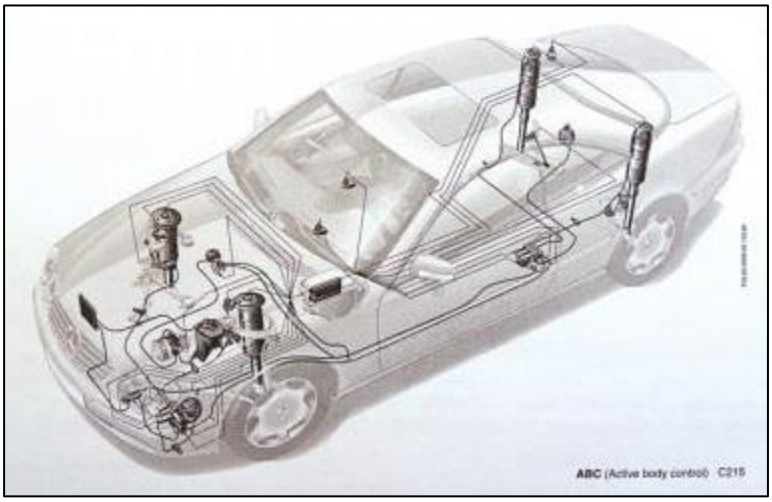


Figure 2.2: The active suspension system

(Source: Adams, 2011)

Since active suspension system capable of manipulating individual struts in real time, the vehicle can be easily altered to adapt to the driving conditions, such as providing stiffer suspension during fast cornering to reduce vehicle roll, and could make the suspension softer in order to increase the ride quality while driving in straight line (McGinn and Geraghty 2010).

The actuators response to the information sent by the central unit, where the controller is located. Many types of controllers are used in the design of active suspension system, and each controller has its own effectiveness in interpreting the data sent by the sensors and produces signal to the actuators. PID controllers are one type of controller that has been used in previous approach in the design of the control structure for active suspension system. Besides PID there are also other types of controller that are being introduced to improve the efficiency of the system, and to minimize the errors.

The active suspension system of a vehicle significantly improves the vehicles performance compared to a passive suspension system in terms of handling and ride comfort.

### 2.3.1 Control Scheme Used in Previous Studies

A control strategy using the time scale separation method has been conducted previous studies (Campos et al. 1999). The inner loop of this control scheme rejects the disturbance from the terrain, while the output loops are function to stabilize the heave and pitch motion experienced by the vehilcle. Decoupling transformation is also applied in this control scheme, and the function of the decoupling transformation is tho blend the two control actions of the outer loop and the inner loop. This scheme has been proposed to reduce the unwanted motions of the vehicle, which includes the heave and pitch motion, and improve the ride quality. Figure 2.3 below shows the closed loop system of the control scheme.