"I hereby declare that I have read through this report entitled "Experimental Investigation of the Motion Characteristics of a Passive Quarter Car Suspension" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronic Engineering"

Signature	:	……………………………….
Supervisors Name	:	……………………………….
Date	:	……………………………….

EXPERIMENTAL INVESTIGATION OF THE MOTION CHARACTERISTICS OF A PASSIVE QUARTER CAR SUSPENSION

TEE SIAU PING

A report submitted in partial fulfillment of the requirement for the degree of Bachelor of Mechatronic Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

I declare that this report entitled “Experimental Investigation of the Motion Characteristics of a Passive Quarter Car Suspension” is the result of my own research except cited in reference. The report has not been accepted in any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………………….

Name : ……………………………….

Date : ……………………………….

To my beloved mother and father

ACKNOWLEDGEMENT

My highest gratitude and appreciation to my final year project supervisor, Dr. Mariam Md binti Ghazaly, for her relentless support and helpful suggestions. Every step that I have achieved in my research is a result of her patient guidance. Without her keen encouragement, the challenges I have faced along this rocky road would have definitely kept me behind.

I would also like to thank my final year project coordinator, Madam Nur Maisarah binti Mohd Sobran, who provided me with useful information and helped in straighten out various matter regarding this subject. Besides that, special thanks go to the Master students in Motion Control Laboratory who helped out a lot in teaching me the basics to some software and hardware setup.

Last but not least, I express my gratitude to my friends and family. Their presence and support fueled my determination to excel in my research to finally achieve the wonderful results that I have today.

ABSTRACT

This research paper will discuss the study of a two degree-of-freedom quarter car model passive suspension system. Vehicle suspension system are rated by the ability to provide good vehicle handling and passenger comfortability. However, these are two conflicting criteria for a passive suspension system. This can be improved by introducing actuators to the system, transforming it into an active suspension system. In this research, the main objectives are to study the motion characteristics of the passive suspension system of a quarter car model. Apart from that, a controller is designed to control platform 1, which represents the road profile of the quarter car model. The setup of the whole research is discussed and illustrated with details. Calibration of the IR sensors used in the research have been carried out. The setup and steps for calibration is included. The calibration results showed the relationship between IR sensor output voltage and measured distance, which output voltage decreases with increasing distance. Besides that, an experiment to determine the effects of tilting the IR sensor is also completed. The results show greater tilt angle decreases IR sensor output voltage at a fixed distance. The output voltage of the IR sensor is converted using a polynomial equation generated from the calibration of sensor. Next, experiments such as open loop characteristics testing using system identification method is carried out to determine the transfer function of the passive suspension system. Once these steps are completed, a closed loop uncompensated system is designed to determine the error between the output and desired input. Then, a proportional-integral-derivative (PID) controller is designed by using manual tuning method. The K_p value is first varied, followed by varying K_i and then K_d. A PID controller with values $K_p = 1.35$, $K_i = 0.021$ and $K_d = 0.0022$ is successfully obtained. Finally, a close-loop evaluation is carried out using the developed PID controller. The controller is able to reduce steady-state error up to 48.9% and rise time up to 67.5%.

ABSTRAK

Kertas penyelidikan ini akan merangkumi kajian tentang sistem suspensi pasif model suku kereta yang mempunyai dua darjah kebebasan. Sistem suspensi kereta selalunya dinilai melalui kemampuannya untuk memberikan pemandu kawalan kereta dan keselesaan yang bagus. Namun, kedua-dua kriteria ini merupakan elemen yang bercanggahan. Penambahan alat-alat penggerak dalam sistem suspensi pasif boleh meningkatkan fungsinya. Ini akan mengubahkan sistem pasif menjadi sistem suspensi aktif. Dalam kertas ini, objektif utama adalah untuk mengkaji ciri-ciri pergerakan sebuah sistem suspensi pasif dengan menggunakan model suku kereta. Satu sistem kawalan akan direka untuk mengawal platform 1 yang mewakili profil jalan raya dalam sistem tersebut. Persediaan untuk semua experimentasi akan dibincang dan disenaraikan secara terperinci. Ini termasuk proses kalibrasi untuk sensor Inframerah (IR) yang digunakan dalam kajian ini. Data menunjukkan voltan keluaran IR sensor semakin kurang apabila jarak menjadi jauh. Untuk mencapai objektif yang telah ditetapkan, beberapa data penting tentang sistem ini seperti rangkap pinda diperolehi dahulu melalui experimentasi gelung buka. Seterusnya, experimentasi gelung tertutup dijalankan untuk mengetahui pembetulan yang harus dilaksanakan oleh sistem kawalan PID. Kertas penyelidikan ini akan membincangkan proses penalaan manual untuk menghasilkan satu sistem kawalan PID bagi meningkatkan prestasi sistem suspensi pasif. Akhirnya, sebuah sistem kawalan PID dengan $K_p = 1.35$, $K_i = 0.021$ and $K_d = 0.0022$ berjaya dihasilkan. Sistem kawalan PID ini digunakan dalam experimentasi terkompensasi gelung tertutup dan dibuktikan mampu mengurangkan ralat sistem sebanyak 48.9% dan masa naik sebanyak 67.5%.

TABLE OF CONTENTS

CHAPTER	TITLE		PAGE

LIST OF TABLES

TABLE	TITLE	PAGE

LIST OF FIGURES

FIGURE	TITLE	PAGE

FIGURE | **TITLE** | **PAGE**

CHAPTER 1

INTRODUCTION

1.1 Motivation

Safety and comfort, the two of the most fundamental aspects that engineers are constantly looking on to improve whenever millions of dollars are channeled into a vehicle development research. Brilliant new invention comes into light whenever new researches are carried out, new safety and comfort features such as parking assisting system, adaptive cruise control, luxurious seats and others, but hardly comes the time when vehicle suspension system becomes the spotlight of a research.

Through time and time, some improvements are made by different car manufacturers. According to luxurious car manufacturer Mercedes-Benz, from its high performance AMG division, comes the newest 2015 Mercedes-Benz S65 AMG coupe. Using a lateral-acceleration sensor paired to a forward-looking camera, the S65 perceives corners and then uses its air suspension to tilt the body in toward the apex. The result, first class comfortability for onboard passengers during curve maneuvers. However, such great technologies can only be discovered after years of development, and frankly vehicle suspension have never been a hot research field.

Hence, the main motivation for this project is to develop a vehicle suspension research foundation that can eventually evolve into a new fascinating car suspension technology. Starting from a low cost quarter car model passive suspension system, what fuels my determination is the goal to ultimately create a new suspension system that can effectively eliminate shock disturbances with minimal cost.

1.2 Problem Statement

The project aims to study and improve a passive suspension system of a quarter car model. The open loop characteristics of the system will be determined through simulations and experiments. A robust and reliable suspension system is always one of the main focuses when automobile manufacturers are launching new vehicles, regardless of a simple 5-seater sedan or a family-fitted minivan. Hence, this serves as one of the main reasons for the work of this project, to enhance the performance and reliability of a passive suspension system for the improvement of vehicle comfortability and handling. However, before that, a controller is needed to control platform 1 of the quarter car model, which represents the road surface of the system. The controller will enable desired road profiles to be generated accurately for future testing of the passive suspension system.

There are of course, significant challenges that have to be carefully thought of and solved in order to succeed. Serving as the starting point for this project, the study of passive suspension system on its open loop characteristics requires sufficient insights of this field so that the research can continue smoothly. Any uncertainty will result in imprecise experiment output, especially the transfer function of the system, thus hindering any further progress of the project. Another challenging task that requires my highest attention is the search for of a suitable controller to be added to the system, in addition to acquire the proper specifications for the controller. The controller have to be effective and efficient to deliver the best results.

As an effective solution to these problems, the project is continued by collecting knowledge from reliable sources, before the start of any work. An experiment is carried out in the end to evaluate the performance of the chosen controller and compare the performances of the new compensated suspension system with the previous uncompensated one.

1.3 Objective

This project contains the following objectives:

a) Study and investigate the motion characteristics for a passive suspension system of a quarter car model
b) Design a suitable controller to be added into the system
c) Evaluate the performance of the controller by comparing output with desired input

1.4 Scope

This project is limited by:

a) Studies on the passive suspension system of a quarter car model will be based on one that is previously built by students
b) The quarter car model will have a base of 345mm×345mm×8mm and height of 1000mm
c) The quarter car model is made from aluminum alloy
d) The passive suspension system will be interfaced with a Terasoft Micro-Box and a PC equipped with MATLAB
e) The research includes adding new Infrared sensors into the system
f) A PID controller will be added to control the extension of the pneumatic cylinder of platform 1
g) Evaluation is done via experiments and simulations, based on the performance of platform 1 of the passive suspension system with new controller

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Suspension System

Shock absorption is a vital area to focus on in the automobile industry. Design engineers are constantly on a lookout for improvements to reduce shocks in vehicles due to irregular road surfaces, drag forces and engine vibrations. The main reason for vehicle body vibration is speed bumps and potholes present in different road terrains. Hence, this is where vehicle suspension system play its ultimate role, to increase car handling and comfort by reducing and isolating shock applied to the vehicle, which would otherwise injure the passenger or damage the load.

A basic suspension system consists of springs, axles, shock absorbers, arms, rods, and ball joints. The three common types of springs in use are leaf spring, coil spring and torsion bars. There are few main challenges faced by engineers in designing suspension system, among them are:

a) Isolating shock disturbances caused by different road profiles from being transferred to the passenger or load.
b) Maintaining contact of the car tires with the road surface to enhance control of vehicle, also known as car handling.
c) Maintaining stability when the car travels at a curved path.

2.2 Types of Suspension System

2.2.1 Passive Suspension System

A passive suspension system is the very basic suspension system, characterized uniquely by its use of spring and dampers only, without any external control being exercised on the system. Movement of passive suspension system rely mainly on the characteristics of spring, damper and road condition. Figure 2.1 shows a simple model of a passive quarter car suspension system.

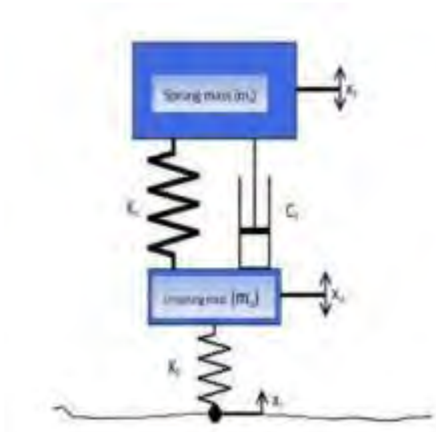

Figure 2.1: Example of a Quarter Car Model for Passive Suspension System [3]

The spring absorbs shock caused by varying road profile and transform it into potential energy of the spring. The damper dissipates shock from road bump without causing undue oscillation in the vehicle. Majority of the vehicles in market are suspended by this method. A key topic is often discussed, that is a passive suspension design actually compromises vehicle stability and ride comfort [1] [2]. A heavily damped suspension will provide good vehicle handling, but however will transfer much of the road disturbances to the contents of the car. This means that a drive on a rough road or a high speed run on a freeway will be perceived as a harsh ride. On the other hand, changing to a lightly damped suspension will provide better car comfort, but significantly reduce vehicle handling when it comes to curved roads or lane changing maneuvers. A study is carried out to simulate passive suspension system with varying spring stiffness and damping coefficients [3]. Using a quarter car model, the researchers experimented to find the optimum stiffness and damping for a passive suspension system by investigating various parameters such as sprung mass acceleration, tire deflection and others, all in frequency domain. In reality, a quality passive suspension system can deliver optimized comfort and stability, but cannot eliminate this compromise.

2.2.2 Pure Active Suspension System

Active suspension system refers to a suspension system that uses controller and actuator of sorts, to control the vertical movement of the wheel in relative to the car body. Basically, this system is altered from a passive suspension system by replacing the spring or damper with actuators and a controller furnished with smart control techniques, to attain greater degree of comfort and handling. This system benefits vehicle by reducing effects of braking, accelerating and vehicle rolling during curved roads. However, active suspension system has a drawback of high power consumption to operate the actuators [1]. Active suspension poses a potential danger if the actuators malfunction, the vehicle would lose its handling and stability, leading to accidents and loss of lives.

2.2.3 Adaptive/Semi-active Suspension System

The most distinguishable difference between semi-active suspension and other suspension systems is the replacement of the conventional damper with a controllable one. Figure 2.2 shows comparison between passive and semi-active suspension using quarter car model.

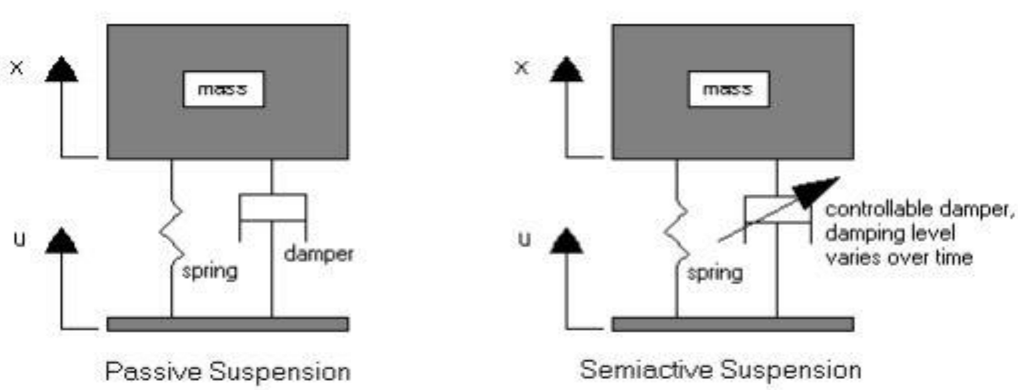

Figure 2.2: Comparing Models for Passive and Semi-Active Suspension

An external power supply is required to power up the controllable damper, equipped with an embedded controller and a set of sensors. However, power consumption is generally lower compared to that in active suspension. This is because external power is used to actually move the vehicle body through the actuators in active case but semi-active suspension only adjusts the damper to achieve the desired damping level determined by a control strategy.

2.2.4 Literature Review on Types of Suspension

The performance of an automotive passive suspension system is analyzed using a quarter car model [4]. It is discovered that the vehicle sprung and unsprung mass displacement overshoot and acceleration amplitude are shockingly high, showing negative impacts on the life span of the suspension system, besides bringing discomfort to the passengers of the vehicle. Their research showed that passive suspension faces a weakness that must be resolved immediately.

An active suspension system with pneumatic actuators is concluded to improve ride comfort and maintains vehicle handling, compared to a passive suspension [5]. The authors provided clear comparison between passive and active suspension system for both car body acceleration and displacement parameters when subjected to road disturbances. Further studies supported the fact that active suspension delivers better performance, reducing more than half of suspension movement in that of a passive case because the excitation force from the actuators in active suspension cancels out the generated force [6]. When crossing over a road bump, active suspension gives much lower peak overshoot and faster settling time, with lesser body displacement compared to passive system. Hence concluding that it is possible to achieve better suspension by adding active elements, instead of using purely passive ones.

The performance of passive suspension and active suspension is investigated using 2 different control algorithms, “Skyhook stability augmentation system (Sky-SAS)” algorithm and “stability augmentation system (SAS)” algorithm [7]. Passive suspension proves to be inferior to active suspension, while Sky-SAS provided better ride quality than SAS-controlled active suspension, indicating that performance of active suspension do rely greatly on the control technique used.

A low cost and simple semi-active suspension system is proposed and showed to provide great damping properties over a wider range of load, in the meantime reducing the compromise of