MODELING AND CONTROL OF ACTIVE SUSPENSION FOR A FULL CAR MODEL

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ABSTRACT

The objectives of this study are to obtain a mathematical model for the passive and active suspensions systems for full car model. Current automobile suspension systems using passive components only by utilizing spring and damping coefficient with fixed rates. Vehicle suspensions systems typically rated by its ability to provide good road handling and improve passenger comfort. Passive suspensions only offer compromise between these two conflicting criteria. Active suspension poses the ability to reduce the traditional design as a compromise between handling and comfort by directly controlling the suspensions force actuators. In this thesis, the Linear Quadratic Control (LQR) technique implemented to the active suspensions system for a full car model. Comparison between passive and active suspensions system are performed by using different types of road profiles.

ABSTRAK

Tujuan kajian ini adalah untuk mendapatkan model matematik sistem gantungan pasif dan aktif untuk model penuh kereta. Sekarang ini sistem gantungan kereta menggunakan bahagian pasif sahaja dengan memberikan pekali pegas lelurus dan peredam getaran pada kadar tetap. Sistem gantungan kereta selalunya diukur dengan kebolehan untuk memberi pengendalian jalan yang bagus dan memperbaiki keselesaan penumpang. Gantungan pasif hanya berada diantara dua pertembungan ciri-ciri tersebut. Gantungan aktif memiliki kebolehan untuk kurangkan rekaan tradisi diantara pengendalian dan keselesaan dengan mengawal terus daya pengerak sistem gantungan kereta. Di dalam thesis ini, hanya teknik Kawalan Lurus Kuadratic (LQR) diaplikasikan untuk sistem gantungan bagi ciri penuh kereta. Perbandingan diantara pasif dan aktif sistem gantungan dilakukan dengan menggunakan rupa bentuk permukaan jalan yang berbeza.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Traditionally automotive suspension designs have been compromise between the three conflicting criteria's namely road handling, load carrying, and passenger comfort. The suspension system must support the vehicle, provide directional control using handling maneuvers and provide effective isolation of passengers and load disturbance. Good ride comfort requires a soft suspension, where as insensitivity to apply loads require stiff suspension. Good handling requires a suspension setting somewhere between it. Due to these conflicting demands, suspension design has to be something that can compromise of these two problems.

A passive suspension has the ability to store energy via a spring and to dissipate it via a damper. Its parameters are generally fixed, being chosen to achieve a certain level of compromise between road handling, load carrying and ride comfort. An active suspension system has the ability to store, dissipate and to introduce energy to the system. It may vary its parameters depending upon operating conditions.

Suspension consists of the system of springs, shock absorbers and linkages that connects a vehicle to its wheels. In other meaning, suspension system is a mechanism that physically separates the car body from the car wheel. The main function of vehicle suspension system is to minimize the vertical acceleration transmitted to the passenger which directly provides road comfort. There are three types of suspension system; passive, semi-active and active suspension system. Traditional suspension consists springs and dampers are referred to as passive suspension, then if the suspension is externally controlled it is known as a semi-active or active suspension.

1.2 Literature Review of Linear Passive Suspension System

Passive suspension system can be found in controlling the dynamics of vertical motion of a vehicle. There is no energy supplied by the suspension element to the system. Even though it doesn't apply energy to the system, but it controls the relative motion of the body to the wheel by using different types of damping or energy dissipating elements. Passive suspension has significant limitation in structural applications. The characteristic are determined by the designer according to the design goals and the intended application. The disadvantage of passive suspension system is it has fix characteristic, for example if the designer design the suspension heavily damped it will only give good vehicle handling but at the same time it transfer road input (disturbance) to the vehicle body. The result of this action is if the vehicle travel at the low speed on a rough road or at the high speed in a straight line, it will be perceived as a harsh road. Then, if the suspension is design lightly damped, it will give more comfortable ride. Unfortunately this design will reduce the stability of the vehicle in make turn and lane changing. Figure 1.1 shows traditional passive suspension components system that consists of spring and damper.

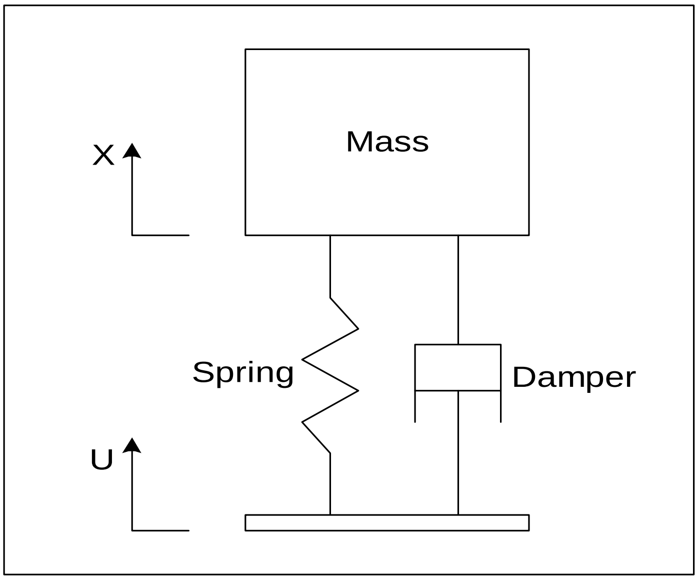

Figure 1.1: Passive Suspension Component

1.3 Literature Review of Linear Semi-active Suspension System

Semi-active suspension system was first proposed in 1970's. It's provides a rapid change in rate of springs damping coefficients. It does not provide any energy into suspension system but the damper is replaced by controllable damper. The controller's determine the level of damping based on control strategy and automatically adjust the damper to the desired levels. This type of suspension system used external power to operate. Sensors and actuator are added to detect the road profile for control input. The most commonly semi-active suspension system is called skyhook damper. Schematic diagram for semi-active suspension is shown is Figure 1.2.

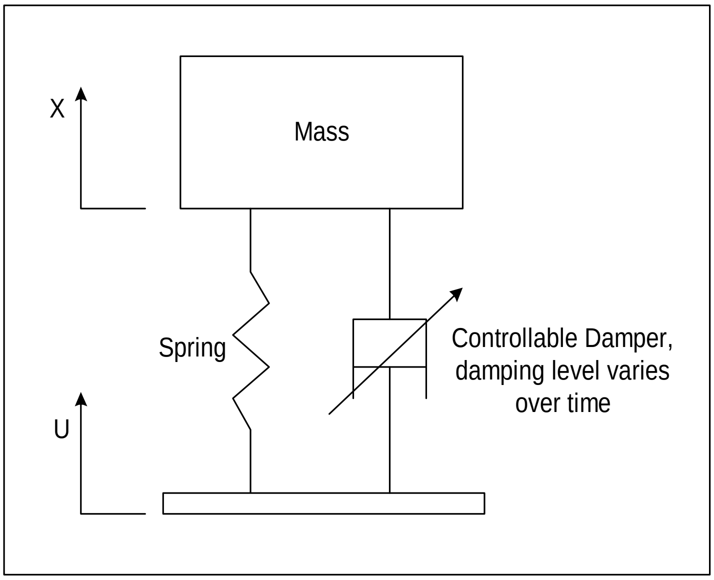

Figure 1.2: Semi-Active Suspension Component

1.4 Literature Review of Linear Active Suspension System

Active suspension system has the ability to response to the vertical changes in the road input. The damper or spring is interceding by the force actuator. This force actuator has it own task which is to add or dissipate energy from the system. The force actuator is control by various types of controller determine by the designer. The correct control strategy will give better compromise between comfort and vehicle stability. Therefore active suspension system offer better riding comfort and vehicle handling to the passengers. Figure 1.3 shows simple block diagram to explain how the active suspension can achieve better performance. Figure 1.4 describe basic component of active suspension. In this type of suspension the controller can modify the system dynamics by activating the actuators.

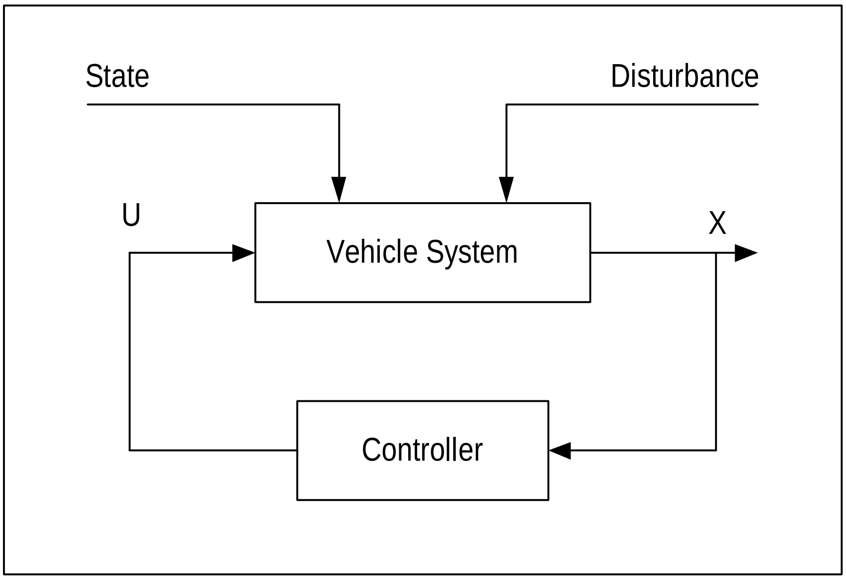

Figure 1.3: Active Suspension Control System

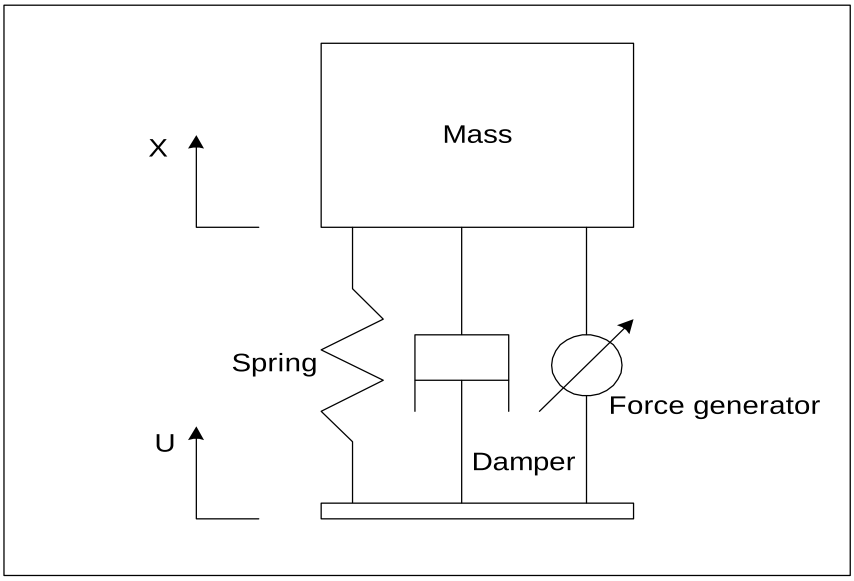

Figure 1.4: Active Suspension Component

All these three types of suspension systems have it own advantages and disadvantages. However researchers are focus on the active car suspension and it is because the performance obtained is better than the other two types of suspension systems as mentioned before. For example the passive suspension system the design is fix depend on the goal of the suspension. The passive suspension is an open loop control system. It doesn't have any feedback signal to correct the error. It means that the suspension system will not give optimal ride comfort. In other side which is active suspension, it has that ability to give ride comfort. This is happen by having force actuator control by the controller. The active suspension system is a close loop control system. It will correct the error and gave the output to the desired level. In this project observation will be made at the vertical acceleration of the vehicle body called sprung mass and tire deflection. By using the right control strategy the ride quality and handling performance can be optimize. Therefore, in this project there will be modeling for active and passive suspension only.

1.5 Literature Review of Vehicle Model

Quarter-car model in Figure 1.5 is very often used for suspension analysis; because it simple and can capture important characteristics of full model. The equation for the model motions are found by adding vertical forces on the sprung and unsprung masses. Most of the quarter-car model suspension will represent the M as the sprung mass, while tire and axles are illustrated by the unsprung mass m. The spring, shock absorber and a variable force-generating element placed between the sprung and unsprung masses constitutes suspension.

From the quarter car model, the design can be expend into full car model by adding the link between the sprung mass to the four unsprung masses (body - front left and right, rear left and right). Generally the link between sprung and unsprung masses will gave roll and pitch angle. The basic modeling is still the same but there is additional consideration about the rolling, pitching and bouncing need to be count. The rolling, pitching and bouncing can be represented in the X, Y and Z axis. Figure 1.6 ~ Figure 1.7 shows the quarter car and full car models.

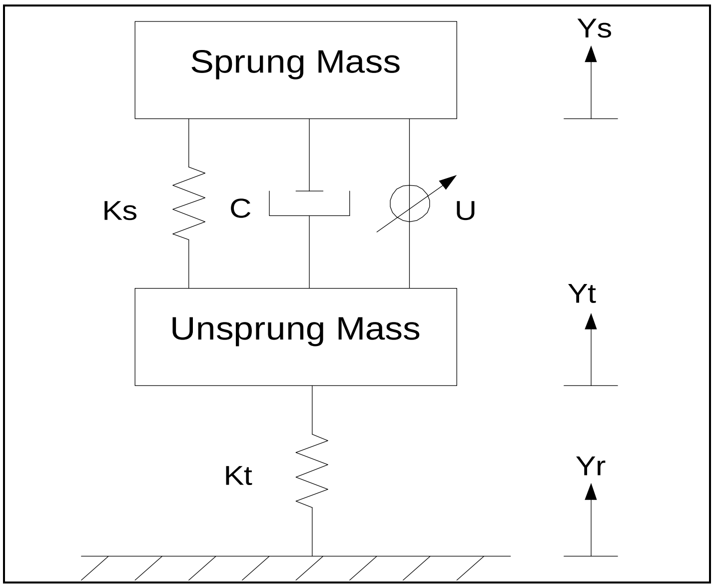

Figure 1.5: Quarter Car Model

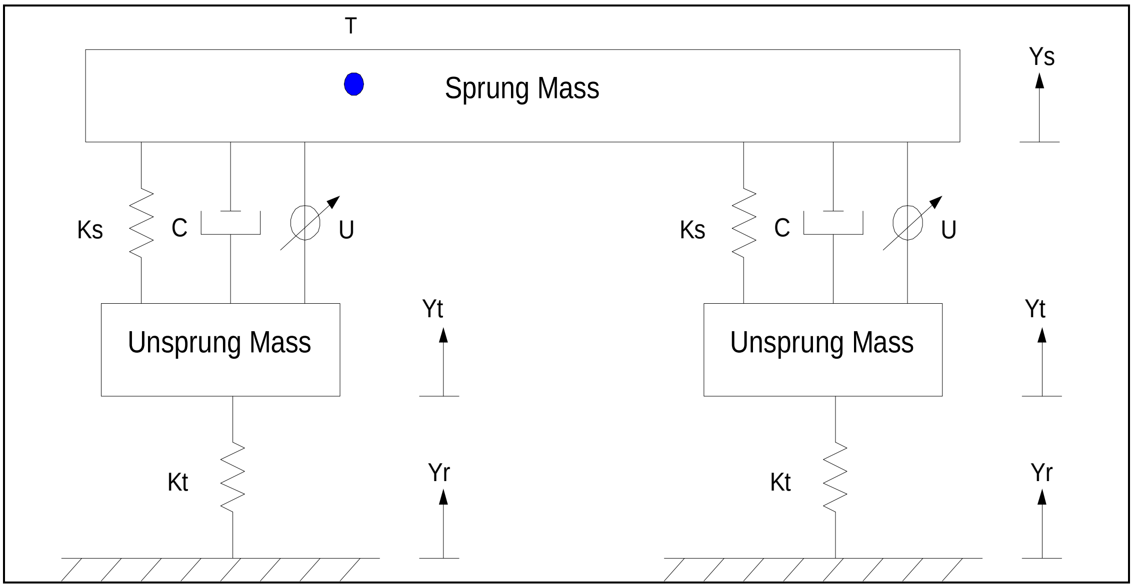

Figure 1.6: Half Car Model

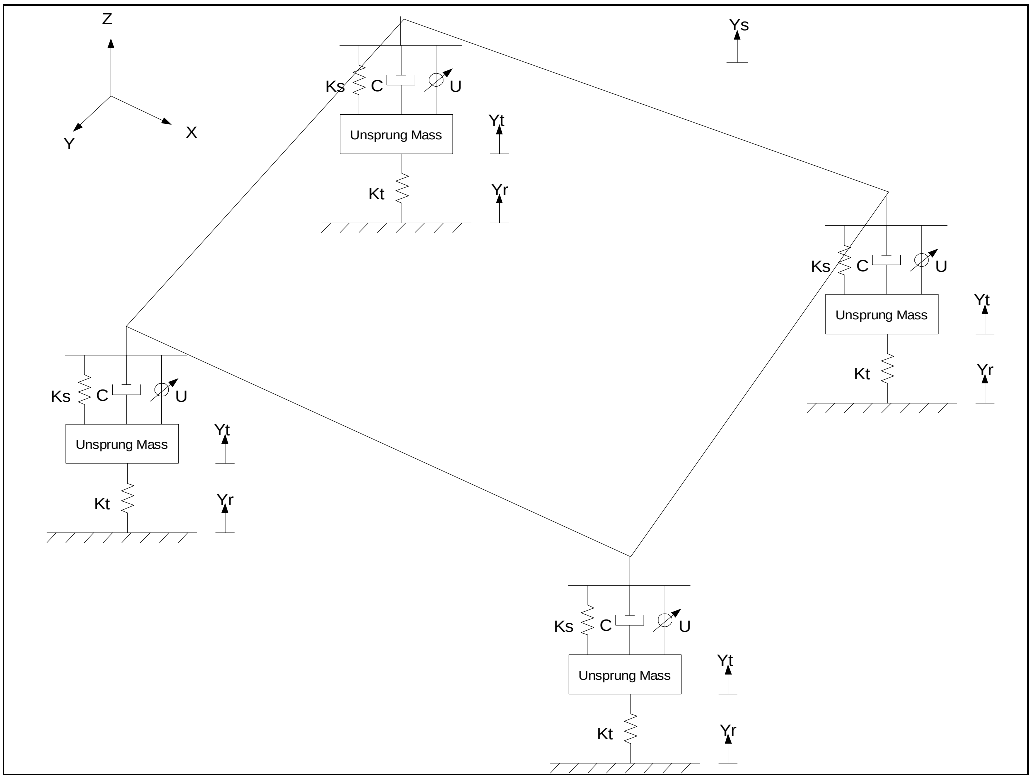

Figure 1.7: Full Car Model

1.6 Problem Statement

The passive suspension system is an open loop control system. It only designs to achieve certain condition only. The characteristic of passive suspension fix and cannot be adjusted by any mechanical part. The problem of passive suspension is if it designs heavily damped or too hard suspension it will transfer a lot of road input or throwing the car on unevenness of the road. Then, if it lightly damped or soft suspension it will give reduce the stability of vehicle in turns or change lane or it will swing the car. Therefore, the performance of the passive suspension depends on the road profile. In other way, active suspension can gave better performance of suspension by having force actuator, which is a close loop control system. The force actuator is a mechanical part that added inside the system that control by the controller. Controller will calculate either add or dissipate energy from the system, from the help of sensors as an input. Sensors will give the data of road profile to the controller. Therefore, an active suspension system shown is

Figure 1.8 is needed where there is an active element inside the system to give both conditions so that it can improve the performance of the suspension system. In this project the main objective is to observe the performance of active by using LQR controller and passive suspension only.

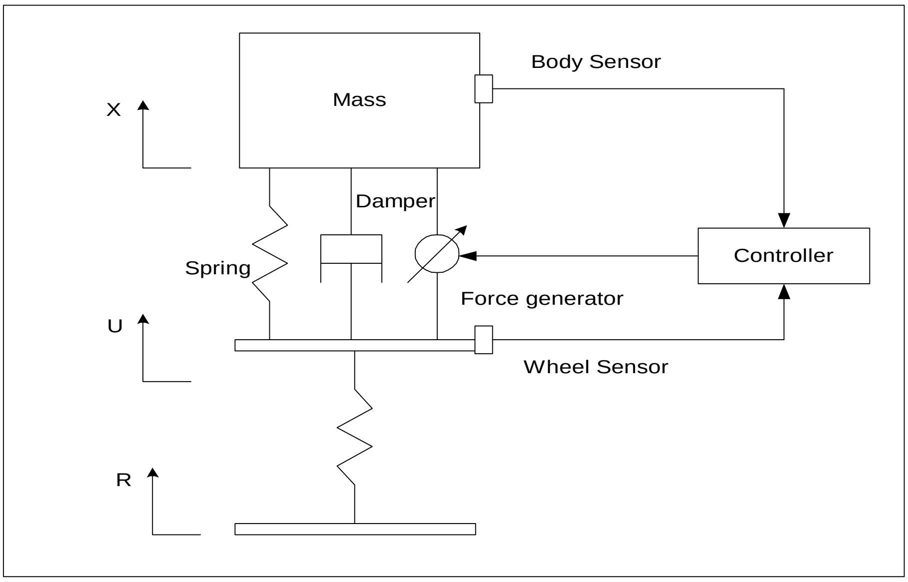

Figure 1.8: Active Suspension System

1.7 Objective

The objectives of this project are:

i) To establish the active and passive suspension system models.

ii) To establish the mathematical model for active and passive suspension system for quarter and full car models.

iii) To observe the performance of active suspension system with LQR controller through the computer simulation work.

1.8 Scope of project

The scopes of work for this project are:

i) To derive and establish the mathematical equation for passive and active suspension for quarter car model for literature purpose.
ii) To implement LQR controller to the active suspension system for full car model.
iii) Computer simulation study by using MATLAB/Simulink

1.9 Research Methodology

a) To understand active and passive suspension component
   (i) Literature research on active and passive suspension
   (ii) Identify type of active and passive suspension component.
   (iii) Literature research about control strategy

b) To derive and establish mathematical model for active and passive suspension system for full car model.
   (i) By using physical laws from the suspension components get the state space equation for quarter car model, continue expand the equation to a full car model.
   (ii) By using the matrix equation given, get the state space equation.
   (iii) Continue to get the state space equation for full car model.

c) Implementation of LQR controller into the system.
   (i) Literature review on the control technique.
   (ii) Use LQR to compare output performance compare with passive suspension.

d) Computer simulation

(i) Involves learning how to transform the state space equation into SIMULINK diagram.

(ii) Simulation of propose controller using MATLAB/Simulink.

e) Result analysis

(i) Involves observation of the preliminary result.

(ii) Simulation to investigate dynamics of active suspension.

(iii) Obtain suitable matrix feedback gain.

(iv) Observe force generated from the simulation.

Flow chart in Figure 1.9 shows overall process for the project research.

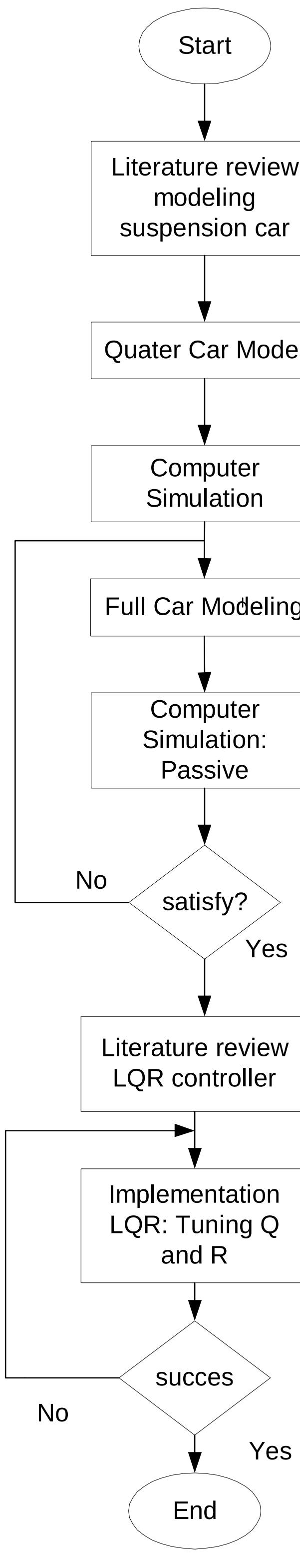

Figure 1.9: Flow Chart for Computer Simulation

1.10 Thesis Outlines

This project is organized into 5 chapters. Chapter 1 discusses literature review on passive, semi-active and active suspension system. Objectives, scope of project and research methodology are explained in this chapter.

Further explanations on the mathematical modeling for a quarter car and a full car model for active and passive suspension system are included in chapter 2. Mathematical model can described behavior of overall system. This chapter explains method used in this research in order to obtain mathematical model for passive and active suspension system for a full car model.

Chapter 3 reviews relevant literatures and previous works regarding controller design. Controller design for the project is also included which is LQR controller.

In chapter 4, computer simulation between passive and active suspension system will be carried out. There are two types of input disturbance that will be used to test the system. Simulation based on the mathematical model of a full car model is done by using MATLAB/SIMULINK software.

At the end of this project report, conclusion and future works will be discussed furthermore in chapter 5. In addition to that, some recommendations to improve the outcomes for this project are discussed in this chapter.

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