# CAR SUSPENSION MODELING

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MAY 2006

"I accepted that have been read this kind of report. In my opinion this kind of report suppose in the scope and quality for purpose to award the Degree of Bachelor in Electrical Engineering (Industry Power)."

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This Report Is Submitted In Partial Fulfillment of Requirement For
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Faculty of Electrical Engineering
Kolej Universiti Teknikal Kebangsaan Malaysia

May 2006

"I hereby declared that this report is a result of my own work except for the excerpts that have been cited clearly in the references"

Signature : ....................................................

Name of the candidate : NUR SYAHEDDATUL SAQINAH SUKIRMAN

Date : 4/5/06

To my parents
for their love

To solely my supervisor
for her teaching and ideas

To lecturers, KUTKM staffing, and all my friends
for their sacrifice and motivation

## ABSTRACT

In this project, designing an active suspension system for a car turns out to be an interesting problem. When the suspension system is design, a one-half-car model (two of the four wheels) is used to simplify the problem to a one dimensional spring damper system. A good car suspension system should have satisfactory road holding ability, while still providing comfort when riding over bumps and holes in the road. When the car is experiencing any road disturbances (i.e. pot holes, cracks and uneven pavement), the car body should not have large oscillations and the oscillations should dissipate quickly. The road disturbances in this problem will be simulated by a step input. This step could represent the car coming out of a pothole. The solution for improve the output response of this project by designing a feedback controller such as PID controller and Negative Feedback controller. In addition, this project is to design a GUI to help user can sees the correlation between the output responses of the car suspension system when the input controller parameters are changes. The target result for this project show that the output response has an overshoot less and a settling time shorter.

# ABSTRAK

Dalam projek ini, mereka bentuk sistem hentakan aktif kereta menjadi satu projek yang menarik untuk dibina. Apabila sistem hentakan ini direka, satu per dua (dua dari empat tayar) digunakan untuk memudahkan rekaan menjadi satu dimensi sistem redaman beranjal. Kereta yang bagus seharusnya berkeupayaan untuk bergerak di atas jalan dengan menyediakan keselesaan kepada penumpang semasa melanggar lubang atau halangan di atas jalan. Badan kereta direka supaya tidak mempunyai ayunan terlalu besar dan ayunan tersebut boleh hilang dalam mase yang singkat ketika sesebuah kereta itu melanggar sebarang halangan di jalan ( seperti lubang, lopak, jalan yang retak dan tidak rata). Halangan di jalan ini akan dijadikan sebagai satu masukkan ke atas rekaan kereta ini yang mana masukan tersebut diandaikan selepas kereta tersebut telah melanggar halangan di jalan. Satu kaedah penyelesaian digunakan untuk memperbaiki reaksi keluaran pada sistem hentakan kereta ini dengan mereka satu kawalan suap balik seperti kawalan PID dan Kawalan Suap Balik Negatif. Dalam masa yang sama, projek ini akan mereka satu sistem antara muka iaitu GUI supaya pengguna dapat melihat hubung kait antara reaksi keluaran sistem hentakan kereta apabila berlaku perubahan pada parameter masukan kawalan. Keputusan yang dijangka dalam projek ini ialah menunjukan reaksi keluaran sistem dapat menguranngkan had maksima hentakan dan masa pengenapan menjadi lebih pendek.

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| | | |
|---|---|---|
| PID | - | Proportional – plus – Integral – plus – Derivative |
| GUI | - | Graphical User Interface |

# CHAPTER 1

# INTRODUCTION

In recent years, the automobile industry has tried to fulfill customers demand. As known, customers enjoy the size, adaptability, solid feel, and commanding view of the road that are hallmarks of any vehicles. In part due to exactly these characteristics, it is more difficult for a suspension designer to create a vehicle that will both be comfortable to the operator and occupants, and perform well during vehicle maneuvers. In order to maintain the level of comfort that customers expect from vehicles, and still maintain the high safety standards of automobiles, suspension designers have been forced to look beyond conventional suspension systems.

## 1.1 Project Background

Suspension systems have been widely applied to vehicles. Generally speaking, a good suspension should provide a comfortable ride and good handling within a reasonable range of deflection. Moreover, these criteria subjectively depend on purpose of the vehicle. For example, a sports car driver will accept a relatively hard ride as a compromise for high speed handling and safe fast cornering. But the same ride would be intolerable for the passengers of a big saloon car.

From a system design point of view, there are two main categories of disturbances on a vehicle, namely road and load disturbances. Road disturbances have the characteristics of large magnitude in low frequency (such as hills) and small magnitude in high frequency (such as road roughness). Load disturbances include the variation of loads induced by accelerating, braking and cornering. Therefore, a good suspension design is concerning with disturbance rejection from these disturbance rejection from these disturbances to the outputs (e.g. vehicle height etc.). Roughly speaking a conventional passive suspension needs to be soft to insulate against road disturbance and hard to insulate against load disturbances. Therefore, suspension design is to compromise between these two goals.

There are two main categories of suspension system, namely passive and active suspensions systems. A passive suspension, which means there is no energy source in the system, provide a simpler and cheaper way of suspension design at the expense of performance limitation of the type described above. A passive suspension system 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 holding, load carrying and comfort.

On the other hand, active suspension incorporate extra energy sources to refine the compromise, though the freedom to shape disturbance response transfer function is still not arbitrary due to factors such as in variant points. Active suspensions are considered to be a way of increasing the freedom one has to specify independently the characteristics of load carrying, handling and ride quality. 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 and can have knowledge other than the strut deflection the passive system is limited to.

In an active suspension, the passive damper or both the passive damper and spring are replaced with a force actuator, as illustrated in Figure 1.1.

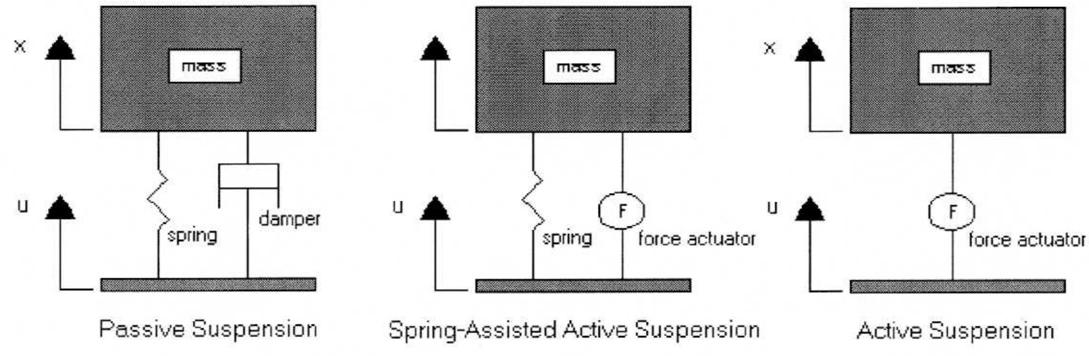


Figure 1.1: Passive and Active Suspensions [8]

The force actuator is able to both add and dissipate energy from the system, unlike a passive damper, which can only dissipate energy. This is due to the ability of the force actuator to apply force independent of the relative displacement or velocity across the suspension. Given the correct control strategy, this results in a better compromise between ride comfort and vehicle stability as compared to a passive system, as shown in Figure 1.2 for a quarter-car model.

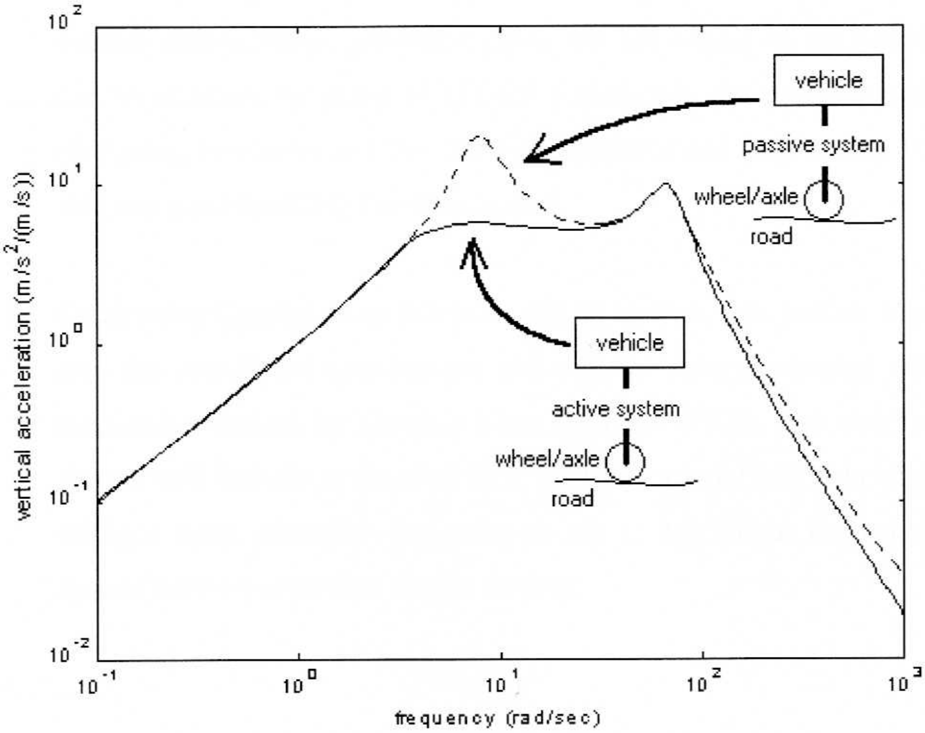


Figure 1.2: Passive and Active Suspension Comparison [3]

## 1.2 Objectives

There are two main objectives of this project which are:

1. To develop and improve the active suspension system of one-half-car model using MATLAB Simulation (software).The MATLAB Simulation is use to develop and improve the active suspension system of a car. The purpose using this software is to minimize chasing and wheels deflection when uneven road surfaces, pavement point, etc. are acting on the tires of running car. In addition, by using MATLAB Simulation, the compromised between the spring constants and the damping constant can improve so that a good ride and good handling can be acquired.

2. To develop Graphic User Interface (GUI) so that, this project can help user sees the correlation between the plot and the system physical response car suspension system by Graphic User Interface (GUI). For that reason, this project will include to develop GUI for user to input any data or parameters changes from controller designing to see clearly about the car suspension system base on controller design method.

## 1.3 Scopes

This project concentrates to model a car as possessing an active suspension system of one-half-car model using MATLAB Simulation (software). It will include modeling the system using open- loop system, close – looping system and designing a controller such as using the PID design method or negative feedback controller method. By using the three different modeling systems, the target is to compare the plot response and make analyzes while develop the suspension system for get the best result. In same time, the targets of this project also include for users to sees practically the car suspension system between the plot and physical response by GUI. So at the final scope, the project can be use to control an active suspension system of one – and – half car in real world.

## 1.4 Problems Statement

The perceived comfort level and ride stability of a vehicle are two of the most important factors in a subjective evaluation of a vehicle. There are many aspects of a vehicle that influence these two properties, the most important of which are the primary suspension components, which isolate the frame of the vehicle from the axle and wheel assemblies.

In the design of a conventional primary suspension system there is a trade off between the two quantities of ride comfort and vehicle handling (safety), as is shown in Figure 1.3.

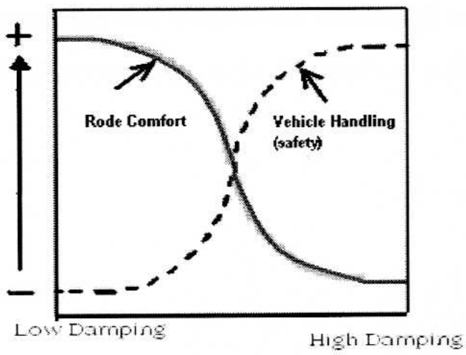


Figure 1.3: Passive Suspension Design Compromise [8]

A good car suspension system should have satisfactory road holding ability, while still providing comfort when riding over bumps and holes in the road. When the car is experiencing any disturbances (i.e. pot holes, cracks and uneven pavement), the car body have large oscillations and the oscillations not dissipate quickly. In same time when driving over a speed bump or into pothole, which causes passenger uncomfortable and also increased wears and tears car components. Therefore, it is necessary to compromise between the spring constants and the damping constant so that a good ride and good handling can be acquired. By designing the car suspension system, a smoother ride for passengers would be obtained.

# CHAPTER 2

# LITERATURE REVIEW

A review of available literature of this project have been performed to ensure more understanding to design the car suspension modeling to get the better response performance. The areas that interest that were focused on within this literature search are active suspension.

## 2.1 Primary Suspension

Primary suspension is the term used to designate those suspension components connecting the axle and wheel assemblies of a vehicle to the frame of the vehicle. This is in contrast to secondary suspensions, which are the elements connecting other components to the frame or body of a vehicle: such as engine mounts, seat suspensions, and cab mounts. There are two basic types of elements in conventional suspension systems. These elements are springs and dampers. The role of the spring in a vehicle's suspension system is to support the static weight of the vehicle. The role of the damper is to dissipate vibration energy and control the input from the road that is transmitted to the vehicle.

The basic function and form of a suspension is the same regardless of the type of vehicle or specific system. Primary suspensions can be generally divided into four categories:

1. Passive suspensions
2. Active suspensions
3. Adjustable suspensions
4. Semiactive suspensions

## 2.2 Active Suspension

The use of active suspension on road vehicles has been considered for many years [16]. A large number of different arrangements from semi – active to fully active schemes have been investigated [4]. There has also been interest in characterizing the degrees of freedom and constraints involved in active suspension design. Constraints on the achievable response have been investigated from "invariant points", transfer-function and energy/passivity point of view in [5]. In [10], a complete set of constraints was derived on the road and load disturbance response transfer functions and results on the choice of sensors needed to achieve this degree of freedom independently were obtained for quarter-car model. The generalization of these results to half and full car models was then presented in [14]. In [9], it was shown that the road and the load disturbance responses cannot be adjusted independently for any passive suspension applied to a quarter – car model.

The need to design the road and load disturbance response independently has been considered elsewhere in the active suspension literature. For example, in [15] a hardware and sensing arrangement was devised so that the feedback part of the scheme would not affect the response to road disturbances, which were design to be suitably soft by means of passive elements in the scheme. In [12] the actuator was placed in series with a spring and damper, which were chosen to give a suitably soft response to road irregularities in the absence of a feedback signal. A controller structure using a filtered combination of the sensor measurements was then selected so that the road disturbance responses were unaffected by the feedback. In this dissertation develop a continuation of this idea by finding in general required controller structure to achieve this property for any set of measurements.

In an active suspension the interaction between vehicle body and wheel is regulated by an actuator of variable length. The actuator is usually hydraulically controlled and applies between body and wheel a force that represents the control action generally determined with an optimization procedure. Active suspensions have better performance than passive suspensions. However, the associated power, which must be provided by the vehicle engine, may reach the order of several 10 kW depending on the required performance. As a viable alternative to a purely active suspension system, the use of mixed active–passive suspensions (an actuator in parallel with a passive suspension) has been considered. Such a system requires a lower power controller. Furthermore, even in case of malfunctioning of the active subsystem the vehicle needs not halt because the passive suspension can still function.

In a study by Chalasani [3], the quarter car model was used to investigate the performance gains possible with an active suspension system. In that study, the road input was modeled as a white – noise velocity input. The study found that, within practical design limitations, an active suspension can reduce the Root Mean Square (RMS) acceleration of the sprung mass by 20%. This suspension configuration exhibited approximately the same level of suspension travel and wheel – hop damping ration as a lightly damped, soft passive suspension. In a further study [2] similar simulation and analyses were performed for half car model. That study estimated that active suspensions could reduce the RMS value of the sprung mass acceleration by 15%.

Active suspension systems have the added advantage of controlling the attitude of a vehicle. They can reduce the effects of braking, which causes a vehicle to nose – dive, or acceleration, which cause vehicle to squat. They also reduce the vehicle roll during cornering maneuvers.

Active suspension systems, though shown to be capable of improving both ride and stability, do have disadvantages. The force actuators necessary in an active suspension system typically have large power requirements. The power requirements decrease the overall performance of the vehicle, and are often unacceptable. Another disadvantage of active suspension system is that they can have unacceptable failure modes. In the case of actuator failure, the vehicle would be left undamped, and possibly unsprung. This is a potentially dangerous situation for both the vehicle and operator.

In any vehicle suspension system, there are a variety of performance parameters which need to be optimized. The trade between ride comfort and handling characteristics is usually a trial and error procedure which represents an optimization problem. There are four important parameters which should be carefully considered in designing a vehicle suspension system:

1. Ride Comfort is directly related to the acceleration sensed by passengers when traveling on a rough road.
2. Body motions which are known as bounce, pitch and roll of the sprung mass are created primarily by cornering and braking maneuvers. Body motions may be present even on perfectly smooth roads.
3. Road handling is associated with the contact forces of the tires and the road surface. These contact forces create the necessary friction which prevents the tires from sliding on the road surface. The contact forces are assumed to depend linearly on the tire deflection.
4. Suspension travel refers to the relative displacement between the sprung and the unsprung masses. All suspension systems trade – off the suspension travel for an improved ride comfort.

No suspension system could minimize all four of the above mentioned parameters simultaneously. The advantage of controlled suspension is that a better set of design trade – offs are possible compared with passive systems. State – feedback control for active suspension is a powerful tool for designing a controller. In this approach a mathematical representation for the ride comfort and road handling will be optimized considering the actuator limitations. Since the body motion and the suspension travel are functions of the system states, they will also be optimized during the design.

Linear optimal control theory provides a systematic approach to design the active suspension controllers and has been used by several investigators. Sinha et al. [11] and Caudill et al. [13] have used this method to design active suspension controllers for railroad vehicles. Esmailzadeh [6] investigated a pneumatic controlled active suspension for automobiles. Another research appends this method with the concept of dynamic absorber for improved performance for quarter – car and half – car models. Previous research considered using integral and state feedback controllers for active suspension for half-car model and also considered the lateral and longitudinal motion for a full car model, and implemented active controller with linear optimal control. Other authors have examined different ways of optimal control theory in active suspension systems.

# CHAPTER 3

# METHODOLOGY PROJECTS

For this chapter, it will discuss the methodology of the project. The Figure 3.1 shows the flowchart of the project. Generally, to complete this project, it has six distinct phase or step:

## 3.1 Phase 1: Numerical Model

This is beginning of the step to design active suspension modeling of car after study and understand the literature review. For the phase 1 it will involve to establish the design requirement and equation of motion of the car. The purpose of this phase is to make clearly about the physical setup of one – and half active suspension car. In mean time, this phase will discuss four subtopic where are include the numerical model development, depict four Degree-of-Freedom car model, mathematical model development and state space equation. In the end of this phase, the variable states will be define and transform the equation of motion of car into state space equation in matrix form.

## 3.2 Phase 2: Open Loop System Design

Before design the open loop system, the system itself must to confirm either it's stable or not. Once the system approve stable, than the output response of the open loop system can get correctly. This output response is the original system performance without any feedback controller. The output response of open loop system will be a reference for any other system to compare before the system don't have any controller and after the system have be designing to have a controller. The criteria of open loop system will be explaining details in Chapter 5.

### 3.3 Phase 3: Close Loop System

By using the close loop system, it is able to correct the system if the system has a disturbance compare than for open loop system which very sensitivity to disturbances. The closed loop system design for this project is easily compensates for disturbances by measuring the output response, feeding that measurement back through a feedback path, and comparing that response to the input at summing junction. In Chapter 5 and Chapter 6 it will explain about the advantages using the closed loop system rather than open loop system and the effect at the system when using the closed loop system.

### 3.4 Phase 4: Controller Design

One of the most important phases in this project is to design the controller. The controller that is design will prove the objectives of this project which is to give the better performance to the system. During designing the controller, a few aspects must be considered to achieve the objectives of the project. The aspects to be consider while designing the controller are

1. The time to take when the system become stable or in steady state condition.
2. The oscillation of the car suspension system must dissipate quickly with shorter rise time.
3. The amplitude of the oscillation must smaller as can be.

The designing of controller will be discussed and elaborated in Chapter 6.