VEHICLE ACTIVE SUSPENSION SYSTEM

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Special dedication to my beloved father and mom, my entire sibling and my kind hearted supervisor Mr. Amat Amir bin Basari, also to all my dearest friends.

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ABSTRACT

The project aim was to establish a mathematical model for active suspension system and controlled by a PID controller. The objective is to improve car comfort and stability. A classic car used a passive suspension and the performance is too low where the body isolation cannot be control when facing road disturbance. This project will focus on improving a car suspension system using proportional-integral-derivative (PID) controller. Therefore to achieve that objective, the passive suspension system must be replaced with the active suspension system. The desired settings of PID controller obtain using the simulink/Matlab.

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ABSTRAK

Projek ini bertujuan menerbitkan model matematik untuk system gantungan aktif dan di kawal oleh pengawal ”proportional-integral-derivative” (PID). Ini bertujuan meningkatkan keselesaan dan stabiliti kereta. Kereta lama menggunakan gantungan pasif dan prestasinya sangat lemah dimana ayunan badan kereta tidak dapat dikawal apabila menghadapi gangguan dari jalan. Projek ini akan menumpukan pada meningkatkan sistem gantugan dengan sistem gantungan aktif menggunakan pengawal ”proportional-integral-derivative” (PID). Kerana itu, sistem gantungan pasif harus digantikan dengan sistem gantungan aktif. Ketetapan yang diperlukan oleh pengawal PID diperoleh menggunakan simulasi simulink/Matlab.

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LIST OF ABBREVIATIONS

PID	-	Proportional Integrate Derivative

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CHAPTER 1

INTRODUCTION

1.1 Project Introduction

Nowadays, vehicle is so importance in our life. It is needed for moving from one place to another. Companies that produce cars struggle to improve their product quality and performance. One of the important performance characteristic that have to be considered in making a car is a good suspension system. Suspension system will determine the comfortness and handling performance of a car. This characteristics deal with body movement. An ideal suspension system should isolate the body from road disturbances and inertial disturbances associated with cornering and braking or acceleration.

A classic car widely used a passive suspension system for passengers but the suspension spring and damper only control the motion of the car body and wheel by limiting the suspension velocity according to the rate determined by the designer. To overcome the problem, active suspension systems have been proposed.

Active suspension system respond to changes in the road because of the controller ability to supply energy to produce relative motion between the body and wheel. Active suspension system include sensors to measure suspension variables. An

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active suspension system has actuators that supply additional forces to the system. These additional forces are determined by a feedback control data from sensors attached to the vehicle.

There are various control strategies such as optimal state feedback, backsteeping method, fuzzy logic control, sliding mode control and many more but for this research, the PID controller is chosen.

1.2 Problem Statement

There are several types of vehicle suspension system, passive suspension system and semi-active suspension system also known as active suspension systems. Combination of traditional spring and damper is referred to a passive suspension system and this type of suspension is leaking of performance. Therefore, this project is to achieve better ride comfort and controllability of vehicles that pursued by automotive industries by considering the use of active suspensions system.

1.3 Objective Project

The objectives of this project is to develop a system that can be control by PID controller and capable to achieve the desired level of performance. Analysis will concentrate on the isolation of the car body from the road disturbance, pitch and roll that happen while abrupt the maneuvers and also the wheels bouncing when the vehicle strike an abrupt bump. A detail study of the model and the classification of the road roughness are presented together with a certain method for comparing the results.

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1.4 Project Scope

Throughout this project, there are several guidelines and specification that must be followed to make sure the project is within the scope.

1. The scope of this project is to develop an Active Suspension System with PID Controller based on a quarter car model.
2. To start this project, fist of all the concept of a passive suspension system have to be studied and understand the characteristic and the limit of the system.
3. The next step is to study the concept of semi-active and active suspension system. Therefore the different of the two systems can be discovered.
4. Then the mathematical model of an active suspension system will be derive to get the desired result.
5. Next is to study and derive a mathematical model of PID controller for an active suspension system using quarter car model.
6. All simulations is performed using Matlab/Simulink

1.5 Methodology

1. Project Planning
    a. Consult with supervisor, En. Amat Amir bin Basari to get the exact information about the project.
    b. Prepare Gantt chart for guidelines and progress report.
    c. Search for information about this project and past research related to suspension system.
    d. Derive mathematical equation for passive suspension system before applying in the SIMULINK.

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CHAPTER 2

LITERATURE REVIEW

2.0 Control System

A control system is an arrangement of physical components connected or related in such a manner as to command, direct, or regulate itself or another system. Control system has two important terms, which is define as input and output. The input is the stimulus, excitation or command applied to a control system, usually from an external energy source in order to produce a specified response from the control system. The output is the actual response obtained from a control system. It may or may not be equal to specified response implied by the input.

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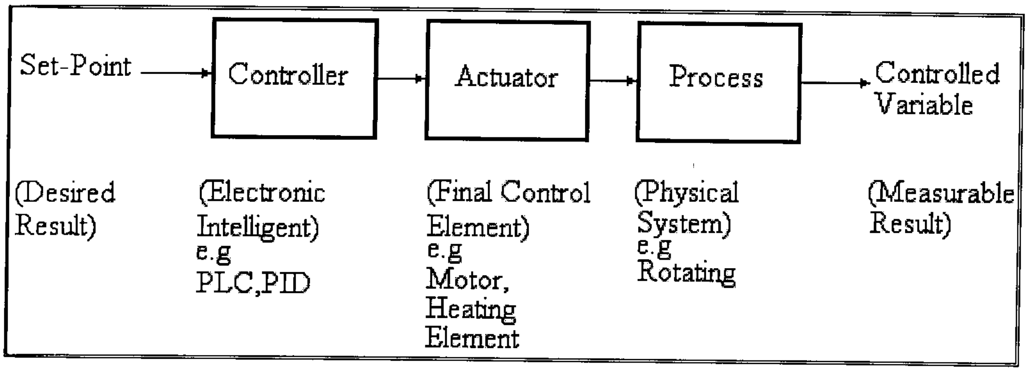

Figure 2.0:- A Block Diagram of general Control System

2.0.1 Open-Loop and Closed-Loop Control Systems

Control systems are classified into two general categories, open-loop and closed-loop systems. An open-loop system is one which the control action is independent of the output. A closed-loop control system is one in which the control action is somehow dependent on the output.

Open-Loop System is a control system that does not use feedback. The controller sends a measured signal to the actuator, which specifies the desired action. This type of system is not self-correcting. If some external disturbance changes the load on machine or process being performed, some degree of physical effort of human operator is required to make necessary modifications. The system manually controlled by the human.

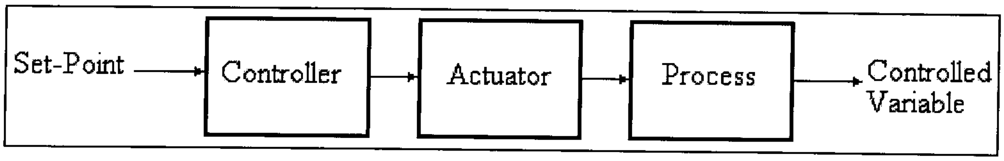

Figure 2.0.1 a: Open Loop System

To avoid the problems of the open-loop controller, the feedback was added. A closed-loop controller uses feedback to control outputs of a dynamical system. Process input has an effect on the process outputs, which is measured with sensors and processed

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by the controller; the result (the control signal) is used as input to the process, closing the loop. Since the controller knows what the system is actually doing, it can make any adjustments necessary to keep the output where it belongs.

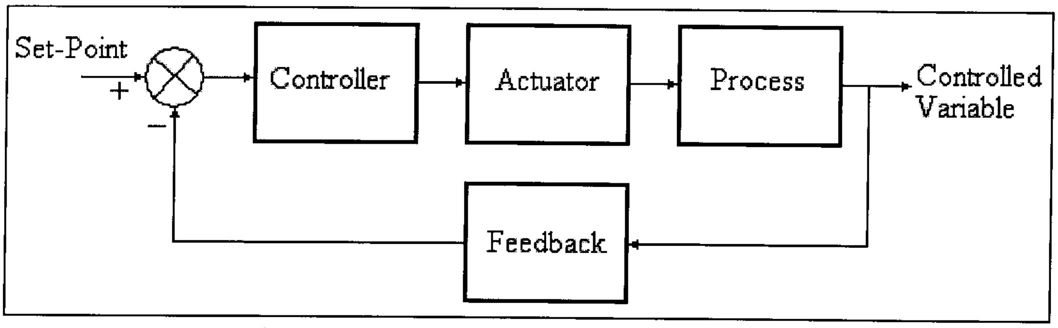

Figure 2.0.1 b: Closed Loop System

Closed-loop controllers have the following advantages over open-loop controllers:

- disturbance rejection (such as unmeasured friction in a motor)
- guaranteed performance even with model uncertainties, when the model structure does not match perfectly the real process and the model parameters are not exact
- unstable processes can be stabilized
- reduced sensitivity to parameter variations
- improved reference tracking performance

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2.1 PID Controllers

A proportional-integral-derivative controller (PID controller) is a generic control loop feedback mechanism widely used in industrial control systems. A PID controller attempts to correct the error between a measured process variable and a desired set-point by calculating and then outputting a corrective action that can adjust the process accordingly.

The PID controller calculation (algorithm) involves three separate parameters; the Proportional, the Integral and Derivative values. The Proportional value determines the reaction to the current error, the Integral determines the reaction based on the sum of recent errors and the Derivative determines the reaction to the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element.

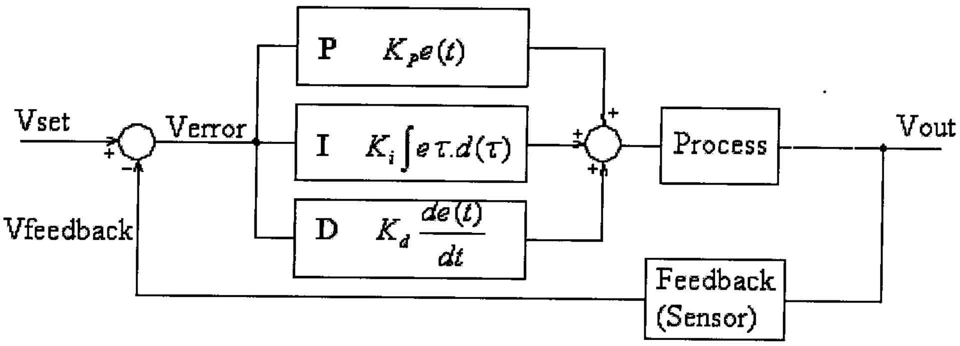

Figure 2.1:- The PID Controllers Block Diagram

By "tuning" the three constants in the PID controller algorithm the PID can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set-point and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system.

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Some applications may require using only one or two modes to provide the appropriate system control. This is achieved by setting the gain of undesired control outputs to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are particularly common, since derivative action is very sensitive to measurement noise, and the absence of an integral value prevents the system from reaching its target value due to the control action.

The table below summarizes the PID terms and their effect on a control system.

Term	***Math Function***	***Effect on Control System***
P Proportional	KP x Verror	Typically the main drive in a control loop, KP reduces a large part of the overall error.
I Integral	KI x ∫ Verror dt	Reduces the final error in a system. Summing even a small error over time produces a drive signal large enough to move the system toward a smaller error.
D Derivative	KD x dVerror / dt	Counteracts the KP and KI terms when the output changes quickly. This helps reduce overshoot and ringing. It has no effect on final error.

Table 2.1: PID Controller Effect

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2.1.1 Proportional Controller

The proportional term makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain. The proportional term is given by:

$$P_{out} = K_p e(t)$$

Where

- P_{out}: Proportional output
- K_p: Proportional Gain, a tuning parameter
- e: Error = $SP - PV$
- t: Time or instantaneous time (the present)

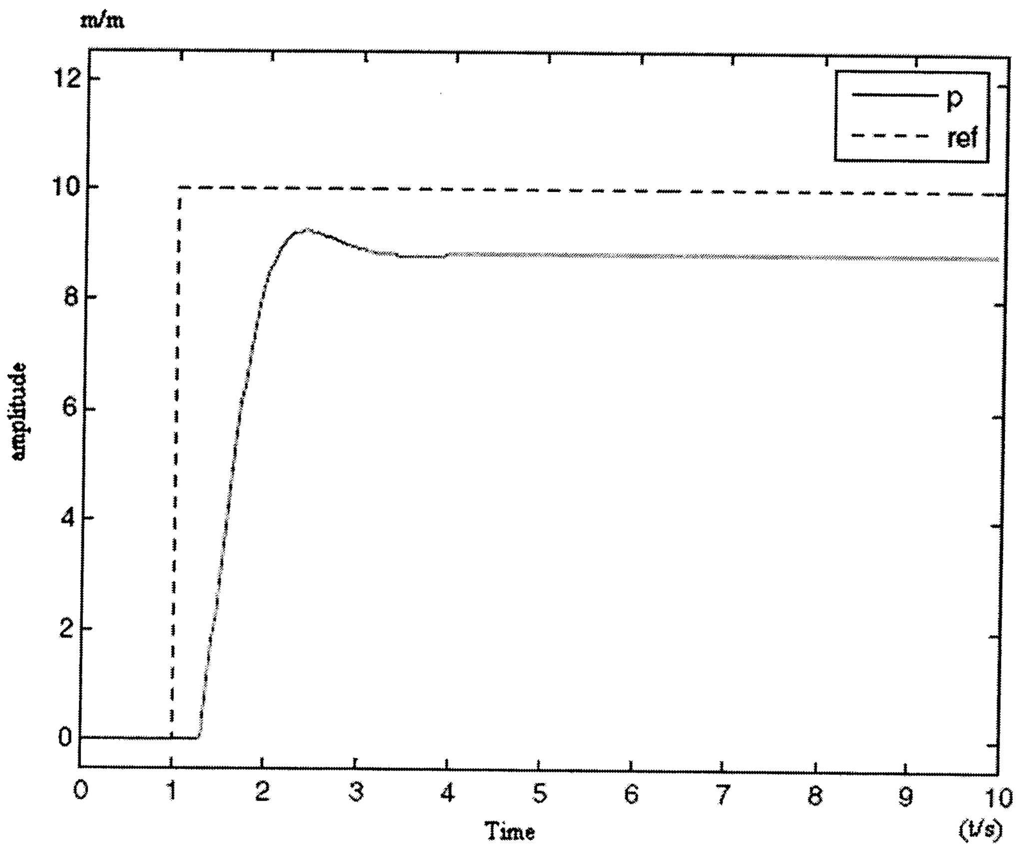

Figure 2.1.1:- The Step Response for P Controller

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A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable (See the section on Loop Tuning). In contrast, a small gain results in a small output response to a large input error, and a less responsive (or sensitive) controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances.

In the absence of disturbances pure proportional control will not settle at its target value, but will retain a steady state error that is a function of the proportional gain and the process gain. Despite the steady-state offset, both tuning theory and industrial practice indicate that it is the proportional term that should contribute the bulk of the output change.

2.1.2 Integral Controller

The contribution from the **integral term** is proportional to both the magnitude of the error and the duration of the error. Summing the instantaneous error over time (integrating the error) gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain and added to the controller output. The magnitude of the contribution of the integral term to the overall control action is determined by the integral gain, K_i. The integral term is given by:

$$I_{\text{out}} = K_i \int_0^t e(\tau)\, d\tau$$

Where

- I_{out}: Integral output
- K_i: **Integral Gain**, a tuning parameter
- e: **Error** = $SP - PV$
- τ: **Time** in the past contributing to the integral response

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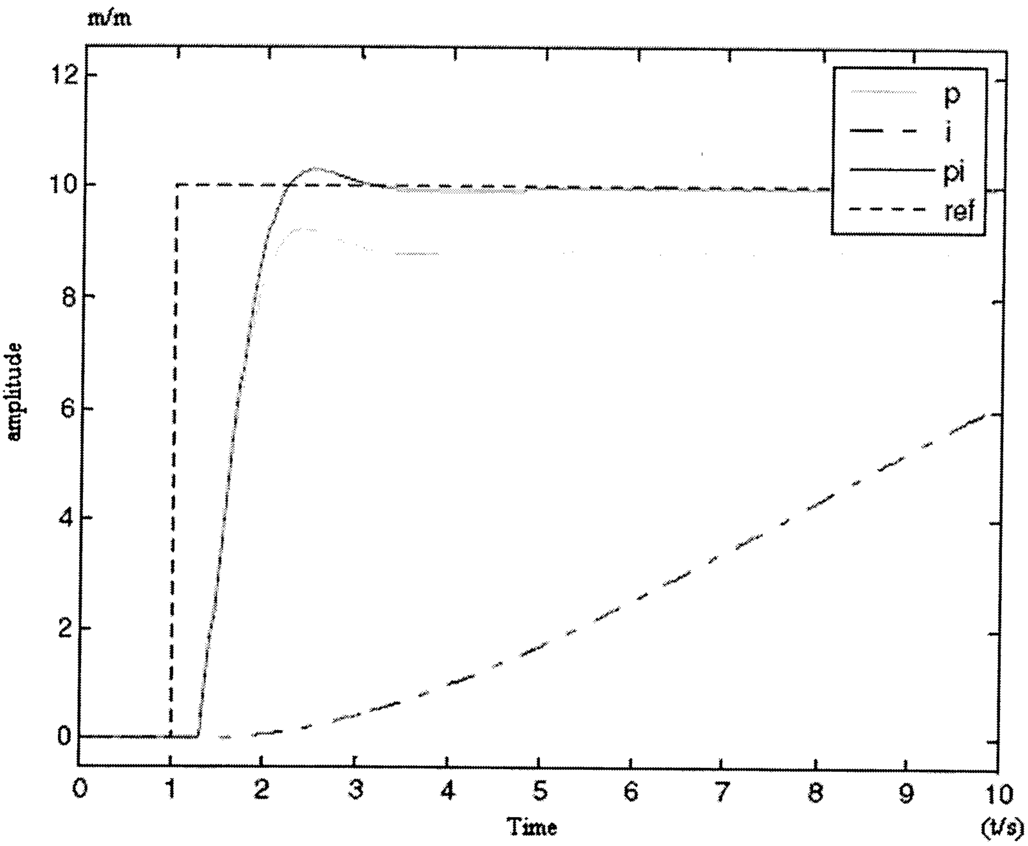

Figure 2.1.2:- The Step Response for P, I and PI Controller

The integral term (when added to the proportional term) accelerates the movement of the process towards setpoint and eliminates the residual steady-state error that occurs with a proportional only controller. However, since the integral term is responding to accumulated errors from the past, it can cause the present value to **overshoot** the setpoint value (cross over the setpoint and then create a deviation in the other direction). For further notes regarding integral gain tuning and controller stability, see the section on Loop Tuning.

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2.1.3 Derivative Controller

The rate of change of the process error is calculated by determining the slope of the error over time (i.e. its first derivative with respect to time) and multiplying this rate of change by the derivative gain K_d. The magnitude of the contribution of the **derivative term** to the overall control action is determined the derivative gain, K_d. The derivative term is given by:

$$D_{\text{out}} = K_d \frac{de}{dt}$$

Where

- D_{out}: **Derivative output**
- K_d: **Derivative Gain**, a tuning parameter
- e: **Error** = $SP - PV$
- t: **Time** or instantaneous time (the present)

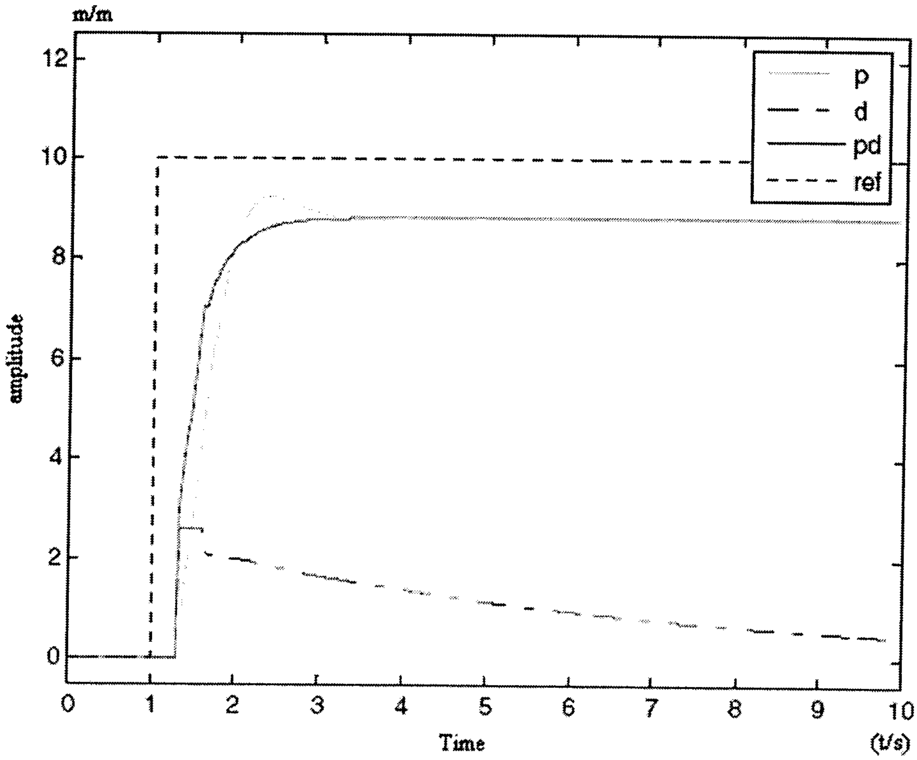

Figure 2.1.3 a:- The Step Response for P, D and PD Controller

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The derivative term slows the rate of change of the controller output and this effect is most noticeable close to the controller set-point. Hence, derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability. However, differentiation of a signal amplifies noise in the signal and thus this term in the controller is highly sensitive to noise in the error term, and can cause a process to become unstable if the noise and the derivative gain are sufficiently large.

The output from the three terms, the proportional, the integral and the derivative terms are summed to calculate the output of the PID controller.

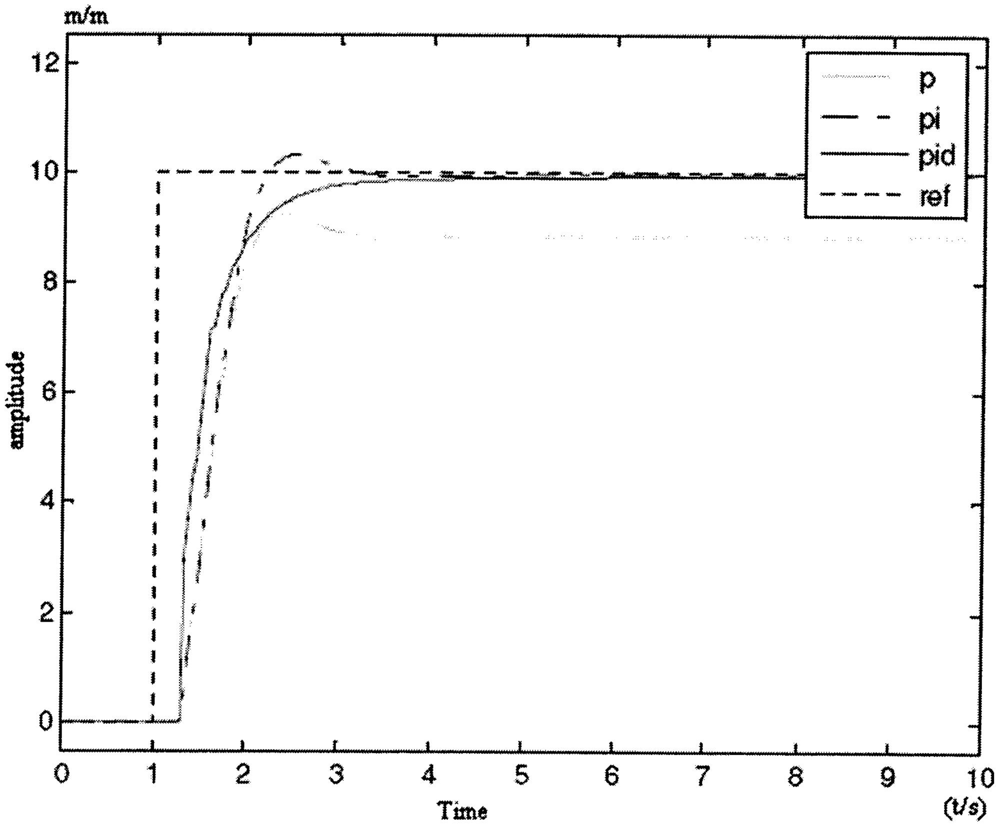

Figure 2.1.3 b:- The Step Response for P, PI and PID Controller

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2.1.4 Characteristic of P, I, and D Contollers

Parameter	Rise Time	Overshoot	Settling Time	S.S. Error
Kp	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small Change	Decrease	Decrease	None

Table 2.1.4: Effects of increasing parameters

2.2 PID Tuning

A lot of methods have been developed over the last forty years for setting the parameters of a PID controller. Some of these methods are based on characterizing the dynamic response of the dynamic system to be controlled with a first-order model or second-order model with a time delay [11]. All general methods for control design can be applied to PID control. A number of special methods that are tailor made for PID control have also been developed, these methods are often called tuning methods. The most well known tuning methods are those that are stated by Ziegler and Nichols. These methods do not need any mathematical calculation to find PID parameters. The Ziegler-Nichols Oscillation Method, Ziegler-Nichol Process Reaction Method and Frequency Response method, and Cohen-Coon Reaction Curve Method are basic Self-Tuning methods. Oscillation method is based on system gain, in other words, system gain is redounded until the system makes oscillation, then PID parameters can be found from system response graphic. Practically, this method is useless for too many sort of real systems, because oscillation at the output of the system can easily damage the system. Frequency response uses frequency domain rules to find PID parameters. Cohen-Coon method uses system step response for an open loop system to find PID parameters. Also Ziegler and Nichols proposed PID parameters for a group of system due to its system parameter values [10]. Ziegler-Nichols process reaction method (PRM) is used to determine PID controller parameters; Kc, Ti and Td.

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2.3 Definition of suspension system

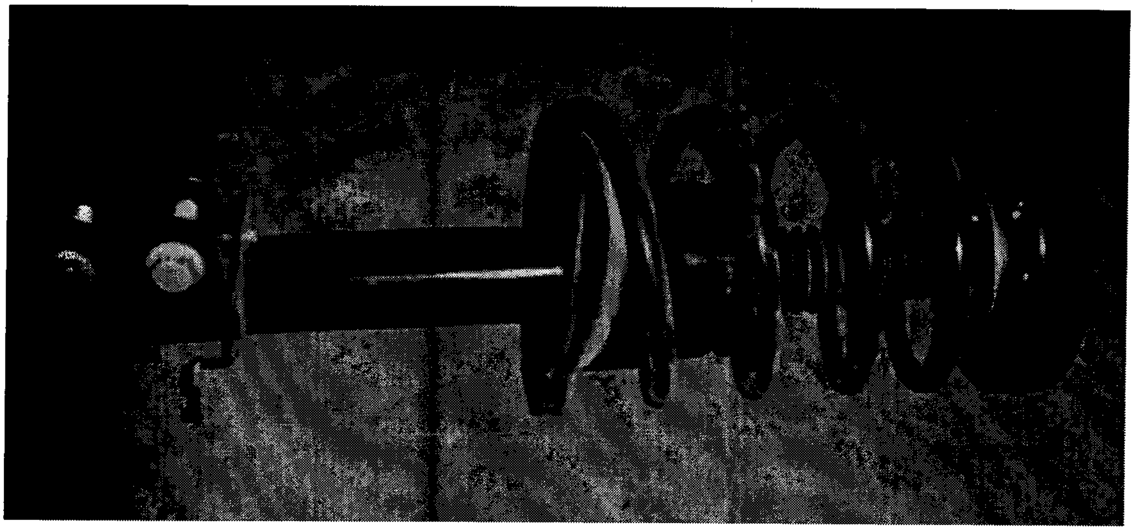

Figure 2.3: Suspension

Suspension is the term given to the system of springs, shock absorbers and linkages that connects a vehicle to its wheels. Suspension systems serve a dual purpose, contributing to the car's handling and braking for good active safety and driving pleasure, and keeping vehicle occupants comfortable and reasonably well isolated from road noise, bumps, and vibrations.

2.3.1 Spring

There are three types of spring, coil springs, torsion bars and leaf springs. The most commonly used spring is the coil spring. The coil spring is a length of round spring steel rod that is wound into a coil. Unlike leaf springs, conventional coil springs do not develop inter-leaf friction. Therefore, they provide a smoother ride. The diameter and length of the wire determine the strength of a spring. Increasing the wire diameter will produce a stronger spring, while increasing its length will make it more flexible. Coil springs require no adjustment and for the most part are trouble-free. The most common failure is spring sag. Springs that have sagged below vehicle design height will change

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the alignment geometry. This can create tire wear, handling problems, and wear other suspension components.

Leaf springs are usually used on most cars up to about 1985 and almost all heavy duty vehicles. Leaf spring looks like layers of metal connected to the axle. The layers are called leaves, hence leaf-spring. The torsion bar on its own is a bizarre little contraption which gives coiled-spring-like performance based on the twisting properties of a steel bar. Instead of having a coiled spring, the axle is attached to one end of a steel shaft. The other end is slotted into a tube and held there by splint. As the suspension moves, it twists the shaft along its length.

Figure 2.3.1 a: Coil spring

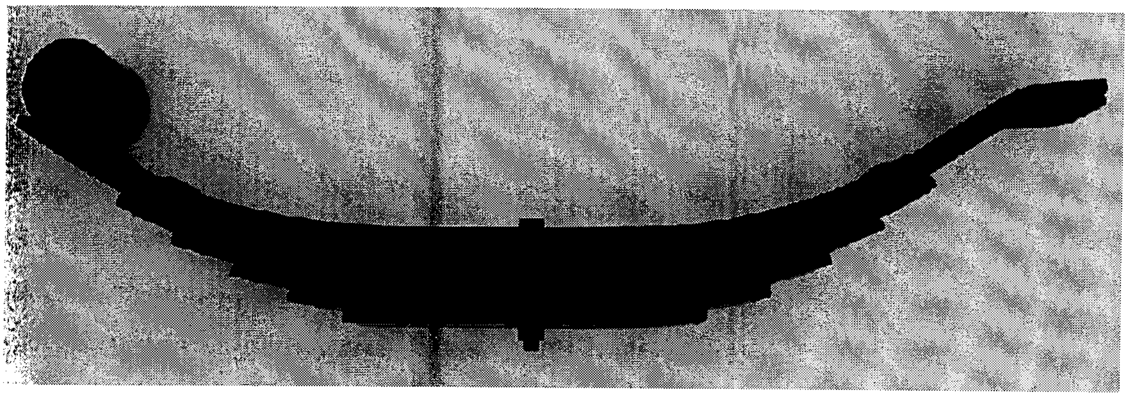

Figure 2.3.1 b: Leaf spring

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2.3.2 Shock absorbers

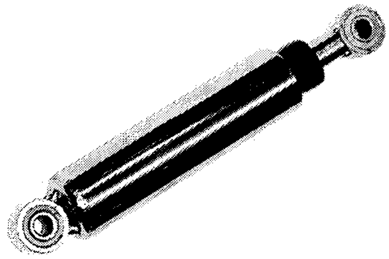

Figure 2.3.2: Shock absorber

Actually the shock absorber damped the vertical motion induced by driving car along a rough surface. Therefore it also called damper. If the car only had springs, it would boat and wallow along the road. Shock absorbers perform two functions. Firstly, they absorb any larger-than-average bumps in the road so that the shock isn't transmitted to the car chassis. Secondly, they keep the suspension at as full a travel as possible for the given road conditions. Shock absorbers keep your wheels planted on the road. Without damper, car would be a travelling deathtrap.

The spring allows movement of the wheel to allow the energy in the road shock to be transformed into kinetic energy of the unsprung mass, whereupon it is dissipated by the damper. The damper does this by forcing gas or oil through a constriction valve (a small hole). Adjustable shock absorbers allow the changeable the size of this constriction, and thus control the rate of damping. The smaller the constriction, the stiffer the suspension will become.

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2.4 Active Suspension

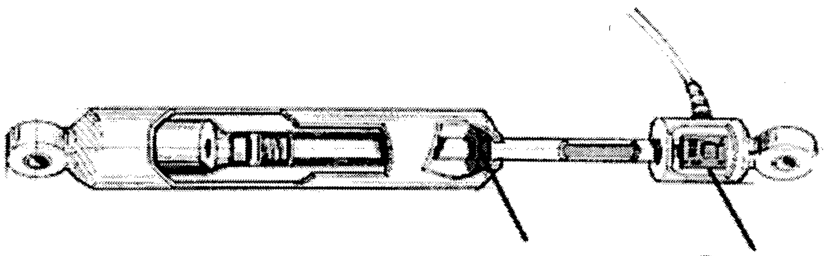

Figure 2.4: Active Suspension

Active suspension is an automotive technology that controls the vertical movement of the wheels via an onboard system rather than the movement being determined entirely by the surface on which the car is driving. It is an adaptive system with modulating properties that can provide a much superior performance in the trade-off between ride and handling.

An active suspension requires sensors to be located at different points of the vehicle to measure the motions of the body, suspension system and the unsprung mass. This information is used in the online controller to command the actuator in order to provide the exact amount of force required. Active suspensions may consume large amounts of energy in providing the control force, and therefore, in the design procedure for the active suspension the power limitations of actuators should also be considered as an important factor. Based on the sensor readings and a designed control algorithm, the actuator(s) in an active suspension can supply energy into the system or modulate the rate of energy dissipation from the system and therefore offer more room for improving the performance of the suspensions.

The system therefore virtually eliminates body roll and pitch variation in many driving situations including cornering, accelerating, and braking. This technology allows car manufacturers to achieve a higher degree of both ride quality and car handling by keeping the tires perpendicular to the road in corners, allowing for much higher levels of grip and control.

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2.5 Others controller

State feedback

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 such as E. Esmailzadehy and H.D. Taghiradz. In their study's, they used a half car as a model and they have developed a stochastically technique for quantitative comparison of the system. By considering the two passengers, the modeling become more complex which it have six degree of freedom.

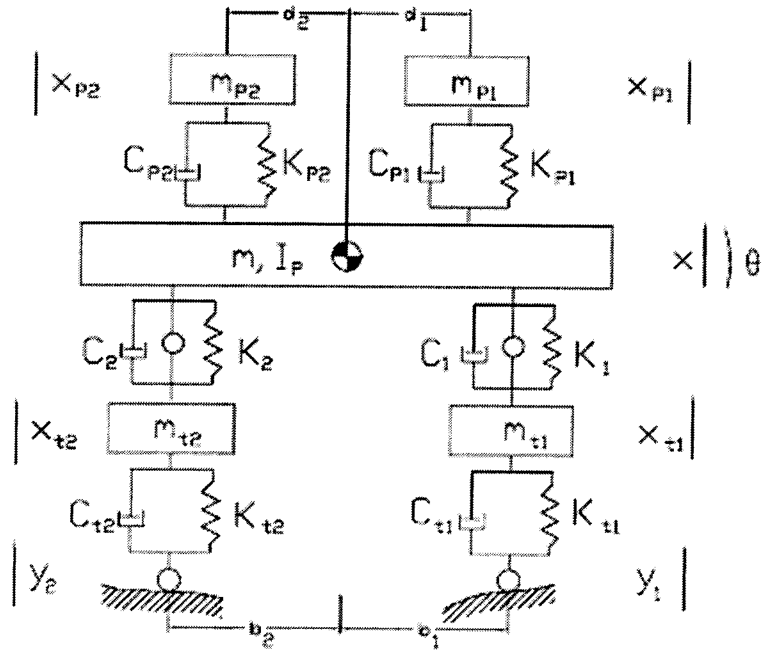

Figure 2.5 a: Half car dynamic model of road vehicle with six degrees of freedom

Which are M_{P1} and M_{P2} are passenger mass, C_{P1} and C_{P2} are passenger damping constants and K_{P1} and K_{P2} are passenger spring constants. The actuators are considered

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to be a source of controllable force, and located parallel with the suspension spring and shock absorber.

Fuzzy logic

This is the other method that has been used to design an active suspension method. Fuzzy logic starts with and builds on a set of user-supplied human language rules. The fuzzy systems convert these rules to their mathematical equivalents. This simplifies the job of the system designer and the computer, and results in much more accurate representations of the way systems behave in the real world.

Fuzzy logic also more simple and flexible. It can handle problems with imprecise and incomplete data, and it can model nonlinear functions of arbitrary complexity. Fuzzy will produce a better solution than conventional control techniques if the system is changing. Fuzzy logic models, called fuzzy inference systems, consist of a number of conditional "if-then" rules. These rules are easy to write, and as many rules as necessary can be supplied to describe the system adequately.

Fuzzy inference systems rely on membership functions to explain to the computer how to calculate the correct value between 0 and 1. The degree to which any fuzzy statement is true is denoted by a value between 0 and 1.

There are researcher that used this controller to design an active suspension such as Kateřina HYNIOVÁ and Antonín STŘÍBRSKÝ and Jaroslav HONCŮ from Czech Technical University [9]. They used a quarter car models for their study with two degree of freedom.

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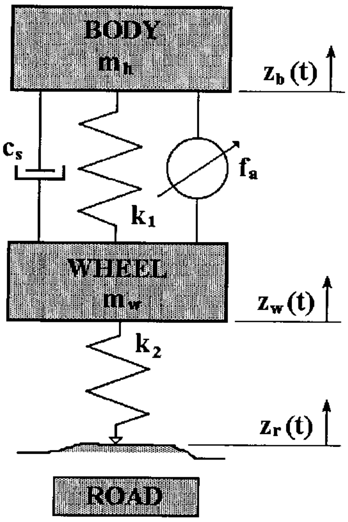

Figure 2.5 b: Quarter car model

The fuzzy logic controller used in the active suspension has three inputs: body acceleration, $\ddot{z}_b$, body velocity, $\dot{z}_b$, body deflection velocity $\dot{z}_b - \dot{z}_w$ and one output : desired actuator force f_a. The control system itself consists of three stages: fuzzification, fuzzy inference machine and defuzzification[9].

The fuzzification stage converts real-number (crisp) input values into fuzzy values while the fuzzy inference machine processes the input data and computes the controller outputs in cope with the rule base and data base. These outputs, which are fuzzy values, are converted into real-numbers by the defuzzification stage.

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CHAPTER 3

METHODOLOGY

3.1 Introduction

There are several ways to design an active suspension system. To design an active suspension system, a controller will be added in the suspension system. The objective is to improve the suspension system toward any disturbances from the road surface. There are many controller that have been used before to archived the objective such as PID controller, state feedback controller, fuzzy logic controller and others controller.

Active suspension requires sensors to be located at different points of the vehicle to measure the motions of the body, suspension system and the unsprung mass. This information is used in the online controller to command the actuator in order to provide the exact amount of force required. Active suspensions may consume large amounts of energy in providing the control force, and therefore, in the design procedure for the active suspension the power limitations of actuators should also be considered as an important factor.

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Study Flow Chart

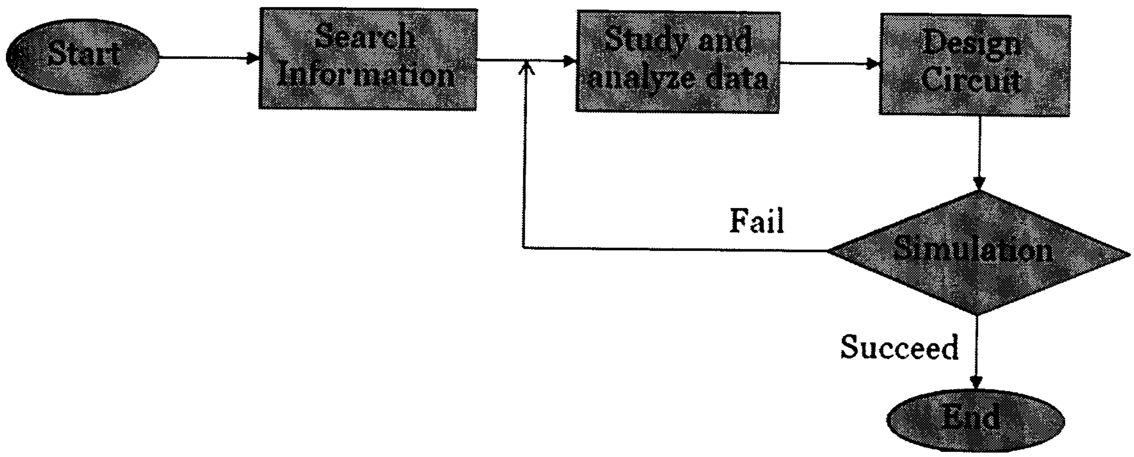

Figure 3.1: Study Flow Chart

3.2 Physical setup

Fist of all, the condition of the design must be understood correctly. For this project, I going to used a quarter car as a model. By considering the body mass, the suspension (unsprung) mass, the damping constants of suspension, the spring constants of suspension, the damping constants of wheel, the spring constant of wheel and the road surface as disturbance, the model can be done like below:

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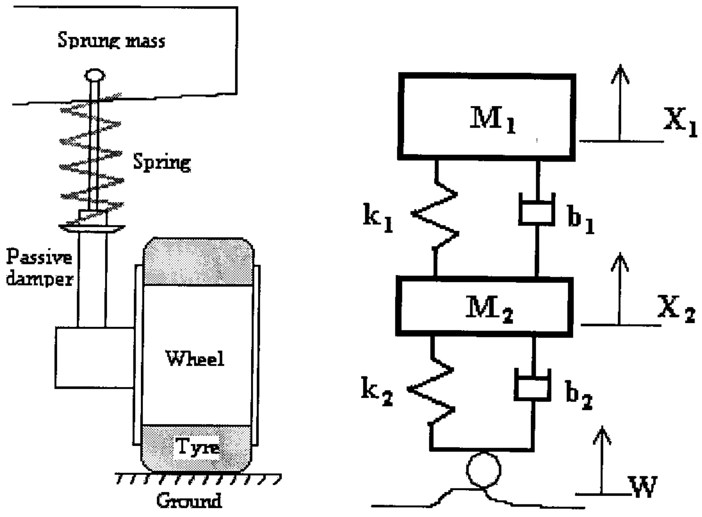

Figure 3.2: Modeling of a quarter car suspension

Where, according to Kateřina Hyniová and Antonín Stříbrský and Jaroslav Honců the value of the variables are;

M_1 : body mass		= 250 kg
M_2 : unsprung/wheel mass		= 35 kg
k_1 : suspension spring constant		= 16000 N/m
k_2 : tire spring constant		= 160000 N/m
b_1 : suspension damping constant		= 980 Ns/m
b_2 : tire damping constant		= 9500 Ns/m

X_1 : vertical displacement of car body

X_2 : wheel displacements

W : Input disturbance

As the objective of the study, this suspension is design to providing comfort when riding over bumps and holes on the road. When the car is facing any road disturbance such as a bump or hole, the body should not have large oscillations, and the oscillations should dissipate quickly.

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