# INTELLIGENT ROBUST CONTROL OF ACTIVE SUSPENSION SYSTEM

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To My Beloved Family...

For their Love, Encouragement, Sacrifice, and Best Wishes.

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# ABSTRACT

This project presents a modelling and control of an active suspension system with hydraulic actuator dynamic for a quarter car model. The objective of designing a controller for the car suspension system is to improve the ride comfort while maintaining the constraints on to the suspension travel and tire deformation subject to different road profile. In this research, a cascade control algorithm which consists of the inner loop controller for force tracking control of the hydraulic actuator model and the outer loop controller for disturbance rejection control is proposed. Particle swarm optimization (PSO) algorithm is employed to optimize the PI controller parameters for force tracking control of the hydraulic actuator model. The outer loop controller utilizes a sliding mode controller scheme which incorporates PSO algorithm to efficiently reduce the influence of mismatched disturbance during sliding motion. In addition to that, the performance of the proposed sliding mode controller is compared with the LQR controller and the existing passive suspension system. Similarly, the values of Q and R for the LQR controller are optimized by PSO algorithm. A simulation study is performed to show the effectiveness and robustness of the proposed control algorithm. Eventually the results prove that the proposed controller improves the ride comfort by maintaining the other constrains (the suspension travel, tire deflection, and control force) in their limits.

# ABSTRAK

Projek ini mempersembahkan pemodelan dan pengendalian sistem suspensi aktif dengan dinamik aktuator hidrolik untuk model kereta satu perempat. Tujuan rekabentuk pengawal sistem suspensi kereta adalah untuk meningkatkan keselesaan perjalanan sambil mengekalkan had-had tertentu terhadap suspensi perjalanan dan deformasi tayar mengikut profil jalan yang berbeza. Dalam projek ini, kami mencadangkan suatu algoritma kawalan sesiri yang terdiri daripada pengawal gelung dalaman untuk kawalan penjejakan daya bagi model aktuator hidrolik dan pengawal gelung luaran untuk pengawal penolak gangguan. *Particle Swarm Optimization* (PSO) digunakan untuk mengoptimumkan parameter kawalan PI untuk kawalan penjejakan daya bagi model aktuator hidrolik. Pengawal gelung luaran menggunakan skim Pengawal Ragam Gelineir (SMC) yang menggabungkan algoritma PSO untuk mengurangkan pengaruh gangguan tidak boleh dipadankan penolakan gangguan secara cekap. Prestasi pengawal SMC yang dicadangkan dibandingkan dengan pengawal LQR dan sistem suspensi yang ada pasif. Nilai Q dan R untuk pengawal LQR dioptimumkan dengan algoritma PSO. Satu kajian simulasi dilakukan untuk menunjukkan keberkesanan dan kelasakan algoritma kawalan yang dicadangkan. Keputusan menunjukkan bahawa pengawal yang dicadangkan meningkatkan keselesaan sambil mengekalkan had-had tertentu yang lain (perjalanan suspensi, pesongan tayar, dan daya kawalan) dalam had-had masing-masing.

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| | | |
|---|---|---|
| $A_p$ | - | Piston area = 0.0044 $m^2$ |
| $C_{d1}$ | - | Discharge coefficient = 0.7 |
| $C_{tm}$ | - | Leakage coefficient = 15e-12 |
| $b_s$ | - | Damper coefficient = 1500Nsec/m |
| $F_a$ | - | Actuator force |
| $k_t$ | - | Spring constant of tyre =165790N/m |
| $k_s$ | - | Spring constant = 17900N/m |
| $m_s$ | - | Sprung mass = 282kg |
| $m_u$ | - | Unsprung mass = 45kg |
| $P_s$ | - | Supply pressure = 20684 $kN/m^2$ |
| $P_L$ | - | Pressure induced by load |
| $u_1$ | - | Spool valve position |
| $u_2$ | - | Bypass valve area |
| V | - | Input voltage command |
| w | - | Spool valve width = 0.008 m |
| α | - | Hydraulic coefficient =2.273e9 $N/m^5$ |
| ρ | - | Specific gravity of hydraulic fluid = 3500 |

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| ASS | - | Active suspension system |
| GA | - | Genetic Algorithm |
| PSO | - | Particle swarm optimization |
| LQG | - | Linear Quadratic Gaussian |
| LQR | - | Linear Quadratic Regulator |
| MIMO | - | Multi-Input Multi-Output |
| PI | - | Proportional Integral |
| PID | - | Proportional Integral Derivative |
| SMC | - | Sliding Mode Control |
| VSC | - | Variable Structure Control |

# CHAPTER 1

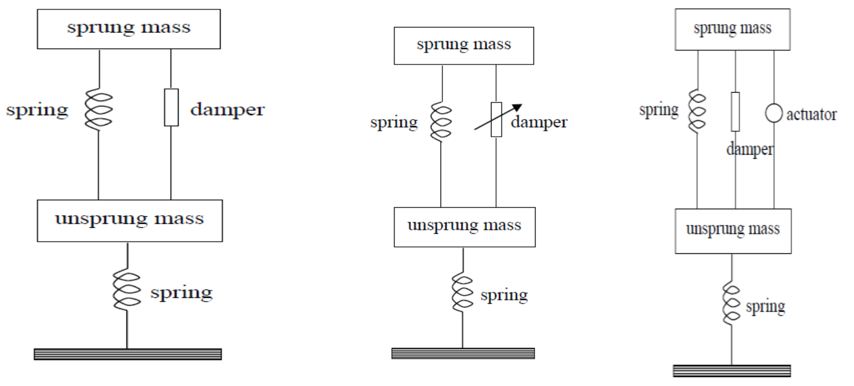
# INTRODUCTION

## 1.1 Introduction

Every vehicle moving on the randomly profiled road is exposed to vibration which is harmful for both the passenger comfort and the stability of the vehicle. Therefore, the main function of a car suspension system is to improve both riding comfort and road holding over a wide range of road profiles. A study conducted by ISO 2631-1 standard indicates that exposing the human body to vibrations with frequencies between 0.5 – 80 Hz could probably cause a great risk of injury to the vertebrae in the lumber region and the nerves connected to these segments. These facts show the significance of improving the control performance of the vehicle's suspension system in order to reduce vehicle vibration arising from road surface [1].

A car suspension system is the mechanism that physically separates the car body from the car wheels. As shown in Figure 1.1, the suspension system can be classified as passive, semi-active or active suspension system (ASS) according to its ability to add or extract energy [2]. The passive suspension system contains only passive elements such as a damper and a spring. For that reason its rates and forces cannot be varied by external signals. The semi-active suspension system provides only moderate performance. It has the ability to vary the rate of energy dissipation using a controllable damper. By contrast,  active suspension system can add power to the system. It can supply energy from an external source and generate force to achieve the optimal desired performance.

Recently, the control of the ASS has been studied by many researchers. The main function of the ASS is to improve efficiency of the control performance and the ride comfort for passengers in a vehicle. In general, a good suspension should provide a ride comfort and road holding within a reasonable range of deflection. Typically, a high-quality ASS can separate the vehicle chassis from the vibration arising from road surface. Furthermore, it ensures a  good tire to road contact for a better ride comfort and safety. The ASS must be able to reduce the vertical force transmitted to the car body for ride comfort. This objective can be achieved by minimizing the vertical car body acceleration, but this will reduce the tire to road contact which would affect the stability of the vehicle.




(a) Passive suspension        (b) Semi-active suspension    (c) Active suspension

**Figure 1.1** Classification of vehicle suspension system

## 1.2 Problem Background

In any control problem the mathematical model used for controller design does not exactly describes the real plant due to the approximation of complex plant or system parameters variations. This uncertainty and the uncertainty due to the environment factors (external disturbance) cannot be avoided in real dynamical systems. Therefore, the designed controller must have the ability to control the plant with the required performance despite of the uncertainty and the external disturbance [3].

For this reason, the problem of controlling dynamical systems in presence of uncertainty and external disturbance has become an important subject of research. As a result, different robust control techniques, such as adaptive control, backstepping, sliding mode control and others, have obtained a considerable progress. Among these techniques, sliding mode control is recognized as one of the simplest methods yet can provide robust performance [4].

Despite the extensive research on SMC development and applications, there are still problems associated with SMC such as effects of the mismatched uncertainty and disturbance on the system during the sliding mode. Various approaches have been developed to solve these problems, although there has not been a perfect solution. . This problem is one of the important subjects under research in SMC for the systems with uncertainty, which will be the main objective of this study.

The diffusion of Soft computing (SC) technologies such as neural networks (NNs), fuzzy logic (FL), Genetic algorithm (GA), and particle swarm optimization (PSO) algorithm have become a major research in SMC theory and applications [3]. These techniques have been integrated with SMC to alleviate the problems or shortcomings of the classical SMC techniques. This research proposes a new sliding mode technology which incorporates PSO algorithm to efficiently reduce the influence of mismatched disturbance during sliding motion [5].

## 1.3 Project Objectives

The objectives of this project are:

1. To develop PI controller for force tracking control of the hydraulic actuator model.
2. To develop a sliding mode controller (SMC) with Particle Swarm Optimization (PSO) algorithm for a system with mismatched disturbance.
3. To apply the designed controller in active suspension model.

## 1.4 Scope of work

This research studies a system which is suffering from mismatched uncertainties. A new sliding mode controller is proposed. PSO algorithm will be used to search for the optimal values of the sliding surface to reduce the effect of the mismatched uncertainties. The developed controller will be applied to an active suspension system with hydraulic actuator for a quarter car model. Simulation result based on Matlab Simulink will be presented to show the ability of the proposed controller to reduce the effect of the mismatched uncertainties.

## 1.5 Problem Statements

The statement of the problem in this project is expressed as follow:
“to design control algorithm based on the fusion of robust control and computational intelligence techniques which guarantees robust performance of the active suspension system and its verifications is performed via computer simulation”.

## 1.6 Thesis Outline

The thesis is organized in 5 chapters. The first chapter gives an overview of the project that provides a brief description about the subject of study, the problem statement, the objective, and the scope of this study. Chapter Two covers literature review on suspension system, related works and controller design.

Chapter Three covers the flow of methodology and description of each procedure. It starts with the modeling of the hydraulically actuated active suspension system for quarter car model. Then, the cascade control strategy of the active suspension model is proposed. The controller structure composed of two major parts; inner loop control (force tracking control) and outer loop controller (disturbance rejection control).

Chapter Four mainly discuss about the results and discussion of this project. It discusses the performance evaluation of the designed controller and the verification of it is performance via computer simulation. In addition to that, the designed controller is compared with LQR controller and the existing passive suspension system.Furthermore, the force tracking performance of the hydraulic actuator is proposed.

Chapter Five presents the conclusion and recommendation of the thesis.

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