CONTROL OF ACTIVE SUSPENSION FOR A FULL CAR MODEL

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This project report is dedicated to my dearest parents, family and all the Muslims ummah for the love of the prophet (PBUH).

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ABSTRACT

The need for passenger comfort, road handling abilities of tires, and vehicle handling characteristics, have been the major challenge in the design of suspension system over the years. However, in the past decades various strategies ranging from semi-active to fully active suspension systems had been developed to minimized the unavoidable compromised adopted in the design of passive suspension system, and improve the performance of suspension system. This leads to many research works on active suspension system, with most of them focusing on quarter car model. The quarter car model was mostly used due to its simplicity and proximity in capturing many of the vehicle characteristics. But in order to capture all or most of the vehicle real characteristics, recent studies are focusing on the full car model so that best performance that is very close to real system can be obtained. This project study full car, seven degree of freedom (DOF), suspension system by simulating both passive and active suspension models under two different road profiles. Actuators and controllers were also studied and a Linear Quadratic Regulator (LQR) is propose due to its robustness, the Q and R parameters were carefully tune using Brayson's rule and Trial and error method for best performance. The results obtained confirmed that LQR controllers can reliably ensure system stability, improved road handling abilities and improved overall system performance. Finally, a Linear Quadratic Regulator (LQG) was designed and implemented in the system to validate the proposed controller, the result obtained are very similar.

ABSTRAK

Keperluan untuk keselesaan penumpang, kebolehan pengendalian jalan tayar, dan ciri-ciri pengendalian kenderaan , telah menjadi cabaran utama dalam reka bentuk sistem penggantungan selama ini. Walau bagaimanapun , dalam beberapa dekad yang lalu pelbagai strategi yang terdiri daripada separuh aktif untuk sistem gantungan aktif sepenuhnya telah dibangunkan untuk meminimakan tidak dapat dielakkan dikompromi pakai dalam reka bentuk sistem penggantungan pasif , dan meningkatkan prestasi sistem penggantungan . Ini membawa kepada banyak kerja-kerja penyelidikan ke atas sistem suspensi aktif , dengan sebahagian besar daripada mereka memberi tumpuan kepada model kereta suku . Model kereta suku telah banyak digunakan kerana kesederhanaan berdekatan dalam menangkap banyak ciri-ciri kenderaan . Tetapi untuk menangkap semua atau sebahagian besar daripada kenderaan yang ciri-ciri sebenar, kajian baru-baru ini memberi tumpuan kepada model kereta penuh supaya prestasi terbaik yang sangat dekat dengan sistem sebenar boleh didapati . Kajian projek kereta penuh, tujuh darjah kebebasan , sistem penggantungan oleh simulasi kedua-dua model penggantungan pasif dan aktif di bawah dua permukaan jalan. Penggerak dan pengawal juga telah dikaji dan Linear kuadratik (LQR) adalah mencadangkan kerana kekukuhannya , Q dan R parameter berada teliti tune menggunakan peraturan Perbicaraan dan Brayson dan kaedah kesesatan dengan prestasi terbaik . Keputusan yang diperolehi mengesahkan bahawa pengawal LQR pasti boleh memastikan kestabilan sistem , kebolehan pengendalian jalan yang lebih baik dan meningkatkan prestasi sistem secara keseluruhan. Akhir sekali , yang linear kuadratik (LQG) telah dirangka dan dilaksanakan dalam sistem untuk mengesahkan pengawal yang dicadangkan itu, keputusan yang diperolehi adalah hampir sama .

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

LQR	-	Linear Quadratic Regulator
PI	-	Proportional Integral
DOF	-	Degree of Freedom
LQG	-	Linear Quadratic Gaussian

CHAPTER 1

INTRODUCTION

1.1 Introduction

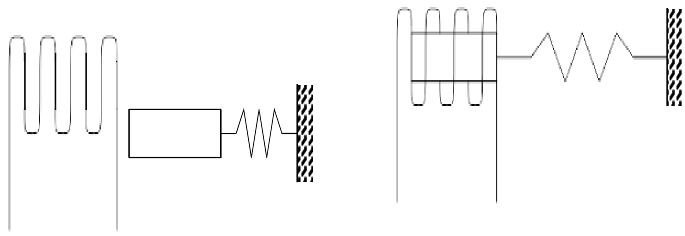
In reality actuator dynamic is quite complicated and its relationship with the vehicle suspension system are interwoven. Therefore, any fault or malfunctions of actuators will affect the performance criteria, especially in active suspension system where actuators contributes immensely in providing reasonable control. Hence, the need to automatically detect and recognize the occurrence and nature of faults in actuator cannot be over emphasize for safe, qualitative and optimal performance. This uncompromised factors cast a great challenge toward studying and designing actuator fault control that will be able to maintain the proper performance of vehicle suspension system even if there is fault in the actuator.

1.2 Actuators

Actuators are devices that convert electrical energy into motions in mechanical systems. It can be electrical, hydraulic, or pneumatic device (such as a relay) that controls the flow of material or power. The commonly used in car suspension systems are:-

1.2.1 Solenoids

Solenoids are electromagnetic type of actuator and the most common actuator components. The basic principle of operation is there is a moving ferrous core (a piston) that will move inside wire coil as shown in Figure 1. Normally the piston is held outside the coil by a spring. When a voltage is applied to the coil and current flows, the coil builds up a magnetic field that attracts the piston and pulls it into the centre of the coil. The piston can be used to supply a linear force. Well known applications of these include pneumatic valves and car door openers.



Current off Current on

Figure 1.1. A Solenoid

1.2.2 Valves

The flow of fluids and air can be controlled with solenoid controlled valves. An example of a solenoid controlled valve is shown in Figure 1.2 and 1.3. The solenoid is mounted on the side. When actuated it will drive the central spool left. The top of the valve body has two ports that will be connected to a device such as a hydraulic cylinder. The bottom of the valve body has a single pressure line in the centre with two exhausts to the side. In the top drawing the power flows in through the centre to the right hand cylinder port. The left hand cylinder port is allowed to exit through an exhaust port. In the bottom drawing the solenoid is in a new position and the pressure is now applied to the left hand port on the top, and the right hand port can exhaust. The symbols to the left of the figure show the schematic equivalent of the actual valve positions. Valves are also available that allow the valves to be blocked when unused.

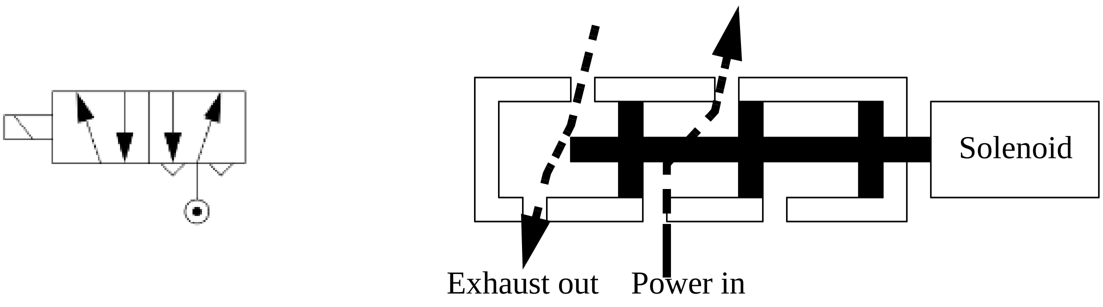


Figure 1.2: A Solenoid Controlled 5 Ported, 4 Way 2 Position Valve (position1)

The solenoid has two positions and when actuated will change the direction that fluid flows to the device. The symbols shown here are commonly used to represent this type of valve.

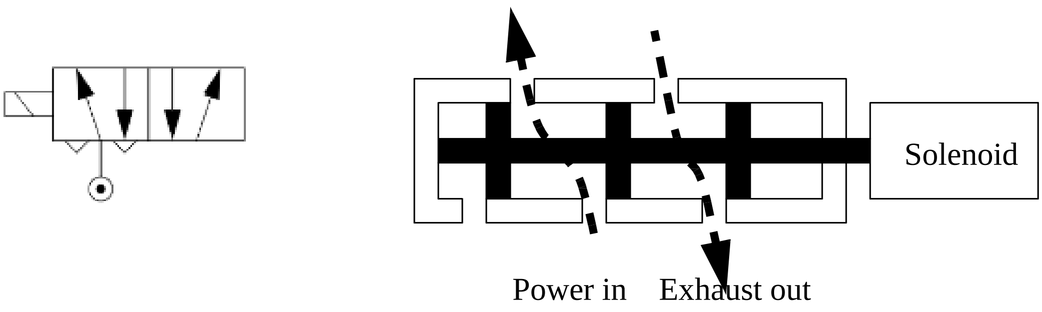


Figure 1.3: A Solenoid Controlled 5 Ported, 4 Way 2 Position Valve (position2)

1.2.3 Cylinder

A cylinder uses pressurized fluid or air to create a linear force/motion as shown in Figure 1.4. In the figure a fluid is pumped into one side of the cylinder under pressure, causing that side of the cylinder to expand, and advancing the piston. The fluid on the other side of the piston must be allowed to escape freely - if the incompressible fluid was trapped the cylinder could not advance. The force exerted by the cylinder is proportional to the cross sectional area of the cylinder.

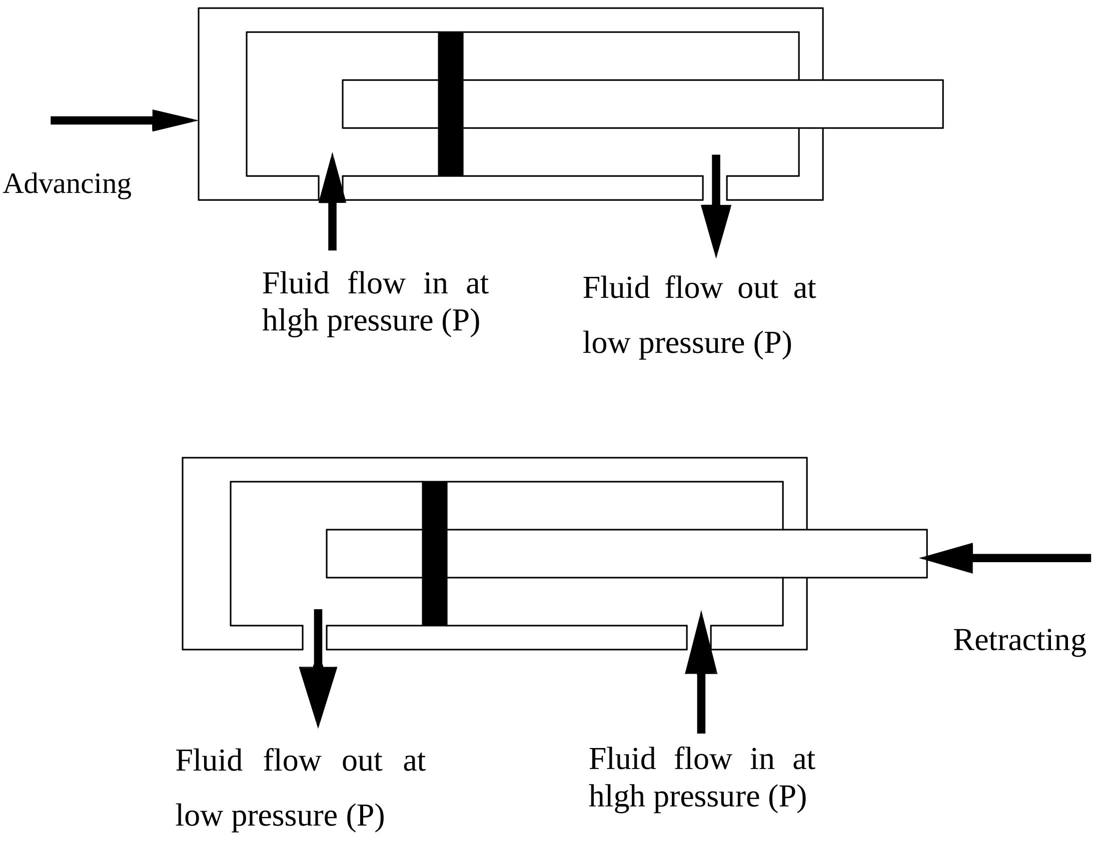


Figure 1.4. A Cross Section of a Hydraulic Cylinder

The Force is given as

$$F = PA$$
$$F = PA \quad . \qquad (1.1)$$

Where

P = the pressure of the hydraulic fluid

A = the area of the piston

F = the force available from the piston rod

1.2.4 Hydraulics

Hydraulics use incompressible fluids to supply very large forces at slower speeds and limited ranges of motion. If the fluid flow rate is kept low enough, many of the effects predicted by Bernoulli's equation can be avoided. The system uses hydraulic fluid (normally an oil) pressurized by a pump and passed through hoses and valves to drive cylinders. At the heart of the system is a pump that will give pressures up to hundreds or thousands of psi. These are delivered to a cylinder that converts it to a linear force and dis- placement.

Hydraulic systems contain the following components in most cases;

i. Hydraulic fluid

ii. An oil reserve.

iii. A Pump to Move Oil, and Apply Pressure.

iv. Pressure line.

v. Control valves (to regulate fluid).

vi. Piston and Cylinder (to actuate external mechanism).

The hydraulic fluid is often a noncorrosive oil chosen so that it lubricates the components. This is normally stored in a reservoir as shown in Figure 1.5. Fluid is drawn from the reservoir to a pump where it is pressurized. This is normally a geared pump so that it may deliver fluid at a high pressure at a constant flow rate. A flow regulator is often placed at the high pressure outlet of the pump. If fluid is not flowing in other parts of the system this will allow fluid to recirculate back to the reservoir to reduce wear on the pump. The high pressure fluid is delivered to solenoid controlled valves that can switch fluid flow on or off. From the valves, fluid will be delivered to the hydraulics at high pressure, or exhausted back to the reservoir.

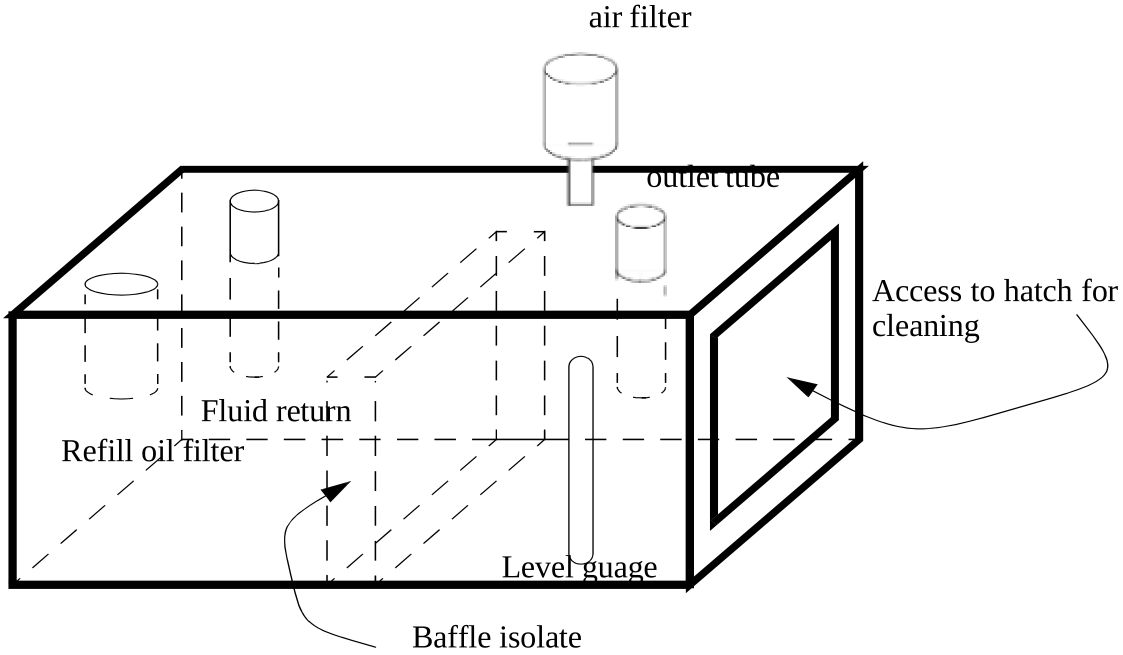


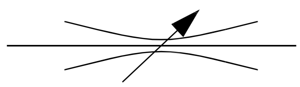
Figure 1.5. A Hydraulic Fluid Reservoir

Hydraulic systems are very effective for high power applications, but the use of fluids, and high pressures can make this method awkward, messy, and noisy for other applications.

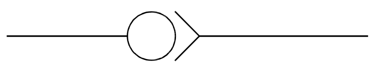
1.2.5 Pneumatics

Pneumatic systems are very common, and have much in common with hydraulic systems with a few key differences. The reservoir is eliminated as there is no need to collect and store the air to be use in the system and also since air is a gas and compressible the use of regulators are not needed to recirculate flow. But, the compressibility also means that the systems are not as stiff or strong. Pneumatic systems respond very quickly, and are commonly used for low force applications in many locations on the factory floor.

Some symbols for pneumatic systems are shown in Figure 5. The flow control valve is used to restrict the flow, typically to slow motions. The shuttle valve allows flow in one direction, but blocks it in the other. The receiver tank allows pressurized air to be accumulated. The dryer and filter help remove dust and moisture from the air, prolonging the life of the valves and cylinders.



Flow control valve



Shuttle valve

Figure1.6: Pneumatics Components

1.2.6 Motor

Motors are common actuators that converts electrical energy to mechanical torque. The electrical energy is used to actuate equipment such as multi-turn valves. It is one of the cleanest and most readily available forms of actuator because it does not involve oil.

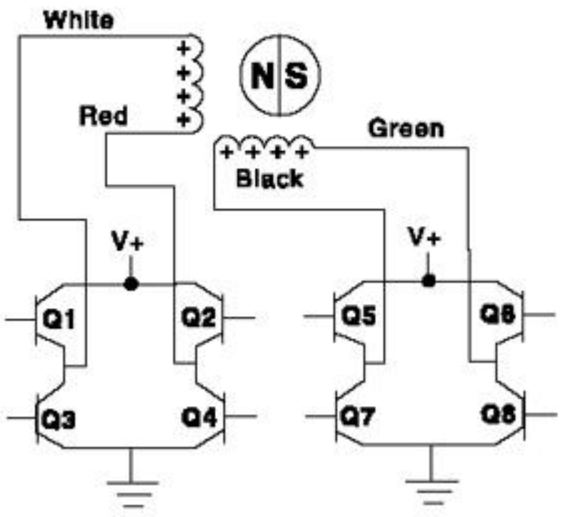


Figure 1.7. Motor

1.2.7 Actuator faults

The most commonly experience actuator malfunctioning mainly includes the following:-

i. Full failure.

ii. Offset and bias.

iii. Change of gain.

iv. Serious hysteresis.

v. Stick-slip faults.

1.3 Literature Review

Various types of actively controlled suspension systems for automotive or agricultural applications have been theoretically studied on the basis of the well-known quarter car model, half car model and full car model subjected to realistic inputs chosen to represent road surface/forward vehicle speed combinations for a range of different conditions. The vehicle response is evaluated through the performance criteria (the ride comfort, dynamic tire load and suspension working space) and Power requirements (the power input to actuator, power dissipated in damper or actuator and power fluctuation in spring and tire). The range of suspension systems includes fully active, semi-active, slow-active, single state feedback active, two state switchable damper and continuously variable damper and conventional passive suspension systems [17]. Some findings and contribution to the vehicle suspension system over recent years are reviewed in the following paragraphs.

The conventional passive suspension is optimize in [15] and it performance is compared with both semi-active and active suspension system. It shows that, using the vibration absorber (split axle) and additional dampers between the engine and axle have improved the ride comfort only slightly, but when the relaxation damping is use the ride comfort is slightly worsened compared with the basic two-mass passive suspension system.

The PC modeling and simulation of a full car suspension system model is presented in [6] by the formulation of the, seven degrees of freedom, mathematical model of a conventional full car passive suspension system based on the mechanical network analysis, then, the simulation of the mathematical model of the suspension system is carried out using MATLAB. The simulation results obtained depict the exact response characteristics of the full car model. For a positive road input at node 1 the suspension displacement turned out to be in positive direction, while a negative road input at node 2 depicted a similar output. This report also suggest that, the main application of this simulation would be in the problem identification of the suspension system in any car. The only modification that has to be made is to supply the parametric values of the particular model which is being investigated.

[10] An active suspension system has been proposed to improve the ride comfort. A quarter-car 2 degree-of-freedom (DOF) system is designed and constructed on the basis of the concept of a four-wheel independent suspension to simulate the actions of an active vehicle suspension system. The purpose of a suspension system is to support the vehicle body and increase ride comfort. The aim of the work described in this paper is to illustrate the application of intelligent technique to the control of a continuously damping automotive suspension system. The ride comfort is improved by means of the reduction of the body acceleration caused by the car body when road disturbances from smooth road and real road roughness is applied, it also describes the model and controller used in the study and the vehicle response is obtained from a range of road input simulations. A comparison of active suspension intelligent control and classical control is shown.

[18] Point out that, the main practical difficulty in implementing active suspension is the power consumption of the actuator. A quarter and full car models are derive and a controller is design base on the standard root locus technique to achieve +/-2% settling time of one second. It is shown that, the active suspension system significantly improve regulator response when compared to the passive suspension system.

The performance of a full car model active suspension system using LQR controller was investigated [1]. In the study, the LQR control method is use to improve road handling and ride comfort in a full car model and the result is compared with the performance of LQR control method in quarter car model, it is observe that although there is improvement in road handling and ride comfort as compared to the passive suspension. The LQR control method perform better in quarter car model.

[2] Addresses the analysis of control performance for a full vehicle active suspension system model via Controller Area Network (CAN) using LQR technique, the system is simulated with True Time toolbox and the system performance is analysed by varying CAN data speed, CAN loss probability, nodes sampling time, clock drift and scheduling techniques. The result shows that the real time performance of the system is very well and meet the system requirement.

[3] Design linear Quadratic Controllers for a system with inverted pendulum on a mobile Robot. The research shows that, by manipulating the state/control weightings and noise covariance matrices properly both LQR and LQG are capable of controlling the system successfully. Although LQR offer better response compared to LQG, (LQG controller has an externally injected noise).

[4] A MATLAB/SIMULINK 7 degree of freedom (7DOF) model of full car is developed, the detail of mathematical modeling with formation of state space matrix were presented. The ride comfort and vehicle handling were analyzed at various vehicle speed. The results shows that, the effect of bump of same amplitude nearly has effect on pitch angle and roll angle.

[5] Presented a full vehicle model with seven degree of freedom (DOF) based on active suspension control. An optimal control theory approach is apply on LQG controller design by using Analytical Hierarchy process (AHP) to select the weighted coefficients of performance indexes. The simulation result shows that the system performance is improved, compared to the passive suspension.

[11] An optimal law is developed for active suspension by the states prediction of a nonlinear quarter car model to show the importance of the nonlinear

characteristics effect of vehicle components. The states of quarter car model are first predicted by Taylor series expansion and then a control law is introduced by minimizing the local differences between the predicted and desired states. In this way, the well-defined skyhook linear model is selected as the reference model to be tracked by the nonlinear optimal controller. In order to decrease the vertical accelerations and improve the behaviour of the reference model, the sky hook model is controlled beforehand by the LQR method. Derived control law has an analytical form which is easy to apply. The simulations show that under the proposed controller, the car has well passenger comfort and safe manoeuvrability. Result from the study shows that the proposed control law minimized the states tracking errors and led to a special case of feedback linearization, shows good performances, through time simulation performed on a nonlinear model. Hence this new active strategy exhibits significant improvements on the achieved performances. Moreover, proposed controller compared to passive suspension. The simulations suggest that the proposed controller is an excellent option for active suspension system.

A method of fault detection and identification (FDI) of an actuator fault and reconfiguring the controller in order to maintain the ride comfort and vehicle performance in the presence of road disturbances is presented, where the proposed scheme consists of a diagnosis module and a controller reconfiguration module [16]. The diagnosis module is based on the Unknown Input Observer approach to detect and identify actuator faults. A bank of observers is designed to generate residual signals such that each of them matches the system in a defined actuator fault mode. The controller reconfiguration module consists of a bank of controllers, each corresponding to a fault mode of the system. The module then changes the control law after the detection and the identification of an actuator fault. Simulation results show that the fault-tolerant strategy preserves the stability and performance properties of the active suspension system during actuator outage. Further work on general actuator faults in active suspension systems, including loss of effectiveness and lock in place types of faults is suggested.

A composite nonlinear feedback control consisting of a linear feedback law and a nonlinear feedback law without any switching element for a class of linear systems with actuator nonlinearities is proposed. The linear feedback part is designed to yield a closed-loop system with a small damping ratio for a quick response, while at the same time not exceeding the actuator limits for the desired command input levels. The nonlinear feedback law is used to increase the damping ratio of the closed-loop system as the system output approaches the target reference to reduce the overshoot caused by the linear part. It is shown that the proposed technique is capable of beating the well-known time-optimal control in the asymptotic tracking situations. The application of such new technique to an actual hard disk drive servo system shows that it outperforms the conventional method by more than 30%. The technique can be extend to systems with multiple control inputs and multiple controlled output with measurement feedback [21].

The Takagi–Sugeno (T–S) fuzzy model approach is adapted in [9] with the consideration of the sprung and the unsprung mass variation, the actuator delay and fault, and other suspension performances. By the utilization of the parallel-distributed compensation scheme, a reliable fuzzy $H\infty$ performance analysis criterion is derived for the proposed T–S fuzzy model. Then, a reliable fuzzy $H\infty$ controller is designed such that the resulting T–S fuzzy system is reliable in the sense that it is asymptotically stable and has the prescribed $H\infty$ performance under given constraints. The existence condition of the reliable fuzzy $H\infty$ controller is obtained in terms of linear matrix inequalities (LMIs). Finally a quarter vehicle suspension model is used to demonstrate the effectiveness and potential of the proposed design techniques. Simulation results have clearly demonstrated that the designed reliable fuzzy controller has the capability of guaranteeing a better suspension performance under sprung and unsprung mass variations, actuator delay, and fault.

[19] Describes the analysis and comparison of a vehicle suspension semi-active controller to a nonlinear passive system. The mathematic model of a suspension system has seven degrees of freedom in order to represent a full vehicle system. The two semi-active control laws used in this work are based on the skyhook theory. In the first one the damping coefficient is continuously variable (semi-active

CVD) and, in the second one the damping coefficient can assume a maximum or a minimum value (semi-active ON-OFF). To analyse the systems, a program was developed using SIMULINK computational tool. This program is capable of evaluating different aspects of vehicle suspension systems. The work explains the importance of considering the nonlinear behaviour of passive systems elements and the results demonstrate that an alternation of better performance exists between the systems: - nonlinear passive, semi-active ON-OFF and semi-active CVD for the passenger security and comfort, except to the roll movement, one semi-active control law (ON-OFF or CVD) presented a better performance than the nonlinear passive system.

A robust adaptive sliding mode controller that is capable of tracking the performance of a suspension system is propose by [8] with the aim of reducing the effect of uncertainties in the behaviour of system parameters and external disturbances on the system performance. An adaptive sliding mode controller was successfully designed based on the robust designing method of adaptive sliding mode controller and Lyapunov stability theory. Numerical simulation base on quarter car suspension system model shows that, the proposed control method could reduce the body acceleration to a large extent by adjusting the adjustable gain of parameter estimation to estimate the unknown upper bound of the uncertainties, It has good dynamic response, high tracking performance and the adaptive algorithm is simple and easy to realize good adaptability, robustness against the parameter variations and external disturbances that can come into the system. Furthermore, a smooth version of the adaptive sliding mode controller is used to reduce the control chattering. The results indicate the efficiency of adaptive sliding mode control over the conventional non-adaptive sliding mode control in the presence of model uncertainties and external disturbances.

[23] Presented a scheme for identifying the time profile of actuator faults that may affect a robot manipulator using two different methods, fault detection and isolation (FDI) based on generalized momenta and fault identification through the $H\infty$-design of a state observer for uncertain systems. For each separate fault channel,

the identifier consists of a linear filter driven by the corresponding residual signal. Under the weak assumption of bounded time derivative for the otherwise unknown fault input to be identified, the fault estimation error is shown to be ultimately uniformly bounded, with ultimate bound that can be set arbitrarily small. The information on the type and severity of the fault may then be used for reconfiguring the control strategy .The proposed fault identification scheme has been experimentally tested on the Quanser Pendubot, a 2R planar robot moving under gravity, with the first joint driven by a DC motor and the second joint passive.

A hybrid suspension was proposed to foster the flexibility of modern mechatronic suspension systems by adapting the dynamic behaviour of the suspension to the driving state of the vehicle, to achieved significant performance in terms of ride comfort and ride safety without violating suspension travel limits, also an adaptive control concepts capable of exploiting the performance potential of mechatronic vehicle suspensions was presented in [24]. In the analysis two different estimators were presented and compared to an Extended Kalman filter as a benchmark in terms of estimation quality, to determine the vehicle’s driving state and to implement the state feedback based suspension controllers. The first estimator consist of parallel Kalman filters and a damper force estimator to take care of the nonlinearity characteristics of the damper. The second estimator uses a filter based concept that is suitable for determining the damper velocity and the dynamic wheel load. The result shows that both concepts offer excellent estimation performance with respect to the Extended Kalman filter and the estimation techniques. Furthermore, the potential of adaptively controlled fully active suspensions with a switching adaptive suspension control concept that dynamically interpolates between different optimal controllers according to the dynamic wheel load and the suspension deflection was analyse. The result shows the controlled suspension system including the nonlinear damper characteristic is stable for arbitrary fast adaptation of the controller parameters base on a quarter vehicle test rig using quadricycle suspension. The analysis and the experimental validations clarify the improved and realizable performance of mechatronic suspension systems under the proposed adaptive suspension control techniques and the hybrid suspension system to be more advantageous over fully active suspension systems.

A system for actuator and sensor fault detection is accomplished by evaluating any significant change in the behaviour of the vehicle with respect to the fault-free behaviour, which is estimated by using observers [14]. Experiments was conducted with an autonomous to collect input–output data in many different conditions. Actuator fault detection has been implemented for stuck actuator type failure; the effectiveness of the proposed approach is demonstrated by means of experimental results and simulations. Five different sensor failure types have been considered. ‘‘Hard’’ failures (zero or constant sensor output) are easily detected by the fault detection system in short time, Outlier data sensor failures, typical of GPS receivers, are also easily detected while ‘‘Soft’’ failures (sensor output with additive or multiplicative error) are detected depending on the error size, small errors cannot be distinguished from noise. This can be combined with GPS signal quality measures that are reported by many GPS receivers to improve position estimation reliability.

A new technique of enhancing the performance of an active fault tolerant control system was proposed based on a modified recovery/trajectory control system in which a reconfigurable reference input is considered when performance degradation occurs in the system due to faults in actuator dynamics, with reducing energy spent to achieve the desired closed-loop performance [13]. Classical fault accommodation methods were considered to design the fault tolerant controller with an appropriate recovery/trajectory control reference input to provides the fault accommodation controller with the capabilities to simultaneously reach their nominal dynamic and steady-state performances and to preserve the reliability of the components. Applying this method to the well-known three-tank system example gives encouraging results. Future work will concern the theoretical definition of the optimal impulse response for flatness control in the FTC framework.

PID and Fuzzy logic techniques are used to control the suspension system four degrees of freedom half body vehicle suspension system is shown and the road roughness intensity is modeled as a filtered white noise stochastic process [7]. Two fuzzy logic controllers for a MIMO system was designed and analyze. The results indicated that, the fuzzy control approach does not cause any degeneration in suspension working limits, while it improves ride comfort and the vehicle body and pitch motion reach zero reference values much faster and more comfortable compared to PID controlled ones. Therefore, the proposed active suspension system is very effective in vibration isolation of the vehicle body, which indicates that the proposed controller proves to be effective in the stability improvement of the suspension system.

Actuator and sensor faults were address in [12].It shows that, provided the system is still observable a complete loss of a sensor can be overcome by compensation method. Because, after the loss of a sensor, the observability property allows the estimation of the lost measurement using the other available measurements. However, when there is a complete loss of an actuator; in this case, the controllability of the system should be checked. Very often, only a hardware duplication is effective to ensure performance reliability. The necessity of developing FTC and FDI was presented based on the fault detection, the fault isolation, the fault estimation, and the compensation for the fault effect on the system. All these steps are taken into consideration. If the fault using all the sensors and actuators, a method based on adding a new control law to the nominal one is described in order to compensate for the fault effect. For actuator faults, the objective of the new control law is to boost the control inputs in order to keep the performance of the faulty system close to the nominal system performance. Regarding sensor faults, the additive control law aims at preventing the total control inputs from reacting when these faults occur. In case of a major fault in the system, such as the loss of an actuator, the consequences are more critical. This case is analyzed and the system should be restructured in order to use the healthy actuators and to redefine the objectives to reach. Therefore, the system will perform in degraded mode.

A least means squares LMS adaptive controller was propose for two-degree-of-freedom vehicle suspension model by [20]. The least means squares LMS adaptive filter algorithm was used in active suspension obtained. For two-degree-of-freedom vehicle suspension model, LMS adaptive controller was designed. The LMS adaptive control suspension was compared with passive suspension base on the acceleration of the sprung mass ,the dynamic tire load between wheels and road ,and the dynamic deflection between sprung mass and unsprung mass were determined as the evaluation targets of suspension performance. The simulation results of the three evaluation indexes in the stimulation of random road signal verify that the LMS adaptive control strategy may largely improve the performances of the suspension system the LMS adaptive control strategy has better control result , its calculation of control algorithm is much less, simple, effective, fit for active control of the suspension system and is a foundation to further approach to vehicle active suspension.

[22] Propose a modification to the adaptive diagnostic algorithm to enhance robustness. Two observers, a fixed detection observer and an adaptive diagnostic observer are constructed separately to detect and diagnose the fault, under the assumption that the observer gain matrix can be selected such that the resulting observation error system is SPR, it has been shown that the adaptive diagnostic algorithms can both give a desired dynamic performance for fault diagnosis. The selection of the threshold for fault detection was presented and its minimum value formulated. The simulated results is applicable and encouraging.

1.4 Problem Statement

Actuator control system is inherently nonlinear associated with road induce disturbance vibration and suspension deflection. It becomes challenging to design a reliable controller such that the stability and performance of the active suspension close-loop system can be tolerated in the presence of different road profile. Hence, the ability to automatically recognize the occurrence and the nature of road disturbance is a prerequisite for the design of actuator fault control strategies with active reconfiguration. In the presence of a generic fault, three phases can be considered: detection, isolation, and identification.

1.5 Objectives

The objectives of this project are:-

i. To study the behavior of a full car active suspension system under different input disturbance.
ii. To analyse the mathematical models of the passive and active suspension system of the full car model.
iii. To design an LQR controller that will be able to overcome the effect of the injected disturbance.
iv. To investigate and validate the performance of the proposed controller using LQG controller.

1.6 Scope of Study

The scope of this project is limited to:-

i. A study of linear and nonlinear control laws.
ii. Study road disturbance and actuator fault in a full car suspension system.
iii. Design LQR and LQG controllers.
iv. Simulate and compare active and passive suspension system of a full car model, using MATLAB/Simulink software.

1.7 Research Methodology

a) To identify and understand different types of actuators.
   i. Literature review on actuator.
   ii. Literature review on actuator fault control.

b) To understand and identify active and passive suspension component
   (i) Literature research on active and passive suspension.
   (ii) Literature research about control strategy.

c) 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 and getting the equation for a full car model.
   (ii) By obtaining the state space equation from the full car model equations.

d) Implement LQR controller into the system: -
   (i) Literature review on the control technique.
   (ii) Use LQR to compare output performance with passive suspension.

e) Implementing LQG controller into the system: -

(i) Literature review on the control technique.

(ii) Use LQR to compare output performance with passive suspension.

f) Computer simulation: -

(i) Involves transform state space equation into Simulink block.

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

g) Validation: -

(i) Comparing the simulation results of LQR, LQG and passive.

(ii) Validate the result obtained by using the propose controller.

Flow chart in Figure 1.7 shows overall process for the project research.

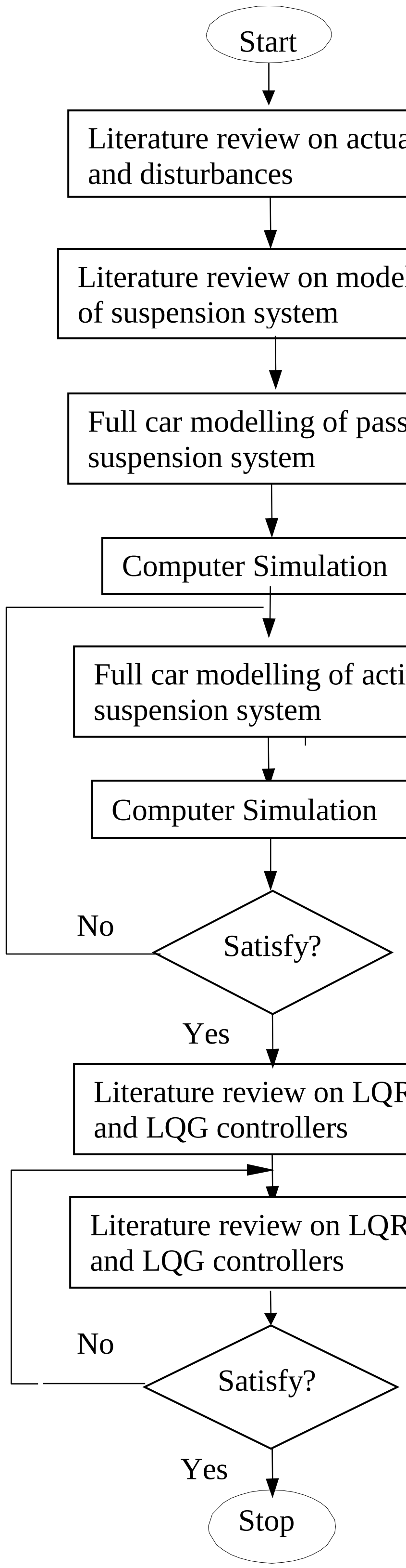


Figure 1.8: Flow Chart for Methodology

1.8 Report outline

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.

The mathematical modelling of active and passive suspension system for a full car model are explained in chapter 2. Mathematical model described the behaviour 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 and LQG controllers.

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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