DEVELOPMENT OF AN AUTOMOTIVE SUSPENSION SYSTEM USING ACTIVE FORCE CONTROL

ABDUL HALIM MUHAIMIN

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ABSTRAK

Kajian ini dilakukan bagi menyelidiki ciri-ciri sambutan dua darjah kebebasan sistem gantungan kenderaan dengan kawalan daya aktif (*AFC*) sebagai elemen kawalam utama. Ciri-ciri sambutan dihubungkaitkan dengan keselesaan penumpang dan kebolehkawalan sesebuah kenderaan. Kedua-dua kaedah iaitu kajian simulasi dan eksperimen telah dilakukan bagi mencapai matlamat ini. Dalam kajian simulasi, dua kaedah kawalan sistem gantungan aktif telah dikaji dan dibuat perbandingan yang melibatkan penggunaan kawalan klasikal *PID* bersama *continuous skyhook* dan *AFC* dengan kaedah *iterative learning* (*ILM*) dan *fuzzy logic* (*FL*). Kebolehan kawalan *AFC* bertindak sebagai satu sistem yang lasak telah dibuktikan.Gangguan permukaan jalan yang sesuai dan keadaan bebanan lain dimodelkan dan diujakan kepada sistem bagi menguji ketahanlasakannya sistem berkenaan. Keputusan daripada simulasi menunjukkan sistem gantungan aktif menggunakan pengawal *AFC* dengan *FL* adalah terbaik dari segi anjakan dan pecutan jisim badan, daya dinamik tayar, ruang fungsi gantungan, daya hidraulik aktuator dan selisih laluan. Dalam kajian eksperimen, sebuah prototaip gantungan yang bersais kecil telah dibina dan diuji. Prototaip dibangunkan menggunakan perisian *MATLAB/SIMULINK* dengan *Real Time Wokshop* (*RTW*) yang dihubungkan dengan kad antara muka melalui sebuah komputer peribadi (*PC*) sebagai pengawal utama. Keputusan-keputusan eksperimen yang didapati menentusahkan kebolehan pengawal *AFC* sebagai pengawal gantungan aktif yang lasak berbanding dengan sistem kawalan lain yang dipertimbangkan.

ABSTRACT

This research was carried out to investigate the response characteristics of a two-degrees-of-freedom (DOF) vehicle suspension system with the proposed active force control (AFC) as the main control element. The characteristics are related to the riding comfort and handling of the vehicle. Both simulation and experimental studies were accomplished in the research work for this purpose. In the simulation study, two active suspension control methods were examined and compared involving the classic proportional-integral-derivative (PID) to be used together with the continuous skyhook and AFC with embedded iterative learning method (ILM) and fuzzy logic (FL) control schemes. The potentials of the AFC schemes as robust systems are particularly highlighted. Appropriate road disturbance and other loading conditions are modelled and applied to the proposed systems to test for the system robustness. The results of the simulation study show that active suspension system using AFC with FL control show its superiority in terms of body mass displacement and acceleration, dynamics tyre load, suspension working space, hydraulic actuator force and the track error. In the experimental study, a prototype of the suspension rig was fully developed and tested. The laboratory scale physical rig was developed using the MATLAB/SIMULINK with Real Time Workshop (RTW) tool that is interfaced with a suitable data acquisition card via a personal computer (PC) as the main controller. Experimental results obtained in the study further verified the potential and superiority of the proposed AFC scheme as a robust active suspension control compared to the other schemes considered in the study.

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LIST OF SYMBOLS

SYMBOL	SUBJECT
μ	Weighting function
A	Proportional element of Iterative Learning Algorithm
AFC	Active Force Control
ASS	Active Suspension System
B	Derivative element of Iterative Learning Algorithm
C	Damping coefficient
C_{max}	Maximum damping coefficient
C_{min}	Minimum damping coefficient
C_s	Skyhook damping coefficient
DAS	Data Aquisition System
EM	Estimated mass
F_a	Actuator force
g_{vel}	Velocity gain
ILM	Iterative Learning Method
IM	Initial mass
K_d	Derivative gain
K_i	Integral gain
K_p	Proportional gain
k_s	Spring stiffness
k_t	Tire stiffness
M_b	Vehicle body mass
M_t	Wheel mass
Q	Actuator gain
RTW	Real Time Wokshop

S_k	Value of the estimated parameter
S_{k+1}	Next step value of the estimated parameter
TE_k	Position track error
V_{rel}	Relative velocity between body mass and wheel
y^*	Crisp output value
Z	Displacement
$\dot{Z}$	Velocity
$\ddot{Z}$	Acceleration

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CHAPTER I

INTRODUCTION

1.1 General Introduction

Since the development of the vehicle suspension system, designers have been faced with the conflict of vehicle safety versus ride comfort. Originally, this trade-off was minimized by the single optimal adjustment of a passive spring and damper. In more recent years, the development of computer-controlled suspension dampers and actuators has increased the investigation of the vehicle safety versus ride comfort trade-off, and has led to the development of numerous active and semi active suspension control designs [1].

Passive suspension system consists of conventional spring and damper with the parameters related to the stiffness and damping typically fixed and cannot be changed by external signal. In view of the conflicting requirements of the suspension and the fact that the vehicle has to operate over a wide range of conditions, there should be a compromise in choosing the spring stiffness and damping parameters. In other words, it is desirable that the above parameters could be made to change with the operating and loading conditions such that the vehicle performance particularly concerning the riding comfort can be improved. This situation leads to a class of suspension system usually known as semi-active system where the parameter of one of the main components (usually the damper) can be made to vary in order to appropriately accommodate the corresponding change in the system interaction with the environment. Another useful method is to introduce an external energy to the conventional passive suspension system in the form of an actuating force coupled with a closed loop (feed back element) incorporated into the system. This physical layout contributes to the so-called active suspension system which has shown some positive signs and promises in terms of its practicality and feasibility as can be seen from a number of research works in this area [2,3,4]. The performance of the system can be further improved with the introduction of intelligent element into the system. Thus, the potential of an intelligent active suspension system with the ability to avoid the compromise as mentioned earlier is clear and evident.

In this research project, the vehicle ride comfort trade-off is studied through a simulation study based on the response of the vehicle model due to passive suspension with open-loop configuration and later compared with the response due to a number of active suspension with closed-loop control schemes. The proposed control strategy for the active suspension system uses an active force control (AFC) method which has been shown to be very robust and effective in countering parameter uncertainties and disturbances [5]. Intelligent elements are also employed with the AFC scheme based on the iterative learning method (ILM) and fuzzy logic (FL). An experimental study was also carried out using a developed laboratory scaled model of an active suspension rig controlled by a personal computer (PC) with suitable a software and hardware interface.

1.2 Objective of Study

The main objective of this research work is to investigate the response characteristics of a quarter car model representing a class of passenger vehicle using passive spring and damper suspension system and active control methods. Both the simulation and experimental responses were studied in this research. The responses obtained could serve as a preliminary findings into the potential application of the proposed active suspension control to the real automotive system.

1.3 Scope of Study

The scope of this study encompasses the computer modelling, simulation and experimental studies of an automotive suspension system. A quarter car model is considered when deriving the equations of motion representing the dynamics of the system. The methods used in the simulation work (apart from the passive method) include the continuous skyhook control with proportional-integral-derivative (PID) element, active force control (AFC) strategy with iterative learning method (ILM) and active force control strategy with fuzzy logic (FL) control. In the experimental study, a fully functional laboratory scaled model of the suspension rig fitted with suitable sensory and actuating devices will be designed and develop to complement the theoretical and simulation study performed earlier. A comparison of the response of the passive method, PID control and AFC plus PID (with crude approximation technique) will be made for the experimental work. Only the vertical displacements constituting a two degrees-of-freedom (DOF) system is assumed in the study. This represents the movement of the sprung mass (car body) and the unsprung mass (tyre). Road disturbances in the form of a ‘bump and hole’ and sinusoidal road surface are to be modelled and practically developed to test for the robustness of the system.

1.4 Research Approach

The research is initiated by deriving the mathematical model of the main dynamic system, i.e., the vehicle quarter car model suspension, using the classic *Newtonian* mechanic. The model used is a two DOF system representing a class of a passenger car. It is assumed to be excited by disturbance forces exerted directly on the vehicle body or those generated by the road surface condition to the wheel (tyre) via a spring and damper mechanism. Again, the disturbances were modelled mathematically taking into account a number of assumptions. A number of control schemes were also developed and modelled. These schemes include the PID with skyhook method and AFC technique employing both crude estimation and intelligent mechanisms (to estimate the inertial parameter necessary for the AFC method). The latter scheme (AFC method) is the focus of the research project which is largely based on the measured and estimated parameters and that it is practical to realize [5].

Based on the derived models, a simulation study using MATLAB and SIMULINK was then rigorously carried out, first considering the passive suspension system with open-loop response and later the closed loop control active suspension system. The results of the simulations were then compared for both the passive and active systems and later assessed quantitatively in terms of the three parameters which are deliberately chosen to represent each of the conflicting requirements of the suspension system. These parameters are the discomfort parameter related to the acceleration of the system, suspension working space (SWS) and dynamic tyre load [6].

A prototype of the proposed system was designed and developed involving the integration of mechanical, electrical/electronics and computer (software programming) control disciplines. Hence, the research adopts a complete mechatronics approach towards realizing the prototype of the proposed system. The SIMULINK with Real Time Workshop (RTW) facility interfaced with suitable data acquisition card will be fully exploited in the study. In the experimental study, the road disturbance was considered as a sine wave function generated from a rotating cam of suitable profile. Here, due to time constraint, the parameter of interest to be assessed is the vehicle body displacements relative to road surface produced by the suspension systems with different modes of control.

1.5 Outline of Masters Project

The necessary component for achieving objective of the study are given in the succeeding chapters. Theoretical information and literature review related to the project background are given in Chapter 2. This includes the description of the different types of vehicle suspension systems. In particular, the concept of passive, semi active and active suspension systems is explained. The mathematical models of the suspension systems based on the equations of motion are presented here. The active suspension control methods used in the research is discussed in greater detail

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