OPTIMIZATION AND CONTROL OF SEMI-ACTIVE SUSPENSION SYSTEM FOR OFF-ROAD VEHICLES

BY

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A thesis submitted in fulfilment of the requirement for the degree of Doctor of Philosophy in Engineering

Kulliyyah of Engineering
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DECEMBER 2014

ABSTRACT

This study evaluates the dynamic response of three semi-active control policies as analyzed on a several off-road models. Two-axle 7DOF, three-axle 9DOF and four-axle 11DOF full vehicle system was developed to evaluate skyhook, groundhook, and hybrid controls. As well as exploring the relative benefits of each of these controllers, the performance of each semi-active controller was compared to the performance of conventional passive system. Each control policy is evaluated for its control performance under three different base excitations: step, bump and random. Corresponding to the bump and random inputs, peak-to-peak, RMS and frequency responses are considered for each control policy along with passive system. Specifically, sprung mass (heavy, pitch and roll acceleration), suspension and tire deflection. A comparison between different suspension systems were examined using half vehicle model and step input used to generate the time domain values of settling time and PTP acceleration for hybrid control policy and compared to fully active and passive systems using two-axle half vehicle model. Furthermore, Due to the importance of ride comfort for off-road vehicles, minimizing the peak-to-peak of the vertical, pitch and roll acceleration and reducing the settling time would lead to better ride comfort. In solving this problem, the step input was used for the optimization of a two-axle full vehicle's semi-active suspension system parameters with respect to ride comfort and handling. Genetic algorithm optimization technique is developed and used. Step input also used to generate the time domain and frequency domain responses of the four-axle full vehicle model. Reponses of sprung mass, suspension and tired deflection are obtained. Results of this study show that semi-active control offers benefits beyond those of conventional passive system. Further, traditional skyhook control is shown to be better in improving the vehicle body acceleration PTP, RMS and PSD responses. The groundhook control is shown to be better in controlling the tire deflection. Hybrid as a combination of both control policies skyhook and groundhook, shows to be better compromise in improving ride comfort and handling of the vehicle compared to passive system in all cases. Result shows also, that GA has consistently found near-optimal solutions within specified parameters ranges for several independent runs. Ride comfort improved without reducing the handling of the vehicle.

ملخص البحث

هذه الدراسة بتقييم الاستجابة الديناميكية لثلاث سياسات السيطرة شبه النشطة وتحليلها على عدة نماذج على الطرق الوعرة .وقد وضعت محورين DOF7 ، ثلاثة محاور DOF 11 نظام السيارة بالكامل DOF-9 وأربعة لتقييم المحور skyhook، groundhook، والتحكم الهجين hybrid.وكذلك استكشاف مزايا النسبية لكل من وحدات التحكم هذه، تمت مقارنة أداء كل وحدة تحكم شبه النشطة لأداء النظام السلبي التقليدية .يتم تقييم كل سياسة مراقبة لأداء سيطرتها تحت ثلاثة الإثارات قاعدة مختلفة: الخطوة، وعثرة وعشوائي .وتعتبر المقابلة لعثرة ومدخلات عشوائية، من الذروة إلى الذروة، RMS والردود تردد لكل سياسة التحكم جنبا إلى جنب مع نظام السلبي . على وجه التحديد، انتشرت الشامل (الثقيلة، والملعب وتسريع لفة) والتعليق وانحراف الاطارات .تم فحص مقارنة بين أنظمة التعليق المختلفة باستخدام نصف نموذج السيارة، تم استخدام الخطوة مدخلا لتوليد القيم نطاق الوقت لتسوية الوقت وتسارع PTP لمدة نصف مركبة لسياسة مكافحة الهجين وبالمقارنة مع أنظمة نشط بشكل كامل والسلبي باستخدام نصف محورين نموذج السيارة . وعلاوة على ذلك، فإن ونظرا لأهمية الراحة للمركبات على الطرق الوعرة، والتقليل من ذروة إلى ذروة العمودي، في الملعب وتسريع لفة وتقليل الوقت تسوية تؤدي إلى تحسين راحة الركوب .في حل هذه المشكلة، تم استخدام الخطوة مدخلا لتعظيم الاستفادة من شبه النشطة المعلمات نظام تعليق السيارة بالكامل لمدة المحور فيما يتعلق ركوب الراحة والمناولة، وكان يستخدم تقنية خوارزمية الجينية .الخطوة مدخلات تستخدم أيضا لتوليد المجال الزمني والردود نطاق تردد من نموذج السيارة كاملة مدتها اربع المحور .الهجين كما مزيج من الاثنين معا سياسات مكافحة سكهووك وgroundhook، ويظهر أن يكون حل وسط أفضل في تحسين راحة الركوب والتعامل مع السيارة بالمقارنة مع نظام السلبي في جميع الحالات .يظهر نتيجة أيضا، أن GA وقد وجدت باستمرار الحلول شبه الأمثل ضمن المعايير المحددة نطاقات لعدة أشواط مستقلة .تحسين راحة الركوب دون التقليل من التعامل مع السيارة.

APPROVAL PAGE

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that is has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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Signature	Date

To my beloved wife, Nabila Selmani, and My lovely daughter, Fatima

For their love and company

To my father, Massoud benlahcene and mother Samta benlahcene

To my beloved brother Badrane for his support

To all my brothers and sisters

May Allah bless and grant upon them mercy

In this world and hereafter

ACKNOWLEDGEMENTS

First and foremost, gratitude and appreciation are for Allah, the Most Merciful and Most Compassionate for granting me a precious opportunity to complete this work and granted me health and strength.

I would like to gratefully thank my supervisor, Prof. Dr. Waleed Fekry Faris for this scholarly guidance and effort in assisting me in this work. Truly this work shall not be completed without his continuous encouragement and support.

I would like to thank my co-supervisor, Dr, Sany Izan Ihsan and post-viva supervisor, Dr, Mohammed Ataur Rahman for their assistance and guidance.

Not to forget also my colleagues at the Vehicle Dynamics Lab Faried Hasbullah, Hamza Baali and Ahmed Becir, also to all academic and non-academic staff for their assistance during the period of my study.

Last but not least, I owe the greatest debt of gratitude to my beloved parents, wife and family. It would surely be impossible for me to complete this work without their love, support and prayers.

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LIST OF ABBREVIATIONS

CG	Center of gravity
DOF	Degree-of-freedom
F-car	Full-car
Q-car	Quarter-car
PTP	Peak-to-Peak
RMS	Root mean square
ER	Electro-rheological
MR	Magneto-rheological
EH	Electrohydraulic
FLC	Fuzzy logic controller
FPID	Fuzzy-PID
NFC	Neuro-Fuzzy Controller
GA	Genetic algorithm
ISO	International Organization for Standardization
LQR	Linear quadratic regulator
NF	Neuro-Fuzzy
PID	Proportional-integral-derivative
PSD	Power spectral density
DFT	Discrete Fourier Transform
FFT	Fast Fourier Transform
SA	Semi-active
SAHC	Semi active hybrid controller

LIST OF SYMBOLS

C_{gnd}	Ground-hook damping
C_{sky}	Skyhook damping
F_{sky}	Skyhook damping force
F_{sa}	Semi-active damping force
m_u	Sprung mass
m_s	Unsprung mass
t_s	Settling time
t	Time
V_{21}	Relative velocity
ω_n	Natural frequency
ω_{input}	Frequency input
ω_{ms}	Frequency for sprung mass
ω_{mus}	Frequency for unsprung mass
$x(t)$	Displacement
α	Relative ratio
v	Vehicle velocity
τ	Time delay between two consecutive axles
$z_r(t)$	Road profile
$w(t)$	White noise signal
$S_g(\Omega_0)$	Road roughness

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

The purpose of this chapter is to provide an introduction showing the overview of this research. At the beginning of this chapter, the motivation of the research described, followed by the problem statement and research philosophy. Then, the determined objectives and the scope of the research explained. The scope is planned based on the objectives. The chapter ended with the thesis organization.

1.2 MOTIVATION

Off-road vehicle is a term refers to any type of vehicles which is able to drive on/off paved surface in different environment such as; military, agriculture and commercial heavy vehicles. Driver of these vehicles are exposed with high level of vibrations transmitted from the uneven road surface, this harms the health and physical condition of the driver. Under these circumstances, it is important to improve the ride comfort and ride safety of off-road vehicles. This improvement can be achieved by using advanced suspension system. Ride quality or sometime called ride comfort, can be defined as how a vehicle responds to road conditions or inputs other than its occupant. Its primary concern is on how this response affects the vehicle occupants. The ride quality concept sweeps over many disciplines in automotive engineering. The vehicle parameters such as suspension spring stiffness and damping coefficient, the temperature control inside the cabin, the ergonomics of the car, and many other factors contribute to this quality. In action, vehicles flounce an extensive range of vibrations that can be sensed by the driver. The causes of the excitation for these vibrations can be road roughness, tire assembly, driveline excitation, engine excitation, aerodynamic forces, and transmission excitation. Usually, road roughness will be the major source that excites the vehicle body through tire assembly and suspension system (Wong, 2001). Other sources give less because of their own design that their vibrations will be transmitted through longer paths until it reaches the inhabitant.

In general, the spectrum of vibrations is divided into two main categories. First is ride, these ranges from 0-25 Hz and noise which ranges from 25-20,000 Hz (Gillespie, 1992). Unfortunately, the main tests for ride quality have been subjective and objective testing is not yet developed in a standardized way. The main three areas of research in ride quality are: human response to vibration, vehicle response to excitation, and methods of testing and evaluating the ride quality. Articulated vehicles were surveyed by (ElMadany et al., 1979) and (Jiang et al., 2001) reviewed ride quality for heavy vehicles. A comprehensive review of heavy truck ride was given by (Gillespie, 1985), and literature on suspension design for heavy road vehicles by (Cole, 2001). The suspension system is the main element in the vehicle to achieve ride comfort and drive safety for a vehicle. The design of passive suspensions focused on obtaining a good compromise between these two targets ride comfort and vehicle handling, but the limitations of the passive structure prevent it from achieving the best performances for both goals. Fully active and semi-active suspension systems can improve driver and passengers comfort perceptions during various driving conditions, achieving a better compromise than the passive suspensions. The key feature of these systems is the generation of a control force in the active case, the variation of one or more parameters of the main suspension in the semi-active setting. A fully active