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# ACTIVE DISTURBANCE REJECTION CONTROL FOR ACTIVE SUSPENSION SYSTEM

BY

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# ABSTRACT

A vehicle suspension system is the main component in a ground vehicle that functions to achieve good ride comfort by isolating vibration of the road from the passenger. Active suspension system has the capability to continuously adjust itself, hence has a better design trade-offs compared to a conventional suspension system. Active disturbance rejection control (ADRC) is a relatively new control method and has not been thoroughly investigated in the area of ride comfort and advanced automotive suspension. In this thesis, ADRC with and without input decoupling transformation (IDT) is proposed to improve the ride quality performance of a vehicle with active suspension system according to several performance criteria: minimizing vehicle body accelerations, suspension working space, and road holding. Three vehicle models: quarter-car, half-car, and full-car model were used in this thesis. The models used in the analysis were limited to discrete models which break down the vehicle model into lumped systems. Through experimental simulation studies, the ability of the proposed controllers to cope with varying process is investigated. The optimized controllers are then compared to an ideal skyhook control to benchmark the performance. Results show that ADRC-IDT was able to produce comparable performance to a typical ADRC control structure, but with less number of control parameters. Both controllers were able to significantly reduce vehicle body acceleration while maintaining other responses. Furthermore, On the whole, it is shown that the performance of the optimized ADRC and ADRC-IDT is close to the performance of an ideal skyhook control especially for the sprung mass vertical acceleration which is the main indicator of vehicle ride comfort.

# خلاصة البحث


نظام التعليق هو المكون الرئيس في السيارة والذي يعمل على تحقيق راحة الجلوس الركاب من خلال عزل الاهتزاز الناشيء عن الطريق. نظام التعليق النشط لديه قدرة على الضبط الذاتي باستمرار، ولذلك له تصميم أفضل من الأنظمة شبه النشطة والسلبية. "Active Disturbance Rejection Control (ADRC)" هو طريقة جديدة نسبيا للتحكم ولم يتم التحقق من فعاليتها بالكامل راحة الجلوس ونظم التعليق المتقدم في السيارات. تقترح هذه الدراسة "ADRC" و "ADRC" مع "Input Decoupling Transformation" (ADRC- IDT) لتحسين راحة الجلوس في السيارة ذات نظام التعليق النشط وفقا لمعاييرأداء متعددة منها :التقليل من تسارع جسم المركبة وانحراف التعليق والإطارات. استخدمت ثلاثة نماذج من المركبات: نموذج ربع السيارة ونصف السيارة ونموذج السيارة بالكامل في هذه الدراسة. جرى التحقيق في قدرة وحدات التحكم المقترحة للتعامل مع حالات مختلفة من خلال دراسات تجارب المحاكاة. ثم تمت مقارنة وحدات التحكم الأمثل ( باستخدام الخوارزمة الجينية) لعنصر التحكم "ideal skyhook" لقياس الأداء. وتشير النتائج إلى أن نظام "ADRC-IDT" كان قادرا على انتاج أداء مماثل لـ "ADRC" مع عدد أقل لبارامترات التحكم. كل من بارامترات التحكم كانتا قادرتين على خفض تسارع جسم المركبة مع الحفاظ على بقية الاستجابات. وعلاوة على ذلك، فإنه يظهر أن الأداء للنظامين "ADRC" و "ADRC-IDT" المثاليين قريب من أداء عنصر تحكم "ideal skyhook" خاصة بالنسبة للاستجابة التسارع العمودي لجسم المركبة الذي هو المؤشر الرئيسي للراحة أثناء ركوب السيارة.

# APPROVAL PAGE

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# DECLARATION

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

Faried Bin Hasbullah

Signature…………………. Date …..................

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*Dedicated to my parents, Hasbullah Bin Ali and Sa'diah Binti Ngador for laying the strong foundation of what I turned out to be in life.*

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ADRC | Active Disturbance Rejection Control |
| ADRC-IDT | Active Disturbance Rejection Control with Input Decoupling Transformation |
| DOF | Degree-of-freedom |
| ESO | Extended State Observer |
| GA | Genetic algorithm |
| IDT | Input Decoupling Transformation |
| LQR | Linear quadratic regulator |
| PID | Proportional- integral-derivative |
| PD | Proportional- derivative |
| PTP | Peak-to-peak |
| RMS | Root-mean-square |
| SAS | Stability Augmentation Systems |

# LIST OF SYMBOLS

| | |
|---|---|
| $F_s$ | Spring force |
| $F_d$ | Damping force |
| $F_a$ | Actuator force |
| $m_u$ | Sprung mass |
| $m_s$ | Unsprung mass |
| $t_s$ | Settling time |
| $t$ | Time |
| $\omega_n$ | Natural frequency |
| $x(t)$ | Displacement |
| $\alpha$ | Relative ratio |
| $\vartheta$ | Pitch angle |
| $\Phi$ | Roll angle |
| $v$ | Vehicle velocity |
| $\tau$ | Time delay between front and rear axles |
| $x_s$ | Sprung mass displacement |
| $x_u$ | Unsprung mass displacement |
| $x_r$ | Road disturbance |
| $w(t)$ | White noise signal |
| $S_g(\Omega_0)$ | Road roughness |

# CHAPTER ONE

# INTRODUCTION

## 1.1 BACKGROUND

Ride comfort is one of the primary criteria in evaluating the performance of a ground vehicle. When a vehicle travels across a rough surface, the disturbance, or the vibration from the surface impacts ride comfort in a negative way. A vehicle suspension is the main part of vehicle to achieve good ride comfort by isolating the vibration caused by travelling over road disturbances from the passengers. At the same time, a vehicle suspension also functions to support vehicle weight as well as to keep good vehicle handling and contact between the tire and the road. The design of a conventional or passive suspension system has always been focused in obtaining a good compromise between these objectives. However, physical limitations prevent passive suspension from achieving the best performance for all goals. A “soft” suspension setting, for instance, facilitates a comfortable ride at the expense of increased tire motions and suspension working space as the tire has to travel further before it stops. Conversely, good road handling characteristics and smaller tire motion is an attribute of “hard” suspension setting.

Active suspension system has the capability to continuously adjust itself, hence has a better design trade-off compared to a conventional suspension system. The desired additional force in active suspension system is usually employed by pneumatic, hydraulic or electromagnetic actuators which are secured in parallel with a spring and a damper. The force generated by each actuator is controlled by the controller based on the motions of the vehicle which is received from various sensors located at different points of the vehicle.

Various control strategies have been implemented on active suspension systems such as LQR (BenLahcene et al., 2014), H-infinity control (van der Sande et al., 2013), PID (Changizi & Rouhani, 2011), and fuzzy control (Cao, Li, & Liu, 2010). Results of these studies show that active suspension systems have the potential to improve ride comfort of a vehicle considerably. However, the model of the system is usually chosen to be linear through various assumptions and approximations. The approximation may become undesirable at certain level which may cause poor control performance, particularly if the control strategy employed is a model-based that is too dependent on the accuracy of the system's analytical description (Madonski & Herman, 2011).

Although it has been in work since the late 80's, active disturbance rejection control (ADRC) was first introduced in English literature in 2001 (Gao et al., 2001; Han, 2009) and has since become an attractive control alternative for its easy applicability and good robustness against process variations (Herbst, 2013). The basis of ADRC concludes that if the external and internal disturbances of a system can be estimated in real time, then they can be cancelled out without having to know the precise model of these disturbances. Current ADRC application includes longitudinal attitude control for aircraft landing (Zhang et al., 2013), permanent magnetic synchronous motor control (Chao, Wu-bin, & Bing, 2013), vibration suppression in two-inertia systems (Zhao & Gao, 2013), flexible-joint manipulator (Kordasz et al., 2012), and tracking of electro-hydraulic servo system for active suspension system (Shi et al., 2011a). To the author's best knowledge, ADRC for improving ride comfort of a vehicle with active suspension system has not been proposed in the current literature.