ACTIVE ENGINE MOUNTING SYSTEM BASED ON NEURAL NETWORK CONTROL

BY

FADLY JASHI DARSIVAN

A thesis submitted in fulfillment of the requirement for the degree of Doctor of Philosophy

Kulliyyah of Engineering
International Islamic University
Malaysia

August 2010

ABSTRACT

In the automotive industry some components and subassemblies which were initially made of steel are now being replaced with alloys and composites which have a higher strength to weight ratio. Therefore, today's vehicles are lighter, stronger and thus have small fuel consumption. However, mounting a more powerful engine to a lighter vehicle could cause vibration induced by the dynamics of the engine and thus affecting the comfort of the passenger. One way to overcome this predicament is to modify the mounting of the engine by introducing an active engine mounting (AEM) system which consists of passive rubber mount and a linear force actuator. At the correct frequency the linear force actuator would trigger a force which has a magnitude approximately equal to the engine's disturbance force but opposite in direction. With this the force transmitted to the chassis of the vehicle would then be minimized and increases passenger's comfort. In controlling the system, especially the force actuator, numerous controllers have been introduced which include but not limited to H_2 controller, hybrid of feedback and feedforward, filtered X-LMS controller, optimal controller based on Haar wavelet and other classical feedback and feedforwad controllers. Determining the controller parameters could be a major and difficult task to perform since these parameters are based on the mathematical model of the engine-chassis system which also includes the mathematical model of the engine disturbance. In this thesis an intelligent controller namely the neural network controller has been introduced to reduce controller parameters identification. The system considered in this research includes two degree and multi degree of freedom systems. The dynamics of a nonlinear actuator was also included. Two types of neural network controller that has been used in this research namely the nonlinear auto regressive moving average (NARMA-L2) and the extended minimal resource allocating network (EMRAN). The performance of the neural network based controllers was then compared with classical controller such as PID for two degree of freedom system and a Linear Quadratic Regulator (LQR) controller for the multi degree of freedom system. The ability of the EMRAN to be trained online makes it advantageous for a non-model based controller. The EMRAN neural network has the ability to add and prune hidden layer neurons and for the purpose of efficiency and additional advantage was the adoption of the "winner-takes-all" algorithm. Results show that the EMRAN controller perform much better as compared to PID and LQR controllers for the purpose of active vibration isolation based on the reduction of the force transmitted to the chassis of the vehicle.

ملخّص البحث

اليوم المركبات هي أخف وزنا وأكثر قوة ، وبالتالي يكون صغيرة من استهلاك الوقود. ومع ذلك ، من تصاعد أقوى محرك للسيارة أخف ويمكن أن تسبب له تأثير الاهتزازات الناجمة عن ديناميات للمحرك ، وبالتالي تؤثر على الراحة للركاب. طريقة واحدة للتغلب على هذا المأزق هو تعديل المتزايدة للمحرك عن طريق إدخال محركا نشطا متصاعدة (AEM) ، وهو النظام الذي يتكون من المطاط السلبي وخطي . في وتيرة تصحيح خطية قوة المحرك من شأنه أن يؤدي إلى القوة التي يبلغ حجمها مساويا تقريبا لقوة المحرك والاضطرابات ولكن في الاتجاه المعاكس. مع هذه القوة والتي أحيلت إلى هيكل السيارة ثم سيكون أدنى حد ممكن ، ويزيد من راحة الركاب. في السيطرة على النظام وخاصة صمام القوة ، والعديد من وحدات التحكم وأدخلت والتي تشمل على سبيل المثال لا الحصر تحكم 2H ، وردود فعل مختلطة من feedforward وتصفيتها إكس إم إس تحكم ، التحكم الأمثل على أساس HAAR المويجات وغيرها من ردود الفعل الكلاسيكية وتحكم feedforwad. تحديد معايير تحكم يمكن أن تكون مهمة كبيرة وصعبة لأداء هذه المعلمات منذ تستند إلى نموذج رياضي للمحرك نظام الشاسيه الذي يشمل أيضا نموذج رياضي لمحرك الاضطرابات. في هذه الأطروحة جهاز تحكم ذكي وهي الشبكة العصبية تحكم عرضه للحد من تحكم معايير تحديد الهوية. نظام النظر في هذا البحث يشمل اثنين من درجة درجة وتعدد النظم الحرية. ديناميات صمام اخطي أدرج أيضا. نوعين من تحكم الشبكة العصبية تم استخدامه في هذا البحث وهي غير الخطية تراجعية المتوسط المتحرك (2L -NARMA) والحد الأدنى من تخصيص الموارد تمديد شبكة (EMRAN). أداء وحدات تحكم الشبكة العصبية بعد ذلك بالمقارنة مع تحكم الكلاسيكية مثل بثها على التردد اثنين درجة من الحرية والنظام الخطي من الدرجة الثانية للنباتات (LQR) للتحكم في درجة متعددة من نظام الحرية. قدرة EMRAN للتدريب على الانترنت يجعل من المفيد بالنسبة لغير نموذجية تقوم وحدة تحكم. الشبكة العصبيةEMRAN لديه القدرة على إضافة طبقة الخلايا العصبية وتقليم والمخفية لهذا الغرض من الكفاءة وميزة إضافية تم اعتماد "الفائز يأخذ كل شيء" خوارزمية النتائج تظهر أن تحكم EMRAN أداء أفضل بكثير بالمقارنة مع معرف المنتج وLQR وحدات تحكم لغرض عزل الاهتزاز النشطة على أساس خفض القوة التي أحيلت إلى هيكل السيارة.

APPROVAL PAGE

The thesis of Fadly Jashi Darsivan has been approved by the following:

Wahyudi Martono
Supervisor

Waleed F. Faris
Co- Supervisor

Momoh-Jimoh E. Salami
Internal Examiner

Hishamuddin Jamaluddin
External Examiner

Mohd Nasir Taib
External Examiner

Asst. Prof. Dr. Amir Akramin Shafie
Chairman

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, 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.

Fadly Jashi Darsivan

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

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSA

DECLARATION OF COPYRIGHT AND AFFRIMATION OF FAIR USE OF UNPUBLISHED RESEARCH

ACTIVE ENGINE MOUNTING SYSTEM BASED ON NEURAL NETWORK CONTROL

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below.

1. Any material contained in or derived from this unpublished research may only be used by others in their writing with due acknowledgement.

2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purposes.

3. The IIUM library will have the right to make, store in a retrieval system and supply copies of this unpublished research if requested by other universities and research libraries.

Affirmed by Fadly Jashi Darsivan.

……………………………	………………..
Signature	Date

To my beloved wife, Juliyana Hanim and my daughters Sophia and Nadia

And

To my beloved father Ridhuan Siradj and mother Darlina Jaffar

ACKNOWLEDGEMENTS

First and foremost I would like to thank Allah the Most Merciful and the Most Compassionate for without Him this research would have never been realized.

I would like to thank my supervisor, Almarhum Prof. Dr. Wahyudi Martono for his scholarly guidance and effort in supporting me for without his encouragement this work would have never been completed.

I would also like to thank my co-supervisor Assoc. Prof. Dr. Waleed F. Faris for his motivation and support in maintaining my interest to this field of research. For which his assistance was truly beneficial and helpful.

Not to forget my colleagues at the Kulliyah of Engineering, IIUM especially Dr. Sany Izan Ihsan who has been motivating and offering friendly advice. Not to forget other academic and non-academic staff for their assistance.

My sincere gratitude to the International Islamic University of Malaysia who has been very supportive and patience in allowing me to complete my studies.

Of course, last but not least my heart felt gratitude to my beloved wife Juliyana Hanim Bt. Abdul Raoff for her patience and understanding. To my two daughters Sophia Fadly and Nadia Fadly who have been there during my studies and making life more interesting and fun. Not to forget my deepest gratitude to my mother, Darlina Jaafar and father, Ridhuan Siradj for their love and prayers.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURE

LIST OF ABBREVIATIONS AND SYMBOLS

PID	Proportional Intergral Derivative
LQR	Linear Quadratic Regulator
NARMA-L2	Nonlinear Autoregressive Moving Average – L2
EMRAN	Extended Minimal Resource Allocating Network
SDOF	Single Degree of Freedom
TDOF	Two Degree of Freedom
MDOF	Multi Degree of Freedom
MR	Magneto Rheological
ER	Electro Rheological
LMS	Least mean square
MIMO	Multi Input Multi Output
EKF	Extended Kalman Filter
ANN	Artificial Neural Network
F	Force
M	Moment
m	Mass
k	Stiffness
c	Damping Coefficient
x	Displacement
θ	Angular Displacment
ω	Natural Frequency
ζ	Damping Ratio

CHAPTER 1

INTRODUCTION

3.1 OVERVIEW

Vehicle weight reduction has been a major topic in the automotive industry since it leads to better fuel consumption and better efficiency. Furthermore, with the current environment situation more and more car manufacturers are looking for alternative hydrocarbon fuels to reduce pollution. However, it is known that alternative power trains such as hybrid engines produce less power compared to the traditional internal combustion engines. Looking at the aspect of power to weight ratio alternative power trains could somehow have an equal performance if not better than internal combustion engine provided the weight of the vehicle can be reduced up to an acceptable level.

However, with this trend of lighter vehicle and more powerful engine has led to an undesirable effect to the comfort of the passenger. This undesirable effect has increased the level of noise, vibration and harshness (NVH) to the vehicle especially at the idling frequency of the engine. Since the engine disturbance is directly transmitted through the engine mounts therefore a lot of effort has been focused in improving engine mount technology (Yu *et al.*, 2001). Engine mounting is one of the essential components in the automobile to basically support the weight of the engine. However, despite its simple design the engine mountings have other complex functions.

1.1.1 Passive Engine Mounts

It was reported by Yu *et al.* (2001) that the passive engine mountings have three purposes. The main purpose is to support the weight of the engine, the second purpose is to isolate the vibration induced by the engine to the chassis and lastly to prevent the engine from bouncing off the chassis would be the third purpose. It was reported by Swanson (1993) and Yang (2001) that engine induced disturbance occurred at frequency between 20 Hz to 200 Hz. This disturbance is mostly caused by the dynamics of the engine components such as pistons, connecting rods and crank shaft as well as the firing pulse (Swanson, 1993; Geisberger, 2000; Krysinski and Malburet, 2007). At this frequency range level for an ideal engine mount to isolate the disturbance effectively the stiffness and damping ratio would be required to be as small as possible. However, at the lower frequency level i.e. below 20 Hz engine is subjected to bounce due to road excitation. To prevent any damages, the stiffness and damping ratio of the engine mount are required to be as large as possible to minimize the relative displacement between the engine and the chassis. This has led to contradictory desirable characteristics of the passive engine mount at both lower frequency and higher frequency levels respectively.

1.1.2 Semi active engine mount

Semi active engine mounting system consists of smart fluids such as electrorheological (ER) fluid or magnetorheological (MR) fluid. The fluids function as adaptive damper that can change their dynamic damping characteristic by applying electric field for ER fluid and by applying magnetic field for MR fluid. Semi active engine mounting systems are normally implemented in a open-loop control architecture. However, these systems are sensitive to the changes in system parameters which make them less robust and they are mostly implemented at the lower frequency range. For the improvement at the higher frequency range a fully active system is implemented.

1.1.3 Active engine mount

To improve the trade-off characteristic of the passive engine mount one alternative is to introduce an active engine mounting system. Active engine mounting system consists of passive mounts such as rubber or hydraulic, an external force actuator and a control system. Different types of force actuators such as electromagnetic, servohydraulic, electrostrictive and magnetostrictive materials could be incorporated into the system. With regards to the control system feedforward or feedback type are commonly used. Although there a lot of controllers which have been created or designed for this purpose, most of the controllers found in the literature are either classical or modern controllers.

Due to the complexity of the system an advance controller such as the neural network has been designed and implemented rather than the classical or modern control, which do not work well for nonlinear system. Furthermore, classical or modern control requires an accurate model to identify the desired controller parameters which is more often than not time consuming and complex. With the ability to be trained on line it was expected that the neural controller would be more robust compared to the classical controller.

3.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

Cars are becoming an integral part of our daily lives where in most areas they are the major mode of transportation. Engine as the heart of any vehicles but at the same time, engines are acting as a vibration exciter and the need to eliminate or minimize this vibration is essential in which active engine mounts are the solution to this problem.

The vibration sources in automotive are many and one of the major sources is the engine. To have a more comfortable vehicle, these vibrations need to be reduced or ideally eliminated. In this work the reduction of vibration is done through the implementation of the active engine mounting system.

3.3 RESEARCH PHILOSOPHY

With the trend of the numerous applications of intelligent control the philosophy of this research was to identify the possibility of the neural network controller as disturbance rejection in the automotive application namely the active engine mounting system. With its capability to be trained without having a prior mathematical model of the system neural network controllers make a good candidate as robust and practical control architecture. Furthermore, neural network controllers are relatively new especially in the automotive industries which provide broad implementation possibilities.

3.4 RESEARCH OBJECTIVES

The objectives of this research are to:-

1. Develop mathematical models for engine mounting system.

2. To benchmark the neural network based controller results against classical PID controllers for a SDOF and TDOF models.
3. To investigate the performance of LQR and neural network based controllers to actively isolate the vibration induced by the engine to the chassis for a MDOF model.
4. To compare the results obtained between NARMA-L2 and EMRAN controllers for the purpose of engine vibration isolation.
5. To investigate the robustness of the neural network based controllers.

3.5 SCOPE

This research is mainly focusing on the simulation of the active engine mounting system. Two types of neural network controllers are implemented in the simulation of the engine vibration system which are the Nonlinear Autoregressive Moving Average L2 (NARMA–L2) and the Extended Minimal Resource Allocating Network (EMRAN). NARMA-L2 has been identified by Narendra (1996), Narendra and Mukhopadhyay (1997) and it has the capability of being trained offline and be used as a controller to reject disturbances, while the EMRAN can be trained online, thus making EMRAN a more robust intelligent controller.

The simulation results of both controllers are then compared with classical PID controller and a Linear Quadratic Regulator controller.