



ACTIVE ENGINE MOUNTING SYSTEM BASED ON
NEURAL NETWORK CONTROL

BY

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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 feedforward 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.

ملخص 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 أحييت 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 وتصفيته إكس إم إس تحكم ، التحكم الأمثل على أساس HAAR الموجبات وغيرها من ردود الفعل الكلاسيكية وتحكم feedforward. 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 الحرة. ديناميات صمام خطي أدرج أيضا. نوعين من تحكم الشبكة العصبية تم استخدامه في هذا البحث وهي غير الخطية تراجعية المتوسط المتحرك (NARMA-2L) 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 العصبية EMRAN 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 أحييت إلى هيكل 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 it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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

And

To my beloved father Ridhuan Siradj and mother Darlina Jaffar

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TABLE OF CONTENT

Abstract	ii
Abstract in Arabic	iii
Approval Page.....	iv
Declration Page	v
Dedication	viii
Acknowledgements.....	viii
List of Tables	xii
List of Figure.....	xiii
List of Abbreviations and Symbols	xx
CHAPTER 1: INTRODUCTION.....	1
1.1 Overview	1
1.1.1 Passive Engine Mounts.....	2
1.1.2 Semi active engine mount	2
1.1.3 Active engine mount.....	3
1.2 Problem statement and its Significance	4
1.3 Research Philosophy.....	4
1.3 Research Ojectives	4
1.4 Research Scope	5
1.5 Research Methodology.....	6
1.6 Thesis Organization	7
CHAPTER 2: LITERATURE SURVEY	9
2.1 Introduction	9
2.2 Engine Mounting System.....	9
2.2.1Passive Engine Mount	11
2.2.1.1 Elastomeric Mount	11
2.2.1.2 Hydraulic Mount	13
2.2.2 Semi Active and Active Engine Mounts	15
2.3 Controller	21
2.4 Neural Network Control.....	24
2.5 Summary.....	27
CHAPTER 3: MODELING OF THE ENGINE MOUNTING SYSTEM.....	27
3.1 Introduction	27
3.2 Passive Engine Mounting.....	27
3.2.1.Single Degree of Freedom.....	27
3.3 Effectiveness of Engine Mount Analysis.....	32
3.4 Active Engine Mounting System	36
3.4.1 Single degree of freedom model.....	36
3.4.2 Two degree of freedom model	40
3.4.3 Multi degree of freedom model.....	43
3.5 Electromagnetic Actuator Dynamics	47
3.6 Summary	49

CHAPTER 4: ADAPTIVE ARTIFICIAL NEURAL NETWORK CONTROLLERS	51
4.1 Introduction	51
4.2 Backpropagation	54
4.3 Winner Takes All Algorithm	56
4.3 Neural Network Controllers	57
4.2.1 Nonlinear Autoregressive Moving Average (NARMA-L2)	55
4.2.2 Extended Minimal Resource Allocating Network (EMRAN)	58
4.6 Training of the Neural Network Based Controllers	63
4.3 Summary	64
CHAPTER 5: SINGLE DEGREE OF FREEDOM ENGINE VIBRATION MODEL	63
5.1 Introduction	63
5.2 Active Control of linear SDOF Engine Mounting Model.....	65
5.2.1 Proportional Integral Derivative (PID) Controller	65
5.2.2 Nonlinear Autoregressive Moving Average – L2 (NARMA-L2) Neural Controller	69
5.2.3 Extended Minimal Resource Allocating Network (EMRAN)	72
5.3 Summary	75
CHAPTER 6: TWO DEGREE ENGINE VIBRATION MODEL	78
6.1 Introduction	78
6.2 Active control of linear TDOF engine mounting system.....	79
6.2.1 Proportional Integral Derivative PID Controller	80
6.2.2 Nonlinear Autoregressive Moving Average-L2 (NARMA-L2) Neural Controller	83
6.2.3 Extended Minimal Resource Allocation Network (EMRAN) Neural Controller	86
6.3 Active control of nonlinear TDOF engine mounting system.....	91
6.3.1 Nonlinear Autoregressive Moving Average L2 (NARMA-L2)	91
6.3.2 Extended Minimal Resource Allocation Network (EMRAN).....	95
6.4 Summary	98
CHAPTER 7: MULTI DEGREE ENGINE VIBRATION MODEL	99
7.1 Introduction	99
7.2 Active Control of MDOF Engine Mounting Model	100
7.2.1 Linear Quadratic Regulator (LQR) Controller	100
7.2.2 Nonlinear Autoregressive Moving Average (NARMA-L2) Controller	103
7.2.3 Extended minimal resource allocating network (EMRAN)	106
7.3 summary	109
CHAPTER 8: Robustness Analysis	111
8.1 Introduction	111
8.2 NARMA-L2 robustness analysis	112
8.2.1 Mass Variations	112
8.2.2 Stiffness Variations.....	113
8.2.3 Damping Coefficient Variation	115

8.2.4 Mass and Stiffness Variations	116
8.3 EMRAN Robustness Analysis	117
8.3.1 Mass Variations	117
8.3.2 Stiffness Variations.....	118
8.3.3 Damping coefficient variations.....	119
8.3.4 Mass and Stiffness Variations	120
8.4 Summary	121
CHAPTER 9: CONCLUSION.....	123
9.1 Conclusion.....	123
9.2 Highlights and Contribution of the Study	123
9.3 Future work and recommendations	126
BIBLIOGRAPHY	127
PUBLICATIONS	133
APPENDIX A: VITA	132

LIST OF TABLES

<u>Table No.</u>		<u>Page No.</u>
2.1	Critical Analysis of Existing Controllers for Vibration Suppression	24
5.1	The parameters for the SDOF engine vibration isolation system	64
5.2	Ziegler-Nichols Tuning for the Regulator for a decay ratio of 0.25	66
5.3	The average magnitude transmitted force reduction comparison	75
6.1	The parameters for the active engine vibration isolation system	79
8.1	Nominal and varying parameters for robustness analysis	111
8.2	Performance comparison between NARMA-L2 and EMRAN controllers	122

LIST OF FIGURE

<u>FIGURE NO.</u>	<u>PAGE NO.</u>
2.1 Elastomeric mount (Courtesy of Westar Industries)	11
2.2 Dynamic Stiffness of Rubber Engine Mount (Swanson, 1993)	12
2.3 Hydraulic mount with inertia track and decoupler (Courtesy of www.landsharkoz.com)	13
2.4 Dynamic stiffness characteristic of hydraulic mount (Ushijima <i>et al.</i> , 1988)	14
2.5 Dynamic stiffness characteristic of hydraulic mount with decoupler (a) Dynamic stiffness magnitude (b) loss angle --- theory — experiment (Singh, 2000)	15
2.6 Mechanical model of the adaptive hydraulic engine mount (Swanson, 1993)	16
2.7 Dynamic damping characteristic of an adaptive fluid mount (Miller and Ahmadian, 1992)	17
2.8 Model of magnethorheological fluid mount (courtesy of Delphi Corp.)	17
2.9 Mechanical model of the active rubber mount (Miller and Ahmadian, 1992)	18
2.10 Mechanical model of the active hydraulic mount (Miller and Ahmadian, 1992)	19
2.11 Dynamic stiffness of the active rubber mount (Swanson, 1993)	20
2.12 Dynamic stiffness of the active hydraulic mount (Swanson, 1993)	20
3.1 Representation of a single degree of freedom base excited system	27
3.2 Single degree of freedom response for various values of ζ	29
3.3 Bode plot of a SDOF response for an increasing value of stiffness, k	29
3.4 A SDOF of a force induced excitation	30

3.5 Response of a single degree of freedom mass excited system	31
3.6 Bode plot of a single degree of freedom response for a decreasing value of stiffness, k	32
3.7 Isolation system model for a single mount (Swanson <i>et al.</i> , 1992)	33
3.8 Schematic diagram of a single degree of freedom vibration system with actuator	36
3.9 Block diagram of the active engine mounting system	37
3.10 The force transmissibility plot of the single degree of freedom active engine mounting	39
3.11 Schematic diagram of an active two degree of freedom system	40
3.12 Schematic diagram of the multi degree of freedom engine vibration system	43
3.13 Schematic diagram of the electromagnetic actuator	47
3.14 The open loop force response of the nonlinear electromagnetic actuator	49
4.1 Nonlinear Autoregressive Moving Average Neural Network Structure	56
4.2 Plant identification of the neural network (Demuth and Beale, 1992)	57
4.3 Radial Basis Function Neural Network (Sundararajan <i>et al.</i> , 1999)	59
5.1 Active vibration isolation simulation block diagram	63
5.2 Transmitted force variations of the open loop system	65
5.3 The response of the system based on the quarter decau ratio	66
5.4 The transmitted force variations of the PID controlled SDOF system	67
5.5 The transmitted force variations of the PID controlled SDOF system at the resonance frequency	67

5.6 The transmitted force variations of the PID controlled SDOF system at final periods of the simulation	68
5.7 The transmitted force variations of the NARMA-L2 controlled SDOF system	70
5.8 The transmitted force variations of the NARMA-L2 controlled SDOF system at the resonance frequency	70
5.9 The transmitted force variations of the NARMA-L2 controlled SDOF system at peridos of the simulation	71
5.10 The transmitted force variations of the EMRAN controlled SDOF system	72
5.11 The transmitted force variations of the EMRAN controlled SDOF system at the resonance frequency	73
5.12 The transmitted force variations of the EMRAN controlled SDOF system at final frequency level seconds of the simulation	73
5.13 Frequency response of the active SDOF system using NARMA-L2 and EMRAN neural controllers.	75
5.14 Vibration isolation performance comparison for a linear SDOF (a) PID controller, (b) NARMA-L2 controller and, (c) EMRAN	77
6.1 The transmitted force variations at (a) front mount (b) rear mount	80
6.2 The transmitted force variations of the PID controlled linear TDOF system (a) front mount (b) rear mount	81
6.3 The transmitted force variations of the PID controlled linear TDOF system at the resonance frequency (a) front mount (b) rear mount	82
6.4 The transmitted force variations of the PID controlled linear TDOF system at the final frequency level (a) front mount (b) rear mount	82
6.5 The transmitted force variations of the NARMA-L2 controlled linear TDOF system (a) front mount (b) rear mount	84
6.6 The transmitted force variations of the NARMA-L2 controlled linear TDOF system at the resonance frequency (a) front mount (b) rear mount	84

6.7 The transmitted force variations of the PID controlled linear TDOF system at the final frequency level (a) front mount (b) rear mount	85
6.8 The transmitted force variations of the EMRAN controlled linear TDOF system (a) front mount (b) rear mount	87
6.9 The transmitted force variations of the EMRAN controlled linear TDOF system at the resonance frequency (a) front mount (b) rear mount	88
6.10 The transmitted force variations of the EMRAN controlled linear TDOF system at the final frequency level (a) front mount (b) rear mount	88
6.11 Frequency response of the active SDOF system using NARMA-L2 and EMRAN neural controllers.	89
6.12 Vibration suppression performance comparison for a linear TDOF (a) PID, (b) NARMA-L2 and, (c) EMRAN	90
6.13 Block diagram of the active engine mounting system with nonlinear dynamics	91
6.14 The transmitted force variations of the NARMA-L2 controlled nonlinear TDOF system (a) front mount (b) rear mount	92
6.15 The transmitted force variations of the NARMA-L2 controlled nonlinear TDOF system between 1 second and 10 seconds (a) front mount (b) rear mount	93
6.16 The transmitted force variations of the NARMA controlled nonlinear TDOF system at the resonance frequency (a) front mount (b) rear mount	93
6.17 The transmitted force variations of the NARMA controlled nonlinear TDOF system at the final frequency level (a) front mount (b) rear mount	94
6.18 The transmitted force variations of the EMRAN controlled nonlinear TDOF system (a) front mount (b) rear mount	96
6.19 The transmitted force variations of the ERMAN controlled nonlinear TDOF system at the resonance frequency (a) front mount (b) rear mount	96

6.20 The transmitted force variations of the EMRAN controlled nonlinear TDOF system at the final frequency level (a) front mount (b) rear mount	97
7.1 The transmitted force variations of the chassis for the open loop linear multi degree of freedom (MDOF) system	100
7.2 Active vibration isolation system using LQR optimal control	101
7.3 The transmitted force variations of the chassis for the LQR controlled linear multi degree of freedom (MDOF) system	102
7.4 The transmitted force variations of the chassis for the LQR controlled linear multi degree of freedom (MDOF) system at the resonance frequency	102
7.5 The transmitted force variations of the chassis for the LQR controlled linear multi degree of freedom (MDOF) system above the resonance frequency	103
7.6 The transmitted force variations of the chassis for the NARMA-L2 controlled linear multi degree of freedom (MDOF) system	104
7.7 The transmitted force variations of the chassis for the NARMA-L2 controlled linear multi degree of freedom (MDOF) system at the resonance frequency	105
7.8 The transmitted force variations of the chassis for the NARMA-L2 controlled linear multi degree of freedom (MDOF) system above the resonance frequency	105
7.9 The transmitted force variations of the chassis for the EMRAN controlled linear multi degree of freedom (MDOF) system	106
7.10 The transmitted force variations of the chassis for the EMRAN controlled linear multi degree of freedom (MDOF) system at the resonance frequency	107
7.11 The transmitted force variations of the chassis for the EMRAN controlled linear multi degree of freedom (MDOF) system above the resonance frequency	108
7.11 Frequency response of the active MDOF system using LQR, NARMA-L2 and EMRAN controllers.	108
7.13 Vibration suppression performance comparison for a linear MDOF (a) PID, (b) NARMA-L2 and, (c) EMRAN	110

8.1 Magnitude variations of the NARMA-L2 controlled system when subjected to a step response reference with varying mass	113
8.2 Magnitude variations of the NARMA-L2 controlled system when subjected to a step response reference with varying stiffness	114
8.3 Magnitude variations of the NARMA-L2 controlled system when subjected to a step response reference with varying damping ratio	115
8.4 Magnitude variations of the NARMA-L2 controlled system when subjected to a step response reference with varying mass and stiffness	116
8.5 Magnitude variations of the EMRAN controlled system when subjected to a step response reference with varying mass	117
8.6 Magnitude variations of the EMRAN controlled system when subjected to a step response reference with varying stiffness	118
8.7 Magnitude variations of the EMRAN controlled system when subjected to a step response reference with varying damping coefficient	119
8.8 Magnitude variations of the EMRAN controlled system when subjected to a step response reference with varying mass and stiffness	120

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; Kryszinski 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.