Structural Control Optimisation and Health Monitoring using Newly Developed Techniques

A thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philosophy

By

Mohsen Askari

Faculty of Engineering and Information Technology
University of Technology, Sydney

March, 2014

To My Beautiful Sister:

Raheleh

CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the 0thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

Production Note:
Signature removed prior to publication.

Date

22 March 2014

ACKNOWLEDGMENTS

I am truly fortunate to have spent four years at the Centre for Built Infrastructure Research (CBIR) at University of Technology, Sydney (UTS) that provided me the great opportunity to accomplish my graduate studies in a friendly but highly competitive environment. I would first like to thank my PhD supervisors, Associate Prof. Jianchun Li and Prof. Bijan Samali who guided, mentored and encouraged me throughout my thesis with their knowledge, jovial disposition and patience.

I would like to acknowledge the members of CBIR Dynamics and Control Group, in particular Dr. Yancheng Li for his generous help during my experimental tests and Dr. Amir Ali Zad for his valuable guidelines about student life in UTS and Australia.

I am also indebted to my true friends who gave me so many helps in different ways during my study at UTS. My special thanks go to Dr. Saad Mahbub Subhani, Dr. Yukari Aoki, Dr. Ikram Mohammad Kabir, Dr. Vahid Behbood, Dr. Ali Parsa Pajouh, Alireza Radman, Kianoosh Keynejad, Amir Reza Bahrami, Rowshanak Rahrooh, Mona Parvaresh, Leila & Peyman, Zubin Kalchuri, Tina Nyhammer…

Last, but not the least, I thank my family for their support through my entire life. My special appreciation goes out to my brother Meisam without whose motivation and encouragement, completion of this degree would be impossible.

LIST OF PUBLICATIONS RELATED TO THIS THESIS

Journal Articles

1. Semi-Active LQG Control of Seismically Excited Nonlinear Buildings using Optimal Takagi-Sugeno Inverse Model of MR Dampers, M Askari, J Li, B Samali, Procedia Engineering 14, 2765-2772

2. Cost effective Multi Objective Placement of Actuators and MR Dampers in High-Rise Structures using a Modified Integer Coded NSGAII, M. Askari, B. Samali, J. Li, Engineering Applications of Artificial Intelligence (Under Review)

3. Intelligent Semi-Active Control of Building-MR Damper Systems using Novel TSK-Inv and Max-Min Algorithms, M.Askari, J. Li, B. Samali, Journal of intelligent material systems and structures, (Revised sent).

4. Application of extended, unscented, iterated extended and iterated unscented Kalman filter for real-time structural identification; an experimental comparison study, M.Askari, J. Li, B. Samali, International Journal of Structural Stability and Dynamics, (Under Review)

5. Experimental forward and inverse modelling of MR dampers using an optimal TSK fuzzy scheme M.Askari, J. Li, B. Samali, Journal of intelligent material systems and structures, (Revised sent).

6. Adaptive Multiple Forgetting Factor Recursive Least Square (AMFF-RLS) for Real-Time Structural Identification with Unknown Input, Advances in Structural Engineering, (Under Review)

.

Book Chapter

7. A Multi-objective Subtractive FCM Based TSK Fuzzy System with Input Selection, and Its Application to Dynamic Inverse Modelling of MR Dampers, M. Askari, J Li, B Samali, Artificial Intelligence and Soft Computing, 215-226

Conference Papers

8. Adaptive Multiple Forgetting Factor Recursive Least square (AMFF-RLS) for real-time structural identification, M Askari, J Li, B Samali, 22nd ACMSM: "Materials to Structures: Advancement through Innovation", Sydney, Australia December 2012.

9. Application of extended, unscented, iterated extended and iterated unscented Kalman filter for real-time structural identification, M Askari, J Li, B Samali, 7th Australasian Congress on Applied Mechanics (ACAM 7), Adelaide, December 2012.

10. Adaptive multiple forgetting factor recursive least square (AMFF-RLS) for Real-Time Structural Identification with Unknown Input, M Askari, J Li, B Samali, 7th Australasian Congress on Applied Mechanics (ACAM 7), Adelaide, December 2012.

11. Multi Objective Optimal Placement of Structural Control Actuators, M Askari, 6th Australasian Congress on Applied Mechanics (ACAM 6), Perth, December 2010.

12. Future Intelligent Civil Structures: Challenges and Opportunities, J. Li, Y. Li, M. Askari, QP. Ha, The International Symposium on Automation and Robotics in Construction and Mining (ISARC 2014), Sydney, July 2014

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Vibration is usually undesirable and yet it occurs in most machines, vehicles, structures, buildings and dynamic systems. The resulting unpleasant motions and the dynamic stresses may lead to fatigue and failure of the structure or machines. In the field of civil engineering, control and identification of the state of health of the structure during the dynamic loads, such as earthquakes and attempt to suppress the vibrations and detect any damage or potential hazard are of vital importance and have posed a great challenge to the research community.

This thesis presents new techniques for optimisation, real-time health monitoring and semi-active vibration control of structures subjected to seismic loads.

First, a new encoding scheme is presented for a fuzzy-based nonlinear system identification methodology, using subtractive Fuzzy C-Mean clustering and non-dominated sorting genetic algorithm. The method is able to automatically select the best inputs as well as the structure of the fuzzy model in such a way that both accuracy and compactness of model are guaranteed. The proposed method is then employed to identify the forward and inverse models of a MR damper. Numerical and Experimental results show that the developed evolving TSK fuzzy model can identify and grasp the nonlinear dynamics of both forward and inverse systems very well, while a small number of inputs and fuzzy rules are required for this purpose.

The optimal design and placement of control devices, is an important problem that affects the control of civil engineering structures. This study also presents a multi-objective optimisationmethod for simultaneous finding of optimal number and location of actuators and MR dampers, in active and semi-active controlled structures. The method is applied to a nonlinear 20-storey benchmark building. The obtained optimal layout of active actuators is compared to the original benchmark problem definition in which 25 actuators are located in non-optimal places. Results show the effect of proposed strategy where similar level of structural performance, in terms of proposed objective indices, is achieved by use of only 7 actuators in optimal locations. Also, the optimal configuration of different number of MR dampers in the same nonlinear benchmark building is also studied. Results are then compared with optimal locations of actuators in the equivalent active system and the differences are shown.

Two new semi-active control algorithms named TSKInv and MaxMin, are also introduced in this research study to convert the force generated by nominal controller to the required voltage of MR dampers. TSKInv algorithm is developed by modelling the inverse dynamics of MR damper using TSK fuzzy inference systems and MaxMin controller is designed based on the maximum ($maximum\ voltage$) and minimum ($minimum\ voltage$) load of MR damper at each time-step. Applications of these two newly developed methods are compared to some other semi-active control strategies through the 20-storey nonlinear benchmark building. Results show the superiority of these two models over the other algorithms in tracking the desired force using less amount of control force and power.

Also, an investigation on different Kalman Filtering algorithms used in system identification is carried out in this dissertation work, on which EKF, IEKF, UKF and IUKF have been applied to some numerical examples to estimate the parameters of targeted structures in real-time using acceleration responses only. Results demonstrate that IUKF and UKF are the most reliable and robust estimators even if the structure is highly nonlinear and measured data are contaminated with noise. Then, a novel recursive least square based method with adaptive multiple forgetting factor is proposed and applied to different structural identification problems with unknown excitations. It is found from the results that, the proposed algorithm can effectively identify the time-varying parameters as well as the unknown inputs to the structure with high computational efficiency.

Using the developed techniques, this project aims to prepare a platform for real-time structural integrity assessment of civil infrastructures, during or after earthquakes.