MR Dampers in Smart Structures with Nonlinear Non-affine Dynamics improvising Intelligent Control

By

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A thesis submitted in fulfilment

of the requirements for the degree of

Doctor of Philosophy

Faculty of Engineering

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Australia

June 2014

Executive Summary

The increasing complexity of high-rise buildings, cable-stayed long-span bridges, deep-sea offshore structures or suspension systems demands effective tools for control and health monitoring. These infrastructure systems are usually integrated with actuation, sensing, computation resources and information networks, taking advantage of the synergy of civil engineering and mechatronics in an emerging area called *civiltronics*. Towards the achievement of high performance smart structures, semi-active vibration control in complex civil structures has been very promising, particularly in the mitigation of external excitations and dynamic loadings owing to its meritorious features of low cost, strong robustness and high reliability against various loading sources. Structural behavior and energy efficiency can be improved via directly controlling the input of the smart devices. For example, semi-active controlled dampers, from the dissipation point of view by using suitable control schemes for parameterized relationships describing the system dynamics of the structure integrated with the smart devices with respect to the applied electrical signal. This research is concerned with the problem of controlling the nonlinear, non-affine dynamics of smart structures with magneto-rheological (MR) dampers. A laboratorial set-up of a one-storey steel frame and a benchmark five-storey building model integrated with MR dampers are used in this research. These smart structures are subject to scaled earthquake vibrations excited by a shake table. A static hysteresis model is adopted for the MR damper, in which current-dependent nonlinear functions are used to represent the damper force-velocity characteristics. Here the semi-active control problem of the smart structure system is formulated in current-input non-affine nonlinear state space equations. The complications in the design are tackled by using intelligent control, whereby adaptive fuzzy logic control is proposed to deal with nonlinearity of the control dynamics and non-affinity in the control input, assuming the availability of the displacement and velocity information of the last floor. Here, self-organising adaptive fuzzy logic control is developed to prevent cases that the resulting fuzzy inference system may be unnecessarily large or too small to adequately represent the complex dynamics of the smart structure under control. The main objectives of this research are thus to model the overall smart structure system and to develop self-organising adaptive fuzzy logic schemes for the continuous-time multiple-input multiple-output uncertain nonlinear dynamics of the structure. The proposed control algorithms are implemented in MATLAB and SIMULINK. To illustrate

their effectiveness in seismic vibration suppression of civil structures due to earthquake excitations, simulation results are presented together with discussions on performance evaluation and further remarks on the implementation aspects.

CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not been submitted for a similar degree nor has it been submitted as part of requirements for any other degree.

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

Zeinab Movassaghi

This thesis is especially dedicated to my dearest father, mother, sisters and brother
for their love, blessings and encouragement.

PUBLICATIONS

The following technical papers have been published based on the work of this thesis:

1. Movassaghi, Z., Ha, Q., Samali, B., "A Self-structuring Adaptive fuzzy Control Scheme for Non-affine nonlinear systems used in Smart Structures", *Sixth International conference on Structural Health Monitoring of Intelligent Infrastructure (ISHMII-6)*, Hong Kong, 9-11 December, 2013
2. Movassaghi, Z., Samali, B., Ha, Q., "Smart Structures Embedded with MR dampers Using Non-Affine Fuzzy Control", *22nd Australasian Conference on the Mechanics of Structures and Materials (ACMSM)*, Sydney, Australia, 11-14 December 2012
3. Royel,S., Movassaghi, Z., Kwok, N., and Ha,Q., "Structural control Using MR dampers with Second Order Sliding Mode Controller", *Proceedings of the 1st international conference on control automation and information sciences (ICCAIS),* Ho Chi Minh City, Vietnam, 26-29 November 2012
4. Movassaghi, Z., "Considering Active Tuned mass dampers in two different structures", *Australian Control Conference (AUCC),* Sydney, Australia, 15-16 November 2012
5. Movassaghi, Z., Samali, B., Ha, Q., "Adaptive Neuro-Fuzzy Modelling of a high-rise structure equipped with an Active Tuned Mass Damper", *6th Australasian Congress on Applied Mechanics, ACAM 6,* Perth, Australia, 12-15 December 2010

ACKNOWLEDGEMENTS

The research project reported in this thesis was supported by the Centre for Built Infrastructure Research (CBIR) of the University of Technology, Sydney. This financial support is greatly acknowledged and appreciated.

I am greatly thankful and indebted to my supervisors, A/Prof. Quang Ha, Prof. Bijan Samali and Prof. Vute Sirivivatnanon for their support and guidance in all aspects of my research activities.

Finally, I would like to express my special thanks to my family for their encouragement and love throughout my candidature.

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NOTATIONS

A System matrix

B Input matrix for control

C Output matrix

D Matrix to represent direct coupling between input and output for control force

E Input matrix for wind/earthquake excitations

F Matrix to represent direct coupling between input and output for wind/earthquake excitations

J_1-J_6 Evaluation criteria

J Performance index

u Control force

v Measured noise vector

W External excitations (wind/earthquake)

x State vector (in the control matrix)

$\mathbf{x}(t)$ Displacement of the storey

$\dot{\mathbf{x}}(t)$ Velocity of the storey

$\ddot{\mathbf{x}}(t)$ Acceleration of the storey

$\ddot{\mathbf{x}}_g$ Ground acceleration

y Measured output vector

z Controlled output vector

M Mass matrix

C Damping matrix

K Stiffness matrix