

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

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To My Beautiful Sister:

Rahelah

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 thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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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 optimisation method 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.