Advanced Science and Technology Letters
Vol.32 (Architecture and Civil Engineering 2013), pp.50-53
http://dx.doi.org/10.14257/astl.2013.32.12

Development of MIMO Fuzzy Control System for Seismic Response Reduction using Multi-Objective Genetic Algorithm

Hyun-Su Kim[1]

[1] Assistant Professor, Division of Architecture, Sunmoon University, Asan-si, Korea
hskim72@sunmoon.ac.kr

Abstract. A multi-input multi-output (MIMO) semi-active fuzzy control system was proposed in this study to reduce dynamic responses of a seismically excited building. A multi-objective genetic algorithm was used to optimize the fuzzy logic controller. Two MR dampers were used as multiple control devices and a scaled five-story building model was selected as an example structure. A clipped-optimal control algorithm was compared with the proposed MIMO fuzzy controller. After numerical simulation, it has been verified that the MIMO fuzzy control algorithm can present better control performance compared to the clipped-optimal control algorithm in reducing both displacement and acceleration responses.

Keywords: Earthquake loads, Vibration control, Multi-objective optimization, Multi-input multi-output control system, Fuzzy logic controller.

1 Introduction

Although significant studies have been conducted in recent years toward development and application of semi-active control schemes for vibration control of building structures in seismic zones, the application of intelligent controllers, including fuzzy logic controllers (FLC), has not been addressed extensively [1, 2]. As an alternative to classical control theory, FLC allows the resolution of imprecise or uncertain information [3, 4]. Because of the inherent robustness and ability to handle nonlinearities and uncertainties, FLC is used in this study to make a multi-input multi-output (MIMO) control algorithm for operating multiple MR dampers. Although FLC has been used to control a number of structural systems, selection of acceptable fuzzy membership functions has been subjective and time-consuming. To overcome this difficulty, a multi-objective genetic algorithm (MOGA) was used to optimize fuzzy rules and membership functions of FLC. In order to compare the control efficiency of the proposed MOGA-optimized FLC, a clipped-optimal control algorithm was considered as the baseline in this study.

[1] Corresponding author. Tel.: +82 41 530 2315; fax: +82 41 530 2839.
E-mail address: hskim72@sunmoon.ac.kr

ISSN: 2287-1233 ASTL

2 Scaled Building Model

In order to develop an MIMO semi-active FLC for effective control of multiple MR dampers, a 5-story example building structure shown in Fig. 1 is employed. This example structure is developed based on a scaled 3-story shear building model used in the previous research [5]. As shown in this figure, two MR dampers are rigidly connected to the first floor and the second floor of the structure, respectively.

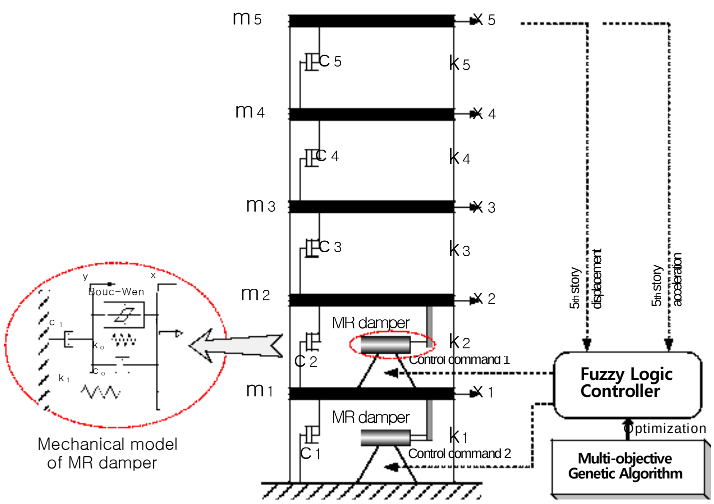

Fig. 1. 5-story example building model

The first five natural frequencies of the example structure model are 3.62, 10.57, 16.94, 22.07 and 25.41 Hz, respectively. In this study, the modified Bouc-Wen model [5] is used to describe how the damping force is related to the velocity and applied command voltage. The mechanical model for the MR damper based on the Bouc-Wen hysteresis model is shown in Fig. 1. The detailed description and the parameter values of the MR damper model are presented in Dyke *et al.*'s work [5]. This MR damper model has a maximum generated force of about 1500 N depending on the relative velocity across the MR damper with a saturation voltage of 2.25 V. In numerical analysis, the model of the example structure is subjected to the NS component of the 1940 El Centro earthquake. Because the system under consideration is a scaled model, the earthquake has been reproduced at five times the recoded rate.

3 Fuzzy Logic Controller

In this study, the 5th floor displacement and the 5th floor acceleration are selected for two input variables of FLC and the output variables are the command voltages sent to two MR dampers and it is shown in Fig. 1. Fuzzy rules and membership functions are optimized by a multi-objective genetic algorithm. Among many available GA-based multi-objective optimization strategies, the fast elitist Non-dominated Sorting Genetic Algorithm version II (NSGA-II) is employed in this study [6]. In order to verify the control performance of the NSGA-II optimized FLC, a clipped-optimal controller based on acceleration feedback [5] is selected as a comparative control algorithm. The reduction of peak responses of the 5^{th} floor displacement and acceleration are selected as two objectives in a multi-objective optimization process. Each response controlled by the NSGA-II optimized FLC is normalized by the corresponding response controlled by the clipped-optimal control algorithm in each objective function.

4 Numerical Studies

A numerical model of the 5-story example building structure with two MR dampers is implemented in SIMULINK and MATLAB. Using this numerical model, time history analyses of 12 seconds with a time step of 0.004 sec are performed in order to investigate the control performance of MR dampers controlled by the NAGA-II optimized FLC. The NSGA-II based optimization is performed with the population size of 100 individuals. An upper limit on the number of generations is specified to be 1000. As the number of generations increases, the control performance of the elite (i.e. non-dominated) individuals is improved. After optimization run, Pareto-optimal front (a set of Pareto-optimal solutions) is obtained. Optimization results show that two objective function values of every solution in Pareto-optimal front are less than 1. It means that the NSGA-II optimized FLCs can provide better control performance in reducing both displacement and acceleration responses compared to the clipped-optimal controller.

Consequently, one controller, that can appropriately control both displacement and acceleration responses, has been selected among the Pareto optimal FLCs. The values of two objectives of the selected FLC are both 0.8 and it means that the selected MIMO FLC can reduce both the peak 5^{th} floor displacement and acceleration responses by 20%, compared to the clipped optimal controller. The peak responses of the MIMO FLC, clipped-optimal controller, and uncontrolled case for the five floors of the seismic-excited example building structure are compared in Table 1.

Table 1. Comparison of peak story responses.

Story	Displacement (cm)			Drift (cm)			Acceleration (cm/sec^2)		
	Uncontrolled	Clipped-optimal	MIMO Fuzzy	Uncontrolled	Clipped-optimal	MIMO Fuzzy	Uncontrolled	Clipped-optimal	MIMO Fuzzy
1	0.355	0.099	0.116	0.355	0.099	0.116	592.2	559.4	293.2
2	0.574	0.187	0.179	0.219	0.099	0.064	693.8	378.7	336.3
3	0.723	0.266	0.240	0.203	0.092	0.084	485.3	387.7	248.7
4	0.847	0.329	0.269	0.192	0.074	0.073	543.3	313.5	268.3
5	0.930	0.352	0.281	0.123	0.053	0.042	858.7	368.1	294.7

Table 1 shows that the peak displacements and accelerations of the 5th floor of the MIMO FLC are 20% smaller than those of the clipped optimal controller. The peak displacement of the 5th floor of the uncontrolled case is 0.930 cm. On the other hand, the peak displacement of the 5th floor of the MIMO FLC is 0.218 cm, which is only 30 % of the uncontrolled case. The peak acceleration of the 5th floor of the MIMO FLC is reduced by 65 % compared to the uncontrolled case. The story drifts of the MIMO FLC are also about 20% smaller than those of the clipped-optimal controller.

5 Conclusions

This study investigates the control performance of the MIMO FLC optimized by an MOGA for control of a 5-story building subjected to earthquake. For comparison purpose, a clipped-optimal control algorithm is considered as the baseline. Based on numerical simulations, it can be seen that the MOGA-optimized MIMO FLC can effectively reduce both displacement and acceleration responses of the building structure by 20% compared to the clipped optimal control algorithm. After single optimization run using NSGA-II, an engineer can simply select another FLC that satisfies the desired performance requirements from among a number of Pareto optimal solutions. It would be important characteristics of the NSGA-II based optimization compared to other optimization methods.

Acknowledgements. This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. 2011-0015166).

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