MR Damper를 이용한 지진하중을 받는 구조물의 반능동 퍼지 제어

Semi-active Fuzzy Control for Seismic Response Reduction Using MR damper

최강민* 정형조** 이종헌*** 이인원****

Choi, Kang-Min Jung, Hyung-Jo Lee, Jong-Heon Lee, In-Won

1. INTRODUCTION

Semi-active control has received a lot of attention recently because it offers great adaptability without a large power requirement. Previous research has demonstrated the effectiveness of semi-active systems in structural vibration control using viscous fluid dampers. Magneto-rheological (MR) damper is one of the semi-active devices that can provide reliable vibration control. Besides its minute power requirement, the MR damper is reliable, fail safe, and is expected to be relatively inexpensive.

Classical control algorithms need an exact mathematical model for an actual structure and especially active control algorithm uses complicated mathematical equations to reduce structure responses. Since especially buildings in civil engineering are getting so higher and bridges are getting so longer that those structures are very complex systems of multi-degree of freedom, it is very difficult to find an exact mathematical model to describe the behavior of the structures. The most advantageous and controversial property is that the fuzzy controller does not rely on the analysis and synthesis of the mathematical model of the process. Therefore, the uncertainties of input data from the external loads and structural responses sensors are treated in a much easier way by the fuzzy controller than by classical control theory. Moreover for a more realistic implementation, nonlinearities incorporated can be overcome easily. And by incorporating human expertise into the fuzzy IF-THEN rules can be constructed to control complex structural systems.

The objective of this paper is to propose a new semi-active control method for seismic reduction of structures with MR damper. To do this, fuzzy set theory based structural control algorithm is employed as a control algorithm and a MR damper is introduced as a supplemental damping device. Fuzzy algorithm is used to calculate the command signal varied as time passed into the MR damper based on structural responses. Since a MR damper is an energy-dissipation device that cannot add mechanical energy to the structural system, the proposed control strategy is fail-safe, in that it guarantees the bounded-input, bounded-output stability of the controlled structure.

*한국과학기술원 건설및환경공학과 박사과정·042-869-5658(E-mail:kmchoi@mail.kaist.ac.kr)
**한국과학기술원 건설및환경공학과 연구조교수·공학박사·042-869-5658(E-mail:hjung@mail.kaist.ac.kr)
***정회원·경일대학교 토목공학과 교수·공학박사·053-850-7226(E-mail:leejh@bear.kyungil.ac.kr)
****정회원·한국과학기술원 건설및환경공학과 교수·공학박사·042-869-3618(E-mail:iwlee@kaist.ac.kr)

2. Control Strategy Using MR Damper

2.1 Introduction to fuzzy control

Fig. 1 shows an algorithm of fuzzy control inference. It consists of three basic parts; fuzzification where continuous input variables are transformed into linguistic variables, fuzzy rule inference that handles rule inference consisting of fuzzy IF-THEN rules, and defuzzification that ensures exact and physically interpretable values for control variables. The design of fuzzy control may include; the definition of input and output variables, the selection of data manipulation method, the membership function design and the rule base design. Using fuzzy rules and membership functions, fuzzy control converts linguistic variables into numerical values required in most applications.

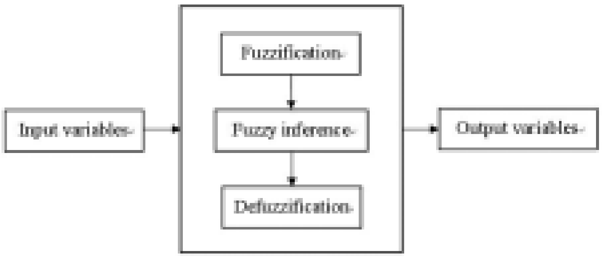


Fig.1. The algorithm of fuzzy control inference

The design of the fuzzy controller began to select the response quantities to be used as inputs to the fuzzy controller and the distribution and type of membership functions to be used for the selected input variables. Moreover, we must consider what control functions are needed, and then define them as output variables.

Fuzzy inference rule is completely based on the selected input variables. Usually, we use the form 'If (a set of condition to be satisfied) Then (a set of consequences to be inferred)' to describe the expert knowledge. Then, the inference conclusion obtained via fuzzification is defuzzified into a crisp output. This paper adopts the Center-of-Gravity (COG) method among the defuzzification methods.

2.2 Semi-active fuzzy control system using MR damper

The strategy of the semi-active fuzzy control algorithm for seismic protection using MR damper is comprised of only one controller compared semi-active clipped-optimal controller has two controllers. The one semi-active fuzzy controller produces directly the desired command voltage using fuzzy rule inference as the desired force demanded is varied so that the actuator can produce forces as close as possible to the desirable forces. The control diagram for the semi-active fuzzy control system is shown in Fig. 2.

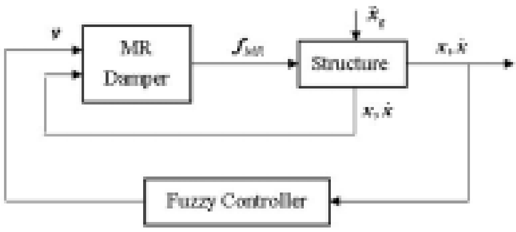


Fig.2. Control diagram using MR damper

This type controller has two merits. One is to have all advantages of fuzzy controller introduced, and the other is to give directly the desired command voltage. This means that it is possible to control effectively dynamic responses of the real civil structure due to the earthquake and strong winds.

3. Numerical Example

A model of a three-story building configured with a single MR damper is considered as shown Fig. 3. The MR damper is

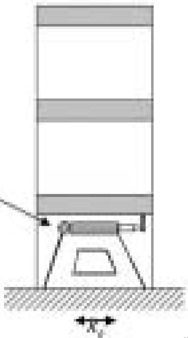


Fig.3. Three-story building structure[2]

rigidly connected between the ground and the first floor of the structure. This system is a simple model of the scaled, three-story, test structure. In this example, the controller is designed using two input variables (i.e. one is first floor velocity and the other is third floor velocity), each one having five membership functions, and one output variable (i.e. command voltage) with three membership functions. The membership functions chosen for the input and output variables are triangular shaped as illustrated in Fig. 4. A reasonable range of input values must be selected for the input membership functions since, if the range is too large and too small, the outermost membership functions will rarely and essentially be utilized respectively and thus limit the variability of the control system. The voltage is the fuzzy control system output for the structural control system.

(a) Input membership function (b) Output membership function

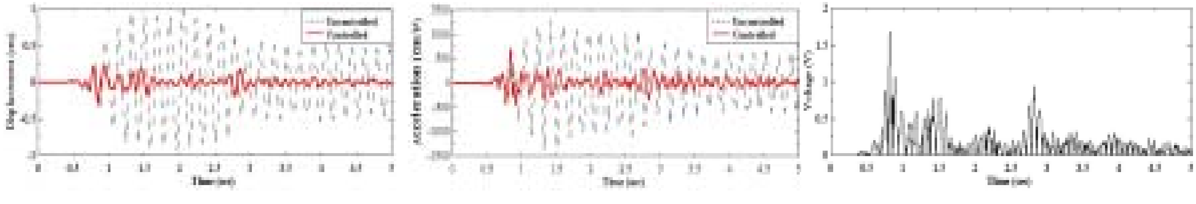
Fig.4. Input and output membership functions

Fuzzy inference rule is completely based on the structural first floor velocity and third floor velocity. In this example, the basic concept of inference rule is that if first floor velocity and third floor velocity are very large, then the output variable, voltage, is large. The fuzzy inference rule and control surface are shown in Table 1.

The test structure is controlled under normal excitation levels of the El Centro earthquake. Because the system under consideration is a scaled model, the earthquake must be reproduced at five times the recorded rate. The MR damper attached three-story building is the prototype model that Dyke et al.[2] used. Fig. 5 shows the responses of uncontrolled and semi-active fuzzy control system such as displacement, acceleration and applied voltage during the normal El Centro earthquakes . As seen from the figure, compared to the cases without a MR damper, the third floor displacement and the third floor acceleration responses are reduced significantly.

Table 1. Fuzzy inference rule

	NL	NS	ZE	PS	PL
NL	L	L	M	L	M
NS	L	M	ZE	M	ZE
ZE	M	ZE	M	ZE	M
PS	ZE	M	ZE	M	L
PL	M	L	M	L	L



(a) displacement (b) acceleration (c) applied voltage

Fig. 5. Time histories of responses in the third floor and applied voltage under the normal El Centro earthquake

The peak responses for the controlled structure are compared to those of an uncontrolled system, two passive systems (i.e. passive-off and passive-on), semi-active clipped-optimal control system, and semi-active fuzzy control as shown in Table 2.

As seen from the Table 2, the maximum ratios of the peak responses in the passive-off system, passive-on system and semi-active fuzzy control system[2] are 0.46, 0.32 and 0.29 for the displacement, 0.51, 0.55 and 0.50 for the interstory displacement and 0.51, 0.55 and 0.50 for the acceleration, respectively. The performance of the system employing the semi-active fuzzy control system surpasses these of both passive systems. Notice that these performance gains are achieved by the semi-active fuzzy controller while requiring smaller control forces than are required in the passive-on case. This means that the semi-active fuzzy control system uses force more efficiently to control structural vibration. The maximum ratios of the peak responses in the semi-active clipped-optimal control system and semi-active fuzzy control system are 0.23 and 0.29 for the displacement, 0.50 and 0.50 for the interstory displacement and 0.82 and 0.50 for the acceleration, respectively. The overall performance of the semi-active fuzzy control system is much superior to that of the uncontrolled system although the performance of the semi-active clipped-optimal control system is slightly better for maximum ratio of the peak displacement and significantly worse for the peak acceleration than that of the semi-active fuzzy controller, respectively. Notice that peak control force of the semi-active fuzzy control system is relatively small compared to that of the semi-active clipped-optimal control system. It is demonstrated that the semi-active fuzzy control system is very effective in reducing the structural responses due to the normal El Centro earthquake.

Table 2. Peak responses under the normal EL Centro earthquake (ratio)

Control strategy	Uncontrolled	Passive-off	Passive-on	Semi-active clipped-optimal	Semi-active fuzzy
x_i (cm)	0.549 (1.00)	0.211 (0.33)	0.080 (0.15)	0.114 (0.21)	0.101 (0.18)
	0.836 (1.00)	0.357 (0.38)	0.197 (0.24)	0.185 (0.22)	0.184 (0.22)
	0.973 (1.00)	0.452 (0.46)	0.307 (0.32)	0.219 (0.23)	0.282 (0.29)
d_i (cm)	0.549 (1.00)	0.211 (0.38)	0.080 (0.15)	0.114 (0.21)	0.101 (0.18)
	0.317 (1.00)	0.153 (0.48)	0.158 (0.50)	0.090 (0.28)	0.137 (0.43)
	0.202 (1.00)	0.104 (0.51)	0.111 (0.55)	0.101 (0.50)	0.101 (0.50)
$\ddot{x}_{ai}$ (cm/s^2)	879 (1.00)	421 (0.48)	281 (0.32)	721 (0.82)	400 (0.46)
	1071 (1.00)	488 (0.46)	499 (0.47)	746 (0.70)	438 (0.41)
	1404 (1.00)	721 (0.51)	772 (0.55)	706 (0.50)	704 (0.50)
f (N)	-	259	981	953	843

4. CONCLUSION

A semi-active fuzzy control method using MR damper is presented for seismic response reduction. Only one controller produces directly the desired command voltage using fuzzy rule inference as the desired force demanded is varied so that the actuator can produce forces as close as possible to the desirable forces. This type controller has all advantages of fuzzy control algorithm in previous studies. The effectiveness of the MR damper in reducing the structural responses has been demonstrated via numerical simulation.

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