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DECENTRALIZED SEMI-ACTIVE SEISMICCONTROL USING FUZZY CONTROLLER

Amin KAVEI DEYLAMI
MSc Student, School of Civil Engineering, University of Tehran,P.O. Box 11155-4563, Tehran, Iran
amin_kavee@ut.ac.ir

Amir K.GHORBANI-TANHA,
Assistant Professor, School of Civil Engineering, University of Tehran, aP.O. Box 11155-4563, Tehran, Iran
ghtanha@ut.ac.ir

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ABSTRACT

There are many different methods to find required control forces or damping values to decrease structural responses due to seismic excitations by a one centralized controller. In tall buildings there are some additional problems like time delay and controller unreliability, because of the higher number of sensors, actuators or dampers. In this paper, a decentralized semi-active control algorithmis proposed. In decentralized control,the structural system is decomposed into several substructures. Different controllers are available each one dealing with one substructure to obtain control properties using a certain that may be different to other subsystems control forces or natural characteristics modifications are applied just to the respective substructure. In present study, based on local substructure information, fuzzy controller calculates damping values for its subsystem.Each controller receives displacement and acceleration values of its floor as feedbacks and controls them. Controlling these values automatically results in decreasing of story drift and other useful values. The effectiveness of decentralized semi-active control algorithms is demonstrated through numerical examples. A model of building subjected to seismic excitations is developed and the dynamic responses are obtained in both uncontrolled and controlled cases by employing proposed decentralized control method. Moreover, the results for controlled case are compared to those obtained by using available decentralized methods to show the efficacy of the proposed algorithm.

INTRODUCTION

Control of building structures using different algorithms and various control mechanismsagainst earthquake or wind loading has gained much attention in the past few decades. However, the reliability of these kinds of control systems are a main concern. If for any reason the central controlunit loses its functionality during an earthquake, the operation of the whole control system will be disrupted.In that regard, the decentralized control approach has been considered by researchers as a substitute in recent years. In this approach, the main structural system is divided into a number of simpler subsystems, each one being controlled independently. Furthermore, this method can reduce the total length of transmission of data between sensors, control center and actuators. This kind of decentralized control approach, where possible, would lead to more reliable control systems(Rofooeiand Monajemi-nazhad, 2007).

In recent years, due to their reliability and adaptability, considerable attention has been directed to research and development of semi-active control devices. One such innovative device is the magnetorheological (MR) damper, which employs MR fluids to provide control capability. An MR damper offers a highly reliable mechanism for response reduction at a modest cost, and is fail-safe because the damper becomes passive if the control hardware malfunction.From this point of view, structural vibration control using MR dampers is one of the most promising fields in civil engineering, and a wide range of theoretical and experimental studies have been performed to assess the efficacy of MR dampers (Dyke et al, 1996).

In past researches decentralized control has been used in two main approaches. In First approach, unknown interconnection forces between adjacent subsystems are treated as a bounded disturbances with Gaussian nature, then by using a recursive estimator like Kalman filter, control forces or damping values and system states will be calculated based on optimal control theory. This approach is called Linear Quadratic Gaussian (LQG) (Loh and Chang, 2008; Lei et al. 2012). In second one, by designing a robust nonlinear controller like sliding mode control, system states like story's velocity and displacement will be determined with robustness to unknown subsystem interconnection forces values variation. It means variation of unknown system parameter has no effect in goodness of system responses (Rofooei and Monajemi-nazhad, 2006).

In this study, fuzzy controllers calculate the damping ratios based on information come from local substructure sensors without need to estimate states like first recent mentioned approach or any nonlinear control algorithms.We use if-then rules come from common available rules that being used for semi-active MR dampers, including mostly triangle andtrapezoidal shapes.

STRATEGY DEFINITION

The equation of motion for a building control system can beexpressed by

$$\mathbf{M}\ddot{x} + \mathbf{C}\dot{x} + \mathbf{K}x = -\mathbf{M}\Gamma\ddot{x}g + \mathbf{b}u \qquad (1)$$

where x is relative displacement vector of the active degrees offreedom; **M**, **C**, and **K** are mass, damping, and stiffnessmatrices of the structural system, respectively;$\ddot{x}_g$is ground acceleration;$u$is control force; Γ is a vector to define the distributionof the ground acceleration; and **b** is a matrix related to thelocation of control devices. The state-spacerepresentation of Eq. (1) is expressed as

$$\dot{z} = \mathbf{A}z + \mathbf{B}u + \mathbf{E}\ddot{x}g \qquad (2)$$

In which

$$z = \begin{vmatrix} x \\ \dot{x} \end{vmatrix} \mathbf{A} = \begin{vmatrix} 0 & \mathbf{I} \\ -\mathbf{M}^{-1}\mathbf{K} & -\mathbf{M}^{-1}\mathbf{C} \end{vmatrix}$$

$$\mathbf{B} = \begin{vmatrix} 0 \\ \mathbf{M}^{-1}\mathbf{b} \end{vmatrix} \mathbf{E} = \begin{vmatrix} 0 \\ -\Gamma \end{vmatrix}$$

Generally, for a systemwith fewer degrees of freedom, such as a low-rise building, thestate-space representation is sufficient for use of a control study(Lohand Chang, 2008).By solving state-space equations of motion, structural responses for each storey will be determined. Control forces will be calculated by fuzzy logic based controllers according to their storey responses, and applied by their storey MR dampers.A schematic diagram for this control strategy is depicted in figure 1.

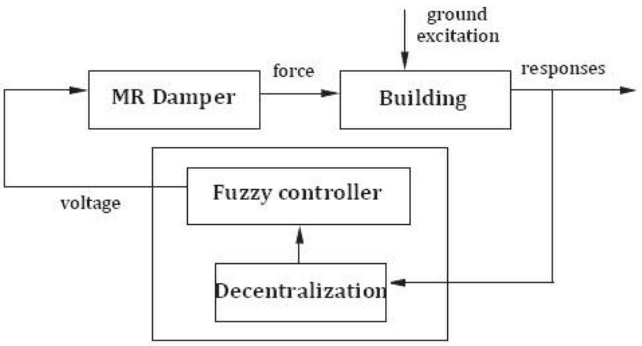

Figure 1. Control strategy for integrated fuzzy logic and decentralized control

FUZZY CONTROLLER

Fuzzy control has become a very popular approach to controller design because it enables human skills tobe transferred into linguistic rules. Consequently, fuzzy control has frequently been applied to poorly definedsystems or systems without mathematical models. Moreover, fuzzy controllers afford a simple and robustframework for specific nonlinear control laws that accommodate uncertainty and imprecision.(Lin, 2007)Each storey displacement and velocity are selected as fuzzy controller input variables and output is suitable voltageto apply controller calculated forces.Membership functions are 9 triangle shaped curves that are normalized in [-1,1]interval. NVL, NL, NM, NS, Z0, PS, PM, PL and PVL are fuzzification symbols (that mean negative very large, negative large,negative medium, negative small, zero, positive small,positive medium,positive large,positive very large) say that inputs belong to which interval. These functions and the control surface rule base have been shown in the Figures2 and 3. If the membership function input variables are not normalizes, we must use constant factors to change input variable ranges into [-1,1] interval and controller will receives product of the this factor and variable. These factors can be determined by unit to maximum absolute value of variable ratio.

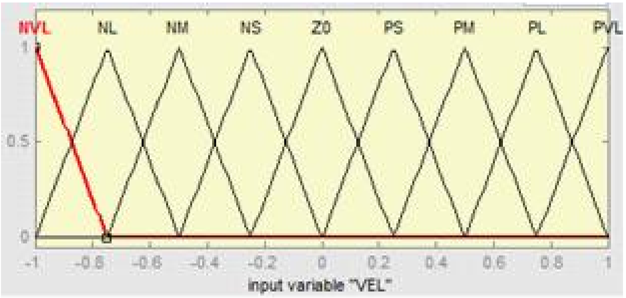

Figure 2. Input membership functions for fuzzy controller

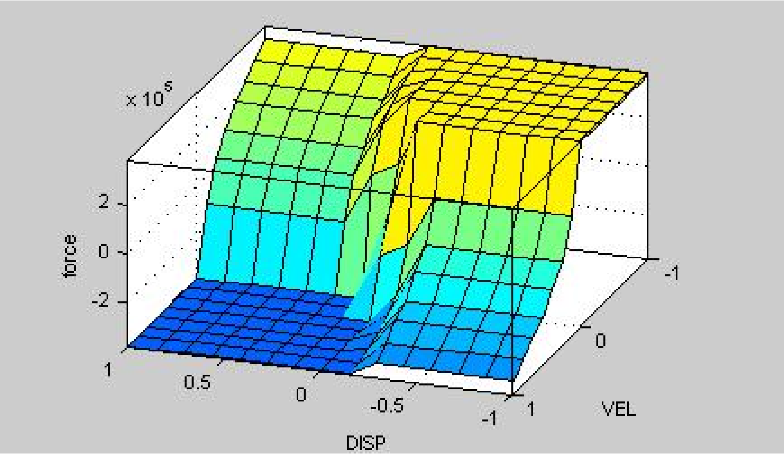

Figure 3. Control surface for the rulebase

Table 1. Fuzzyset rulebase matrix

		DISPLACEMENT										
		NVL	NL	NM	NS	NVS	Z0	PVS	PS	PM	PL	PVL
VELOCITY	PVL	NL	NVL	NVL	NVL	NVL	NVL	NVL	NVL	NVL	NVL	NVL
	PL	NM	NL	NVL	NVL	NVL	NVL	NVL	NVL	NVL	NVL	NVL
	PM	NS	NM	NL	NVL	NVL	NVL	NVL	NVL	NVL	NVL	NVL
	PS	Z0	NS	NM	NL	NVL	NVL	NVL	NVL	NVL	NVL	NVL
	Z0	PVL	PVL	PVL	PVL	PVL	Z0	NVL	NVL	NVL	NVL	NVL
	NS	PVL	PVL	PVL	PVL	PVL	PVL	PVL	PL	PM	PS	Z0
	NM	PVL	PVL	PVL	PVL	PVL	PVL	PVL	PVL	PL	PM	PS
	NL	PVL	PVL	PVL	PVL	PVL	PVL	PVL	PVL	PVL	PL	PM
	NVL	PVL	PVL	PVL	PVL	PVL	PVL	PVL	PVL	PVL	PVL	PL

.A $K_1 = 30$ factor for displacement and a $K_2 = 3.5$ factor for velocity have been considered to normalize the input values(Symansand Kelly, 1999).

NUMERICAL EXAMPLE

A 5-storey shear frame building has been considered to verify the efficacy of the proposed control algorithm. Each storey floor has similar $m = 150 \times 10^3 \mathrm{kg}$ mass and each storey columns have lateral stiffness equal to $k = 200 \times 10^3 \mathrm{kN/m}$.We assumed that each degree of freedom has a $c = 512.3 \times 10^3 \mathrm{Ns/m}$ value for structural damping. Floor to floor storey height is equal to 4 m for all storeys. Two 20-ton MR dampers have been considered in each storey of building that receivescommand from their storey controller. Each storey has been considered as a subsystem that controlled by a local controller. Responses of each storey (displacement and velocity of floors) have been measured by sensors that have been placed in every storey.The maximum value of the calculated control force has been limited to a certain value according to dampers capacity.Structure has been excited by El Centro ground acceleration. Structural responses and control forces have been calculated with a MATLAB program code. Results have been calculated again for a similar structure but with a centralized controller to compare with decentralized control scheme. In centralized method model, one fuzzy controller gives information from all strata sensors and commands to all dampers. Other details in centralized method model aresimilar to decentralized one.As a benchmark displacement and velocity of top storey of building of decentralized method model in compare with centralized method model have been presented in figures below. The maximum absolute relative displacement of strata and maximum absolute value of strata drift have been showed in table 2 in different conditions of uncontrolled, centralized controlled method and decentralized controlledmethod of structure.

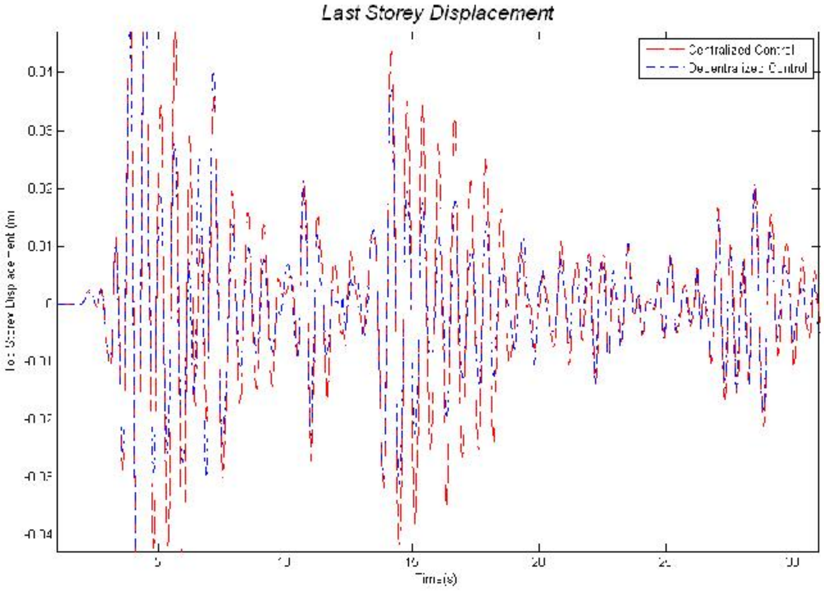

Figure 4. Top Storey displacement in decentralized and centralized control

Table 2.Maximum drift, maximum relative displacement value between adjacent strata and top storey displacement and velocity

	Uncontrolled	Centralized Control	Decentralized Control
Max. Relative Displacement (10^{-2}m)	2.126	1.849	1.556
MaximumDrift (10^{-3})	5.316	4.622	3.891
Top Storey Displacement (10^{-2}m)	8.420	7.351	6.452
Top Storey Velocity (10^{-1}m/s)	10.293	9.667	8.763

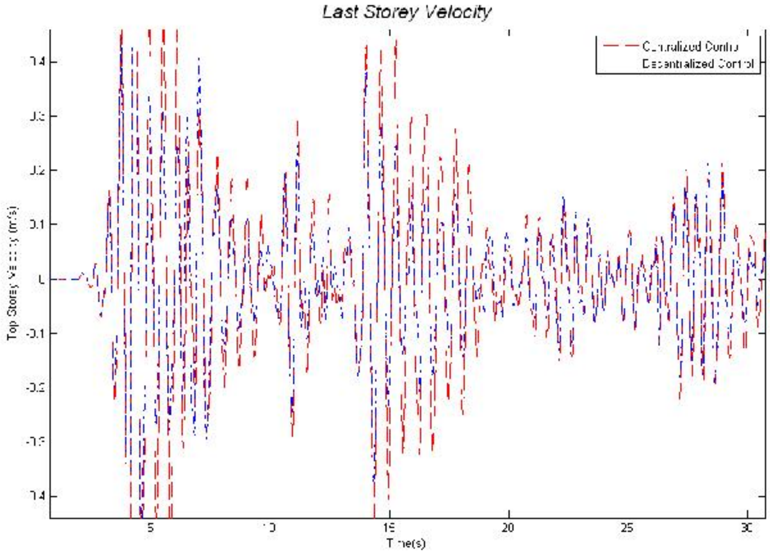

Figure 5. Top Storey velocity in decentralized and centralized control

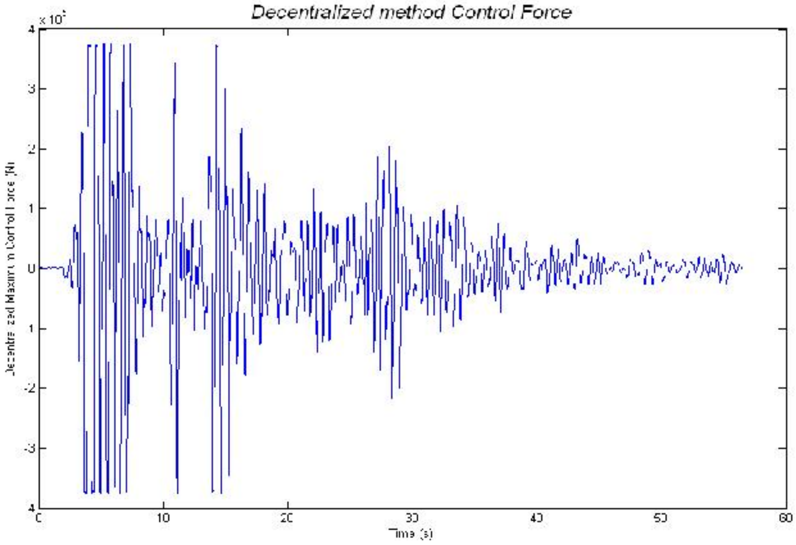

Figure 6. Maximum control forces generated by 2 dampers in decentralized method.

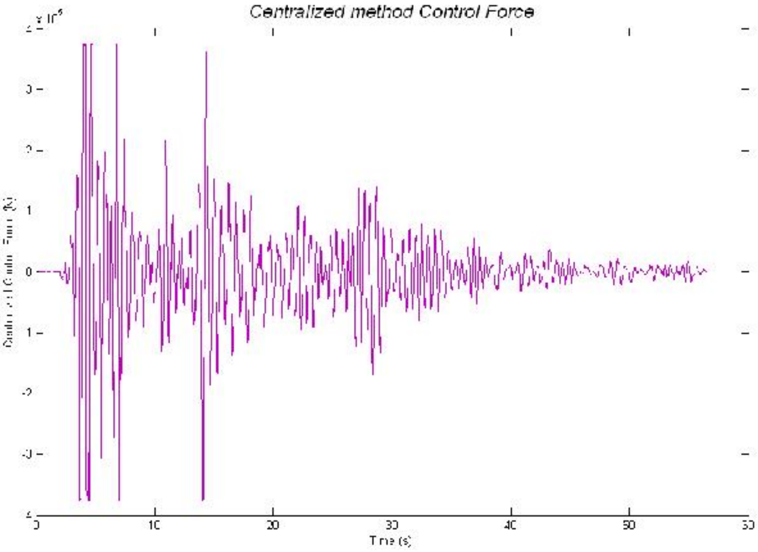

Figure 7. Control force generated by each 2 dampers in Centralized method

CONCLUSION

This paper aimed to propose a fuzzy logic decentralized algorithm to decrease structural responses in seismic excitation. We can see the improvement of benchmarkslike top storey velocity, displacement and drifts in this method in comparison to uncontrolled and centralized control method. Also we can see the decrease in relative displacements and drifts is more obvious. In centralized control method we have a 13.0 percent decrease of maximum structural drift and relative storey displacement in compare to uncontrolled structure, but in decentralized method this value is 26.8 percent in compare to uncontrolled structure,we see a 13.8 percent improve in using of decentralized method. Also we see a 12.7 and 6.1 percentof displacement and velocity of top storey in centralized control method than uncontrolled structure versus 23.4 and 14.9 percent decrease of these values in decentralized method.

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