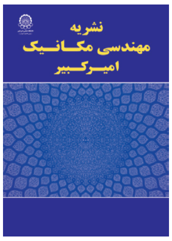

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Design of a Hybrid Adaptive Neuro-Fuzzy Inference System Proportional–Integral–Derivative Controller for Vibration Mitigation of a Structure against Earthquake

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ABSTRACT: This paper proposes a new hybrid controller based on combining adaptive neuro-fuzzy inference system method and proportional–integral–derivative controller, for vibration mitigation of structural system. The proposed controller although has the proportional–integral–derivative controller features, create a fuzzy inference system that has fewer bugs and errors than neural networks in calculations. The whale optimization algorithm is used for optimum tuning of the proposed method and also for identification of parameters related to the experimental structure. Considering four well-known earthquake real data the performance of the proposed controller is evaluated. Then the results are compared with two other controllers namely, fuzzy logic control and adaptive neuro-fuzzy inference system, which are designed for a four-degree of freedom building. The simulation results show that the proposed controller performs better than other strategies which are developed. The results obtained from the simulation show the better performance of the suggested method than the other control methods in reducing the displacement and acceleration of all floors. The results show that the maximum acceleration related to the building's floors while using proposed method has improvement of 36.3% for the El Centro, 35.4% for the Northridge, 27.7% for the Athens and 22.5% for the Mexico City earthquakes regarding fuzzy control and adaptive neuro-fuzzy inference system control.

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1- Introduction

Earthquake and also Natural hazards such as strong storms always cause serious damages to the structure. The scientists have the concern about this issue and always research on how to decrease these the structural responses of the structure due to a seismic situation. The last four hazard Earthquakes, such as El Centro, Mexico City, Athens, and Northridge brought undeniable, irrecoverable and destructive harms to the multi-degree of freedom structures. There have been many different ways and also many kinds of control mechanism for vibration control of structures. Bozorgvar and Zahrai [1] inspired a method based on an adaptive fuzzy model for decreasing the structural responses of the structure in a seismic situation. The proposed method by Etedali et al. [2] was identification the parameters and control a kind of dampers which are installed on a two-story building to mitigate the vibration of a structure due to an earthquake seismic data. To reduce the displacement and acceleration of structures, the authors proposed and addressed an control for analyzing the closed-loop stability of a building which is excited by earthquake ground motions. Zamani et al. [3] presented a fractional order Proportional–Integral–Derivative (PID) controller for active control of a smart structure with an active tuned mass damper attached in the last floor. However, the last research and articles in this field which used Adaptive Neuro-Fuzzy Inference System (ANFIS) and classical PID did not consider the uncertainties and variation in building parameters such as, stiffness, mass and damping coefficient, in this study the authors had inspired to design a new generation of hybrid controller which deal with uncertainties in the parameters related to the structure. To assess the value of the structural responses of the building equipped with an Active Tuned Mass Damper (ATMD) on each floor has caused authors to design and developed an ANFID control method combining with a classical PID controller. The Whale Optimization Algorithm (WOA) [4] is used for optimum tuning of the PID section of the proposed method. In order to evaluate the performance of the suggested control algorithm, an experimental four-story structure with a shaking table have been developed and constructed in the research laboratory and also WOA is used for parameter identification of constructed structure and the numerical study carried out on a four degree of freedom building which is equipped with ATMD subjected to various earthquake ground motions. The simulation results show the strong ability of the proposed method in decreasing the amplitude of structural responses of the examined structure.

2- Methodology

The Selecting the dynamic equation of motion of an n-story shear frame structure, subject to ground acceleration can be

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expressed as follows:

$$M\ddot{x}(t)+C\dot{x}(t)+Kx(t)=-M\gamma\ddot{x}_g(t) \quad (1)$$

Where is a displacement vector, is a mass matrix, is a damping coefficient, is a stiffness coefficient matrix and $\ddot{x}_g(t)$ ،is a vector of earthquake force. The model of a structural system is shown in Fig. 1. This paper proposed a new kind of hybrid controllers in the field of structural control for vibration control of a four-degree-of-freedom building. The proposed method namely hybrid ANFIS-PID. Furthermore, an experimental structure with a shaking table (see Fig. 1) is constructed in the laboratory and many kinds of the controller have been developed as active control strategies on the experimental structure to reduce the displacement of each floor. The whale optimization algorithm is used for optimum tuning of PID part of suggested method and also it is used for identification of structural parameters such as mass, stiffness, and damping. Some of features of proposed method are listed as below:

1) The application of PID controller makes the proposed method a robust control against input disturbances.

2) Establish a fuzzy inference system which has less difficulty in case of using linguistic knowledge.

3) Neuro-fuzzy systems have the ability to learn in case of memorizing the fuzzy benefits.

3- Results and Discussion

In order to test the efficiency of the hybrid algorithm, this paper chooses three earthquake data such as Northridge, Mexico City, Athens, and El Centro earthquake data set. For comparison, the same structure is used for numerical simulation. WOA [8] is used for parameter identification of the experimental structure and also it is used to find the optimal values of the PID coefficients in the hybrid method to produce an allowable maximum peak control force. The output of the numerical simulation for the uncontrolled, fuzzy control, ANFIS method and finally hybrid ANFIS-PID control are shown in figure 2 for the first floor floors due to 30 sec of motion. The uncontrolled structure is the structure without passive or active control devices. In order to evaluate the performance of the proposed controller during different earthquake excitations, the relative displacements of the first floor and last floor of the structure are listed in Table 1 hwith 15% uncertainties in building parameters such as mass, stiffness, and damping during El Centro earthquake. Considering all earthquakes, the results also show that the proposed controller performs better than ANFIS and fuzzy control in reducing the structural responses of the structure.

4- Conclusions

To increase the performance of the PID controller and ANFIS method in the field of structural control, a new generation of hybrid controllers namely ANFIS-PID was design and developed in this research. The proposed hybrid ANFIS-PID controller while containing the heuristic knowledge of fuzzy logic and the ability of neural networks in establishing a complex accommodation between input and output, is easy to use for active vibration attenuation of buildings against earthquake. To show the effectiveness of active control of structures a four-story structure has been constructed in the research laboratory. The whale optimization algorithm is used for optimum tuning of PID coefficients and also for identification of the structural parameters of the experimental structure such as mass, stiffness and damping coefficient. The numerical analysis was established and designed on a four-story building. Four different earthquake real-data of ground motions were selected and entered the simulation. The results showed the strong ability of the suggested ANFIS-PID controller among other designed methodologies in the field of structural control especially in reducing the amplitude of displacement and acceleration of all floors of the seismic-excited benchmark building.

Table 1. The amount of displacement of the first floor and fourth floor of the structure due to the El Centro 1940 earthquake based on different indices.

	Uncontrolled	ANFIS controller	Fuzzy controller	proposed Method
Mean Square Error				
1st floor	0.0060	0.0003	0.0007	0.0002
4th floor	0.0708	0.0036	0.0075	0.0018
Mean Absolute Error				
1st floor	0.0663	0.0151	0.0221	0.0115
4th floor	0.2277	0.0496	0.0736	0.0365

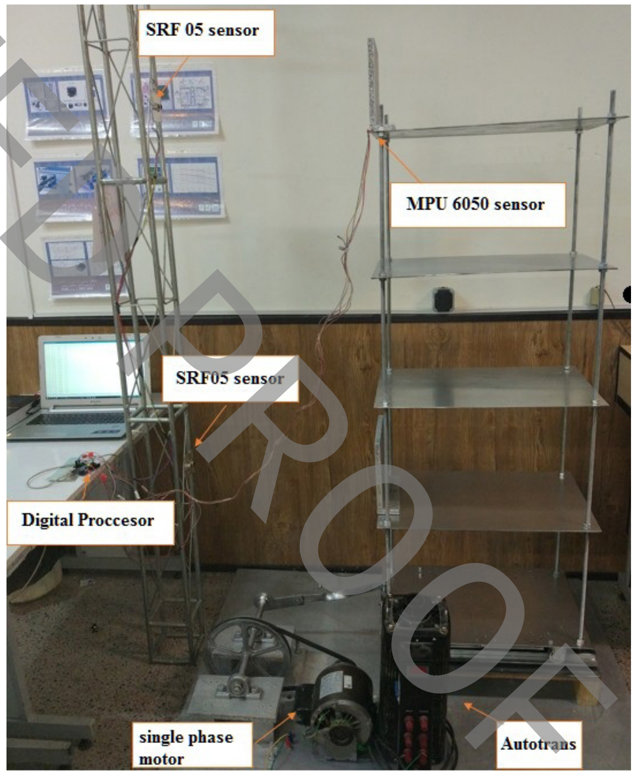

Fig. 1. A view of the constructed structure in the research lab for identification of structural parameters.

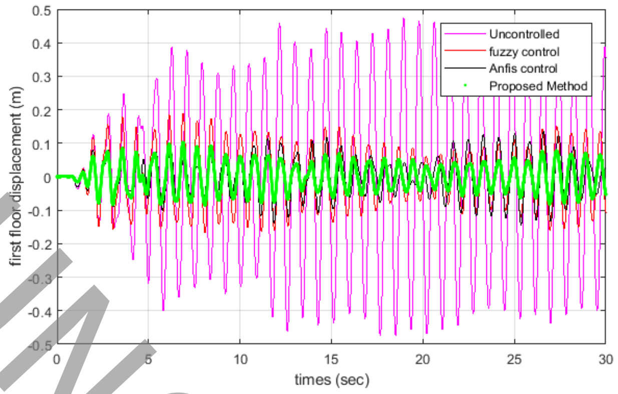

Fig. 2. The time history of the first floor displacement due to EL Centro 1940 earthquake which controlled by the proposed method compared with uncontrolled, ANFIS method and fuzzy logic controller.

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