Fuzzy Logic application in buildings vibration control in civil engineering

Mostafaaddin Zohrabzadeh [a], Dr.Mohammadali Afsharkazemi[b], Dr. Vahidreza Mirabi [c]

[a] Master of Administration Department of Information Technology Management, Islamic Azad University Electronic Campus,
Tehran, Iran

[b] Associate Professor Depatment Management , Azad University, Tehran Central Branch, Tehran, Iran

[c] Associate Professor Depatment Management , Azad University, Tehran Central Branch, Tehran, Iran

1 Corresponding Author name. Tel.: +98-912-333-6731

E-mail address: dr.mafshar@gmail.com

Abstract - The aim of the current research was investigating the application of fuzzy logic when controlling building vibrations. Thus, this research has introduced fuzzy and neuro-fuzzy system and has discussed the role of neuro-fuzzy system when helping to improve the response to the issue of controlling building vibrations. According to the results, using neuro-fuzzy inference system could regulate membership function parameters and fuzzy controller could control and reduce the damages to buildings up to 20%. The used system was a fuzzy controller of Sugeno type having 2 inputs, 1 output and 9 rules. After applying the data on the system, it faced the sum of square errors equal to 0.5150.

KEWORDS: Fuzzy logic, Building vibrations, Neuro-fuzzy inference system

Introduction

Controlling buildings vibrationcaused by wind or earthquake can be performed by passive, active, semi-active or compound control systems. In each of the above control systems, different tools are provided to reduce the seismic responses. Since the semi-active systems are reliable and tolerable like passive and active systems, it has attracted a number of researcher's attention in the field of structural control. Extensive studies have shown that semi-active systems have the ability to access the performance of an active system to a large extent which significantly operates better than that of passive systems. Although in the structural engineering, the reduction of damage caused by large loads is the most important purpose, but, since now, there has not been enough attention to ensure that damage indicators are directly controlled. This is because valid damage indicators include variety, while modern control theories includeing LQR , LQG, and sliding mode control, which are based on space-state model, can only incorporate state variables in performance indicators.

Due to easy implementation, Linear Quadratic Regulator (LQR) and Linear Quadratic Gaussian (LQG) are used as theoretical basic methods of modern control, the most common linear optimization control theory in engineering issues, and the most common algorithm in the calculation of control forces which can be used in active and semi-active structural control [2].

Fuzzy inference system is a method that can be used as a classical algorithm with far more extensive capabilities than Neural Networks and Evolutionary Algorithms and its modeling can be performed by lingual variables which provide system modeling and less computational intelligence to the control system. Fuzzy inference system is a systematic process that converts a database into a nonlinear map. Hence, the systems based on knowledge (including fuzzy system) are used in engineering and decision-making applications [12].

In 1975, Mamdani and Asilian used the fuzzy inference system to control the ingredients of a steam engine and boiler using lingual control rules in experiences of human operators (Mamdani and Asilian, 1975). In 1978, Holmblad and Wooster used the first fuzzy controller to control a complete industrial process like cement kiln. Since then, the fuzzy controllers were used in many industrial processes and devices such as subways and robotics and many other issues that need decision-making.

In 2007, Pourzeynali et al., studied the active structural control of high structures using fuzzy logic. Kim and Kang (2012), introduced the semi-active control of a structure using a multi-purpose Genetic Algorithm. In 2004, Aldawod et al., used fuzzy control to control the active structural nonlinear behavior in terms of seismic stimulation. In 2006, Rilay and Simeanz, studied the viscous semi-active damper and fuzzy control on the separated structure. Also in 2006, Kim et al., used fuzzy control and magnetorheological damper (MR) to control the separated structure.

In 2003, Samali et al., studied the experimental model of five-floor structure as well as Active Massive Damper (ATMD) in terms of different earthquakes using Linear Quadratic Regulator (LQR) and fuzzy control. In 2013, Mostashari, explained the fuzzy system's application in civil engineering [15]. In 2009, Ebrahimnejad and Fallah evaluated the fuzzy controller performance and LQR comparison in buildings vibration control [10]. In

2014, Fathi Sepahvand and Akbari evaluated steel optimal structural active control using fuzzy logic controller [11]. In 2009, Taarzi and Amini [3] considered the structural control using MR dampers and fuzzy method. In 2012, Daviee Markazi and Rabiee studied the buildings vibrationsliding-adaptive fuzzy active control in terms of earthquake stimulation [9]. In 2014, Joiee and Pourzeynali defined the optimization of rules table and fuzzy logic membership function shape in the structural semi-active structure using variable Stiffness [13].

In 2002, Amini and Farahmand [2] evaluated seismic active control in high structures using optimal allocation of poles. Also in 2012, Karamadin et al., studied the effect of the fuzzy controller on reducing the structural damage. In this study, the fuzzy system is used as the buildings vibrationcontroller according to research background as well as advantages of a fuzzy inference machine and interpretative capability and its power in modeling lingual variables [14].

Shariatmadar et al. (2014) investigated the seismic control of structures utilizing active tuned mass dampers with an interval type-2 fuzzy controller [17]. Their results revealed that notwithstanding the fact that an active tuned mass damper with a type-1 fuzzy controller functions is more efficient than a passive damper, yet, it cannot manage uncertainty in the fuzzy rule base which does not result in the wanted decrease in responses under earthquakes. Nyawako et al. (2015) presented comparative studies of vibration mitigation performance among a direct velocity feedback controller and a fuzzy controller scheme [16]. They noticed that somewhat less control force is needed for the fuzzy controller scheme at medium to low response levels.Zhang et al. (2015) investigated the fuzzy control of seismic structure with an active mass damper experimentally [19]. Achour-Olivier and Afra develops (2016) successfully used fuzzy logic and proposed a novel control algorithm for single degree of freedom structures based in Lyapunov method[1]. Bathaei et al. (2017a) investigated the vibration control of the bridge using multiple tuned mass dampers [6]. In another study, they assessed semi-active seismic control of an 11-DOF building model by an approach according to the upward and downward motion applying type-1 and type-2 fuzzy logic algorithms. Their results confirmed the great performance of the suggested control system [8]. Bathaei et al. (2017c) studied the application of type-1 and type-2 fuzzy inference system (FIS) in semi-active seismic vibration control of the College Bridge applying magnetorheological (MR) dampers [7]. They showed the greater performance of the type-2 FIS for decreasing the unwanted vibrations than that of type-1. Furthermore, the type-2 fuzzy controller was able to reduce more the maximum displacement, base shear, and moment of the bridge in comparison with the type-1 fuzzy controller. Azimi (2017) designed structural vibration control utilizing smart materials and devices [5]. They stated that the wavelet-based fuzzy logic control works better as compared with the classical fuzzy logic controller in term of decreasing the displacements and acceleration responses simultaneously. Azadvar et al. (2018) designed an Interval Type-2 Fuzzy Logic Controller (IT2FLC) to investigate the efficacy of this system to control the uncertainties directing the structure [4]. The results revealed that IT2FLC is more efficient in decreasing the uncertainties governing the structure as compared with other controllers. Zabihi-Samani and Ghanooni-Bagha (2018) proposed an optimal semi-active Cuckoo- Fuzzy algorithm to drive the hydraulic semiactive damper for efficient control of the dynamic deformation of building structures in earthquake loadings [18].

Research Methodology

Generally, a fuzzy system includes four basic components.

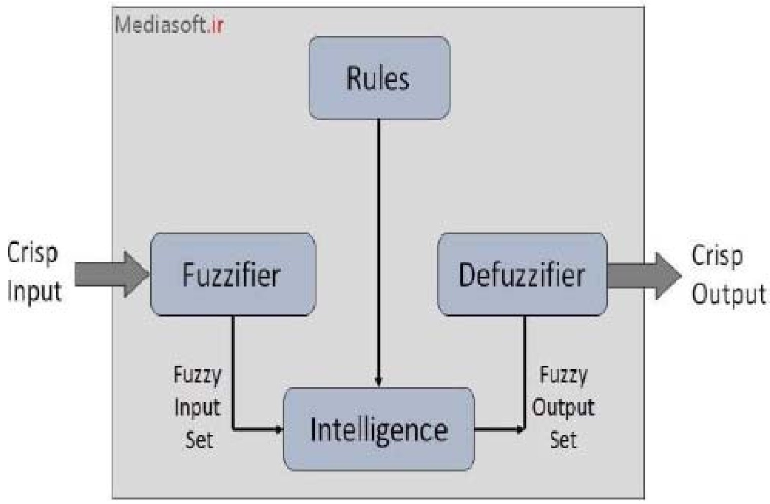

Figure 1: Fuzzy Inference System

The fuzzy inference systems are well-known computational frameworks based on the fuzzy set concepts, "if-then" rules and fuzzy logic.

The basic structure of fuzzy inference systems consists of three conceptual parts. The first part includes a selection of fuzzy rules. The second part is the database in which membership functions are used in the fuzzy rule framework. Finally, the third part is the inference mechanism where the inference procedure is done using the existing rules and facts to achieve a reasonable output (figure 1).

Despite interpretations and uncertainty management in the fuzzy system and suffering from non-compliance with the environment, the Neural Network adds this feature to the fuzzy system by intrinsic learning from the environment. Therefore, the fuzzy system and Neural Network can play a complementary role in intelligent systems. Neural Networks are made up of simple operating components working together in parallel. These components are inspired by biological nervous systems. In nature, the function of the Neural Networks is determined by how the components are connected. Therefore, it is possible to construct an artificial structure according to the Neural Networks to determine each component connection procedure by adjusting each connection value in terms of connection weight.

In order to implement the proposed model, the project is carried out in the form of a flowchart in Figure 2.

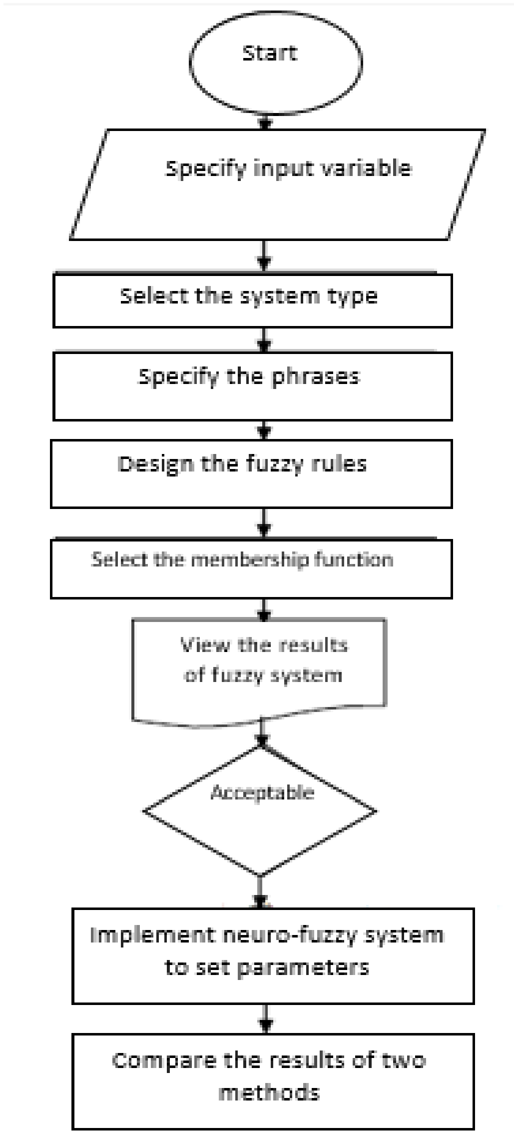

Figure2: procedure flowchart

The first step is to specify input/output variables in which the earthquake velocity, drift between two stories and velocity-drift are considered as input and damper coefficient is used as output.

The second step is to select the fuzzy system type. Because the neuro-fuzzy adaptive system parameters have been selected, this system works within its structure with a Sugeno fuzzy system. Therefore, the Sugeno fuzzy inference system is chosen.

The third step is to identify the language expressions that are used to input the drift and the drift input between two stories. In both cases of the linguistic expressions “very large negative, large negative, average negative, small negative, zero, small positive, average positive, large positive, very large positive” is selected.

Zero degree function is used for the output variable with values from zero to five.

The fourth step is to design the fuzzy rules that are performed by an expert. In the fifth step, a triangle membership function is used. In the sixth step, the fuzzy system is applied to the inputs and the system response is obtained for a particular input. The seventh step is performed to adjust the triangular function parameters of neuro-fuzzy system. In the eighth step, the results are compared with each other. Considering the proposed idea of this study, Sugeno fuzzy system must be selected. Therefore trapezium membership function with 5 membership function is changed into 5 constant functions with values of 2,1,3,4, and 5.

The designed fuzzy system is a Sugeno type with 2 inputs and one output of AND method, multiplication method using PROD, OR method using PROBOR, summation method using SUM, and non-fuzzifier method using WTAVER. Drift input and its design is illustrated in figure 3.

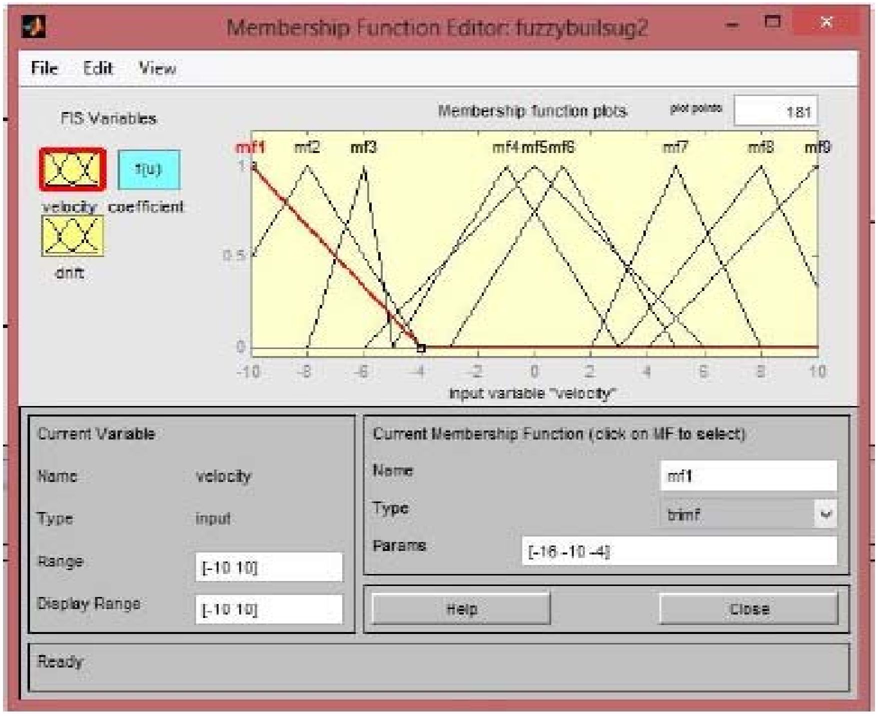

Figure 3: velocity membership functions

As shown in Fig. 3, the velocity input is designed with 9 membership functions. The velocity range is specified between -10 cm/s to 10 cm/s. The range of each membership function is as follows:

[Input1]

Name='velocity'

Range=[-10 10]

NumMFs=9

MF1='mf1':'trimf',[-16 -10 -4]

MF2='mf2':'trimf',[-12 -8 -4]

MF3='mf3':'trimf',[-8 -6 -5]

MF4='mf4':'trimf',[-5 -1 3]

MF5='mf5':'trimf',[-6 0 6]

MF6='mf6':'trimf',[-3 1 5]

MF7='mf7':'trimf',[2 5 8]

MF8='mf8':'trimf',[3 8 11]

MF9='mf9':'trimf',[4 10 16]

The drift input and its design is illustrated in figure 4.

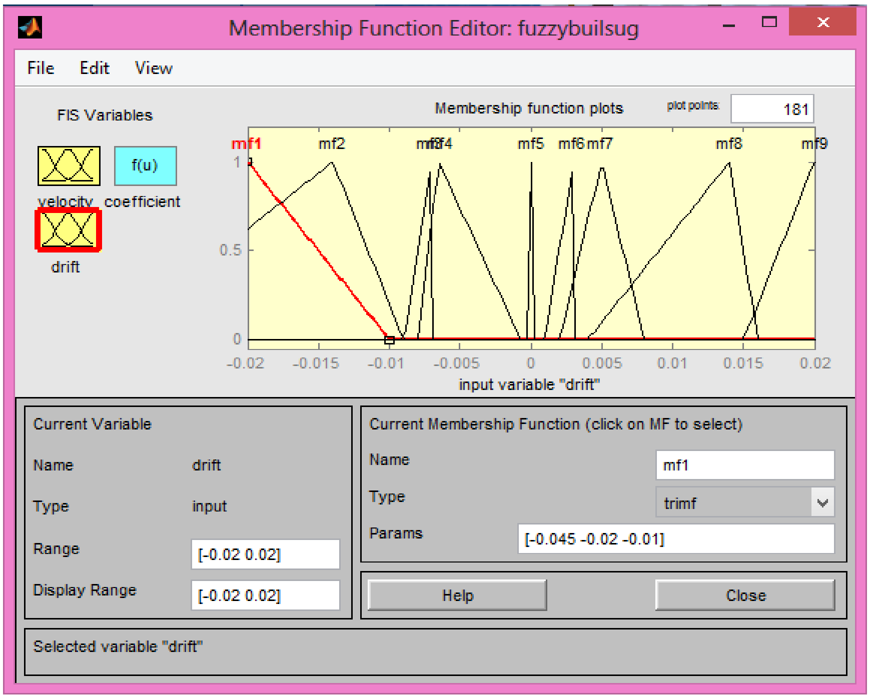

Figure 4: Drift membership functions between two stories

As can be seen in figure 4, the drift input (displacement between stories or drift) is designed with 9 membership functions. The drift range also varies from -0.02 m to 0.02m. The range of each membership function is as follows:

[Input2]

Name='drift'

Range=[-0.02 0.02]

NumMFs=9

MF1='mf1':'trimf',[-0.045 -0.02 -0.01]

MF2='mf2':'trimf',[-0.03 -0.014 -0.009]

MF3='mf3':'trimf',[-0.009 -0.007 -0.007]

MF4='mf4':'trimf',[-0.008 -0.0065 -0.0007]

MF5='mf5':'trimf',[-0.0001 0 0.0001]

MF6='mf6':'trimf',[0.001 0.003 0.003]

MF7='mf7':'trimf',[0.002 0.005 0.008]

MF8='mf8':'trimf',[0.004 0.014 0.016]

MF9='mf9':'trimf',[0.015 0.02 0.04]

The output of this system, as mentioned above, is a damper coefficient which is specified from 1 to 5. Figure 5 illustrates this output.

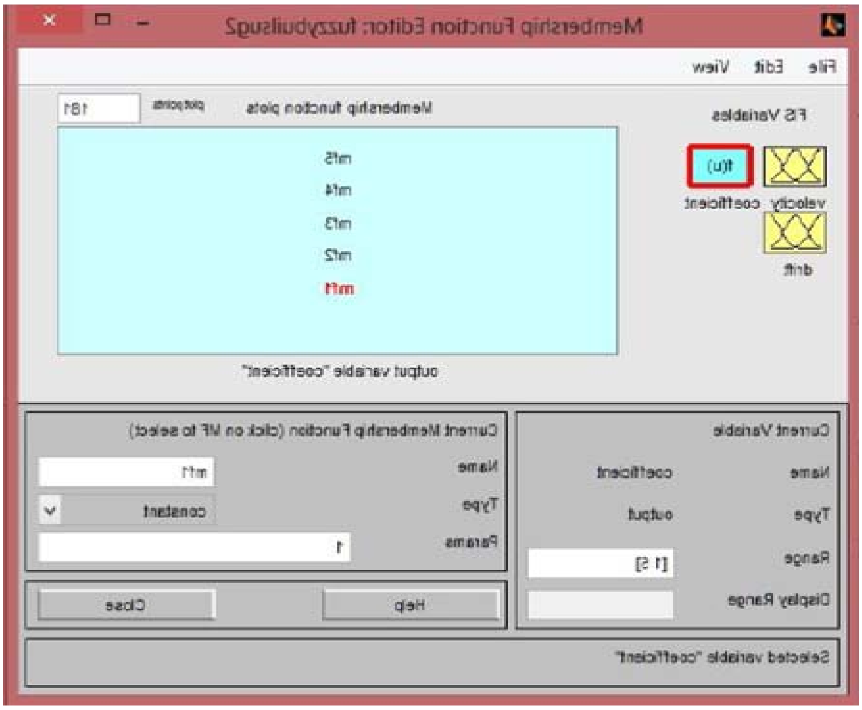

Figure 5: The damper coefficient output

The output characteristics is determined as follows:

[Output1]

Name='coefficient'

Range=[1 5]

NumMFs=5

MF1='mf1':'constant',[1]

MF2='mf2':'constant',[2]

MF3='mf3':'constant',[3]

MF4='mf4':'constant',[4]

MF5='mf5':'constant',[5]

In order to extract knowledge, the reference document is used.The inputs include drift and drift between two stories which are specified among the mentioned language expressions. Also, the output is a degree function from zero to 5 and provided as follows:

If the drift is “positive very large” or “negative very large”, then the damper coefficient equals 5.

If the drift is “positive large” or “negative large”, then the damper coefficient equals 4.

If the drift is “positive average” or “negative average”, then the damper coefficient equals 3.

If the drift is zero, then the damper coefficient equals 1.

If the drift between two stories is “positive very large” or “negative very large”, then the damper coefficient equals 5.

If the drift between two stories is “positive large” or “negative large”, then the damper coefficient equals 4.

If the drift between two stories is “positive average” or “negative average”, then the damper coefficient equals 3.

If the drift between two stories is “positive small” or “negative small”, then the damper coefficient equals 2.

If the drift between the two stories is zero, then the damper coefficient equals 1.

If the drift and drift are “positive very large” or “negative very large”, then the damper coefficient equals 5.

If the drift and drift are “positive large” or “negative large”, then the damper coefficient equals 4. If the drift and drift are “positive average” or “negative average”, then the damper coefficient equals 3. If the drift and drift are “positive small” or “negative small”, then the damper coefficient equals 2. If the drift and drift are zero, then the damper coefficient equals 1.

A fuzzy controller is designed using the above rules and the database where the damper coefficient is specified by expert judgment. This fuzzy controller can be installed in a building where the drift vibration and displacement between two floors are measured by drift sensors and sent to the fuzzy controller. The fuzzy controller, then, sends the damper coefficient changing command. The damper coefficients can be variable by installing additional types of equipment. After sending the control command, the damper coefficient is changed and the buildings vibrationis controllable. Therefore, it can prevent the widespread destruction of the building. Figure 6 illustrates the fuzzy rules base.

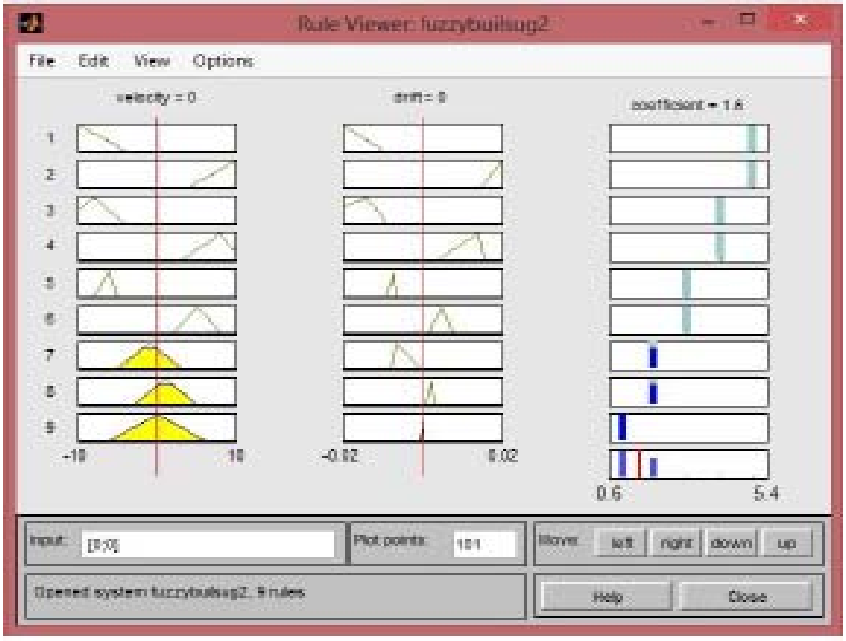

Figure 6: fuzzy rules base

In order to implement and evaluate this system a database of 100 drift and drift data is used between two stories which are obtained as input and output using drift equations and damper coefficient. In order to evaluate the system, the Mean Squared Error (MSE) method is used. This system was trained and tested by 100 lines of data and then resulted in MSE of 0.5150.

Results

Figure 7, illustrates the designed system error.

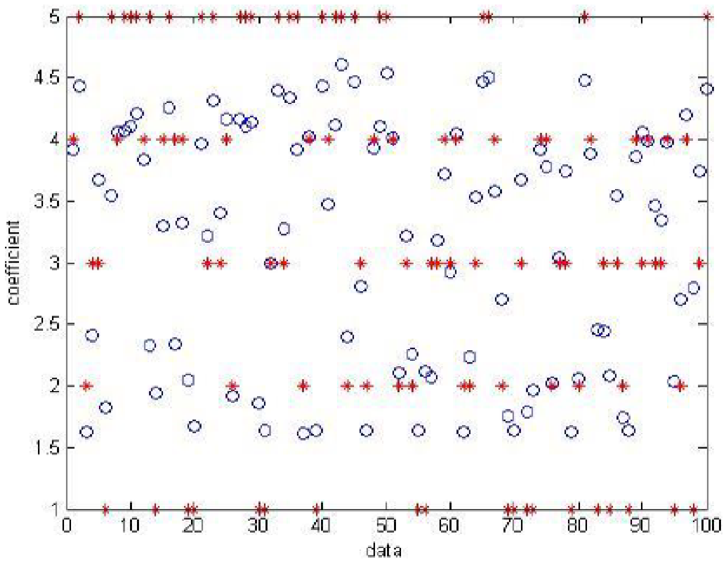

Figure 7: fuzzy system MSE error

In this graph, X-axis represents 100 data and Y-axis represents the rate of damper coefficient. In this graph, the circle and the stars show system response and response of mathematical relations, respectively. As you can see, about 50% of the responses are correct. But this rate is not acceptable. One of the reasons for this error rate is the non-regulating parameters of the membership function. This is why the neuro-fuzzy system is used to regulate the parameters of the membership function.

As we can see in this graph, the system responses have little difference with the target. Regarding the fact that this is a fuzzy system considering uncertainty, it is more reliable than a mathematical formula.Given that in the fuzzy system, the parameters of the input membership functions are considered to be approximate and are automatically regulated by the Neural Networks in the neuro-fuzzy system, the error rate decreased from 0.5 to 0.2.

Table1: the fuzzy error rate

System type	Fuzzy	Neuro-fuzzy
Error rate	0.5092	0.2561

In this table, the error rate of 100 samples in fuzzy and neuro-fuzzy systems is 0.5092 and 0.2561, respectively. The result obtained in this comparison is improved about 30%, which seems to be an acceptable rate. This comparison is shown in figure 27.

Conclusions

The results showed that the neuro-fuzzy inference system can be used to set parameters of the membership function.

Also, in this study, the fuzzy logic application in buildings vibration control using “if p then q” rules are defined. According to this research, the fuzzy controller in structural damage control can be reduced up to 20%. The proposed system is a Sugeno-type fuzzy controller which includes 2 inputs, 1 output, and 9 rules. After applying the data to the system, the Mean Squared Error of 0.5150 has resulted. Since 50% error means 50% structural damage, the neuro-fuzzy system is designed to set parameters of membership functions to increase the accuracy. The neuro- fuzzy system adjusts the parameters of the input membership functions automatically so that the least error in the output is observed using the back propagation method and comparison of the solutions with the optimal response. In this type of system, the back propagation Neural Network with 2 inputs, 1 output and 9 triangular membership functions are designed for each input. After applying the data to the neuro-fuzzy system, the error rate decreased to 0.3545 which is an acceptable result.

Given that in the fuzzy system, the parameters of the input membership functions are considered to be approximate and are automatically regulated by the Neural Networks in the neuro-fuzzy system, the error rate decreased from 0.5 to 0.2. Since the neuro-fuzzy system has acceptable performance, now, it is possible to improve the system performance by using 500 to 1000 data to make a monolithic system.

Thus, in order to increase the accuracy of evaluation, K-fold algorithm or multi-layered algorithm can be used to classify the data into a testing and training set. Another suggestion here seems to be the use of a Genetic Algorithm to extract rules from the data that can turn the system into a complete smart system.

References

[1] Achour-Olivier F, Afra H, (2016). Lyapunov based control algorithm for seismically excited buildings. Periodica Polytechnica Civil Engineering 60(3): 413-420.

[2] Amini, Fereidon, and Farahmand Azar, February, 2002, the active control of high seismic structures using optimal allocation of poles. Faculty of Engineering, Tabriz University: spring and summer, 2002, volume 27, number 26, electronics, pages 21 to 29.

[3] Amini, Fereidon, and Hamed Tarzi, 2009, structural control using fuzzy method MR dampers, the fourth national congress of Civil engineering, Tehran University, Tehran.

[4] Azadvar M, Hajkazemi H, Karamoddin A. 2018. Structural Damage Control with Interval Type-2 Fuzzy Logic Controler. AUT Journal of Civil Engineering 2(2): 125-134.

[5] Azimi M. 2017. Design of structural vibration control using smart materials and devices for earthquake-resistant and resilient buildings. MSc Thesis, North Dakota State University of Agriculture and Applied Science, Fargo, North Dakota.

[6] Bathaei A, Ramezani M, Ghorbani-Tanha AK. 2017a. Seismic Vibration Control of College Bridge Using Genetic Algorithm and Multiple Tuned Mass Dampers. Modares Civil Engineering Journal 16(5): 21-32, (In Persian).

[7] Bathaei A, Ramezani Meysam, Ghorbani-Tanha AK. 2017c. Type-1 and Type-2 Fuzzy Logic Control Algorithms for Semi-Active Seismic Vibration Control of the College Urban Bridge Using MR Dampers. Civil Engineering Infrastructures Journal 50(2): 333 – 351.

[8] Bathaei A, Zahrai SM, Ramezani M, (2017b). “Semi-active seismic control of an 11-DOF building model with TMD+ MR damper using type-1 and-2 fuzzy algorithms”, Journal of Vibration and Control, DOI: 10.1177/1077546317696369

[9] Davaiee Markazi, Amir Hossein Rabiee, 2012, Adaptive-seismic fuzzy active control of buildings vibration s under earthquake stimulation, earthquake conference, structures and computational method, Academic center for Education, Culture and research, Kerman

[10] Ebrahimnezhad, Salmai, Milad and Nosratollah Fallah, 2010, the performance of fuzzy controller and LQR comparison in buildings vibration control, the sixth national congress of Civil engineering, Shiraz University, Shiraz.

[11] Fathi Sepahvand, Mostafa and Jalal Akbari, 2015, the ptimal active control of steel structures with nonlinear behavior using fuzzy logic controller, the eighth national congress of Civil engineering Anoshiravani university of technology , Babol.
[12] Ghafarzadeh Dizaji, Homa, 2002, Submarine classification using fuzzy systems, bachelor thesis, Arak University, Arak.
[13] Joee, Peyman, and Saied Pourzeinali, 2014,semi-active control of structural response versus earthquake using variable stiffness and fuzzy logic, the seventh national congress of Civil engineering, Zahedan University, Zahedan
[14] Karamaldin, Abbas, Irani, Freidon, Baqban, Amir, 2012, the fuzzy controller effect on reduction of damage to the structure. The sixth national congress of Civil engineering, May, 2012, Semnan University, Semnan, Iran.
[15] Mostashari, Yaser, 2013, fuzzy systems in civil engineering, National conference on civil and sustainable development, Mashad, Khavaran Institute of higher education.
[16] Nyawako DS, Reynolds P, Pimentel RL, Hudson E. 2015. Fuzzy Logic Controller Scheme for Floor Vibration Control. MATEC Web of Conferences, 24: 06005, http://dx.doi.org/10.1051/matecconf/20152406005.
[17] Shariatmadar H, Golnargesi S, Akbarzadeh Totonchi MR. 2014. Vibration control of buildings using ATMD against earthquake excitations through interval type-2 fuzzy logic controller, Asian Journal of Civil EngineeringBuilding And Housing, 15(3): 321-338.
[18] Zabihi-Samani M, Ghanooni-Bagha M. 2018. An optimal Cuckoo search-fuzzy logic controller for optimal structural control. International Journal of Optimization in Civil engineering 8(1):117-135.
[19] Zhang W; Liu X; Xu G. Fuzzy Control of Seismic Structure with an Active Mass Damper. In Proceedings of the 6th International Conference on Advances in Experimental Structural Engineering, Champaign, IL, USA, 1–2 August 2015.