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Intelligent algorithm and optimum design of fuzzy theory for structural control

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Abstract. The optimal design of structural composite materials is a research topic that attracts the attention of lots researchers. For many more thirty years, there has been increasing interest in the applications in all kinds of topics, which means taking advantage of fuzzy set theory, fuzzy analysis, and fuzzy control for designing high-performance and efficient structural systems is a fundamental concern for engineers, and many applications require the use of a systems approach to combine structural and active control systems. Therefore, an intelligent method can be designed based on the mitigation method, and by establishing the stable of the closed-loop fuzzy mitigation system, the behavior of the closed-loop fuzzy mitigation system can be accurately predicted. In this article, the intelligent algorithm and optimum design of fuzzy theory for structural control has been provided and demonstrated effective and efficient in practical engineering issues.

Keywords: composite structures; energy equations; intelligent control function; structural control; tuned mass damper

1. Introduction

In recent decades, many scholars have done a lot of theoretical and experimental research in the field engineering applications and bridge fatigue life assessment. Much work has been done to demonstrate, investigate, refine, systematize, and control structural responses (Bai *et al*. 2021, Gu *et al*. 2022, Hao *et al*. 2022, Ma *et al*. 2021, 2022, Tian *et al*. 2021a, b, Shan *et al*. 2022, Wang *et al*. 2022, Wu *et al*. 2022, Yuan *et al*. 2022, Huang *et al*. 2020, Ni *et al*. 2020, Safa *et al*. 2016, Shariat *et al*. 2018). There methodology has been developed to examine the robustness and applicability of nonlinear systems, especially in engineered structures. For example, Casciati (1997), Casciati and Casciati (2018), Casciati and Faravelli (2009) and Casciati *et al*. (2014) provide an artificial intelligence-based approach for applications in engineering and nonlinear structures. That is, among the results produced in the field, we can cite the establishment of fatigue damage models, the study of the initial crack mechanism, and the evaluation of the overall fatigue life of the structure (Zhang *et al*. 2021a, b, c, 2022a, b, c, Zheng and Jin 2022). However, there is little literature on routes to prolong the fatigue life of steel bridges, and relatively few studies employing intelligent control techniques, especially in railway applications. Therefore, here we propose a method to reduce the response of civil engineering structures and reduce the magnitude of stress cycles using a tuned mass damper control system.

Composites fabricated using curing different temperatures and curing times exhibited different fracture behaviors. Predicting failure behavior is important for understanding what failures will occur. Recent research has been focused on sensor and actuator applications in smart structures. Therefore, the use of fuzzy controllers for vibration control of smart structures is feasible because it can handle nonlinearity, ambiguity, and inaccuracy, and easily captures the qualitative aspects of human knowledge, and has received attention for its ability to provide alternatives. The benefits of the simple designs procedure of fuzzy controllers have led to successful applications in various engineering systems. Following the seminal work of Ott, Grebogi, Yorke (OGY) (Ott, Grebogi, Yorke, 1990), fuzzy control has become a topic in challenging the field of nonlinear dynamics. In the paper, the Takagi Kanno (TS) fuzzy dynamic model consists of fuzzy IF-THEN rules. The concept of Parallel Distributed Compensation (PDC) scheme is introduced. Wang *et al*. (1996) were used to design a fuzzy controller to stabilize a fuzzy model. It is well known that injecting a high frequency signal called jitter into a nonlinear system can improve its performance. Lin *et al*. (2010a, b, c, d) and Zhang *et al*. (2022a, b, c) performed a rigorous analysis of the stability of common nonlinear systems with jitter control. The relaxed model could be stable by appropriately adjusting the jitter parameters. It has been displayed that the trajectory of a shaking system can be accurately predicted by getting the trajectory of the corresponding model as a relaxed model.

In addition, intelligence is also a hot field that has attracted the attention of many researchers. This area contains many algorithms inspired by the little wisdom of Mother Nature. Generally speaking, swarm intelligence

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methods require evolutionary computation and imitate certain behaviors and survival skills of living things. In addition, this paper also applies the grey optimal algorithm to solve the control problem. Based on the above theory, the welding residual stress and the dynamic action applied to the bridge joint are obtained respectively. Based on the realization of the sub-model, a multi-scale model of the overall building model of the important nodes in the mid-span is jointly established. In addition, we will establish the motion equation of the control system with the new evolutionary fuzzy control. The entire methodology, along with estimating the required control capabilities, is performed using commercial software submodeling solutions.

2. Motion systems and structure problems

Assume the motion equation can be written as

$$M\ddot{\bar{X}}(t) + C\dot{\bar{X}}(t) + K\bar{X}(t) = \bar{B}U(t) - M\bar{r}\ddot{x}_g \quad (1)$$

where $\bar{X} = [\bar{x}_1, \bar{x}_2, \ldots \bar{x}_n]^T \in R^n$ is an n-vector. Matrices M, C and K are n × n mass, damping and stiffness matrices, respectively. The m-dimensional control force vector U(t) corresponds to the actuator forces. The standard first-order state equation for controller design corresponding to Eq. (1) is

$$\dot{X}(t) = AX(t) + BU(t) + E\ddot{x}_g \quad (2)$$

where

$$X^T = [\bar{X}^T \quad \dot{\bar{X}}^T] \quad (3)$$

where $\bar{X}(t) = [\bar{x}_1(t), \bar{x}_2(t) \cdots \bar{x}_n(t)] \in R^n$ is the n vector representing the alcove drift for the specified ith layer of cells. The matrices M, C, and K are the n × n mass, damping, and stiffness matrices, respectively. The m-dimensional control force vector U(t) corresponds to the actuator force (e.g., generated by an active tendon system or active mass damper). This is a static model that ignores the dynamic equations of the actuator. These dynamic delay effects are described in the next section.

In controller design, the standard linear state equation corresponding to Eq. (1) is

$$\dot{X}(t) = AX(t) + BU(t) + E\ddot{x}_g$$

where $X^T = [\bar{X}^T \quad \dot{\bar{X}}^T]$ is a 2n vector and

$$A = \begin{bmatrix} 0 & I_{n\times n} \\ -M^{-1}K & -M^{-1}C \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ -M^{-1}\bar{B} \end{bmatrix}, \quad E = \begin{bmatrix} 0 \\ -\bar{r} \end{bmatrix}.$$

In structural mechanics, passive dampers are often used as a mechanism to continuously absorb energy from a structure. It is an ideal device for damping the transient vibration of the structure without destabilizing the structure. Since available passive dampers do not always provide an adequate damping coefficient, speed feedback control systems are often used to mimic their behavior. The side-by-side speed feedback is robust. It doesn't break passive structures. When the juxtaposed velocity loops are closed with an appropriate gain, the structural poles be ready to move further into the left in the complex plane or towards the slightly attenuated open-loop zeros (Chen 2020). These near-zero open-loop models simplify system I/O relationships, allowing more efficient model reduction later in controller design (Yamamoto *et al*. 1982). Once you have a properly scaled model, you can use the LQG/LTR robust control method to get an active controller of the same order as the downscaled model.

3. Collocated velocity feedback

In mechanics of structure, passive dampers are often used as a mechanism to continuously absorb energy from a structure. Once you have a properly scaled model, you can use the LQG/LTR robust control method to get an active controller of the same order as the downscaled model. After the parallel speed feedback loop is closed, the linear state equation corresponding to Eq. (1) is

$$\dot{X}(t) = (A - BK_vC)X(t) + E\ddot{x}_g \quad (4)$$

where $C = [0 \quad \bar{B}^T]$ is the location matrix representing collocated sensors. This feedback gain

$$K_v = diag(K_{v1}, K_{v2}, \cdots, K_{vi}, \cdots, K_{vm}), \quad 1 \le i \le m \quad (5)$$

In the report, the study desire that the reduced structural model be such that

$$G(s) = \hat{G}_r + \tilde{\Delta}_a \quad (6)$$

Let us neglect the earthquake excitations effect, and prepare the full-order structural model G(s) given by

$$\begin{aligned} \dot{X}(t) &= AX(t) + BU(t) \\ Y(t) &= CX(t) + DU(t) \end{aligned} \quad (7)$$

The r-vector contains the components to be retained. Now partition the matrices A, B and C conformably with X to obtain

$$A = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}, \quad B = \begin{bmatrix} B_1 \\ B_2 \end{bmatrix}, \quad C = [C_1 \quad C_2]. \quad (8)$$

Given low-frequency behavior by setting

$$\dot{X}_2(t) = 0 \quad (9)$$

and

$$X_2(t) = -A_{22}^{-1}(A_{21}X_1(t) + B_{22}U(t)) \quad (10)$$

The rth-order reduced model given by state-space truncation method is

$$\begin{aligned} \hat{G}_r(s) &\equiv T_r(A, B, C, D) \equiv (\hat{A}_{11}, \hat{B}_1, \hat{C}_1, \hat{D}) \\ &= \hat{C}_1(sI - \hat{A}_{11})^{-1}\hat{B}_1 + \hat{D} \end{aligned} \quad (11)$$

A balanced realization (A_b, B_b, C_b, D_b) is the Lyapunov equations

$$A_bP + PA_b^T + B_bB_b^T = 0 \quad (12)$$

and

$$A_b^TQ + QA_b + C_b^TC_b = 0 \quad (13)$$

We now present an algorithm forming for balanced realization implemented in some steps

$$AP + PA^T + BB^T = 0 \quad (14)$$

and

$$A^TQ + QA + C^TC = 0 \quad (15)$$

Then, obtain the factorization

$$Q = R^TR \quad (16)$$

Find the decomposition

$$RPR^T = U\Sigma^2U^T \quad (17)$$

Form the

$$(A_b, B_b, C_b, D_b) = (TAT^{-1}, TB, CT^{-1}, D) \quad (18)$$

By algebraic simple manipulations, this system output Y(t) satisfy

$$\int_0^\infty Y^T(t)Y(t)dt = X_{0b}^TQX_{0b} = X_{0b}^T\Sigma X_{0b}. \quad (19)$$

$$\min_{u\in L_2(-\infty,0)} \int_{-\infty}^0 U^T(t)U(t)dt \quad (20)$$

subject to

$$\dot{X}_b = A_bX_b + B_bU(t) \quad \text{with} \quad X_b(0) = X_{0b}. \quad (21)$$

Suppose it is a balanced realization as

$$\Sigma = \begin{bmatrix} \Sigma_1 & 0 \\ 0 & \Sigma_2 \end{bmatrix}. \quad (22)$$

$$\left\|\tilde{\Delta}_a(s)\right\|_\infty \equiv \left\|G(s) - \hat{G}_r(s)\right\|_\infty \le 2(\sigma_{r+1} + \sigma_{r+2} + \cdots + \sigma_n) \quad (23)$$

$$\left\|\tilde{\Delta}_a(s)\right\|_\infty \equiv \sup_\omega \bar{\sigma}\left[\tilde{\Delta}_a(j\omega)\right]. \quad (24)$$

Recall that singular values of matrix A are the square roots of the eignvalues of $A \times A$; i.e.,

$$\sigma_i^2(A) = \lambda_i(A \times A), \quad (25)$$

$$\frac{\bar{\sigma}\left(\tilde{\Delta}_a(j\omega)\right)}{\bar{\sigma}\left(\hat{G}_r(j\omega)\right)}\bar{\sigma}\left[\hat{G}_r(j\omega)K(j\omega)\left(I + \hat{G}_r(j\omega)K(j\omega)\right)^{-1}\right] < 1 \quad (26)$$

$$\omega_r \equiv \max\left\{\omega | \underline{\sigma}\left(\hat{G}_r(j\omega)\right) \ge \bar{\sigma}\left(\tilde{\Delta}_a(j\omega)\right)\right\} \quad (27)$$

$$\underline{\sigma}\left(\hat{G}_r(j\omega)K(j\omega)\right) \gg 1, \quad (28)$$

for all

$$\bar{\sigma}\left\{\hat{G}_r(j\omega)K(j\omega)\left(I + \hat{G}_r(j\omega)K(j\omega)\right)^{-1}\right\} \approx 1 \quad (29)$$

and hence

$$\underline{\sigma}\left(\hat{G}_r(j\omega)\right) > \bar{\sigma}\left(\tilde{\Delta}_a(j\omega)\right) \quad (30)$$

The following equation can be derived

$$\begin{aligned} Y(s) = \hat{G}_r(s)K(s)\left[I + \hat{G}_r(j\omega)K(s)\right]^{-1}\left[r(s) - n(s)\right] \\ +\left[I + \hat{G}_r(s)K(s)\right]^{-1}d(s) \end{aligned} \quad (31)$$

The overall controller is

$$K(s) = (I/s)K_{LQG/LTR}(s) \quad (32)$$

The state-space representation of could be written, so the LQG/LTR design procedures can be followed to devise the controller for augmented system. The grey wolf is a carnivorous canine, their characters specialize in agile, rapid and long-range galloping, and possess majestic adaptability for the environment. Inheriting similar the grey wolf's capability, the GWO possessed the optimization procedure of encircling, social stratification, and attacking prey. The improved grey model-based fuzzy neural network scheme-algorithm combines the grey evolved algorithm and the laypunov based model based neural network scheme control laws with a greedy strategy.

4. Robust minimax controller

To explain the structure of the control system in the white paper, the section remainder is divided into two parts. A Takagi–Sanno fuzzy chaotic model of the system is established, the fuzzy controller is designed by the PDC method, and the stability criterion for judging whether the closed-loop fuzzy system is stable is given.

Closed-loop fuzzy system:

To facilitate stability analysis, we $Q = P^{-1}$ can assume and further define as follows, $W_i = K_iQ$ so $Q > 0$ yes $K_i = W_iQ^{-1}$.

Lemma 4.1 (Wang *et al.* 1996) The closed-loop ambiguity, if present, is large and stable via the PDC, allowing the condition to be satisfied.

$$QA_i^T + A_iQ - B_iW_i - W_i^TB_i^T < 0 \quad (33)$$

Build the TS fuzzy model of the relaxed model. The fuzzy controller is then retrieved through the PDC scheme.

The ith rule of the fuzzy mitigation model is $F_R(0;0)$ expressed as

$$\dot{x}_R(t) = \frac{\sum_{i=1}^{r} W_i(x_R(t),\alpha_m,\beta_m)\{A_i(\alpha_m,\beta_m)x_R(t) + B_i(\alpha_m,\beta_m)u_R(t)\}}{\sum_{i=1}^{r} w_i(x_R(t),\alpha_m,\beta_m)} \quad (34)$$

Control rule i

IF $x_{R1}(t)$ is $M_{ik}^{R}(\alpha_m,\beta_m) \ldots M_{i1}^{R}(\alpha_m,\beta_m)$ and $x_{Rk}(t)$

Then

$$u_R(t) = -K_i(\alpha_m,\beta_m)x_R \qquad i = 1,2,\ldots,r \quad (35)$$

From the above discussion, it can be inferred that if the frequency of dithering is high enough and a suitable membership function is selected, the trajectories of the fuzzy closed-loop relaxed system and this closed-loop dithering chaotic system will be relatively close. as follows. feasible. From now on, we no longer discuss the stability of closed-loop dithering chaotic systems, but the stability of $N(C;d)$ closed-loop fuzzy mitigation systems $F_R(C;0)$. Therefore, the stability criteria are listed below.

Theorem 4.1 The closed-loop relaxed system is asymptotically stable if there exist a $Q > 0$ and $W_i(\alpha_m,\beta_m)$ such that the following LMI conditions hold

$$QA_i^T(\alpha_m,\beta_m) + A_i(\alpha_m,\beta_m) - B_i(\alpha_m,\beta_m)W_i(\alpha_m,\beta_m) - W_i^T(\alpha_m,\beta_m)B_i^T(\alpha_m,\beta_m) < 0 \quad (36)$$

where

$$W_i(\alpha_m,\beta_m) = K_iQ \quad (37)$$

$$W_j(\alpha_m,\beta_m) = K_jQ \quad (38)$$

The proof of the above theorem can be similarly derived by following the same procedure as that in the proof of Wang *et al*. (1996) Theorem 3 but without being replaced by $A_i(\alpha_m,\beta_m)$, $A_j(\alpha_m,\beta_m)$, $W_i(\alpha_m,\beta_m)$ and $W_j(\alpha_m,\beta_m)$, respectively. This proof is lengthy, so it is not repeated here.

5. A numerical example

To explain the application of the proposed methodology, the design controller procedure was used. A parameter lumped model was applied for simulations. The lumped schematic model is written in terms of the relative motion of the floors. Using $\bar{X}$ as the interfloor vector of drifts, straightforward manipulations results in

$$M^{-1}K = \begin{bmatrix} k_1/m_1 & -k_2/m_1 & 0 & 0 & 0 & 0 \\ -k_1/m_1 & (k_2/m_1)+(k_2/m_2) & -k_3/m_2 & 0 & 0 & 0 \\ 0 & -k_2/m_2 & (k_3/m_2)+(k_3/m_2) & -k_4/m_3 & 0 & 0 \\ 0 & 0 & -k_3/m_3 & (k_4/m_3)+(k_4/m_4) & -k_5/m_3 & 0 \\ 0 & 0 & 0 & -k_4/m_4 & (k_5/m_4)+(k_5/m_4) & -k_6/m_5 \\ 0 & 0 & 0 & 0 & -k_5/m_5 & (k_6/m_5)+(k_6/m_5) \end{bmatrix}$$

Similarly, $M^{-1}C$ and $\ddot{x}_g$ will be the earthquake ground acceleration. The control influence matrix $\bar{B}$, depends on the number and locations of actuators used. We will have

$$M^{-1}\bar{B} = \begin{bmatrix} 1/m_1 & -1/m_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1/m_3 & -1/m_3 - 1/m_4 & 1/m_4 & 0 \end{bmatrix}^T \quad (38)$$

If there is only one actuator on the first floor, the second column will be removed. Seismic motion for EL-CENTRO earthquakes. It has an intelligently controlled vibration isolation system and an actuator. Mass, stiffness and damping properties are as follows. For mass $m_1 = 6810\,kg$ m_i, for i = 2, 3, 4, 5 and 6, = 5897 kg. For stiffness $k_1 - k_6$, the stiffness of the 6-layer element is 1210, 33832, 29593, 28921, 25954, and 19069 kN/m, respectively. The viscous damping coefficients of the 6-layer elements $c_1 - c_6$ are 2.4, 68, 56, 47, 40 and 39 kNs/m, respectively. In this basic insulation system, the natural frequencies of the structure are 0.79, 5.66, 10.23, 14.24, 19.41 and 20.38 Hz, respectively, and the damping ratio of the first mode shape is 0.58%. EL-CENTRO seismic ground acceleration was used as input excitation.

Actuators are installed on the ground floor to protect the safety and integrity of the underlying insulation system and further reduce the building's response.

Singular value Bode plot of the transfer function of the actuator input to the first-order deformation, assuming that the juxtaposed velocity and first-order deformation can be measured, closing the juxtaposed velocity loop $K_v = 4e5$ (as shown in Fig. 1). closed before. The first two equilibrium state vectors are retained, and the other is removed by engineering, since $\bar{X}_1$ each σ_i^2 state vector is a measure of the corresponding state vector's participation in the transfer of energy from past inputs to future outputs in the state space. judge. Singular value Bode plots of these two state low-dimensional models $\hat{G}_{r=2}(s)$. To improve the low frequency performance of the feedback system, before designing the LQG/LTR controller, an integrator can be used to expand the plant to obtain a state-space representation of the expanded system $G_a(s)$. Now follow the step-by-step LQG/LTR design procedure $K_{LQG/LTR}(s)$ to find a controller for your expansion system $G_a(s)$.

Step 1. In this step, we construct and analyze the transfer function $G_{TFL}(s)$ of the target feedback loop. In the LQG/LTR design procedure, $G_{TFL}(s)$ is designed using Kalman Filter concepts. Note that the 0 dB crossover frequencies are about 0.4 Hz and that at low frequency they decay with a slope of -20 dB/decade, which means that the TFL satisfies both requirements of the stability robustness constraint and the low frequency disturbance rejection.

Step 2. The general structure of the LQG/LTR controller $K_{LQG/LTR}(s)$ is defined by Eq. (53). In this design example, the numerical values are chosen as follows

$$Q_C = C_a^T C_a$$
$$= [3.96 \times 10^{-8} \quad -1.21 \times 10^{-3} \quad -1.51 \times 10^{-3}]$$
$$\times [3.96 \times 10^{-8} \quad -1.21 \times 10^{-3} \quad -1.51 \times 10^{-3}]$$
$$= \begin{bmatrix} 1.57 \times 10^{-15} & -4.8 \times 10^{-11} & -5.99 \times 10^{-11} \\ -4.8 \times 10^{-11} & 1.47 \times 10^{-6} & 1.83 \times 10^{-6} \\ -5.99 \times 10^{-11} & 1.83 \times 10^{-6} & 2.29 \times 10^{-6} \end{bmatrix}$$

$$Q_C = \rho I = 1.0 \times 10^{-15}$$

and the control gain matrix F is $F = [10.5 \quad 2.89 \times 10^4 \quad 1.47 \times 10^4]$.

For $\rho \to 0$ (sufficiently small), the LQG/LTR method guarantees that in the absence of right half plane zeros the transfer function $G_a(s)K_{LQG/LTR}(s)$ asymptotically approach the transfer function $G_{TFL}(s)$. Since $G_{TFL}(s)$ designed in step 1 meets the specifications, the approximations guarantees that the LQG/LTR design.

You can now use the controller with the base isolation building full-order structural model G(s) to simulate active structural control systems. The interlayer deformation and absolute acceleration of layers 1 and 4 are represented by solid curves. It can be seen from the table that the deformation of the base separation system (single-layer unit) is reduced by more than 85%, the response of the superstructure is also reduced by more than 50%, and the magnitude of acceleration is significantly reduced. Floor (Yuka. Singular plate diagram of transfer function from seismic excitation input to first-order element deformation before and after implementation of active structural controller. $\frac{\ddot{x}_1(j\omega)}{\ddot{x}_g(j\omega)}$ Control system foundation separation under all seismic excitations. System response can be effectively reduced. Frequency The components, especially in the fundamental vibration mode 0.89 Hz, are not only designed for EL-CENTRO seismic excitation.

Assuming you can use modeling

$$\dot{u}(t) = -bu(t) + bv(t).$$

where $v(t)$ is the command input to the actuator and u(t) is the output of the actuator, which actually applies to the basic insulation system. The constant b is the parameter of the actuator. The standard approach to this problem is to form uncontrolled structural models in the extended state.

$$\begin{bmatrix} \dot{X}(t) \\ \dot{u}(t) \end{bmatrix} = \begin{bmatrix} A & B \\ 0 & -b \end{bmatrix} \begin{bmatrix} X(t) \\ u(t) \end{bmatrix} + \begin{bmatrix} 0 \\ b \end{bmatrix} v(t) + \begin{bmatrix} E \\ 0 \end{bmatrix} \ddot{x}_g.$$

The command input to the actuator in Fig. 1 (dashed curve) and the actuator output $(u(t))$ of the base separation system (solid curve). The structural parameters of the nominal controller design shown in Case B were investigated. The stiffness ki of all floor units varies by 45% from the nominal value. ± The active structural controller is the same as in case B and does not account for stiffness fluctuations.

Based on the definitions, the general T-S fuzzy model can be represented as the 4-rule TSFRM. It shows that RPR^1 involves PR^1, PR^2, PR^6 and PR^7. Similarly, RPR^2 involves PR^2, PR^3, PR^7 and PR^8. Therefore, the fuzzy model can be replaced as follow

RPR^1
IF $x_2(\,)$k is $Region_{12}$ and x_3(k) is $Region_{13}$
THEN
Local Plant Rule[1]
IF $x_2(\,)$k is around $-\pi$ and x_3(k) is around 0
THEN $\mathbf{x}(k+1) = \mathbf{A}_{11}\mathbf{x}(k) + \mathbf{A}_d\mathbf{x}(k-\tau) + \mathbf{B}_{11}u(k)$

Local Plant Rule[2]
IF $x_2(\,)$k is around $-\pi/2$ and x_3(k) is around 0
THEN, $\mathbf{x}(k+1) = \mathbf{A}_{12}\mathbf{x}(k) + \mathbf{A}_d\mathbf{x}(k-\tau) + \mathbf{B}_{12}u(k)$
Local Plant Rule[3]
IF $x_2(\,)$k is around $-\pi$ and x_3(k) is around $\pm\pi/2$
THEN, $\mathbf{x}(k+1) = \mathbf{A}_{13}\mathbf{x}(k) + \mathbf{A}_d\mathbf{x}(k-\tau) + \mathbf{B}_{13}u(k)$
Local Plant Rule[4]
IF $x_2(\,)$k is around $-\pi/2$ and x_3(k) is around $\pm\pi/2$
THEN $\mathbf{x}(k+1) = \mathbf{A}_{14}\mathbf{x}(k) + \mathbf{A}_d\mathbf{x}(k-\tau) + \mathbf{B}_{14}u(k)$
RPR^2
IF $x_2(\,)$k is $Region_{22}$ and x_3(k) is $Region_{13}$

RPR^4
IF $x_2(\,)$k is $Region_{42}$ and x_3(k) is $Region_{13}$
THEN
Local Plant Rule[1]
IF $x_2(\,)$k is around $\pi/2$ and x_3(k) is around 0
THEN, $\mathbf{x}(k+1) = \mathbf{A}_{41}\mathbf{x}(k) + \mathbf{A}_d\mathbf{x}(k-\tau) + \mathbf{B}_{41}u(k)$

Local Plant Rule[4]
IF $x_2(\,)$k is around π and x_3(k) is around $\pm\pi/2$
THEN $\mathbf{x}(k+1) = \mathbf{A}_{44}\mathbf{x}(k) + \mathbf{A}_d\mathbf{x}(k-\tau) + \mathbf{B}_{44}u(k)$,

From the above results, it can be seen that the design method of the active structural controller shown in this

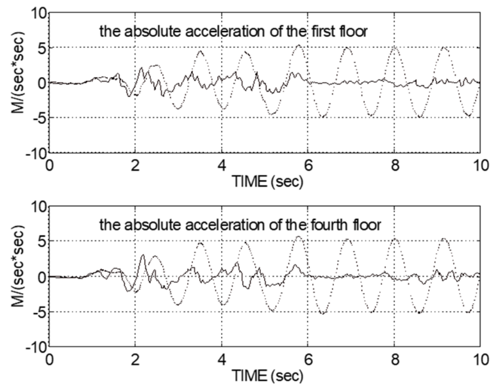

Fig. 1 Absolute acceleration of first and fourth floors

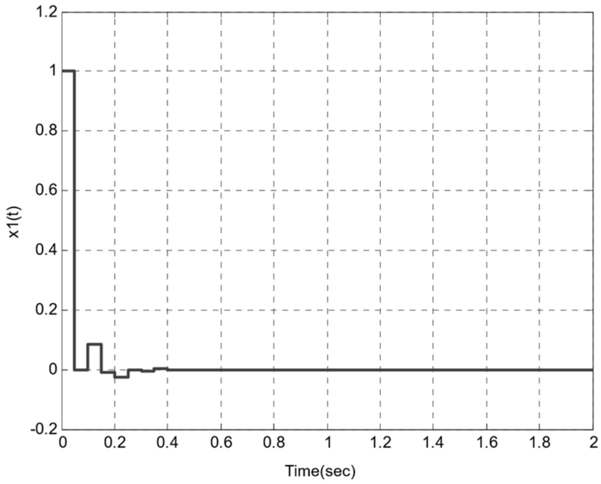

Fig. 2 The state response of $x_1(t)$

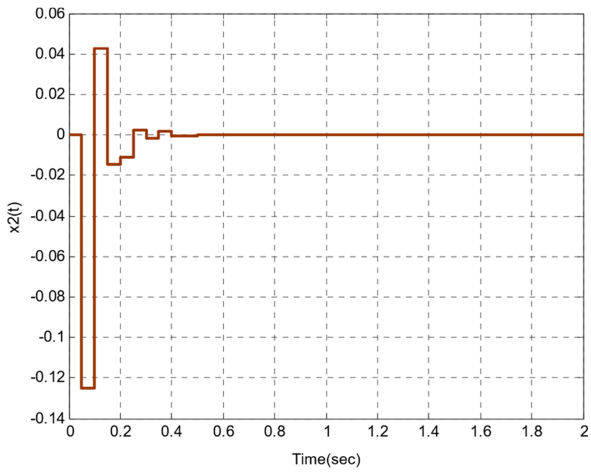

Fig. 3 The state response of $x_2(t)$

report is very effective in reducing the response of the building. In fact, after careful consideration, the low-oled active controller $K(s) = K_{LQG/LTR}(s)\frac{1}{s}$ is the only quaternary controller incorporating parallel velocity feedback that can meet both the performance and robustness requirements of structural systems. The state response is shown in Figs. 2-5.

6. Conclusions

This study paper adopts a new approach in which chaos can be controlled using fuzzy controllers and appropriate dithering. If the fuzzy controller is not stabilizing the chaotic system, then the dither has been injected in the system of chaotic to assist the controller, and the chaotic system is asymptotically stabilized by adjusting the dithering parameters. The paper has been organized in the following. Preliminary notation for the entire white paper is given in Section 1. Fuzzy control design is introduced in Sections 2-3. See Section 4 for stability analysis. The algorithm is presented in Section 5. Section 6 gives numerical examples to explain the devised algorithm. Finally, a nonlinear simulation of an inverted pendulum

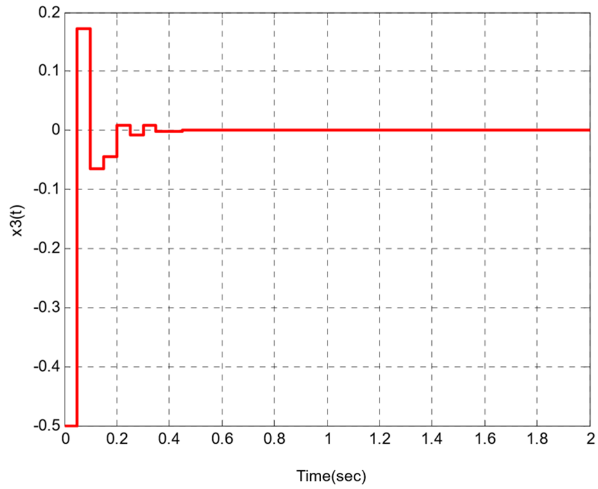

Fig. 4 The state response of $x_3(t)$

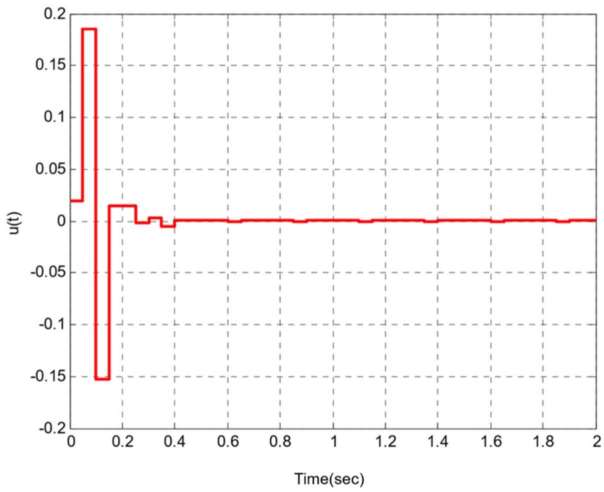

Fig. 5 The response of $u(t)$

system is shown. The numerical experimental results show that the grey model using the proposed fitness function occupies an average of 95% ballpark success rate in finding feasible solutions.

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