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Aerodynamic numerical analysis with linear matrix inequality theorem of intelligent control

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Abstract. In this paper we proposed the aerodynamic numerical analysis with linear matrix inequality theorem of intelligent control, which is believed to be applicable in the application not only a function of the block size and reduced wind speed but itself depends on both the size and the aspect ratio of the structure, not on the total scruton number. In order to improve the accuracy of the results, the optimization curve was optimized for the test to evaluate the response in the time of achieving the results and we focus on the results that found a significant influence from the assumptions used for damage propagation for aircraft structural analysis of composite materials. Finally, the numerical simulations confirmed the effectiveness of the method.

Keywords: aerospace vehicles; LMI; nonlinear systems; smart control; stability analysis

1. Introduction

Modernization due to economic growth has led to rapid population growth in cities, and has made it easier to build more and more housing in many cities where space is very limited. This has an impact on the air quality because it decreases. This is especially true for high-rise buildings where the excess response is related to the wind flow and the so-called wind elastic materials (for example, Refs. Safa *et al.* 2016, Shariat *et al.* 2018). Therefore, it is important and necessary from an engineering point of view to investigate solutions to eliminate air pollution for high-rise buildings (for example, using Bedirhanoglu 2014 and others). The change of structure is usually classified as vortex-induced vibration and creep (noise-induced vibration). The vortex-induced vibration is due to the vortex flow behind the body model, if it occurs, with turbulence from the resulting flow fluctuations, and the stability robustness in the life of the system uncertainty Wang *et al.* (1996) respectively. At a specific wind speed, when the erosion frequency is close to the standard frequency, there is a large response which is called resonance (such as Wang *et al.* 1996 Tsai *et al.* 2015). The time history of vortex-induced locking from rest is a self-limiting process. As for creep, theoretically it can be interpreted as an aerodynamic damping effect caused by the angle of stop change because the relative strength of the structure against the flow in the quasi-static assumption will (Wu and Chang 2011).

The vortex-induced lock-in effect and creep effect in wind cross-motions of high-rise buildings

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should be avoided as much as possible because of the possible nonlinear behavior of the normal response spectrum analysis will be non-conservative (for example, ref. Safa *et al.* 2016, Shariah *et al.* 2018). For some high-rise buildings, the occurrence of resonance and lock-in is inevitable because they have low natural frequencies, so the concept of aerodynamic damping is introduced to estimate the response (Gahinet and Apkarian, 2020). After the research. of vortex-induced vibration, especially theoretical connection with experimental data is still difficult to better understand this behavior This study aims to investigate its process for two-dimensional block structure in the wind as the first step in the three-dimensional model instead of searching for change. The structure of the oscillating body, this study adopted a concept of the self-limiting model as an important step to create a recognition for the block model by analyzing their measurements aerodynamic (including aerodynamic damping and stiffness) by measuring wind parameters. The big system approach provides this process by controlling the structure of the system in some way. Therefore, research in design, mathematics, analysis, storage, optimization and management of large-scale systems has been of great interest. Recently, many such methods have been proposed to analyze the stability of data and the stability of large systems (Chang 1996, Bedirhanoglu 2014, 2004, 2005, Chiang *et al.* 2007, Liu *et al.* 2009, Liu *et al.* 2010, Hung *et al.* 2019, Eswaran and Reddy 2016 and references included).

In the computer network, since the different communication subnets and network architectures adopt different change control, the change delay in the communication subnet is determined by the network state and the delay time. time is fixed by the electrical signal field. The response time is shorter, the delay is shorter, the bandwidth is bigger, and the transmission is more. Therefore, the larger the bandwidth of the channel, the smaller the delay. The delay time is the time it takes to send a packet from a specific location. The delay time is usually the balance between the response delay and the transmission delay. There are often delays in other technology. For example, computer control systems, there are delays because the computers take a long time to do digital work. In addition, there are remote control, radar, electric grid, transportation, slow metal and so on. The results of these systems do not respond to input data until the time has passed. The introduction of the delay often leads to insecurity and often makes analysis difficult. Therefore, the analysis of the stability of the system with research (Mori 1985 and Trine Aldeen 1995, Tsai *et al.* 2012, 2015, Tim *et al.* 2019, Chen 2011, 2014, Tim *et al.* 2020, Chen *et al.* 2015, 2020) published and completed by opposition.

In recent years there has been much interest in management. There are many successful applications. Despite its success, it is clear that basic problems must be solved very well and the main problem of management is the design of a stable system Recently there have been many sustainability studies (see Sugeno 1992, Tim *et al.* 2021, Jen *et al.* 2021, Chen *et al.* 2022, Hsiao *et al.* 2005, Wang *et al.* 1996, Tanaka *et al.* 1996, Feng *et al.* 1997 and references). The history of the application of artificial intelligence tools to engineering problems is presented in some papers. For example, Chiang *et al.* (2001, 2002, 2004) provided a new model for the system, Chengwu *et al.* (2002) provided an LMI form for the system, Hsiao *et al.* (2003, 2005) using system AI theory in nonlinear systems, Hsieh *et al.* (2006) propose security analysis for AI, Lin *et al.* (2010) provide control in TLP system, Chen *et al.* (2006, 2007, 2009) also show good performance with neural network-based LDI theory. Recently, Chen *et al.* (2019, 2020) have some studies on the change model for engineering applications. However, the studies in the literature have not yet solved the problem of stability and instability of large systems with multiple delays.

Therefore, this study has a stability model based on the Lyapunov method to provide asymptotic stability for large systems with multiple delays. is represented by the fuzzy Takagi-

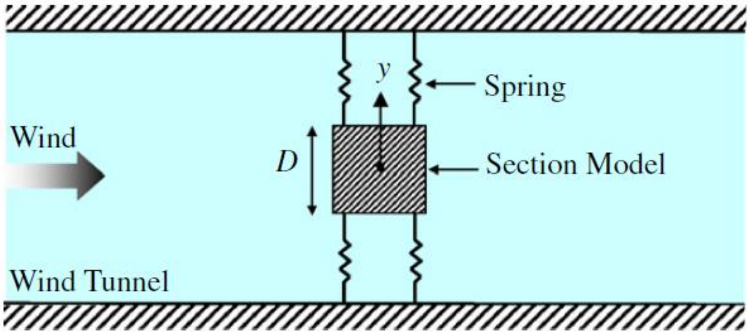


Fig. 1 Schematic diagram of a section model.

Sugeno model of various delays. Each rule in this model is represented by a linear system model, so linear feedback control can be used as a form of feedback stability. Therefore, the control mode is based on the fuzzy model that uses the proportional-difference (PDC) technique. That's the idea if those all linear local linear model control responses show the same location. And we focus on the results that show a significant impact from the assumptions used to damage the expansion plane analysis of composites.

In summary, we briefly introduce the fuzzy model of Takagi Sugeno with some delay and explain the system. Stability is not derived and determined according to the Lyapunov method, which ensures asymmetric stability of systems with multiple delays and we focus on the results that show a significant impact of the expected use for damage to the general expansion of the composite material. Finally, the results draw explanations and conclusions from the numerical examples they refer to.

2. System description

Those Cross the wind pace of a part pattern below wind flow, accordingly shown in Figure 1, can do show accordingly

$$m(\ddot{y} + 2\xi\omega_1\dot{y} + \omega_1^2 y) = F(y, \dot{y}, \ddot{y}, U, t)$$

where m is the size of a unit length, ω is the natural frequency process, ξ is the standard inhibition ratio, y is the cross-wind pattern displacement, F is the wind-induced force per unit length, U is the average wind speed. The wind-induced force F near resonance and lock-in, according to Ehsan and Scanlan (1986), Simiu and Scanlan (1999), can be written as a non-uniform interaction.

$$F = \frac{1}{2}\rho U^2(2D)\left[Y_1(K)\left(1 - \varepsilon\frac{y^2}{D^2}\right)\frac{\dot{y}}{U} + Y_2(K)\frac{y}{D} + \frac{1}{2}C_L(t)\right]$$

in which D is the tributary extension of the wind, r air density (about 1.25 kg/m^3 depending on the temperature), K is the dimensionless frequency (discharge frequency) where ω the vortex damping frequency in radians per second, ε, Y_1, Y_2, and C_L are various dimensionless aerodynamic parameters. In Eqs. (2), two types of forces are involved, one affected by the eddy current, expressed as the time-carrying force C_L(t), and the other excited by the response itself, the so-called kinetic induced force expressed as a combination of aerodynamic damping and rigid impact.

The linear and nonlinear parts of the aerodynamic damping are not represented by Y_1 and *e*, respectively, while the aerodynamic stiffness parameter is shown as Y_2 and the nonzero parameter *e* gives the character of self-limiting speed.

First, the carrying force $C_L(t)$ is considered to be harmonic with amplitude $C_{L0}(K)$ and phase *y*, viz

$$C_L(t) = C_L(K)\sin(\omega t + \theta)$$

By combining the above equations, the resulting equation can be written as follows, unimporting for all quantities

$$\eta''(s) + 2\xi K_1\eta'(s) + K_1^2\eta(s) = m_r Y_1[1 - \varepsilon\eta^2(s)]\eta'(s) + m_r Y_2\eta(s) + \frac{1}{2}m_r C_{L'}\sin(Ks + \theta)$$

where η is the dimensionless structural displacement, m_r is the size ratio, K_1 is the dimensionless structural frequency, *s* is the dimensionless time where the derivative is the dimensionless time *s*. Note that mr is the density of the sample block, so mr is inversely proportional to the ideal density if the air density is calculated as the original which is usually the data.

Observations from existing experiments show that the vortex damping force is insignificant compared to the motion-induced force as the sample response is very large near resonance, lock-in this case the vortex damping force will decrease and Eq. (4) As can be easily done

$$\eta''(s) + 2\xi K_1\eta'(s) + K_1^2\eta(s) = m_r Y_1[1 - \varepsilon\eta^2(s)]\eta'(s) + m_r Y_2\eta(s)$$

or

$$\eta''(s) + K_1^2\eta = F_1(\eta, \eta')$$

in which

$$F_1(\eta, \eta') = (m_r Y_1 - 2\xi K_1)\eta' - m_r Y_1\varepsilon\eta^2\eta' + m_r Y_2\eta$$

It can be assumed that the solution has the form of

$$\eta(s) = A(s)\cos[Ks - \psi(s)]$$

That is, the solution is harmonic with slowly varying amplitude $A(s)$ and phase $c(s)$. In other words, the so-called quasilinear mechanism. Because of the behavior of locking, the reduced *K* in the equation is *K*. (8) is not the negative of the vortex damping frequency, but the reduced vortex-induced frequency during lock. Since this expression of the solution involves two unknowns $A(s)$ and $c(s)$, the additional conditions used by Van der Pol (1989) can be used to supplement the solution problem, viz

$$A'(s)\cos[Ks - \psi(s)] + A(s)\psi'(s)\sin[ks - \psi(s)] = 0$$

The meaning of Eq. (9) if $A(s)$ and $c(s)$ are considered constant when given over $Z(s)$. Based on the above, the first differential equation for $A(s)$ and $c(s)$ can be derived as follows

$$A'(s) = -\frac{1}{K}\{F_1(\eta, \eta') + A(s)[K^2 - K_1^2]\cos[Ks - \psi(s)]\}\sin[ks - \psi(s)]$$

$$\psi'(s) = -\frac{1}{A(s)K}\{F_1(\eta, \eta') + A(s)[K^2 - K_1^2]\cos[Ks - \psi(s)]\}\cos[ks - \psi(s)]$$

$$\psi(s) = \frac{1}{2K}[m_r Y_2 + (K^2 - K_1^2)]s + \psi_0$$

in which ψ_0 is the initial condition at s=0. Hence the solution of the response η can be written as

$$\eta(s) = \frac{\beta}{\left[1 - \left((A_0^2 - \beta^2)\right)/A_0^2)\exp\left((-\alpha\beta^2/4)s\right)\right]^{1/2}}\cos\left\{Ks - \frac{1}{2K}[m_r Y_2 + (K^2 - K_1^2)]s - \psi_0\right\}$$

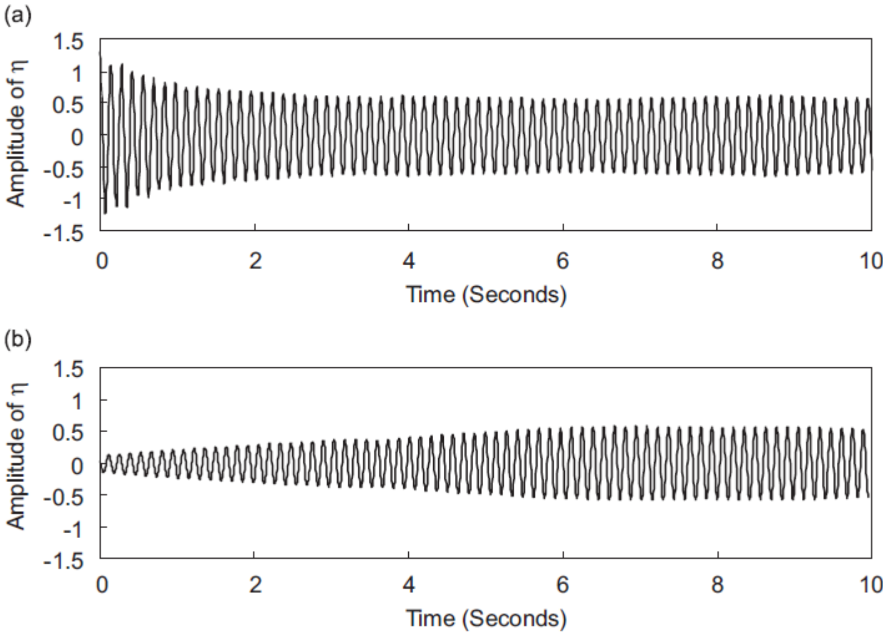


Fig. 2 Transient response near lock-in (a) DTR Method and (b) CTR Method

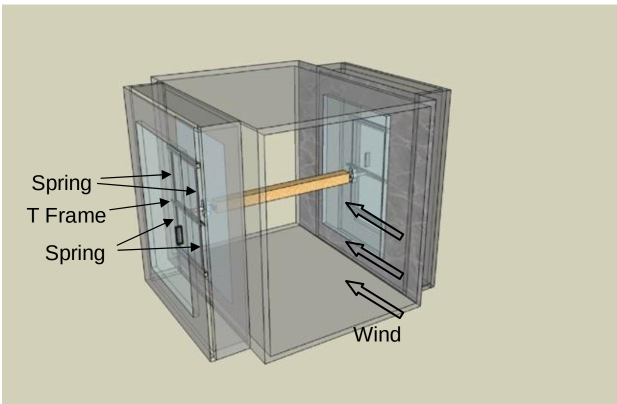


Fig. 3 Experimental setup in the wind tunnel

According to the equation above, when the bluff body locks, the initial amplitude will eventually cause the amplitude to remain constant b as the time passes. Depending on the size of the initial amplitude is larger is smaller than b, the process shows the function such as a decaying or increasing process see 2(a)) or Growing is called -to-Resonance (GTR) method (see Fig. 2(b)), respectively. According to the experimental results as shown in Fig. 2, it takes longer to reach the steady state response in the GTR case than in the DTR case. explained below.

As shown in Fig. 3, the block structure of the test mockup is supported by two groups of springs connected in the T-frame outside the two sides of the ventilation system. from the difference in their speed. The configuration and characteristics of the four test block models where the model names are identified as DN1, DN2, DN3 and DN4. Note that, except for the average

Table 1 Configurations and structural properties of the section models

Model name (1)	D (m) (2)	Density ρ_m (kg/m^3) (3)	Natural frequency f_1 (Hz) (4)	Mass ration m_r (5)	Damping ration ξ(%) (6)	Scruton no. Scr (7)	f/f_1 (8)	Reynolds no. (× 10^4) (9)
DN1	0.1	226	8.214	0.005165	0.18	0.3485	0.94-0.96	3.89-5.44
DN2	0.1	245	8.681	0.004873	0.19	0.3899	0.96-0.98	4.15-5.59
DN3	0.1	300	7.276	0.003905	0.18	0.4610	0.98-0.99	3.58-4.58
DN4	0.1	409	7.038	0.002818	0.22	0.7806	0.98-0.99	3.34-4.39

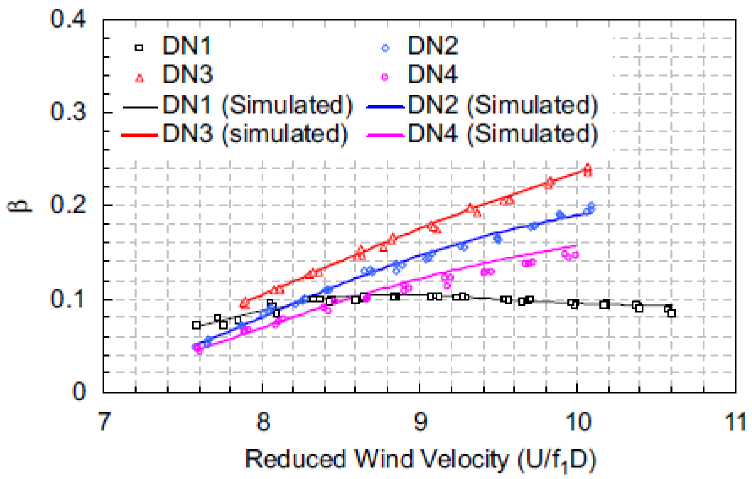


Fig. 4 Steady-state amplitude versus reduced wind velocity after lock-in

wind speed, rather than the total scruton number, the two parameters, the mass ratio mr and the turbidity ratio x, are the same without the aerodynamic Y_1, e, and Y_2 related, however the scruton number is still tabulated as a general reference. Since the damping for all sections is pretty close, the difference between the four cases will be different only by m_r. In other words, they differ from the standard density rm. As in ordinary buildings, the density of 226 to 409 kg/m^2 is chosen for the tests for the needs. The efficiency in the center of the ventilation system where the model is now is 0.5-0.6% in the ventilation system.

In order to ensure the reliability of the test, each test in a wind speed test is performed two to three times before completing the analysis plan based on the GTR-DTR method. Avoidance of consistency of experimental results Plotting reduced wind speed after -in phase, indicated by the open symbols in Fig. 4. As shown in Fig. 4, the stable- State amplitude after Lock-in will generally increase with decreasing wind speed for conditions DN2, DN3, and DN4. In the case of DN1, however, the tail is slightly reversed from an increase to a decrease of 8.5. Notice that the reverse of the reduced wind speed is close to the value of the Strouhal number, which is 0.13 for square blocks.

3. Fuzzy differential inclusion

To simplify the construction of an equation, Eq. (3.1), we consider the nonlinear J According to the intersection of subsystems $F_j, j = 1, 2, \cdots, J$. The j th as isolated subsystem s (no intersection) $\boldsymbol{F}$ is represented by the process of Takagi-Sugeno's IF-THEN delay control model. The main feature of the Takagi-Sugeno fuzzy model with multiple delays is the expression of each rule by the state equation, and the model is as follows (Chen 2014, Chen *et al.* 2019, Chen *et al.* 2020):

Rule i: If (3.1) exists. $x_{1j}(t)$ is M_{i1j} and $\cdots$ and $x_{g\,j}(t)$ is $M_{ig\,j}$

$$\text{so}\,\dot{x}_j(t) = A_{ij}x_j(t) + \sum_{k=1}^{N_j} A_{ikj}x(t-\tau_{kj}) + B_{ij}u_j(t) \tag{3.1}$$

where $x_j^T(t) = [x_{1j}(t), x_{2j}(t), \cdots, x_{gj}(t)]$, $u_j^{\,T}(t) = [u_{1j}(t), u_{2j}(t), \cdots, u_{mj}(t)]$

r_j IF-THEN rule of $A_{ij}\,j$ th subsystem is umber, A_{ikj} and B_{ij} are the system matrices, states $x_j(t)$, inputs $u_j(t)$, interval τ_{kj} fuzzy sets $M_{ipj}(p = 1, 2, \cdots, g)$, and areas $x_{1j}(t)\sim x_{gj}(t)$ used to estimate the fuzzy dynamic model

$$\begin{aligned}\dot{x}_j(t) &= \frac{\sum_{i=1}^{r_j} w_{ij}(t)\left\{A_{ij}x_j(t) + \sum_{k=1}^{N_j} A_{ikj}x(t-\tau_{kj}) + B_{ij}u_j(t)\right\}}{\sum_{i=1}^{r_j} w_{ij}(t)} \\ &= \sum_{i=1}^{r_j} h_{ij}(t)\left\{A_{ij}x_j(t) + \sum_{k=1}^{N_j} A_{ikj}x(t-\tau_{kj}) + B_{ij}u_j(t)\right\}\end{aligned} \tag{3.2}$$

with

$$w_{ij}(t) = \prod_{p=1}^{g} M_{ipj}(x_{pj}(t)),\; h_{ij}(t) = \frac{w_{ij}(t)}{\sum_{i=1}^{r_j} w_{ij}(t)} \tag{3.3}$$

where $M_{ipj}(x_{pj}(t))$ if $w_{ij}(t) \ge 0,\ \ i = 1, 2, \cdots, r_j$ and $\sum_{i=1}^{r_j} w_{ij}(t) > 0$,. $h_{ij}(t) \ge 0,\ \ x_{pj}(t)\ \ M_{ipj}$

$i = 1, 2, \cdots, r_j,\ \ \sum_{i=1}^{r_j} h_{ij}(t) = 1$.

Finally, we have

$$\dot{x}_j(t) = \sum_{i=1}^{r_j} h_{ij}(t)\left\{A_{ij}x_j(t) + \sum_{k=1}^{N_j} A_{ikj}x(t-\tau_{kj}) + B_{ij}u_j(t)\right\} + \sum_{\substack{n=1\\ n\neq j}}^{J} C_{nj}x_n(t) \tag{3.4}$$

where C_{nj} the intersection.

Theorem 1: The multi -time delay fuzzy large-scale system s $\boldsymbol{f}$ yes asymptotically considered stable, if the response increases (K_{ij}) selected to satisfy at least one of the $j = 1, 2, \cdots, J$ following conditions:

$$\textbf{(I)}\ \bar{\lambda}_j \equiv \max_k \lambda_M(\bar{Q}_{kj}) < 0 \ \text{ to } \ k = 1, 2, \cdots, N_j.$$

or

$$\text{(II)}\quad \Lambda_j \equiv \begin{bmatrix} -\bar{\lambda}_j & 0 & 0 & \cdots & 0 \\ 0 & \lambda_{1j} & 1/2\lambda_{12j} & \cdots & 1/2\lambda_{1r_j j} \\ 0 & 1/2\lambda_{12j} & \lambda_{2j} & \cdots & 1/2\lambda_{2r_j j} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 1/2\lambda_{1r_j j} & 1/2\lambda_{2r_j j} & \cdots & \lambda_{r_j j} \end{bmatrix} > 0 \tag{3.5}$$

where

$$\bar{Q}_{kj} \equiv I - P_{kj}, \quad k = 1, 2, \cdots, N_j \tag{3.6}$$

$$Q_{ij} = -\left\{ (A_{ij} - B_{ij}K_{ij})^T P_j + P_j(A_{ij} - B_{ij}K_{ij}) + \bar{P}_j + P_j \bar{A}_{ij} P_j + \sum_{n=1}^{J} \left[(\frac{J-1}{J})I + P_j C_{nj} C_{nj}^T P_j \right] \right\} \tag{3.7}$$

with

$$\bar{P}_j = \sum_{k=1}^{N_j} P_{kj}, \quad \bar{A}_{ij} = \sum_{k=1}^{N_j} A_{ikj} A_{ikj}^T, \quad G_{ifj} = \frac{(A_{ij} - B_{ij}K_{fj}) + (A_{fj} - B_{fj}K_{ij})}{2} \tag{3.8}$$

$\lambda_M(.)$ has maximum eigenvalues, $\lambda_m(.)$ minimum eigenvalues.

Proof: See Appendix.

Note 1: Both conditions are followed by default. The stability of F systems with delays can be verified using Eqs. (3.4) and (3.5). Therefore it is advisable to try for asymmetric stability in certain conditions. If this fails, there must be another condition.

An evolutionary bat algorithm (EBA) is proposed from the complex system of bats in the wild. Unlike other group search algorithms, the strength of EBA lies in the fact that only one of the parameters (called the environment) is considered and therefore the algorithm must be used to solve the problem (Yan *et al.* 1998, Tsai *et al.* 2015, Zandi *et al.* 2018). The choice of support during development determines the different stages of this study. In this study, we chose air because it is the oldest habitat for bats. EBA can be written in four stages:

Initialization: Random assignment of synthetic reagents, diffusion into the chemical zone.

Movement: A tricky example is movement. Generate a random number and make sure it exceeds the heart rate. If positive, a random walk is used to run the design. $x_i^t = x_i^{t-1} + D$, in which These x_i^t show the controls in the i-th artifacts s rather in the t-th iteration, then the last iteration is x_i^{t-1} the i-th artifact s, and the difference D is as follows.

$$D = \gamma \cdot \Delta T$$

where $\gamma = 0.17$, $\Delta T \in [-1,1]$ is a random number when the chosen medium s is air.

$$x_i^{t_R} = \beta\left(x_{\text{best}} - x_i^t\right), \beta \in [0, 1]$$

where it is random β, x_{best} Often the best solution is very long in all artificial products, and the new controls in the $x_i^{t_R}$ prosthesis tax for all walks.

We then use the fitness rules to calculate the appropriate medical equipment and modify them using the best solutions.

4. Example

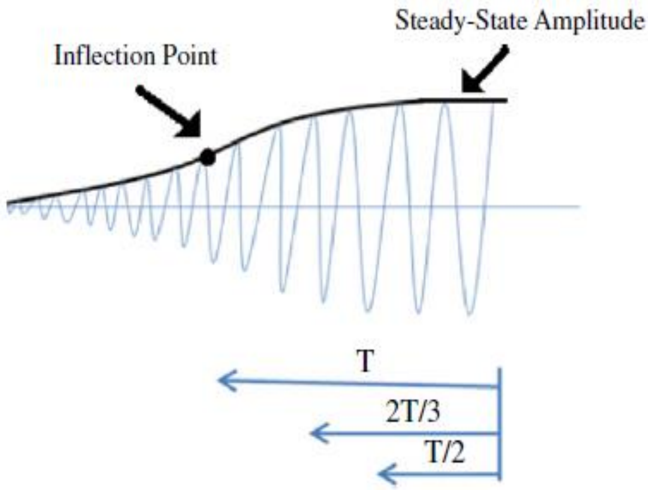
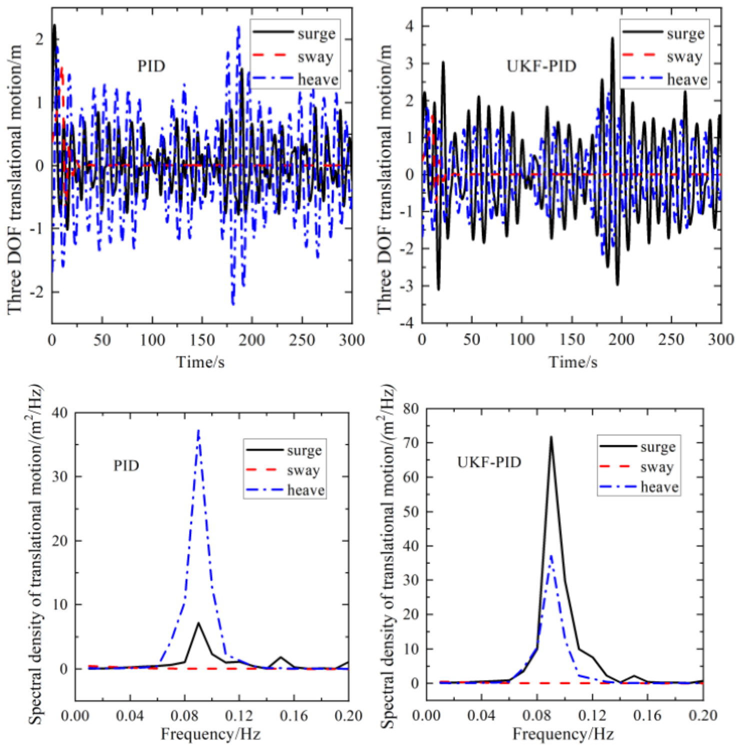


Fig. 5 Schematic diagram of the transient time history of the gradually increased amplitude after lock-in



Figs. 6-9 The response demonstrated by the proposed control of algorithm

In order to ensure the reliability of the test, each test in a wind speed test is performed two to three times before completing the analysis plan based on the GTR-DTR method. Avoidance of consistency of experimental results Plotting reduced wind speed after -in phase, indicated by open symbols in Fig. 5. As shown in Fig. 5, the stable- State amplitude after Lock-in will generally increase with decreasing wind speed for conditions DN2, DN3, and DN4. In the case of DN1, however, the tail is slightly reversed from an increase to a decrease of 8.5. Note that the reverse of the reduced wind speed is close to the value of the Strouhal number.

The upper bounds on the delay are m^{sc}=0.8/T=80 and m^{ca}=0.8/T=80. M=180, which is considered the maximum delay in ocean engineering. Based on the above variables, we obtained the following simulation results with different values of packet loss $m1$ and $m2$. Figs. 6-9 shows countries with different package departure rates.

The building without control has three natural frequencies and conditions, which are 7.363, 22.933, 37.966 rad/s, 1.38%, 2.46%, and 1.32%, Building for zero control into the strength of the earthquake to compare the response, which is called “uncontrolled” as follows. ~54s, rms. Because of the high use of distance and speed measurement, the speed of the three layers is selected as a different answer, however, the above answer includes seven. This is in the design phase of the value of the eight-state system used by Chen (2021) according to LQG control which is created by a model of the system with a known equation of subtraction method and find that the accuracy of these models is reduced. than that of the actual model. In order to clarify the difference between the set system and the actual system is given the feedback change function created by the actuator function U. Uncertainty of amplitudes leads to reduction in the system exceeds the uncertainty of the height.

The results of damping values of 4134.9 and 3161.1 from the LMI-based solution are the controls H1 and H2. Therefore, two daks=1 The state received of the controller 15 and the state of the controller 8 can be easily added by the continuous method, which is good for the performance of the work.

5. Conclusions

An updated fuzzy mechanical control of large-scale multi-time delay dynamical systems in the state is considered in this paper. To do this, a two-level strategy is proposed to divide the main system into several interconnected subsystems of the first level. The solution of the cross-wind lock-in behavior by the self-constraint design showed that the aerodynamic limitations are not only a function of the block size and are rare wind speed but also depends on the mass ratio and closed structure, but according to the number. of Scrutons all. Cross-wind aerodynamic parameters of the four block models (DN1-DN4 varying in density from 226 to 409 kg/m^3) after the lock-in stage in the flow well were identified using the GTR method according to the wind-tunnel test More possible.

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CC

Appendix: Proof of theorem 1

(I): Let these Lyapunov function in these multiple time-delay fuzzy large-scale systems ***F*** are defined as

$$V = \sum_{j=1}^{J} v_j(t) = \sum_{j=1}^{J} \left\{ x_j^T(t) P_j x_j(t) + \sum_{k=1}^{N_j} \int_0^{\tau_{kj}} x_j^T(t-\tau) P_{kj} x_j(t-\tau) d\tau \right\} \tag{A1}$$

where $P_j = P_j^T > 0$ and $P_{kj} = P_{kj}^T > 0$, $k = 1, 2, \cdots, N_j$. We therefore evaluate these time derivatives of V in the trajectories of Eq. (3.3), so we have

$$\dot{V} = \sum_{j=1}^{J} \dot{v}_j(t)$$

$$= \sum_{j=1}^{J} [\dot{x}_j^T(t) P_j x_j(t) + x_j^T(t) P_j \dot{x}_j(t) + \sum_{k=1}^{N_j} (x_j^T(t) P_{kj} x_j(t) - x_j^T(t-\tau_{kj}) P_{kj} x_j(t-\tau_{kj}))]$$

$$= \sum_{j=1}^{J} \{ [\sum_{i=1}^{r_j} \sum_{f=1}^{r_j} h_{ij}(t) h_{fj}(t) ((A_{ij} - B_{ij} K_{fj}) x_j(t) + \sum_{k=1}^{N_j} A_{ikj} x(t-\tau_{kj}) + \phi_j(t))]^T P_j x_j(t)$$

$$+ x_j^T(t) P_j [\sum_{i=1}^{r_j} \sum_{f=1}^{r_j} h_{ij}(t) h_{fj}(t) ((A_{ij} - B_{ij} K_{fj}) x_j(t) + \sum_{k=1}^{N_j} A_{ikj} x(t-\tau_{kj}) + \phi_j(t))]$$

$$+ \sum_{k=1}^{N_j} (x_j^T(t) P_{kj} x_j(t) - x_j^T(t-\tau_{kj}) P_{kj} x_j(t-\tau_{kj}))\}$$

$$= \sum_{j=1}^{J} \sum_{i=f=1}^{r_j} h_{ij}^2(t) x_j^T(t) [(A_{ij} - B_{ij} K_{ij})^T P_j + P_j (A_{ij} - B_{ij} K_{ij}) + \bar{P}_j] x_j(t)$$

$$+ \sum_{j=1}^{J} \sum_{i \neq f}^{r_j} h_{ij}(t) h_{fj}(t) x_j^T(t) [(A_{ij} - B_{ij} K_{fj})^T P_j + P_j (A_{ij} - B_{ij} K_{fj}) + \bar{P}_j] x_j(t)$$

$$+ \sum_{j=1}^{J} [\phi_j^T(t) P_j x_j(t) + x_j^T(t) P_j \phi_j(t)] - \sum_{j=1}^{J} \sum_{k=1}^{N_j} [x_j^T(t-\tau_{kj}) P_{kj} x_j(t-\tau_{kj})]$$

$$+ \sum_{j=1}^{J} \sum_{i=1}^{r_j} \sum_{f=1}^{r_j} h_{fj}(t) \sum_{k=1}^{N_j} h_{ij}(t) [x_j^T(t) P_j A_{ikj} A_{ikj}^T P_j x_j(t) + x_j^T(t-\tau_{kj}) x_j(t-\tau_{kj})]$$

$$= \sum_{j=1}^{J} \sum_{i=f=1}^{r_j} h_{ij}^2(t) x_j^T(t) [(A_{ij} - B_{ij} K_{ij})^T P_j + P_j (A_{ij} - B_{ij} K_{ij}) + \bar{P}_j] x_j(t)$$

$$+ \sum_{j=1}^{J} \sum_{i \neq f}^{r_j} h_{ij}(t) h_{fj}(t) x_j^T(t) [(A_{ij} - B_{ij} K_{fj})^T P_j + P_j (A_{ij} - B_{ij} K_{fj}) + \bar{P}_j] x_j(t)$$

$$+ \sum_{j=1}^{J} [\phi_j^T(t) P_j x_j(t) + x_j^T(t) P_j \phi_j(t)] - \sum_{j=1}^{J} \sum_{k=1}^{N_j} [x_j{}^T(t-\tau_{k_j}) P_{kj} x_j(t-\tau_{kj})]$$

$$+ \sum_{j=1}^{J} \sum_{i=f=1}^{r_j} h_{ij}{}^2(t) [x_j^T(t) P_j \bar{A}_{ij} P_j x_j(t)]$$

$$+\sum_{j=1}^{J}\sum_{\substack{i=1\\ i\neq f}}^{r_j} h_{ij}(t)h_{fj}(t)[x_j^T(t)P_j\bar{A}_{ij}P_jx_j(t)] + \sum_{j=1}^{J}\sum_{k=1}^{N_j} x_j^T(t-\tau_{kj})Ix_j(t-\tau_{kj})$$

$$=\sum_{j=1}^{J}\sum_{i=f=1}^{r_j} h_{ij}^2(t)x_j^T(t)[(A_{ij}-B_{ij}K_{ij})^T P_j + P_j(A_{ij}-B_{ij}K_{ij}) + \bar{P}_j + P_j\bar{A}_{ij}P_j]x_j(t)$$

$$+\sum_{j=1}^{J}\sum_{i<f}^{r_j} h_{ij}(t)h_{fj}(t)x_j^T(t)[2(G_{ifj}^T P_j + P_jG_{ifj} + \bar{P}_j + P_j\bar{A}_{ij}P_j)]x_j(t)$$

$$+\sum_{j=1}^{J}[\phi_j^T(t)P_jx_j(t) + x_j^T(t)P_j\phi_j(t)] + \sum_{j=1}^{J}\sum_{k=1}^{N_j}\left\{x_j^T(t-\tau_{kj})[I-P_{kj}]x_j(t-\tau_{kj})\right\}$$

$$= D_1 + D_2 + D_3 + D_4\,, \tag{A2}$$

where

$$D_1 \equiv \sum_{j=1}^{J}\sum_{i=f=1}^{r_j} h_{ij}^2(t)x_j^T(t)[(A_{ij}-B_{ij}K_{ij})^T P_j + P_j(A_{ij}-B_{ij}K_{ij}) + \bar{P}_j + P_j\bar{A}_{ij}P_j]x_j(t)\,, \tag{A3}$$

$$D_2 \equiv \sum_{j=1}^{J}\sum_{i<f}^{r_j} h_{ij}(t)h_{fj}(t)x_j^T(t)[2(G^T{}_{ifj}P_j + P_jG_{ifj} + \bar{P}_j + P_j\bar{A}_{ij}P_j)]x_j(t)\,, \tag{A4}$$

$$D_3 \equiv \sum_{j=1}^{J}[\phi_j^T(t)P_jx_j(t) + x_j^T(t)P_j\phi_j(t)]$$

$$=\sum_{j=1}^{J}\sum_{n\neq j}^{J}[x_n^T(t)C_{nj}^TP_jx_j(t) + x_j^T(t)P_jC_{nj}x_n(t)] \le \sum_{j=1}^{J}\sum_{n\neq j}^{J}[x_n^T(t)x_n(t) + x_j^T(t)P_jC_{nj}C_{nj}^TP_jx_j(t)]$$

$$+\sum_{j=1}^{J}\sum_{i\neq f}^{r_j}\sum_{n=1}^{J} h_{ij}(t)h_{fj}(t)x_j^T(t)\left[(\frac{J-1}{J})I + P_jC_{nj}C_{nj}^TP_j\right]x_j(t)\,, \tag{A5}$$

$$D_4 \equiv \sum_{j=1}^{J}\sum_{k=1}^{N_j}\{x_j{}^T(t-\tau_{kj})[I-P_{kj}]x_j(t-\tau_{kj})\} \le \sum_{j=1}^{J}\sum_{k=1}^{N_j}\lambda_M(I-P_{kj})\left\|x_j(t-\tau_{kj})\right\|^2\,. \tag{A6}$$

Substituting Eqs. (A3)-(A6) into Eq. (A2) yields

$$\dot{V} \le \sum_{j=1}^{J}\sum_{i=f=1}^{r_j} h_{ij}^2(t)x_j^T(t)[(A_{ij}-B_{ij}K_{ij})^T P_j + P_j(A_{ij}-B_{ij}K_{ij}) + \bar{P}_j + P_j\bar{A}_{ij}P_j]x_j(t)$$

$$+\sum_{j=1}^{J}\sum_{i<f}^{r_j} h_{ij}(t)h_{fj}(t)x_j^T(t)[2(G_{ifj}^T P_j + P_jG_{ifj} + \bar{P}_j + P_j\bar{A}_{ij}P_j)]x_j(t)$$

$$+2\sum_{n=1}^{J}\left[(\frac{J-1}{J})I + P_jC_{nj}C_{nj}^TP_j\right]\Big\}x_j(t) + \sum_{j=1}^{J}\sum_{k=1}^{N_j}\lambda_M(I-P_{kj})\left\|x_j(t-\tau_{kj})\right\|^2$$

$$=-\sum_{j=1}^{J}\left\{\sum_{i=f=1}^{r_j} h_{ij}^2(t)x_j^T(t)Q_{ij}x_j(t) + \sum_{i<f}^{r_j} h_{ij}(t)h_{fj}(t)x_j^T(t)Q_{ifj}x_j(t) - \sum_{k=1}^{N_j}\lambda_M(I-P_{kj})\left\|x_j(t-\tau_{kj})\right\|^2\right\}$$

$$\leq -\sum_{j=1}^{J}\left\{[\sum_{i=1}^{r_j} h_{ij}^2(t)\lambda_m\,(Q_{ij}) + \sum_{i<f}^{r_j} h_{ij}(t)h_{fj}(t)\lambda_m(Q_{ifj})]\left\|x_j(t)\right\|^2 - \bar{\lambda}_j\sum_{k=1}^{N_j}\left\|x_j(t-\tau_{kj})\right\|^2\right\} \quad \text{(A.7)}$$

According to these Eq. (3.4), we therefore get $\dot{V} < 0$ as well as the proof in condition (I) is then satisfied.

(II): Based in Eq. (A.7), we then get

$$\dot{V} \leq -\sum_{j=1}^{J}\left\{[\sum_{i=1}^{r_j} h_{ij}^2(t)\lambda_m\,(Q_{ij}) + \sum_{i<f}^{r_j} h_{ij}(t)h_{fj}(t)\lambda_m(Q_{ifj})]\left\|x_j(t)\right\|^2 - \bar{\lambda}_j\sum_{k=1}^{N_j}\left\|x_j(t-\tau_{kj})\right\|^2\right\}$$

$$= -\sum_{j=1}^{J}\{\begin{bmatrix}\sqrt{\sum_{k=1}^{N_j}\left\|x_j(t-\tau_{kj})\right\|^2} & h_{1j}(t)\left\|x_j(t)\right\| & h_{2j}(t)\left\|x_j(t)\right\| & \cdots & h_{r_j j}(t)\left\|x_j(t)\right\|\end{bmatrix}$$

$$\cdot\begin{bmatrix}-\bar{\lambda}_j & 0 & 0 & \cdots & 0\\ 0 & \lambda_{1j} & 1/2\lambda_{12j} & \cdots & 1/2\lambda_{1r_j j}\\ 0 & 1/2\lambda_{12j} & \lambda_{2j} & \cdots & 1/2\lambda_{2r_j j}\\ \vdots & \vdots & \vdots & \vdots & \vdots\\ 0 & 1/2\lambda_{1r_j j} & 1/2\lambda_{2r_j j} & \cdots & \lambda_{r_j j}\end{bmatrix}\cdot\begin{bmatrix}\sqrt{\sum_{k=1}^{N_j}\left\|x_j(t-\tau_{kj})\right\|^2}\\ h_{1j}(t)\left\|x_j(t)\right\|\\ h_{2j}(t)\left\|x_j(t)\right\|\\ \vdots\\ h_{r_j j}(t)\left\|x_j(t)\right\|\end{bmatrix}\} = -\sum_{j=1}^{J} H_j^T\Lambda_j H_j\,,$$

in which $H_j^T \equiv \begin{bmatrix}\sqrt{\sum_{k=1}^{N_j}\left\|x_j(t-\tau_{kj})\right\|^2} & h_{1j}(t)\left\|x_j(t)\right\| & h_{2j}(t)\left\|x_j(t)\right\| & \cdots & h_{r_j j}(t)\left\|x_j(t)\right\|\end{bmatrix}$. The Lyapunov math derivatives are negative if one of these matrices Λ_j ($j = 1, 2, \cdots, J$) is positive digit, which accomplish one of the proof in condition (II).