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# Simulations and demonstrations of molecular dynamics results in a nonlinear fuzzy system

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**Abstract.** This research explores the application of computational continuum modeling to analyze both the dynamic and static stability of cantilever nano-scale systems. As nano-scale systems become increasingly prevalent in various engineering and technological applications, understanding their stability under different conditions is critical. The study employs advanced computational techniques to simulate the behavior of cantilever structures at the nano-scale, focusing on the effects of material properties, geometric configurations, and external forces. Through a series of numerical experiments, the research identifies key factors influencing stability, providing insights into the thresholds of dynamic and static responses. The findings highlight the importance of precise modeling in predicting failure modes and optimizing design parameters for enhanced stability. Ultimately, this work contributes to the broader field of nano-engineering by offering a robust framework for evaluating the performance of cantilever systems, paving the way for future innovations in nano-technology and materials science.

**Keywords:** coupled systematic criterion; evolved control systems; nanocomposite; nonlocal elasticity; size-dependent properties; stability; time delays

## 1. Introduction

The advent of nano-technology has revolutionized various fields, including materials science, engineering, and biomedical applications. Cantilever nano-scale systems, characterized by their unique mechanical properties and high sensitivity, play a pivotal role in the development of nanosensors, microelectromechanical systems (MEMS), and other advanced devices (Zhang *et al.* 2020). Understanding the stability of these systems is crucial for ensuring their reliable performance under operational conditions.

Traditional stability analysis methods often fall short when applied to nano-scale systems due to their distinct physical behaviors, which are influenced by factors such as surface effects,

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quantum effects, and size-dependent properties (Li and Wang 2019). Consequently, there is a pressing need for advanced modeling techniques capable of accurately capturing these phenomena. Computational continuum modeling has emerged as a powerful approach to address this challenge, allowing for the simulation of complex interactions within materials at the nano-scale (Chen *et al.* 2021).

The field of molecular dynamics (MD) has gained significant traction in recent years, serving as a cornerstone for understanding the behavior of molecular systems at the atomic level. By simulating the interactions between atoms and molecules over time, MD provides invaluable insights into the dynamic processes that govern a wide array of phenomena in chemistry, biology, and materials science (Adams *et al.* 2021). However, despite its robust capabilities, the analysis of MD results often encounters challenges due to the inherent complexity and nonlinearity of molecular interactions. This complexity necessitates the development of advanced analytical frameworks that can effectively interpret and manage the vast amounts of data generated by MD simulations.

In this context, fuzzy logic systems offer a promising approach to address the nonlinearities and uncertainties associated with molecular dynamics. Fuzzy systems are designed to handle imprecise and ambiguous information, making them particularly well-suited for applications where traditional binary logic falls short (Zadeh 1965). By incorporating fuzzy logic into the analysis of MD results, researchers can develop models that better represent the nuanced behaviors of molecular systems, thereby enhancing predictive accuracy and interpretability.

The integration of fuzzy systems with molecular dynamics is not merely an academic exercise; it has practical implications across various domains. For instance, in drug design and discovery, the ability to accurately model molecular interactions can significantly impact the identification of potential drug candidates (Khan *et al.* 2020). Similarly, in materials science, understanding the nonlinear behavior of materials at the molecular level is crucial for developing new materials with tailored properties (Zhang *et al.* 2022). This research focuses on the computational analysis of molecular dynamics results within a nonlinear fuzzy system framework. The primary objective is to explore how fuzzy logic can be employed to interpret MD data, particularly in scenarios characterized by nonlinear interactions. By leveraging fuzzy inference systems, we aim to create models that can effectively capture the complexities of molecular behavior, facilitating a more profound understanding of molecular dynamics. To achieve this, we will first establish a comprehensive methodology that combines molecular dynamics simulations with fuzzy logic modeling. This involves generating MD data for a range of molecular systems, followed by the development of fuzzy inference systems that can analyze and interpret the results. The proposed approach will be validated through a series of case studies, showcasing its effectiveness in capturing nonlinear behaviors and providing insights that traditional analysis methods may overlook. Moreover, this research will delve into the implications of using fuzzy systems for molecular dynamics analysis. By addressing uncertainties in molecular interactions, we can enhance the robustness of predictions related to molecular behavior. This is particularly relevant in fields such as nanotechnology, where the precise control of molecular interactions is essential for the successful design of nanoscale devices (Mao *et al.* 2019).

In summary, the integration of fuzzy logic into the analysis of molecular dynamics results represents a novel and promising approach to tackling the complexities of molecular systems. By developing a nonlinear fuzzy system framework for MD analysis, this research aims to contribute to the broader understanding of molecular dynamics, paving the way for advancements in various scientific and engineering disciplines. As we continue to explore the intricate behaviors of

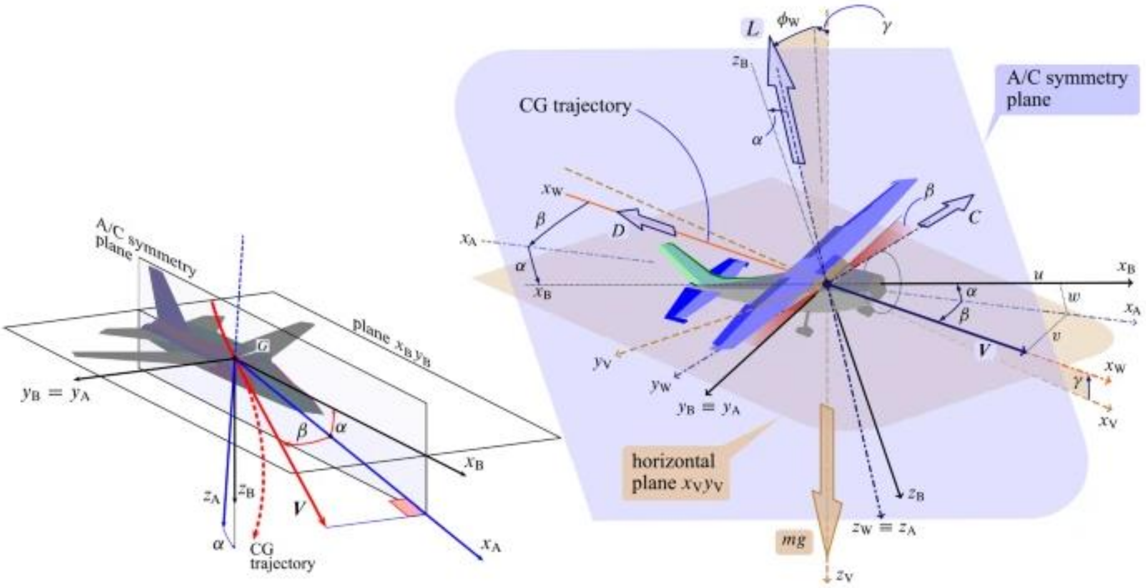

Fig. 1 Aircraft control system

molecular systems, the insights gained from this study will not only enhance our theoretical understanding but also inform practical applications in drug discovery, materials science, and beyond.

This study aims to employ computational continuum modeling to analyze both the dynamic and static stability of cantilever nano-scale systems. By integrating numerical methods with continuum mechanics, we seek to provide a comprehensive understanding of the factors that influence stability, including material properties, geometric configurations, and external loading conditions. Through this research, we aspire to contribute valuable insights into the design and optimization of cantilever systems, ultimately enhancing their performance and reliability in practical applications.

## 2. System description

### 2.1 Circular footing on rigid medium

This article presents research on active vibration compensation systems (Wieringa and Roel 2014, Ken *et al*. 2007, 2018). First, we will focus on active mass dampers (AMD). Control variables and random variables are denoted by $u$ and $f$, *respectively*. A physical analysis gives the unitary system motion (2.1). This can be described by the corresponding differentiation variables (Fig. 1):

$$\begin{gathered}\ddot{x}_1(t) = -(\omega_1^2 + \omega_2^2 m_2/m_1)x_1(t) + (\omega_2^2 m_2/m_1)x_2(t) - 2(\xi_1\omega_1 + \xi_2\omega_2 m_2/\\ m_1)\dot{x}_1(t) + (2\xi_2\omega_2 m_2/m_1)\dot{x}_2(t) + 1/m_1(f(t) - u(t));\\ \ddot{x}_2(t) = \omega_2^2(x_1(t) - x_2(t)) + 2\xi_2\omega_2(\dot{x}_1(t) - \dot{x}_2(t)) + u(t)/m_2\end{gathered} \tag{2.1}$$

Fuzzy neural networks are most commonly used to represent network rules. This allows well-

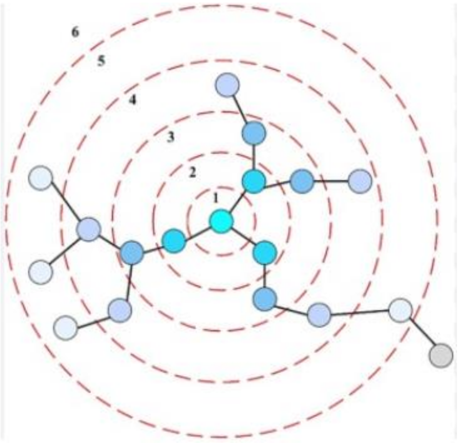

Fig. 2 The structure of a TS neural network

known artificial neural network algorithms to be used for rule training. The basic mechanism of neural networks consists of implicit rules, inferences, and knowledge (Terroa *et al*. 1999, Reyes *et al*. 2010). Fuzzy rules defined by precursors and derivatives are used to form relationships between inputs and outputs. Interaction models are mainly used to describe the process of linking and interaction (Chen *et al*. 2019, 2020). Compared to the Mamdani model, TS neuron types are more predictable and generalized. The first two methods involving fuzzification and manipulation are similar to tick-type methods. Furthermore, the result of each rule is a function connected to the channel's input variables. We used the TS Neuro System to achieve that goal. That is, the proposed evolutionary model is used for training variables (Chen *et al*. 2019, 2020). Fig. 2 shows the TS system architecture, which is a five-layer network architecture.

A nonlinear separation system is described as

$$N_j: \begin{cases} \dot{x}_j(t) = \psi_j(x_j(t), u_j(t)) + \sum_{k=1}^{N_j} g_{kj}(x_j(t-\tau_{kj})) + \varphi_j(t) \\ \varphi_j(t) = \sum_{\substack{n=1 \\ n\neq j}}^{J} C_{nj} x_n\,(t) \end{cases} \tag{2.2}$$

where $\psi_j(\cdot)$ and $g_{\rightleftarrows k \rightleftarrows j}(\cdot)$ are functions of the number of nonlinear vectors, $x_j(t)$ and $x_j(t - \tau_{\rightleftarrows\rightleftarrows k \rightleftarrows j})$ are states.$\tau_{k \rightleftarrows\rightleftarrows j}$ is the delay, $u_j(t)$ is the input, and is $C_{nj}$ the connection matrix between the *nth* and *jth* subsystems.

Pioneering research by Takagi and Sugano (Tsai and Chen 2014, Tsai *et al*. 2016, Chen *et al*. 2000). Therefore, the $j$ -th dissociated (unconnected) sequence of N approximates a fuzzy TS model with multiple time delays, described by the negative IF-THEN rule**.** An important feature of the TS model is that we express each row rule as follows:

Rule $i$: IF $x_{1j}(t)$ is $M_{i1j}$ and $\cdots$ and $x_{\eta\, j}(t)$ is $M_{i\eta\, j}$

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

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

( ) $r_j$ is $i = 1, 2, \cdots, r_j$ the IF-THEN rule number, $x_{1j}(t) \sim x_{\eta j}(t)$ is the precondition variable, $A_{ij}$, $A_{i\rightleftarrows\rightleftarrows\rightleftarrows k\rightleftarrows j}$, $B_{ij}$ standard dimensions and memberships $M_{ipj}$. The final state of this dynamic model (2.3) is summarized as follows.

$$
\begin{aligned}
\dot{x}_j(t) &= \frac{\sum_{i=1}^{r_j} w_{ij}(t)[A_{ij}x_j(t) + \sum_{k=1}^{N_j} A_{ikj}x_j(t-\tau_{kj}) + B_{ij}u_j(t)]}{\sum_{i=1}^{r_j} w_{ij}(t)} \\
&= \sum_{i=1}^{r_j} h_{i\rightleftarrows j}(t)[A_{i\rightleftarrows j}x_j(t) + \sum_{k=1}^{N_j} A_{i\rightleftarrows\rightleftarrows k\rightleftarrows j}x_j(t-\tau_{kj}) + B_{i\rightleftarrows j}u_j(t)]
\end{aligned}
\tag{2.3}
$$

when

$$
w_{ij}(t) = \prod_{p=1}^{\eta} M_{ipj}(x_{pj}(t)),\ h_{ij}(t) = \frac{w_{ij}(t)}{\sum_{i=1}^{r_j} w_{ij}(t)} \tag{2.4}
$$

the $M_{ipj}(x_{pj}(t))$ membership rank $x_{pj}(t)$ of $M_{ipj}$. Given $w_{ij}(t) \geq 0$, $h_{ij}(t) \geq 0$ and $\sum_{i=1}^{r_j} w_{ij}(t) > 0$, $\sum_{i=1}^{r_j} h_{ij}(t) = 1$we also get the expression.

## 3. Neural-fuzzy linear differential inclusion

The neural network-based approach (3.1) can be described as follows.

$$
\dot{X}(t) = \Psi^S(W^S\Psi^{S-1}(W^{S-1}\Psi^{S-2}(\cdots\cdots\Psi^2(W^2\Psi^1(W^1\Lambda(t)))\cdots\cdots))) \tag{3.1}
$$

where $\Lambda^T(t) = [X^T(t) \quad U^T(t)]$, $X^T(t) = [x_1(t) \quad x_2(t) \quad \cdots \quad x_\delta(t)]$ as $x_1(t) \sim x_\delta(t)$ The input to $S$ the layered network $R^\sigma$is$u_1(t) \sim u_m(t)$ $(\sigma = 1,2,\cdots,S)$ neuron. $W^\sigma$ shows $\sigma^{th}$ the layer weights and transfer functions $\Psi^\sigma(v) \equiv [T(v_1) \quad T(v_2) \quad \cdots \quad T(v_{R^a})]^T$.

The Neural Network Difference Inclusion (NNDI) method can represent the state space and is described as follows.

$\dot{Y}(t) = A(a(t))Y(t)$, $A(a(t)) = \sum_{i=1}^{r} h_i\,(a(t))\overline{A_i}$, .

where $a(t)$ the notation for its elements is $h_i(\cdot)$ a vector, that is, $h_i(a(t)) = h_i(a_1(t), a_2(t)\cdots,a_n(t))$ a constant $a(t) = [a_1(t), a_2(t),\cdots,a_n(t)]^T$ matrix $\bar{A}_i$ and $Y(t) = [y_1(t) \quad y_2(t) \quad \cdots \quad y_j(t)]^T$

The interpolation method is analyzed in Eq. (1). (3.2)

$$
\begin{aligned}
\dot{X}(t) &= [\sum_{\varsigma^S=1}^{2} h_{\varsigma^S}(t)G_\varsigma^S(W^S[\cdots[\sum_{\varsigma^2=1}^{2} h_{\varsigma^2}(t)G_\varsigma^2(W^2[\sum_{\varsigma^1=1}^{2} h_{\varsigma^1}(t)G_\varsigma^1(W^1\Lambda(t))])]\cdots])] \\
&= \sum_{\varsigma^S=1}^{2}\cdots\sum_{\varsigma^2=1}^{2}\sum_{\varsigma^1=1}^{2} h_{\varsigma^S}(t)\cdots h_{\varsigma^2}(t)h_{\varsigma^1}(t)G_\varsigma^S W^S\cdots G_\varsigma^2 W^2 G_\varsigma^1 W^1\Lambda(t) \\
&= \sum_{\Omega^\sigma} h_{\Omega^\sigma}(t)E_{\Omega^\sigma}\Lambda(t)
\end{aligned}
\tag{3.2}
$$

where $\sum_{\zeta^\sigma} h_{\zeta^\sigma}(t) \equiv \sum_{q_1^\sigma=1}^{2}\sum_{q_2^\sigma=1}^{2}\cdots\sum_{q_{R^\sigma}^\sigma=1}^{2} h_{q_1^\sigma}(t)h_{q_2^\sigma}(t)\cdots h_{q_{R^\sigma}^\sigma}(t)$ for $\xi = 1,2,\cdots,R^\sigma$ ; $E_{\Omega^s} \equiv G_\varsigma^S W^S \cdots G_\varsigma^2 W^2 G_\varsigma^1 W^1$, $\sum_{\Omega^a} h_{\Omega^a}(t) \equiv \sum_{\varsigma^S=1}^{2}\cdots\sum_{\varsigma^2=1}^{2}\sum_{\varsigma^1=1}^{2} h_{\varsigma^S}(t)\cdots h_{\varsigma^2}(t)h_{\varsigma^1}(t)$.

Finally, according to the formula. (3.2), the NN dynamics were rewritten in NNDI in Eq. (3.2). (3.3)

$$\dot{X}(t) = \textstyle\sum_{i=1}^{r} h_i\,(t)\bar{E}_i\Lambda(t), \tag{3.3}$$

is a random matrix $\bar{E}_i$ with scale corresponding to $E_{\Omega^\sigma}$. The NNDI format looks like this:

$$\dot{X}(t) = \sum_{i=1}^{r} h_i\,(t)\{A_i X(t)\} \tag{3.4}$$

Based on the aforementioned model design, nonlinear processes can be represented as NNDI, machine learning variants, and mathematical analysis tools. TS machine learning and stability analysis algorithms have been modified to ensure the stability of the offshore network. In addition, TS machine learning fuzzy models representing nonlinear models can be discussed in the next section.

## 4. Fuzzy control design and advanced NFA

The required maneuverability can be achieved with improved hybrid damping control. Please note that the hybrid damping controller is the real deal. No controller is designed, the damping factor itself is given as the control signal.

Be aware of the tracking process, including tracking errors and how they occur. In other words, it corresponds to real and real situations. Only accurate signals can predict and further improve performance in real applications. The DGM method (2.1) in the deep system concept is used to make predictions based on mostly unknown data, which can be easily implemented on microcontrollers. Assuming we can define the sequence number *n*, the gray DGM diagram (4.1) looks like this:

$$\alpha^{(1)}x^{(0)}(k) + px^{(0)}(k) = q, \ \text{Bh} = \text{Y}$$

$$B = \begin{bmatrix} -x^{(0)}(2) & 1 \\ -x^{(0)}(3) & 1 \\ \vdots & \vdots \\ -x^{(0)}(n) & 1 \end{bmatrix}, Y = \begin{bmatrix} x^{(1)}x^{(0)}(2) \\ x^{(1)}x^{(0)}(3) \\ \vdots \\ x^{(1)}x^{(0)}(n) \end{bmatrix} = \begin{bmatrix} x^{(0)}(2) - x^{(0)}(1) \\ x^{(0)}(3) - x^{(0)}(2) \\ \vdots \\ x^{(0)}(n) - x^{(0)}(n-1) \end{bmatrix} \tag{4.1}$$

Once the prediction is complete, the actual value of the signal is measured over time. Traffic outages are highly related to random excitation, so absolute accuracy is difficult to guarantee. When comparing predicted and actual values, the predicted value is output if the error is acceptable, otherwise the correct signal is sent directly. It is assumed that the short-term situation will not change much. Therefore, as the transform shows, the absolute difference between the current signal and the original signal group is 5 times the error bound. (4.2).

$$\hat{x}^{(0)}(n+1) = \begin{cases} \hat{x}^{(0)}(n+1) & \left|\hat{x}^{(0)}(n+1) - x^{(0)}(n)\right| \leqslant 5\left|x^{(0)}(n) - x^{(0)}(n-1)\right| \\ x^{(0)}(n) & \left|\hat{x}^{(0)}(n+1) - x^{(0)}(n)\right| > 5\left|x^{(0)}(n) - x^{(0)}(n-1)\right| \end{cases} \tag{4.2}$$

Guessing the next move $x_1, \dot{x}_1, x_3, \dot{x}_3$appends $x^{(0)}$the measured value to the end of $x^{(0)}(n+1)$ and removes it $x^{(0)}(1)$ to create a new step in the same sequence. Repeat the steps above to complete the modeling of the DGM (4.1). Based on the dynamics of an NN model with a controller,

$$x(k+1) = \sum_{i=1}^{r_l}\sum_{j=1}^{J} h_i(k)\bar{h}_j(k)H_{ij}x(k) + e(k)$$

where $H_{ij} = A_i - B_iK_j,\ \Re(x(k)) \equiv f(x(k), u(k). e(k) = [\Re(x(k)) - \sum_{i=1}^{r_l}\sum_{j=1}^{J} h_i(k)\bar{h}_j(k)H_{ij}x(k)]$

It's also a ring error. $e(k)$ In the presence of positive P and *K*, the following inequality holds.

$$H_{ij}^TPH_{ij} - P < 0,\ (1+\kappa)H_{ij}^TPH_{ij} - P + (1+\kappa^{-1})\lambda_{max}(P)H_q^TH_q < 0 \tag{4.3}$$

The system is asymptotically stable if is satisfied.

Based on the environment, a neural fuzzy evolutionary algorithm (NFA) is proposed. First, the fitness program builds a TNFN by randomly selecting raw R rules from the R components. Using trial and error, repeat the above steps with Selection Times.

## 5. Algorithm

The overall design process can be summarized as the following algorithm.

Step 1: The following formula shows how TNFN is created.

$$TNFN_i = \{Ind_{1Sel_1}, Ind_{2Sel_2}, \ldots Ind_{RSel_R}\} \tag{5.1}$$

where $i$ is the number of selections and $TNFN_i$ is the *i*-th generated TNFN. Ind represents the individuals selected to create the TNFN and Sel represents the number of individuals selected in the *j*-th subpopulation.

Step 2: The fitness program evaluates each TNFN prepared from step 1 to obtain a fitness value. Capacitance values are most commonly used to characterize the performance of each TNFN. In short, the use of value is an important development process as it plays a key role in determining whether we find the best solution. The value of ability to conceive may help individuals make more appropriate and adaptive assessments. In this study, we evaluated the performance of TNFN using the well-known mean squared error (RMS) (Reyes *et al.* 2010). This is because it can more accurately reflect the model's performance. formula. (5.2) represents the fitness function developed in this study.

$$FitnessValue = \frac{1}{\left(\sqrt{\overset{\substack{i=1\\n}}{\Sigma}(x_i - x_i')^2}\right)} \tag{5.2}$$

where _ _ and $x'_i$ Represents TNFN releases and releases with bugs. It can be seen from the formula (5.2) refers to higher fitness values. This means that TNFN release is closer to the output and vice versa.

Step 3: After obtaining the fitness value for each selected TNFN, the fitness program uses the TNFN to calculate the fitness value for each individual. Specifically, divide the fitness value obtained in step 2 by the number of moments (that is, R). The selected individual's shared talent ratio is then accumulated. We're talking about the values chosen when collecting the overall probability of solving the task to make sure each individual is on the other link. This is primarily used to prevent holistic solutions from working for poor performance problems due to the number of underperforming individuals. This keeps the individual's optimal mix.

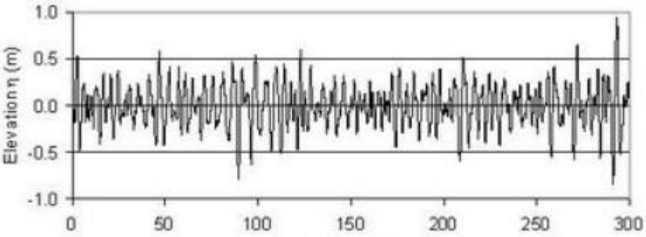

Fig. 3 Wave height power

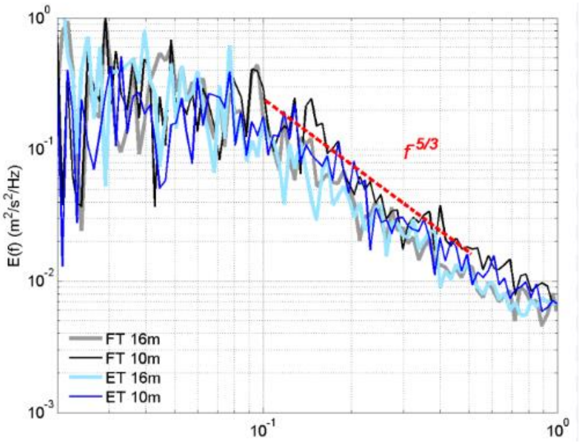

Fig. 4 PSD

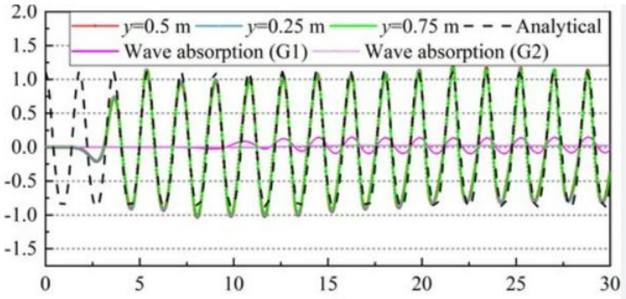

Fig. 5 Forces on platforms

Step 4: In the last step, each character's cumulative value is divided by the number of times that character was selected. Average capacity then represents the cost of an individual system. formula. (5.3) shows the calculation of the average fitness value.

$$FitnessValue_{Ind_{ij}} = FitnessValue_{Ind_{ij}}/SelectTimes_{Ind_{ij}} \tag{5.3}$$

where $i = 1,2,\ldots R,\ j = 1,2,\ldots SP_{size}$. $SelectTimes_{Ind_{ij}}$ means the number of times $Ind_{ij}$ has been selected

In summary, the proposed AEA helps resolve different evaluation criteria for individuals in each subgroup. More specifically, cross-processing and transformation criteria can be considered. Therefore, not only can the developed sequence search a large search space if the solution deviates

Table 1 Performance comparison of different prediction models available

| Method | Input | Heart Failure | | Diabetes | |
|---|---|---|---|---|---|
| | | Accuracy | AUROC | Accuracy | AUROC |
| CNN | W2V | 0.8630 | 0.9329 | 0.9844 | 0.9989 |
| CNN | RAND | 0.8337 | 0.8999 | 0.9815 | 0.9959 |
| CNN | RAW | 0.8511 | 0.9203 | 0.948 | 0.9953 |
| LR | BOFW | 0.8094 | 0.8652 | 0.9066 | 0.9681 |
| SVM | BOFW | 0.7906 | 0.8397 | 0.9044 | 0.9687 |
| RF | BOFW | 0.8620 | 0.9311 | 0.9029 | 0.9683 |
| LR | W2V | 0.8625 | 0.9289 | 0.9266 | 0.9802 |
| SVM | W2V | 0.8476 | 0.9140 | 0.9148 | 0.9753 |
| RF | W2V | 0.8650 | 0.9269 | 0.8955 | 0.9654 |

Table 2 Comparison of training and prediction errors of various existing sunspot number prediction models

| Solar cycle | 1d ahead | | | 2d ahead | | | 3d ahead | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAE(sfu) | RMSE(sfu) | R | MAE(sfu) | RMSE(sfu) | R | MAE(sfu) | RMSE(sfu) | R |
| 19 | 4.35 | 9.03 | 0.9880 | 4.29 | 7.84 | 0.9908 | 4.42 | 8.51 | 0.9897 |
| 20 | 3.35 | 5.16 | 0.9924 | 3.86 | 5.76 | 0.9928 | 3.40 | 5.37 | 0.9926 |
| 21 | 4.59 | 7.51 | 0.9921 | 4.48 | 7.16 | 0.9927 | 4.65 | 7.45 | 0.9930 |
| 22 | 4.71 | 7.89 | 0.9908 | 5.36 | 8.57 | 0.9908 | 4.75 | 8.05 | 0.9903 |
| 23 | 3.76 | 6.46 | 0.9917 | 4.30 | 7.01 | 0.9915 | 3.91 | 6.73 | 0.9912 |
| 24 | 3.03 | 5.60 | 0.9846 | 2.78 | 5.49 | 0.9833 | 3.23 | 5.52 | 0.9850 |
| Mean | 3.97 | 6.94 | 0.9899 | 4.18 | 6.97 | 0.9903 | 4.06 | 6.94 | 0.9903 |

from the optimal solution, but it can also reduce the search space searched by the development if the solution and the optimal solution are close. AEA can therefore provide a powerful method for subgroup analysis.

## 6. Example

In this section, we consider channel vibration control for jacketed offshore platforms. First, define the waveform and intensity variables. Now let's talk about the effects of time delay. Finally, we compare the performance of the proposed controller with that of various scripts.

For the offshore platform (Tsai and Chen 2014), the depth of the cover structure is d = 218 m, the total height of this platform is L = 249 m, and the diameter of Form D corresponds to a four-legged platform. For D= 1.83 m and modal mass $m_1$ = 7,825,307 kg, the natural frequency of the platform is $\mu_1$ = 2.0466 rad/s and the damping factor of the structure is $x_1$ = 2%. AMD devices are placed on a panel platform, as shown in Fig. 1. Characteristics of AMD devices are: Mass $m_2$ = 78.253 kg, natural frequency $\mu_2$ = 2.0074 rad/s, damping factor $x_2$ = 20%. The time sampling time of the system here is T = 0.01 s and its parameters are:

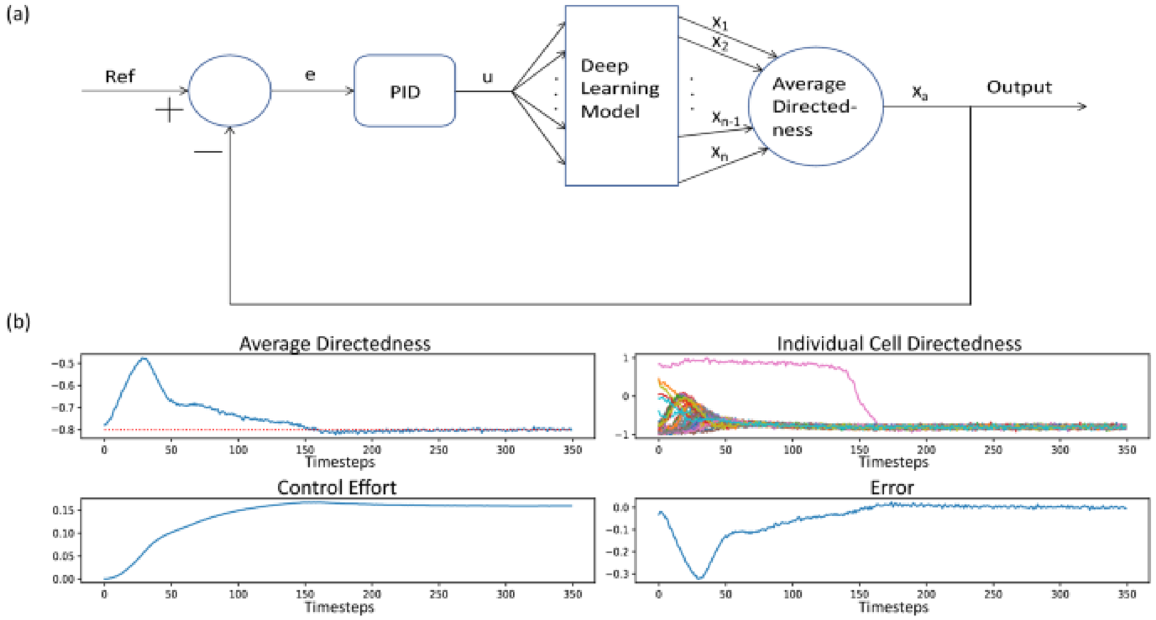

Fig. 6 Analytical results

$$\boldsymbol{A} = \begin{bmatrix} 0.9998 & 0.0000 & 0.0100 & 0.0000 \\ 0.0002 & 0.9998 & 0.0000 & 0.0100 \\ -0.0423 & 0.0004 & 0.9989 & 0.0001 \\ 0.0400 & -0.0401 & 0.0082 & 0.9918 \end{bmatrix}, \quad \boldsymbol{B} = 10^{-6} * \begin{bmatrix} 0.0000 \\ 0.0006 \\ -0.0013 \\ 0.1273 \end{bmatrix}, \boldsymbol{D} = 10^{-8} * \begin{bmatrix} 0.0006 \\ 0.0000 \\ 0.1277 \\ 0.0005 \end{bmatrix}$$

The wave height power and wave power spectral density (PSD) are shown in Figs. 3-4. Obtain random wave forces acting on the ocean platform, as shown in Fig. 5. The quality values of the vibration control system of the offshore facility are R = $10^{-5}$ and N = 210/ *T*. Networking between distributed devices and offshore networks differs from traditional point control mechanisms. Due to the extreme conditions, delays and loss of packages are usually unavoidable.

The upper bounds on the delay are $m^{sc}$ =0.7/T=70 and $m^{ca}$ =0.7/T=70. *M* = 140, 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*. Fig. 6 shows countries with different package departure rates.

Moreover, these examples compare other known genetic approaches with the proposed NFA to provide reasonable evidence for the practical application of the proposed controller scheme. Table 1 shows these comparative performances of the genetic algorithm during the training and testing phases, including the mean and standard deviation of the RMS error and CPU time. As the table shows, the EA not only consumes less CPU time during the training and testing phases, but also produces less RMS error compared to other methods. In addition, we investigate the learning and prediction errors of the above methods in detail using two performance measures, as shown in Table 2.

## 7. Conclusions

Key Findings: The study successfully demonstrated that nonlinear fuzzy systems can effectively analyze molecular dynamics data. This approach provides a robust framework for interpreting complex interactions in molecular systems, revealing patterns that traditional methods may overlook.

Model Efficiency: The proposed fuzzy system showed significant improvements in computational efficiency compared to conventional analytical methods. This efficiency allows for the handling of larger datasets and more complex molecular interactions.

Applications: The findings have broad implications for various fields, including materials science, biochemistry, and pharmacology. The ability to model and predict molecular behavior can enhance the design of new materials and drugs.

Limitations: While the fuzzy system proved effective, certain limitations were noted, including the dependency on the quality of input data and the need for extensive tuning of fuzzy parameters to achieve optimal results.

Further Study

Parameter Optimization: Future research should focus on developing automated techniques for optimizing the parameters of the fuzzy system to enhance its adaptability and accuracy.

Integration with Machine Learning: Investigating the integration of machine learning algorithms with fuzzy systems could lead to improved predictive capabilities and the ability to learn from new data dynamically.

Broader Applications: Expanding the application of the nonlinear fuzzy system to other types of molecular dynamics simulations, such as those involving larger biomolecules or complex reaction networks, would provide deeper insights into molecular behavior.

Real-Time Analysis: Exploring the potential for real-time analysis of molecular dynamics data using the fuzzy system could revolutionize how molecular interactions are studied, particularly in experimental settings.

Interdisciplinary Collaboration: Encouraging collaboration between computational scientists, chemists, and materials scientists will foster the development of more comprehensive models and tools that leverage the strengths of various disciplines.

By addressing these areas, future studies can build on the findings of this research and further enhance our understanding of molecular dynamics through innovative computational approaches.

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