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Coupled aircraft systematic theorem and analysis for nonlinear fuzzy systems

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Abstract. In this paper, we propose a coupled systematic reference model-related method for dynamic controller design of evolutionary processes to overcome the effects of model errors. To ensure a robust model, the stability criterion is directly proved by the Lyapunov method. NFA solves the problem based on a complex echolocation TS fuzzy model. Based on these standards and distributed control methods, the use of NFA is a cluster-based fuzzy control method for designing predictive signals and active controls. Finally, a numerical example is given in the presented results to show that the stability analysis can be applied to nonlinear responses and that the application of this principle depends on the precise degree of multi-degree-of-freedom (MDOF) vibration compensation. In addition to robust logic, control system effectiveness can also reduce risk in industrial applications.

Keywords: coupled systematic criterion; disordering; evolved control systems; predictive control; time delays

1. Introduction

Sea level monitoring is one of the most important processes in the field of control systems, especially since the introduction of control forces carries the risk of accidents. Many of these problems arise during botched surgeries and can lead to serious consequences such as death, injury and financial loss. Reasons for this include lack of well-organized facilities, lack of trained and inexperienced staff, poor communication, and general failure of hardware. Among the available control systems, active control has been introduced due to its high level of efficiency (Sakthivel *et al.* 2014). For adiabatic metal (AMD) jacket types, time delays should be considered (Sakthivel *et al.* 2014, Chen 2014). To remedy this shortcoming, the most popular learning algorithms, called intelligent algorithms, have been proposed to constrain local solutions (Goldberg 1989). Moreover, the modified algorithm can also be used in various neural networks. In other words, the algorithm does not need to generate new formulas to train different hierarchy variables in the neural network. Therefore, training dynamics in neural networks is preferable to using traditional approaches.

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Recently, several evolutionary approaches have been used to tune neural network parameters to increase the probability of meeting an optimal solution (Koza 1992, Fogel 1994, Rechenberg 1994). Such algorithms not only provide parallel search technology for finding solutions, but can also evaluate multiple factors within the search space. Various evolutionary approaches such as genetic modeling (GA) (Goldberg 1989), genetic programming (Koza 1992), evolutionary programming (Fogel 1994), and evolutionary modeling (Rechenberg 1994) to train a neural parameter social network. Such algorithms not only provide parallel techniques and searches for finding solutions, but can also analyze many points simultaneously in the search space. By doing so, the neural key parameters of the network can be properly trained and the accuracy of the output obtained from the neural key network can be improved.

Based on a newly developed methodology, this article aimed to experimentally investigate the changes affecting the stability of various concrete mattresses subjected to external wave forces. First, we briefly review the Takagi-Sugeno (TS) fuzzy model and present an explanation of how to do it. A set of distributed fuzzy controllers using parallel dispersion compensation (PDC) and powerful neural network (NFA) algorithms are then proposed to overcome the effects of model errors. Stability criteria are then provided to ensure nonlinear multi-delay stability for large arrays. Finally, we present numerical examples, illustrate the results with simulations, and draw some conclusions.

2. System description

This article presents research on active vibration compensation systems suitable for buildings (Wieringa and Roel 2014, Ken *et al.* 2007, 2018). First, we will focus on point-to-point management of jacketed offshore platforms with active mass dampers (AMD). A diagram showing a typical Tension Leg Platform (TLP) and Active Mass Damper (AMD) combined system configuration is shown in Fig. 1. This platform can be designed as a system with only one degree of freedom (SDOF). The first mode encourages movement more. This method is sufficient to control vibrations.

The model parameters of the SDOF system are denoted by m_1, u_1, and x_1. and the corresponding equation related to the motion of the offshore station is denoted by x_1. AMD's mass, natural frequency and damping ratio are denoted by m_2, u_2, x_2 and AMD's displacement is denoted by x_2. 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

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

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

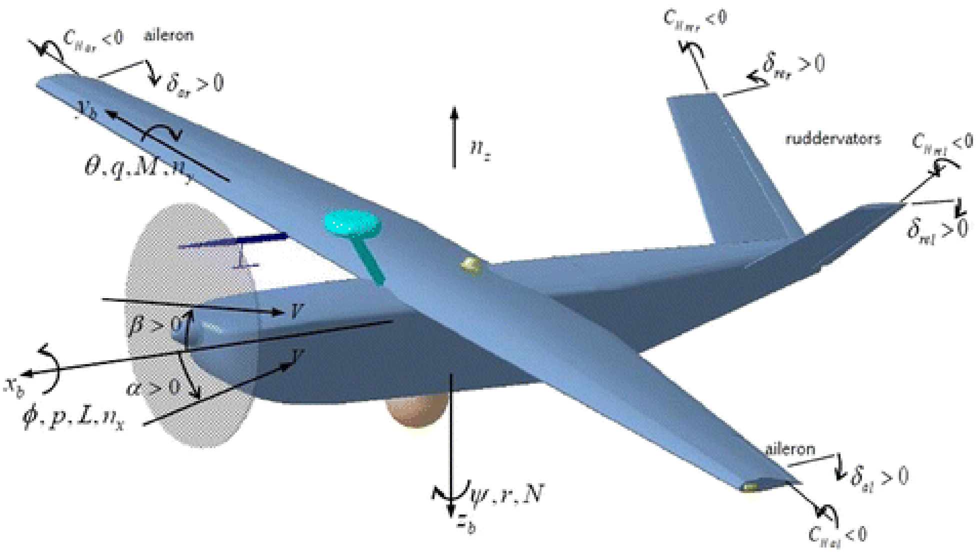

Fig. 1 Aircraft control system

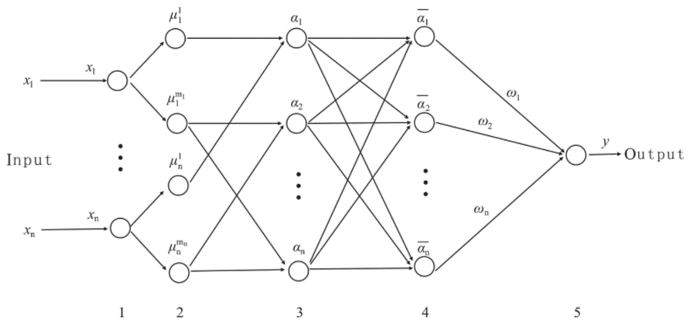

Fig. 2 The structure of a TS neural network

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

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

where $\psi_j(\cdot)$ and $g_{kj}(\cdot)$ are functions of the number of nonlinear vectors, $x_j(t)$ and $x_j(t-\tau_{kj})$ are states.τ_{kj} 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_{ikj} , B_{ij} standard dimensions and memberships M_{ipj}. The final state of this dynamic model (2.3) is summarized as follows.

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

When

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

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. (2.5)

$$N_j: \begin{cases} \dot{x}_j(t) = \sum_{i=1}^{r_j} h_{ij}(t)(A_{ij}x_j(t) + B_{ij}u_j(t) + \sum_{k=1}^{N_j} A_{ikj}x_j(t-\tau_{kj})) + [\psi_j(x_j(t), u_j(t)) \\ + \sum_{k=1}^{N_j} g_{kj}(x_j(t-\tau_{kj})) - \sum_{i=1}^{r_j} h_{ij}(t)(A_{ij}x_j(t) + B_{ij}u_j(t)) - \sum_{i=1}^{r_j}\sum_{k=1}^{N_j} h_{ij}(t)(A_{ikj}x_j(t-\tau_{kj}))] + \varphi_j(t) \\ \varphi_j(t) = \sum_{\substack{n=1 \\ n\neq j}}^{J} C_{nj}x_n(t) \end{cases} \tag{2.5}$$

to discuss the stability of the formula. (2.5), NFA differential insertion in section 3 is used to design opaque controls.

3. Neural-fuzzy linear differential inclusion

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

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

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

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

$$\dot{Y}(t) = A(a(t))Y(t), A(a(t)) = \sum_{i=1}^{r} h_i(a(t))\bar{A}_i,$$

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

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

$$\dot{X}(t) = \left[\sum_{\zeta^S=1}^{2} h_{\zeta^S}(t) G_\zeta^S (W^S[\dots[\sum_{\zeta^2=1}^{2} h_{\zeta^2}(t) G_\zeta^2 (W^2[\sum_{\zeta^1=1}^{2} h_{\zeta^1}(t) G_\zeta^1 (W^1 \Lambda(t))])]\dots])\right]$$
$$\sum_{\zeta^S=1}^{2} \dots \sum_{\zeta^2=1}^{2} \sum_{\zeta^1=1}^{2} h_{\zeta^S}(t) \dots h_{\zeta^2}(t) h_{\zeta^1}(t) G_\zeta^S W^S \dots G_\zeta^s W^2 G_\zeta^1 W^1 \Lambda(t) \quad (3.2)$$
$$= \sum_{\Omega^\sigma} h_{\Omega^\sigma}(t) E_{\Omega^\sigma} \Lambda(t)$$

Where

$\sum_{\zeta^\sigma} h_{\zeta^\sigma}(t) \equiv \sum_{q_1^\sigma=1}^{2} \sum_{q_2^\sigma=1}^{2} \dots \sum_{q_{R^\sigma}^\sigma=1}^{2} h_{q_1^\sigma}(t)\ h_{q_2^\sigma}(t) \dots h_{q_{R^\sigma}^\sigma}(t)$. for $\zeta = 1,2,\dots,\mathrm{R}^\sigma$; $E_{\Omega^\sigma} \equiv G_\zeta^S W^S \dots G_\zeta^2 W^2 G_\zeta^1 W^1$, $\sum_{\Omega^\sigma} h_{\Omega^\sigma}(t) \equiv \sum_{\zeta^S=1}^{2} \dots \sum_{\zeta^2=1}^{2} \sum_{\zeta^1=1}^{2} h_{\zeta^S}(t) \dots h_{\zeta^2}(t) h_{\zeta^1}(t)$.

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

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

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

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

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.

5. 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

$$\alpha^1 x^0(k) + p x^0(k) = q,\ Bh = Y$$
$$B = \begin{bmatrix} -x^{(0)}(2) & 1 \\ -x^{(0)}(3) & 1 \\ \vdots & \vdots \\ -x^{(0)}(n) & 1 \end{bmatrix}, Y = \begin{bmatrix} \alpha^1 x^0(2) \\ \alpha^1 x^0(3) \\ \vdots \\ \alpha^1 x^0(n) \end{bmatrix} = \begin{bmatrix} x^0(2) - x^0(1) \\ x^0(3) - x^0(2) \\ \vdots \\ x^0(n) - x^0(n-1) \end{bmatrix} \quad (4.1)$$

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).

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

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 κ, the following inequality holds.

$$\boldsymbol{H}_{ij}^T\,\boldsymbol{P}\boldsymbol{H}_{ij} - \boldsymbol{P} < 0,\ (1+\kappa)\boldsymbol{H}_{ij}^T\,\boldsymbol{P}\boldsymbol{H}_{ij} - \boldsymbol{P} + (1+\kappa^{-1})\lambda_{max}(\boldsymbol{P})\boldsymbol{H}_q^T\,\boldsymbol{H}_q < 0 \tag{4.3}$$

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 SelectionTimes.

5. Algorithm

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

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

$$TNFN_i = \{Ind_{1Sel_1}, Ind_{sSel_2} \dots Ind_{RSel_2}\}, \tag{5.1}$$

where *i* is the number of selections and *TNFNi* 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.

$$Fitness\ Value = \frac{1}{\left(\sqrt{\frac{\sum_{i=1}^{n}(x_i - x_i')^2}{n}} + 1\right)}. \tag{5.2}$$

where 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.

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. 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 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 $m1$=7,825,307 kg, the natural frequency of the platform is $u_{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 $u_{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:

$$\mathbf{A}=\begin{bmatrix} 09998 & 0.0000 & 0.0100 & 0.0000 \\ 0.0002 & 0.9998 & 0.0000 & 0.0100 \\ -0.0423 & 0.0004 & 0.9989 & 0.0001 \\ 0.0400 & -0.0401 & 0.0082 & 0.9918 \end{bmatrix}, \mathbf{B}=10^{-6}\times\begin{bmatrix} 0.0000 \\ 0.0006 \\ -0.0013 \\ 0.1273 \end{bmatrix}, \mathbf{D}=10^{-8}\times\begin{bmatrix} 0.0006 \\ 0.0000 \\ 0.1277 \\ 0.0005 \end{bmatrix}$$

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

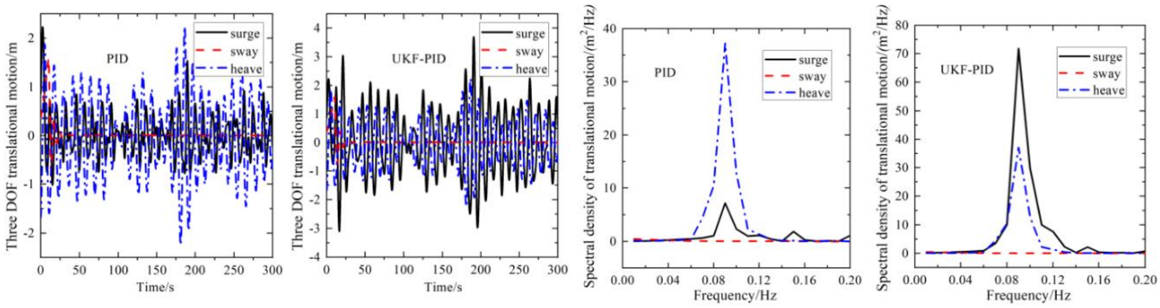

Fig. 6 Offshore destination migration with different packet dropout values

Table 1 Performance comparison of different prediction models available light field number

algorithm	RMS error (training)		RMS error (experimental)		CPU time (training)	
	average	deviation	average	deviation	average	deviation
EA's suggestion	5.4	0.4	5. 6.	0.7	113.2	4.8
(Koza 1992)	28.3	3.5	30.2	4.2.2	143.5	6.5
(Vogel 1994)	19.5	1.5	20.1	4.3	257.2	8.5
(Rechenberg 1994)	14.7	1.7	1 6.2	2.1	216.3	9.2.2

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

algorithm	error in training		estimation error	
	average	deviation	average	deviation
EA's suggestion	4.1.1	0.3.	6.2.2	0.4.
(Koza 1992)	12.9	1.5	18.2	2.1
(Vogel 1994)	1 0.2	1. 1. 1.	15.3	2.2.2.2
(Rechenberg 1994)	8.2.2	0.8	1 3.2	1.6

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

In order to ensure asymptotic stability and improve driving comfort, this paper develops a neuro-fuzzy algorithm (*NFA*) to generate a gray signal predictor for the offshore position of a kind of steel jacket subjected to constant wave force. Design an adaptive backstepping controller with This model is described in Sea Level Oscillation Control to solve management problems using new results of the Lyapunov Stability Criterion based on previously obtained weather packets. The bat algorithm developed is used to simplify computations and reduce storage space required in utility applications. Results show that the proposed operator can easily compensate for random delays, large packet losses, and interruptions. Our findings show that the proposed controller can easily compensate for random delays and disturbances. The predictive optimization process means that vibrations in offshore structures can be significantly reduced while maintaining the optimal small-scale control capabilities required.

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