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Fuzzy adaptive control method with biological character*

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Abstract. Aiming at a type of complex nonlinear dynamic systems, a T-S fuzzy control system based on niche model is proposed in this paper. The ecological environment actually occupied by the organism, and the organism's ability to exploit and use it, is regarded as a unit of a dissipative structure-"niche". The "costae escarole" theory of niche is used to found a general fuzzy mathematic model. The biological adaptation is combined with the design of fuzzy control system to found a fuzzy inference system and give out a fuzzy T-S model with biotechnology. The measurement of niche is regarded as a consequence of fuzzy control regularity. In this paper, the theoretical proof of this method's universal approximation is given out, and the method is applied in the control of nonlinear systems. The simulation results suggest this controller is effective.

Key word: fuzzy control, niche, self-adaptive, identification

1. Introduction

The application of fuzzy control in engineering has become a very effective method, fuzzy logical system is a systemically inference method, which is transferred into a control strategy based on linguistics information the experts found. The prominent character is the controller has strong robustness. So it can be applied to resolve many complex systems that cannot be controlled by regular control methods, such as nonlinear systems, time-variation systems, and delay systems. But when observing and recognizing the subjection, fuzzy control cannot reach actually intelligent effect. It still needs to be improved and perfected continuously to be adaptive, self-organized and self-learning. There are many discussions about the perfecting and improving of fuzzy controllers. Such as fuzzy controller with good self-adaptation [1,2], fuzzy controller with parameters self-rectifying [3], adaptive fuzzy control based on model reference [4], and so on. In recent years, many researchers associated neural network and genetic algorithms with fuzzy control and made fuzzy controls reach a higher level [6-11]. Takagi and Sugeno [19] proposed a new fuzzy control model. This model, which regards polynomial functions as consequences rather than fuzzy sets, promoted the further development of fuzzy systems. Cao et al[12], Feng et al[13], and Tanaka et al[14] proposed stability conditions of T-S fuzzy system and introduced a new optimizing design method which ensured the stability based on Lyapunov equations and LMIS method. The fundamental idea of these methods is to design a feedback control for local model, generate a global fuzzy controller, found a theory frame to solve the analysis of nonlinear system and the calculation of synthesized problems of T-S fuzzy model, and make the design of fuzzy controllers have rigid theoretical foundations. From the concept of ecosystem, this paper regards the organisms' abilities of self-adaptation, self-organization, self-learning and the environment they live as a unit of a dissipative structure--"niche". Besides, it introduces this concept into fuzzy control system and applies the organisms' adaptation in designing new fuzzy control method with biological character.

This paper is composed of four sections. In the first section, the fuzzy mathematic model of niche is founded. Then we construct a niche-based T-S fuzzy model in the second section. Further, in the third section, the reversal diffusing algorithm of parameters adjust is given. Finally, a practical example is used to illustrate the effectiveness of the control method proposed in this paper in the last section and the simulate

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results are given.

2. Mathematical model of niche's dissipative structure

The ecosystem system is a complex system. The interaction and inhibition among organisms and between system and outer enlarge the difficulty to describe the inherent dynamical behaviors in ecosystem. But because of the redundant structure of the ecosystem, organisms in the ecosystem have ability to adapt to the environment, develop toward better survival environment and make the ecosystem balanceable finally. The redundant structure of ecosystem is a multiple parallel-connection system. When the system is disturbed, it is possible to lead to the loss of a certain part (or hierarchy). But the system can recover through the redundancy supplement. That is to say, the biological system can exhibit rapid self-restoration function. In this paper, this redundant structure and redundancy-supplement trait are added to the design of control system to propose a new adaptive fuzzy control method based on organisms' niche. This new method improves the robustness and adaptation of the control system and reaches the system's global stability.

In the ecosystems, the organisms and the communities all have their niches, which are closely related with the nonlinear character, adaptive character, and robustness of the ecosystems. Niche refers to the sum of the capability of species to occupy the ecological environment and the capability of the organism to exploit and utilize environment. In the view of geometry significance, it is a n-dimensional hyper-volume, which includes two contents: one is the survival space of the organism, that is the state of biological unit (where the state includes energy, organism value, species' number, and the ability to occupy resource, adaptation and so on), and the result of the past growth, development and the accumulation by interacting with environment; the other is the organisms' ability to exploit and utilize the survive space, is the ability of biological unit to influence or dominate the environment in practice, such as the velocity of the change of energy and substance, the productivity, growth rate and the ability to occupy new environment.

Definition 1. Considering the ecosystem with n biological units, the measurement of the ith biological unit's niche is defined as:

$$r_j = \frac{s_j + C_j p_j}{\sum_{i=1}^{n}(s_i + C_i p_i)} \quad (i = 1,2,\cdots,n\,;\, j = 1,2,\cdots,n\,).$$

Where s_i is the costae of the ith biological unit, expressing the state of the biological unit variation and the accumulate result of the past ecological effect to biological unit.

p_i is the escarole of the ith biological unit, expressing the change rate of the ith biological unit and reflecting the dynamical result of ecological effect to the ith biological unit; C_i is the convert parameter of the dimensions.

This formula shows that $r_j \in [0,1]$. It also suggest that the niche r_j is bigger, the effect that the organism exert in the system is bigger; on the contrary, r_j is smaller, the effect that the organism exert in the system is smaller.

The "costae escarole" theory of the organism's niche synthetically reflects the history, realistic effect and development tendency of a certain biological unit, and compares these with other biological units in the system at the same time, showing the contrastive importance of different biological units. It seems that the expansion of the organism's niche is the determinate factor [18] and is also the quantitive description of the organisms' adaptation to the environment and their self-adjustment. So, adding this character to fuzzy control can enhance the "intelligent" trait of fuzzy control.

3. Niche T-S fuzzy models

In the design of the fuzzy system, the adaptive structure body is combined with T-S fuzzy model. The consequent rule of the T-S fuzzy model is changed into the organism's niche, so the niche-based T-S fuzzy model is constructed. Because that the biological redundant structure is incorporated in such fuzzy model, the founded fuzzy system has biological robustness and global stability.

The fuzzy rules are defined as

$$R^j: \text{If } x_1 \text{ is } X_1^j \text{ and} \dots \text{and } x_n \text{ is } X_n^j \text{ then } y^j = k_1 r_1^j + k_2 r_2^j + \cdots + k_n r_n^j$$

where R^j is the *j*th fuzzy rule, X_i^j denotes the antecedent fuzzy sets of fuzzy rules. x_i is the *i*th input variant, y^j is the output variant of the *j*th rule, and r_i^j is the niche of the *i*th species.

The biological meaning of Niche T-S model is: the antecedence of fuzzy control rules denotes the geometry expression of the organism's living state, the consequence of the rules denotes the organism's niche. So, the niche-based fuzzy T-S model not only has clear physics meanings, but also incorporates the organism's biological character, including the biological evolution and development, the biological adaptation, and the fault-tolerant ability of organisms. At the same time while dealing with such model, it can be treated the same as the general fuzzy T-S model.

Adopting central mean operator to defuzzificate, choosing the reasoning rule of product and Gauss-type membership function, and taking single value fuzzized method, the global output of the niche-based fuzzy system:

$$f = \frac{\sum_{j=1}^{m} y^j (\prod_{i=1}^{n} \mu_{X_i}^j (x_i))}{\sum_{j=1}^{m} \prod_{i=1}^{n} \mu_{X_i}^j (x_i)}$$

The Gauss-type membership function is defined as:

$$\mu_{X_i}^j (x_i) = \exp(-(\frac{x_i - x_i^j}{\delta_i^j})^2)$$

For the convenience of application in reality, fetch:

$$s_i = x_i \;; p_i = \Delta x_i ; \; r_i^j = \frac{x_j + C_j \Delta x_j}{\sum_{i=1}^{n} (x_i + C_i \Delta x_i)} \qquad i = 1,2,\cdots,n; j = 1,2,\cdots,m;$$

let

$$a_j = \frac{1}{\sum_{i=1}^{n} (x_i + C_i \Delta x_i)}, \; b_j = \frac{C_j}{\sum_{i=1}^{n} (x_i + C_i \Delta x_i)};$$

At this moment, we have: $r_i^j = a_j x_j + b_j \Delta x_j$, $(0 \le a_j, b_j \le 1)$, then:

$$y^j = \sum_{i=1}^{n} r_i^j = \sum_{i=1}^{n} (a_i x_i + b_i \Delta x_i)$$

Then the global output with biological characters is

$$f = \frac{\sum_{j=1}^{m} y^j (\prod_{i=1}^{n} \mu_{X_i}^j (x_i))}{\sum_{j=1}^{m} \prod_{i=1}^{n} \mu_{X_i}^j (x_i)} = \frac{\sum_{j=1}^{m} \sum_{i=1}^{n} (a_i x_i + b_i \Delta x_i) \cdot \prod_{i=1}^{n} \exp[-(\frac{x_i - x_i^j}{\delta_i^j})^2]}{\sum_{j=1}^{m} \prod_{i=1}^{n} \exp[-(\frac{x_i - x_i^j}{\delta_i^j})^2]} \tag{1}$$

Where a_i, b_i, x_i^j and δ_i^j are tunable parameters, which has nonlinear relation with fuzzy logical system f. The tuning of these parameters can utilize the reverse spread learning algorithm.

Since the system in this paper considers individuals' niche as the consequence of control rules, and the antecedence of control rules is the same one as in the normal T-S fuzzy model. The membership function in this T-S model is adopted as triangle-type or Gauss-type. So the fuzzy inference system given in this paper is also a universal approximation. Then we have the following theorems.

Theorem1 For any continuous function g defined in a sequential compact set $U \in R^n$ and $\forall \varepsilon > 0$, there must be a niche-based fuzzy function *f*, which satisfies

$$\sup_{x\in U}\left|f(x)-g(x)\right|<\varepsilon \quad .$$

Proof: We assume that Y is a set of the Gauss-type fuzzy logical system. At first, let us prove (Y,d_∞) is an algebra.

Let $f_{1,}f_2\in Y$, and they can be written as

$$f_1(x)=\frac{\sum_{j=1}^{k1} y_1{}^j(\prod_{i=1}^{n}\mu_{A1_i}{}^j(x_i))}{\sum_{j=1}^{k1}\prod_{i=1}^{n}\mu_{A1_i}{}^j(x_i)} \tag{2}$$

$$f_2(x)=\frac{\sum_{j=1}^{k2} y_2{}^j(\prod_{i=1}^{n}\mu_{A2_i}{}^j(x_i))}{\sum_{j=1}^{k2}\prod_{i=1}^{n}\mu_{A2_i}{}^j(x_i)} \tag{3}$$

Then, we can get:

$$f_1(x)+f_2(x)=\frac{\sum_{j1=1}^{k1}\sum_{j2=1}^{k2}(y_1{}^{j1}+y_2{}^{j2})(\prod_{i=1}^{n}\mu_{A1_i}{}^{j1}(x_i)\mu_{A2_i}{}^{j2}(x_i))}{\sum_{j1=1}^{k1}\sum_{j2=1}^{k2}(\prod_{i=1}^{n}\mu_{A1_i}{}^{j1}(x_i)\mu_{A2_i}{}^{j2}(x_i))}. \tag{4}$$

Because $\mu_{A1_i}{}^j$ and $\mu_{A2_i}{}^j$ are Gauss-type, the multiplication is Gauss-type too. Similarly:

$$f_1(x)\cdot f_2(x)=\frac{\sum_{j1=1}^{k1}\sum_{j2=1}^{k2}(y_1{}^{j1}\cdot y_2{}^{j2})(\prod_{i=1}^{n}\mu_{A1_i}{}^{j1}(x_i)\mu_{A2_i}{}^{j2}(x_i))}{\sum_{j1=1}^{k1}\sum_{j2=1}^{k2}(\prod_{i=1}^{n}\mu_{A1_i}{}^{j1}(x_i)\mu_{A2_i}{}^{j2}(x_i))}. \tag{5}$$

So, $f_1\cdot f_2\in Y$. Then considering to any constant $c\in R$, we have:

$$cf_1(x)=\frac{\sum_{j=1}^{k1} cy_1{}^j(\prod_{i=1}^{n}\mu_{A1_{l_i}}{}^j(x_i))}{\sum_{j=1}^{k1}\prod_{i=1}^{n}\mu_{A1_{l_i}}{}^j(x_i)} \quad . \tag{6}$$

Since $\mu_{A1_{l_i}}{}^j$ is Gauss type, $cf_1\in Y$. So, (Y,d_∞) is algebra.

Secondly, we will prove that (Y,d_∞) can segregate the points of U.

Given the number of fuzzy sets defined on U and R, the parameters of Gauss-type membership function, the number of fuzzy rules and the expressions of these rules, the structure of f is founded to satisfy: to any given $x^0,y^0\in U$ and $x^0\neq y^0$, defining two fuzzy sets $(A_i^1,\mu_{A_i^1})$ and $(A_i^2,\mu_{A_i^2})$ on the *i*-th subspace of U, their membership function are:

$$\mu_{A_i^1}(x_i)=a^i\exp\left(-\left(\frac{x_i-x_i^0}{\delta_i^0}\right)^2\right), \tag{7}$$

$$\mu_{A_i^2}(x_i) = a^i \exp\left(-\left(\frac{x_i - y_i^0}{\delta_i^0}\right)^2\right). \tag{8}$$

If $x^0 = y^0$, then $A_i^1 = A_i^2$ and $\mu_{A_i^1} = \mu_{A_i^2}$, at this point, only one set is defined on the *i*th subspace of U. Defining two fuzzy sets $(B_i^1, \mu_{B_i^1})$ and $(B_i^2, \mu_{B_i^2})$ on the output domain, their membership functions are:

$$\mu_{B_j^1}(x_j) = a^j \exp\left(-\left(\frac{x_j - x_j^0}{\delta_j^0}\right)^2\right), \tag{9}$$

$$\mu_{B_j^2}(x_j) = a^j \exp\left(-\left(\frac{x_j - y_j^0}{\delta_j^0}\right)^2\right) \tag{10}$$

Assuming that there are two fuzzy rules, so we get

$$f(x^0) = \frac{\bar{y}^1 + \bar{y}^2 \prod_{i=1}^n a^i \exp(-\frac{(x_i^0 - y_i^0)^2}{\delta_i^0})}{1 + \prod_{i=1}^n a^i \exp(-\frac{(x_i^0 - y_i^0)^2}{\delta_i^0})} = \alpha\bar{y}^1 + (1-\alpha)\bar{y}^2$$

$$f(y^0) = \frac{\bar{y}^2 + \bar{y}^1 \prod_{i=1}^n a^i \exp(-\frac{(x_i^0 - y_i^0)^2}{\delta_i^0})}{1 + \prod_{i=1}^n a^i \exp(-\frac{(x_i^0 - y_i^0)^2}{\delta_i^0})} = \alpha\bar{y}^2 + (1-\alpha)\bar{y}^1$$

where $\alpha = \dfrac{1}{1 + \prod_{i=1}^n a^i \exp(-\frac{(x_i^0 - y_i^0)^2}{\delta_i^0})}$.

Since $x^0 \neq y^0$, there must be $x_i^0 \neq y_i^0$ so that $\prod_{i=1}^n \exp\left(-\frac{(x_i^0 - y_i^0)^2}{\delta_i^0}\right) \neq 1$ or $\alpha \neq 1-\alpha$. If adopt $\bar{y}^1$=0 and $\bar{y}^2$=1, then $f(x^0) = 1-\alpha \neq \alpha = f(y^0)$. This verifies that (Y, d_∞) can segregate the points of algebra U.

Theorem 2 For any $g \in L_2(u)$, and $\forall \varepsilon > 0$, there must be a niche-based fuzzy function *f*, which satisfies

$$[\int_U |f(x) - g(x)|^2 dx]^{\frac{1}{2}} < \varepsilon,$$

where $U \in R^n$ is a sequential compact set, $L_2(U) = \left\{ g : U \to R \middle| \int_U |g(x)|^2 dx < \infty \right\}$ and the integration is Lebesgue integration.

Proof: Because $U \in R^n$ is sequential compact, $\int_U dx = V < \infty$. Since the sequential function subset $L_2(u)$ is also sequential compact, there must be a continuous function $\bar{g}$ on U for any $g \in L_2(u)$,

$$[\int_U |g(x) - \bar{g}(x)|^2 dx]^{\frac{1}{2}} < \varepsilon/2.$$

Besides, according to theorem 1, there must be a Gauss-type fuzzy logical system $f \in Y$, which satisfies

$$\sup_{x\in U}\left|f(x)-\bar{g}(x)\right|<\frac{\varepsilon}{2\left(V^{1/2}\right)}.$$

So we get:

$$[\int_U[\left|f(x)-g(x)\right|^2dx]^{\frac{1}{2}}\le[\int_U[\left|f(x)-\bar{g}(x)\right|^2dx]^{\frac{1}{2}}+[\int_U\left|g(x)-\bar{g}(x)\right|^2dx]^{\frac{1}{2}}$$

$$<[\int_U\left(\sup_{x\in U}\left|f(x)-\bar{g}(x)\right|\right)^2dx]^{\frac{1}{2}}+\varepsilon/2<\left(\frac{\varepsilon^2}{2^2V}\times V\right)^{1/2}+\varepsilon/2=\varepsilon.$$

4. The parameter optimization method of Niche T-S model

The given input and output data is $(x^p,d^p),x^p\in U\subset R^n,d^p\in V\subset R$. Our task is to determine the parameters of Niche T-S model as (1), so as to $e^p=\frac{1}{2}[f(x^p)-d^p]^2$ be the minimum.

Assuming that m is known, the tuning of the parameters a_j,b_j,x_i^j,δ_i^j can let e^p reach minimum. For discussing conveniently, e,f,d are denote $e^p,f(x^p),d^p$ respectively.

(1) Adjust parameters a_j,b_j:

$$a_j(k+1)=a_j(k)-\alpha\frac{\partial e}{\partial a_j}|_k,\ j=1,2,\cdots,m,k=0,1,2,\cdots,$$

where α is the determinate step-length. So

$$\frac{\partial e}{\partial a_j}=\frac{\partial e}{\partial f}\cdot\frac{\partial f}{\partial a_j}=(f-d)\cdot s_j(k)\frac{1}{b}Z^j,$$

where $b=\sum_{j=1}^m Z_j,Z^j=\prod_{i=1}^n\exp[-(\frac{x_i-x_i^j}{\delta_i^j})^2]$, then

$$a_j(k+1)=a_j(k)-\alpha\frac{f-d}{b}s_j(k)Z^j. \tag{11}$$

Similarly

$$b_j(k+1)=b_j(k)-\alpha\frac{f-d}{b}p_j(k)Z^j$$

(2) Adjust parameters x_i^j,δ_i^j by the same method:

$$\begin{aligned}x_i^j(k+1)&=x_i^j(k)-\alpha\frac{\partial e}{\partial x_i^j}|_k\\&=x_i^j-\alpha(f-d)(f-\frac{N}{b})\cdot\frac{2(x_i-x_i^j(k))}{(\delta_i^j(k))^2}\end{aligned} \tag{12}$$

$$\begin{aligned}\delta_i^j(k+1)&=\delta_i^j(k)-\alpha\frac{\partial e}{\partial\delta_i^j}|_k\\&=\delta_i^j-\alpha(f-d)(f-\frac{N}{b})\cdot\frac{2(x_i-x_i^j(k))^2}{(\delta_i^j(k))^3}\end{aligned} \tag{13}$$

where $N=\sum_{j=1}^m(a_js_j+b_jp_j)$.

5. Niche T-S adaptive fuzzy control of aneurysm systems

Aneurysm model[20]

$$\ddot{x} + p\dot{x} + ax - bx^2 + cx^3 = F\cos(wt) + u \tag{14}$$

Our goal is to control the system output x tracking the reference signal x_d, therefore, the problem is to design a controller $u(t)$ satisfying that item $x - x_d$ converges to zero. In other words, the following control system:

$$\ddot{x} = -p\dot{x} - ax + bx^2 - cx^3 + F\cos(wt) + u \tag{15}$$

needs to be stabilized.

Let $x_1 = x_1$, $x_2 = \dot{x}_1 = \dot{x}$, the equation above is equal to

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -px_2 - ax_1 + bx_1^2 - cx_1^3 + F\cos(wt) + u \end{cases}. \tag{16}$$

Let tracking error $e(t) = x(t) - x_d(t)$,

$$g(x, \dot{x}, t) = -p\dot{x} - ax + bx^2 - cx^3 + F\cos(wt) + u,$$

$$\ddot{x} = g(x, \dot{x}, t) + u.$$

$$\delta = (\frac{d}{dt} + \gamma)^{n-1} e(t), \qquad \gamma > 0.$$

then $\dot{\delta} = \ddot{x} - \ddot{x}_d + G(e) = g(x, \dot{x}, t) + u(t) - \ddot{x}_d + G(e)$,

$$G(e) = \sum_{k=1}^{n-1} \frac{(n-1)!\gamma^{n-k}}{(n-k)!(k-1)!} e^{(k)},$$

$$u = -\hat{g} + \ddot{x}_d - \gamma e - \rho\,\mathrm{sgn}(\delta). \tag{17}$$

where ρ is parameter.

$$\mathrm{sgn}(\delta) = \begin{cases} 1, & \delta > 0, \\ 0, & \delta = 0, \\ -1, & \delta < 0, \end{cases} \quad \hat{g}(x, \dot{x}, t) = \frac{\sum_{j=1}^{m} y^j \cdot \prod_{i=1}^{n} \exp[-(\frac{x_i - x_i^j}{\delta_i^j})^2]}{\sum_{j=1}^{m}\prod_{i=1}^{n} \exp[-(\frac{x_i - x_i^j}{\delta_i^j})^2]},$$

which is the Niche T-S fuzzy system proposed in this paper.

In the simulation, let $w = 1.8, F = 2.1, a = -1.1, b = 1, c = 1, p = 0.4$. The following figure is the time-response of x_1, x_2 without control, sees Fig.1 and Fig.2.

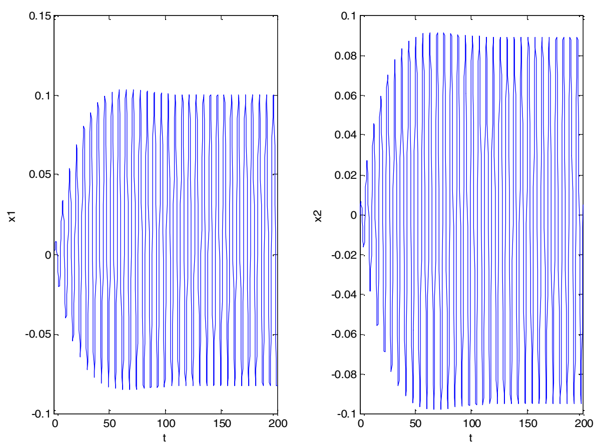

Fig.1. The time-response of state x_1, x_2 of Willis systems.

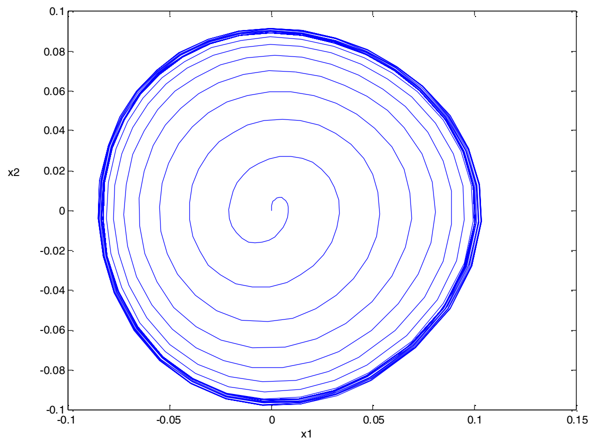

Fig.2. The phrase figure of state x_1, x_2 of Willis systems.

From the simulate Fig.1.and Fig.2, the most part of x_1 and x_2's value is gotten in [-0.1, 0.15]. To the identification fuzzy system $\hat{g}(x,\dot{x},t)$, the linguistic value of two input variant x_1 and x_2 are defined as the following three fuzzy set {NS, ZERO, PS}, respectively, which cover the whole space. The Gauss-type membership function is founded as:

$$\mu_{x_{NS}}(x_i) = \exp[-(\frac{x_i + 0.0375}{0.0625})^2],\ \mu_{x_{ZERO}}(x_i) = \exp[-(\frac{x_i - 0.025}{0.0625})^2],$$

$$\mu_{x_{PS}}(x_i) = \exp[-(\frac{x_i - 0.0875}{0.0625})^2].$$

In the controller design, Niche T-S fuzzy model is applied, back propagation algorithm (10), (11), (12) and (13) are used to optimize the parameters. And the Niche T-S fuzzy system with 9 rules is founded to form $\hat{g}(x,\dot{x},t)$.

$$R^j\text{: if } x_1 \text{ is } X_1^j \text{ and } x_2 \text{ is } X_2^j \text{ then } y^j = a_{j1}x_1 + b_{j1}\Delta x_1 + a_{j2}x_2 + b_{j2}\Delta x_2,\ j = 1,2,\cdots,9$$

Let $x_d = \frac{\pi}{40}\sin(\pi t)$, $\gamma = 0.1$, $\rho = 1.2$, $c = 1$, operate parameters with (11),(12),(13) and (14) we get rules:

Table. Consequent coefficients of the nine Niche T-S fuzzy models describing the Willis systems

a_{j1}	b_{j1}	a_{j2}	b_{j2}
-0.0017	-0.5712	0	0
0.0041	-0.7618	-0.0001	-0.004
-0.7622	-0.0088	0.0022	0
0.0027	0.12834	0.0003	0
0.0062	-0.00122	0.07623	-0.0022
0.5249	-0.0002	0	0.10237
0.02516	0.00264	0.0007	0
-0.0018	0.06383	0.00003	-0.00087
-0.0012	-0.0099	0.0026	0.0027

We get a controller (17) and apply it into Willis system and use Matlab command "ODE45" to simulate the control system with step size 0.001. Fig.3 reflects the figures of Niche T-S fuzzy system's output, tracking goal and tracking error. Fig.4 is the simulation of the uncertain Willis system. It shows that the fuzzy adaptive control scheme is effective in controlling the uncertain Willis system. Theoretical and simulation results have both proven that this control approach is robust and stable.

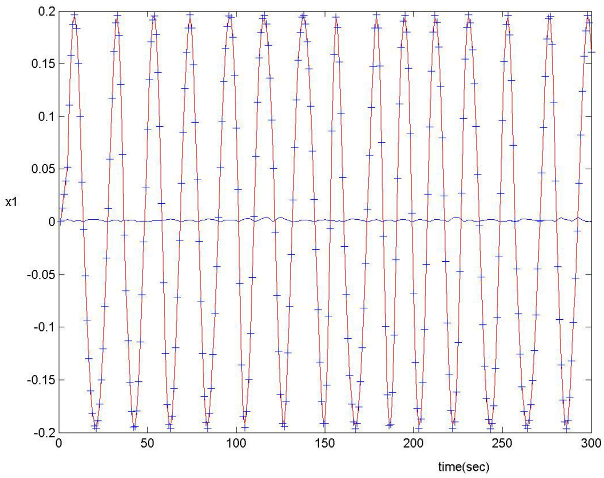

Fig.3. The time-response of state x_1 of Willis systems: the tracking goal ("+"), Niche T-S models (the smooth line) and the tracking error (the middle line)

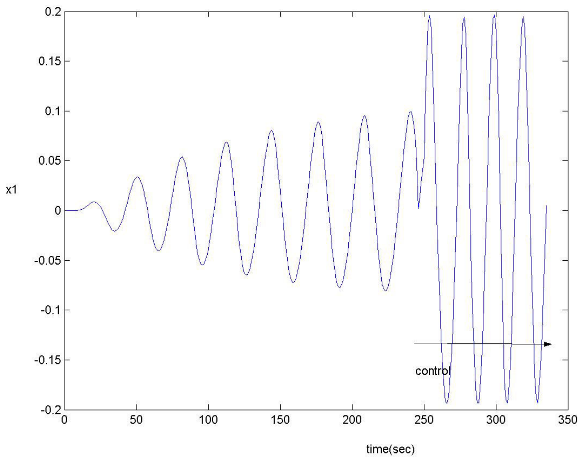

Fig.4. The control figure of state x_1 of Willis systems (the control is realized at t>236)

6. Conclusions

Because biological individual and living environment form an integration of evolving together, namely the biological individual's niche, the adaptation that the bio-system has itself is closely related to niche. This paper incorporates the biological adaptation in the design of the fuzzy control system on the basis of quantitation model of niche, and proposes fuzzy T-S control system based on niche model. To the complicated non-linear systems, the Niche T-S fuzzy system is set up in this paper.

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