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Bionic Fuzzy Sliding Mode Control Based on Switching Control Term Fuzzification

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Abstract: This article introduces the biological adaptation strategies under uncertain boundary circumstance and disturbances into sliding mode control. The trait of this new method is adds biological initiative adaptation to the design of controller. Moreover, we can utilize biological initiative adaptation to design switching-type control term in the sliding mode controller. This way makes the system has initiative adaptation under uncertain boundary circumstance and disturbances. The chattering phenomenon in the sliding mode control is avoided and zero steady tracking error can be ensured which makes the system to achieve the ideal state. The closed-loop system is stable in the sense of Lyapunov. Finally, the simulation results for the circle of inverted-pendulum system are effective and feasible.

Keywords: sliding mode control; fuzzy system; bionic; initiative adaptation

1 Introduction

Sliding mode control method is a kind of good robust control method[1,2]. But in practice application, it will produce chattering phenomenon[3,4]. By introducing fuzzy system in the sliding mode control, A. Shahraz provided the enlightening method of fuzzy sliding mode control. References [5 - 13] used the adaptive fuzzy sliding mode control algorithm to soften the control signal, lighten or avoid the chattering phenomenon in general sliding mode control. However, when observing and cognizing the objectives, fuzzy control cannot reach the really intelligence effect [14], lack of the research on tracking objective function with time varying and specific meaning of the system itself [15]. So, it is needed for the fuzzy control system to constantly improve, perfect and develop toward the direction of adaption, self-organization and self-repairing. Based on the fuzzy logical system, the bionic fuzzy logical systems are proposed [14, 16 - 19]. Based on these studies, the active adaptive strategy of biological individual is introduced in the sliding mode control of a class of uncertain nonlinear systems in this paper. Adjusting the system state through adaptive law not only make the individuals in the system have ability to adapt to environment changing, but also make them develop in a direction conducive to the individual survival. Furthermore, the global stability of the close-loop system is proven by the using of Lyapunov stability theory. At last, the simulation is done to the inverted-pendulum system. Its result shows the proposed method is effective and feasible.

2 Problem description

Consider the following SISO nonlinear system:

$$\begin{cases} x^{(n)} &= 7f(x,t)+g(x,t)u(t)-d(t), \\ y &= x, \end{cases} \tag{1}$$

where, f and g are both unknown nonlinear functions,$X = [x, \dot{x}, \cdots, x^{(n-1)}]^T \in R^n$ is the system's state vector, $u \in R,\ y \in R$, and $d(t)$ is the unknown disturbance.

Suppose that$|f(x,t)| \le F,\ |d(t)| \le D,\ g(x,t) \neq 0,\ g(x,t) > 0$. Define the sliding mode surface as

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$$s(x,t) = -\left(k_1 e + k_2 \dot{e} + \cdots + k_{n-1} e^{(n-2)} + e^{(n-1)}\right) = -K^T e, \tag{2}$$

where $k_1, k_2, \cdots, k_{n-1}$ satisfying Hurwitz Polyomial $p(\lambda) = \lambda^{n-1} + k_{n-1}\lambda^{n-2} + \cdots + k_2\lambda + k_1$.

Let $X_d = [x_d, \dot{x}_d, \cdots, x_d^{(n-1)}]^T$ is the position command signal, so the tracking error is

$$e = X_d - X = [x_d - x, \dot{x}_d - \dot{x}, \cdots, x_d^{(n-1)} - x^{(n-1)}]^T = [e, \dot{e}, \cdots, e^{(n-1)}]^T.$$

Design the sliding mode control as

$$u(t) = \frac{1}{g(X,t)}\left[-f(X,t) + \sum_{i=1}^{n-1} k_i e^{(i)} - d(t) + X_d^{(n)} - u_{sw}\right], \tag{3}$$

where $u_{sw} = \eta sgn(s)$, and

$$sgn(s) = \begin{cases} 1 & , \quad for s > 0 \\ 0 & , \quad for s = 0 \\ -1 & , \quad for s < 0 \end{cases}$$

When f, g and d are unavailable, the control law (3) would be not applicable and the switching item u_{sw} would produce chattering phenomena. Through the fuzzy approximation of the switching item in sliding mode control by applying the adaptive fuzzy control method, the switching item can be turned to be continuous, so the chattering phenomena would be effectively reduced [9]. That is, adopt the conventional fuzzy systems $\hat{f}(X|\theta_f)$, $\hat{g}(X|\theta_g)$ and $\hat{h}(s|\theta_h)$ to approximate $f(X,t)$, $g(X,t)$ and $\eta sgn(s)$.

The lth fuzzy If-Then rule is:

R^l: if x_1 is A_1^l and ... and x_n is A_n^l, then y is B^l,

where $l = 1, 2, \cdots m$, A_1^l and B^l are fuzzy sets.

Using center-average defuzzification, product inference and singleton fuzzifier, it holds that

$$\hat{f}(X|\theta_f) = \hat{\theta}_f^T \xi(X), \quad \hat{g}(X|\theta_g) = \hat{\theta}_g^T \xi(X), \quad \hat{h}(s|\theta_h) = \hat{\theta}_h^T \phi(s),$$

where $\xi(X) = \left[\xi^1(X), \cdots, \xi^m(X)\right]^T$, $\phi(s) = \left[\phi^1(s), \cdots, \phi^m(s)\right]^T$. $\xi^l(X)$, $\phi^l(s)$ are the fuzzy basis functions as

$$\xi^l(X) = \frac{\prod_{i=1}^{n} \mu_{A_I}^l(x_i)}{\sum_{l=1}^{m}\left(\prod_{i=1}^{n} \mu_{A_I}^l(x_i)\right)}, \tag{4}$$

where $\mu_{A_i}^l(x_i)$ is the membership function of x_i.

Then the controller can be expressed as

$$u(t) = \frac{1}{\hat{g}(X|\theta_g)}\left[-\hat{f}(X|\theta_f) + \sum_{i=1}^{n-1} k_i e^{(i)} + X_d^{(n)} - \hat{h}(s|\theta_h^*)\right], \tag{5}$$

where $\hat{h}(s|\theta_h^*) = \eta_\Delta sgn(s)$, $\eta_\Delta = D + \eta$, $\eta \geq 0$, $|d(t)| \leq D$.

Although the fuzzy sliding mode control smoothes the control signals, alleviates and avoids the chattering phenomena of general sliding mode control, it lacks of adaptivity. So, the control system still need to be improved and perfected toward the adaptive, self-organizing, self-learning direction.

3 Fuzzy systems based on the biological adaptation strategies

Due to the redundant structure and the fault-tolerance of ecosystems, the individuals have the ability of initiatively adapting to the environment, always develop in a direction conducive to survival, and coordinate with the environment and the relationship with others step by step. All these behaviors cause the development of the whole system, finally make the system in a state of balance. Therefore, integrating the biological good adaptation strategies into the design of fuzzy control system and constructing fuzzy systems and fuzzy control with biological characteristics has very important theoretical significance and practical application value. Using the "costae, escarole" theory of niche, a fuzzy system with biological characteristics is built and given specific biological meaning.

The lth fuzzy If-Then rule is:

R^l: if x_1 is A_1^l and ... and x_n is A_n^l, and y_1 is B_1^l and ... and y_n is B_n^l, then $f^l = N^l$,

where $l = 1, 2, \cdots m$, A^l and B^l are fuzzy sets. $(x_1, x_2, \cdots, x_n)$ denotes the costae of biological units' niche, $(y_1, y_2, \cdots, y_n)$ denotes the escarole of biological units' niche. The output value f^l denote biological units' niche, expressed as

$$N^l = \frac{x_l + Cy_l}{\sum\limits_{i=1}^{n}(x_i + Cy_i)},$$

C is the dimension conversion coefficient, $N^l \in [0, 1]$.

Each fuzzy rule reflects if a biological individual has a better state and has a better development trend, then the individual has bigger niche.

In order to discuss conveniently and better reflect the biological active adaption, set

$$\theta_1^l = \frac{x_l}{\sum\limits_{i=1}^{n}(x_i + Cy_i)}, \quad \theta_2^l = \frac{y_l}{\sum\limits_{i=1}^{n}(x_i + Cy_i)}.$$

Applying center-average defuzzification, product inference and singleton fuzzifier, adopting the Gauss fuzzy membership function, the fuzzy system based on the biological adaptation strategies can be expressed as the following:

$$f(x) = \frac{\sum\limits_{l=1}^{m} \frac{x_l + Cy_l}{\sum\limits_{i=1}^{n}(x_i + Cy_i)} \cdot \prod\limits_{i=1}^{n} \exp\left[-\left(\frac{x_i - \bar{x}_i^l}{\delta_i}\right)^2\right]}{\sum\limits_{l=1}^{m}\prod\limits_{i=1}^{n} \exp\left[-\left(\frac{x_i - \bar{x}_i^l}{\delta_i}\right)^2\right]} = \theta_1^T \xi(x) + C\theta_2^T \xi(x) = (\theta_1 + C\theta_2)^T \xi(x), \quad (6)$$

where $\theta_1 = (\theta_1^1, \theta_1^2, \cdots, \theta_1^m)^T \in R^{1\times m}$, $\theta_2 = (\theta_2^1, \theta_2^2, \cdots, \theta_2^m)^T \in R^{1\times m}$ denote the biological individual's present state and prospective development trend, respectively. $\xi(x) = (\xi^1(x), \xi^2(x), \cdots, \xi^m(x))^T \in R^{1\times m}$ is the fuzzy basis vector, $\xi^l(x)$ is expressed as (4).

The designed fuzzy system above is called niche T-S fuzzy system, which has following characteristics:

(1) The system has specific biological significance and is integrated by the organism's biological characteristic– initiative adaption;

(2) The structure and expression of this niche T-S fuzzy system are same as the regular T-S fuzzy system. So, it has the same universal approximation as the regular one.

(3) The consequent of the niche T-S fuzzy system is a Type-1 T-S fuzzy system, which can be designed by the using of the existing fuzzy system. So the calculation is more simple.

4 Bionic fuzzy sliding mode control design

For making the system (1) can initiatively adapt to the environment, using the fuzzy design based on the biological adaption strategies[19], $f(X,t)$, $g(X,t)$ and $\eta sgn(s)$are substituted by$\hat{f}(X\,|\theta_f\,)$, $\hat{g}(X\,|\theta_g\,)$ and $\hat{h}(s\,|\theta_h\,)$. Then

$$\hat{f}(X\,|\theta_f\,) = (\theta_{1f} + C\theta_{2f})^T \xi(X) \triangleq \hat{f}(X,t),$$

$$\hat{g}(X\,|\theta_g\,) = (\theta_{1g} + C\theta_{2g})^T \xi(X) \triangleq \hat{g}(X,t),$$

$$\hat{h}(s\,|\theta_h\,) = (\theta_{1h} + C\theta_{2h})^T \phi(s) \triangleq \hat{h}(s),$$

where $\xi(X) = \left[\xi^1(X), \xi^2(X), \cdots, \xi^m(X)\right]^T$, $\phi(s) = \left[\phi^1(s), \phi^2(s), \cdots, \phi^m(s)\right]^T$, $\xi^l(X)$ and $\phi^l(s)$ are the fuzzy basis function expressed as (4). Let$\theta_f = \theta_{1f} + C\theta_{2f}$, $\theta_g = \theta_{1g} + C\theta_{2g}$, $\theta_h = \theta_{1h} + C\theta_{2h}$ are adjustable vectors.

The controller is

$$u(t) = \frac{1}{\hat{g}(X,t)}\left[-\hat{f}(X,t) + \sum_{i=1}^{n-1} k_i e^{(i)} + X_d^{(n)} - \hat{h}(s)\right]. \tag{7}$$

The adaptive laws are designed as:

$$\dot{\theta}_f = \dot{\theta}_{1f} + C\dot{\theta}_{2f} = r_1 s(1 + C^2)\xi(X), \tag{8}$$

$$\dot{\theta}_g = \dot{\theta}_{1g} + C\dot{\theta}_{2g} = r_2 s(1 + C^2)\xi(X)u(t), \tag{9}$$

$$\dot{\theta}_h = \dot{\theta}_{1h} + C\dot{\theta}_{2h} = r_3 s(1 + C^2)\phi(s), \tag{10}$$

where $\dot{\theta}_{1f} = r_1 s\xi(X)$,$\dot{\theta}_{2f} = Cr_1 s\xi(X)$, $\dot{\theta}_{1g} = r_2 s\xi(X)u(t)$, $\dot{\theta}_{2g} = Cr_2 s\xi(X)u(t)$, $\dot{\theta}_{1h} = r_3 s\phi(s)$, $\dot{\theta}_{2h} = Cr_3 s\phi(s)$, r_1, r_2, r_3 are the designed parameters.

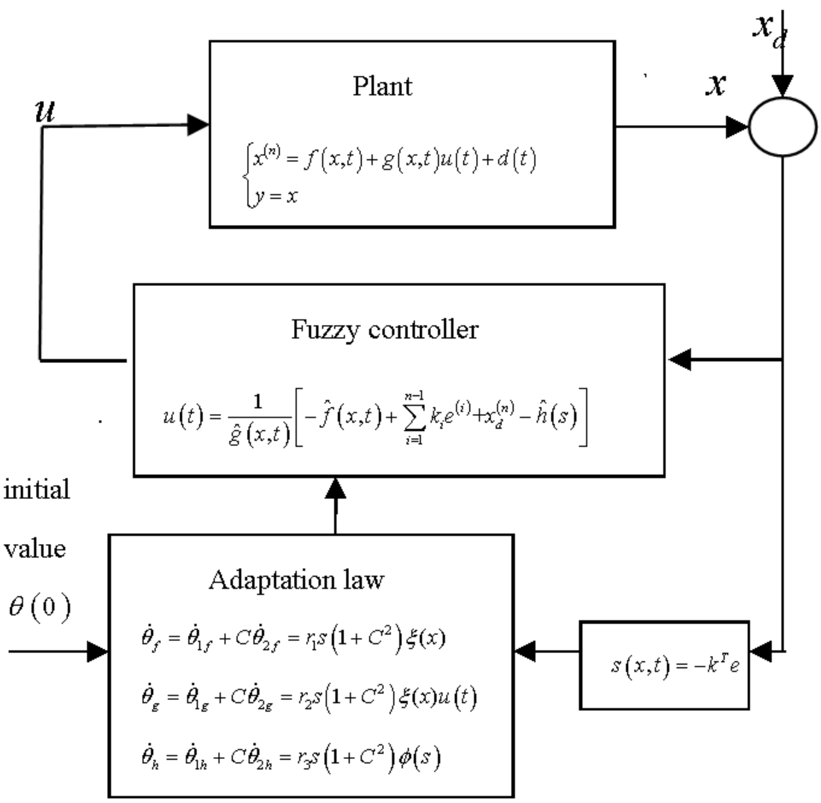

Figure 1: System control block diagram

Notes:

(1) θ_{1f}, θ_{1g} and θ_{1h} denote the system's present states, θ_{2f}, θ_{2g} and θ_{2h} denote the system's prospective development trend.

(2) The adaptive laws $\dot{\theta}_{1f}$, $\dot{\theta}_{1g}$ and $\dot{\theta}_{1h}$ adjust the system state according to the variation of the system error e, which embodies the system adaption to the environment changes.

(3) The adaptive laws $\dot{\theta}_{2f}$, $\dot{\theta}_{2g}$ and $\dot{\theta}_{2h}$ adjust the system development trend according to the variation of the system error e, which embodies the system ability to exploit and utilize environment.

(4) Through the adjustment of $\dot{\theta}_{1f}$, $\dot{\theta}_{2f}$, $\dot{\theta}_{1g}$, $\dot{\theta}_{2g}$ and $\dot{\theta}_{1h}$, $\dot{\theta}_{2h}$, the changing of $\dot{\theta}_f = \dot{\theta}_{1f} + C\dot{\theta}_{2f}$, $\dot{\theta}_g = \dot{\theta}_{1g} + C\dot{\theta}_{2g}$ and $\dot{\theta}_h = \dot{\theta}_{1h} + C\dot{\theta}_{2h}$ reflect the system adaption strategies to the extra environment and various disturbances are initiative.

5 System stability

Theorem 1 *Consider the control problem of the nonlinear system (1). Apply controller (7), adopt the parameter adaptive laws (8), (9) and (10), then the closed-loop system signals will be uniformly ultimate bounded and the tracking error will converge to zero asymptotically.*

Proof. Define the optimal parameters as:

$$\theta_{1f}^{*} = \arg\min_{\theta_{1f}\in\Omega_{1f}}\left[\sup_{x\in R^Q}\left|\hat{f}(X\,|\theta_f\,) - f(X,t)\right|\right],\quad \theta_{2f}^{*} = \arg\min_{\theta_{2f}\in\Omega_{2f}}\left[\sup_{x\in R^Q}\left|\hat{f}(X\,|\theta_f\,) - f(X,t)\right|\right],$$

$$\theta_{1g}^{*} = \arg\min_{\theta_{1g}\in\Omega_{1g}}\left[\sup_{x\in R^Q}\left|\hat{g}(X\,|\theta_g\,) - g(X,t)\right|\right],\quad \theta_{2g}^{*} = \arg\min_{\theta_{2g}\in\Omega_{2g}}\left[\sup_{x\in R^Q}\left|\hat{g}(X\,|\theta_g\,) - g(X,t)\right|\right],$$

$$\theta_{1h}^{*} = \arg\min_{\theta_{1h}\in\Omega_{1h}}\left[\sup_{x\in R^Q}\left|\hat{h}(s\,|\theta_h\,) - u_{sw}\right|\right],\quad \theta_{2h}^{*} = \arg\min_{\theta_{2h}\in\Omega_{2h}}\left[\sup_{x\in R^Q}\left|\hat{h}(s\,|\theta_h\,) - u_{sw}\right|\right],$$

where Ω_{1f}, Ω_{2f}, Ω_{1g}, Ω_{2g} and Ω_{1h}, $\Omega_{2h}$are the constraint sets of θ_{1f}, θ_{2f}, θ_{1g}, θ_{2g} and θ_{1h}, θ_{2h}. Let $\theta_f^* = \theta_{1f}^* + C\theta_{2f}^*$, $\theta_g^* = \theta_{1g}^* + C\theta_{2g}^*$,$\theta_h^* = \theta_{1h}^* + C\theta_{2h}^*$, and define the minimum approximation error as

$$w = [f(X,t) - \hat{f}(X\,|\theta_f^*\,)] + [g(X,t) - \hat{g}(X\,|\theta_g^*\,)]\,u, \tag{11}$$

where $|w| \le w_{\max}$, then

$$\begin{aligned}\dot{s} &= -\sum_{i=1}^{n} k_i e^{(i)} = -\sum_{i=1}^{n-1} k_i e^{(i)} + X^{(n)} - X_d^{(n)}\\ &= -\sum_{i=1}^{n-1} k_i e^{(i)} + f(X,t) + \hat{g}(X,t)u(t) + [g(X,t) - \hat{g}(X,t)]u(t) + d(t) - X_d^{(n)}\\ &= \varphi_{1f}^T\xi(X) + C\varphi_{2f}^T\xi(X) + \varphi_{1g}^T\xi(X)u(t) + C\varphi_{2g}^T\xi(X)u(t) + \varphi_{1h}^T\phi(s) + C\varphi_{2h}^T\phi(s) + d(t) + w - h(s\,|\theta_h^*\,)\end{aligned} \tag{12}$$

where $k_n = 1$, $\varphi_{1f} = \theta_{1f}^* - \theta_{1f}$, $\varphi_{2f} = \theta_{2f}^* - \theta_{2f}$, $\varphi_{1g} = \theta_{1g}^* - \theta_{1g}$, $\varphi_{2g} = \theta_{2g}^* - \theta_{2g}$, $\varphi_{1h} = \theta_{1h}^* - \theta_{1h}$, $\varphi_{2h} = \theta_{2h}^* - \theta_{2h}$.

Define Lyapunov function as

$$V = \frac{1}{2}s^2 + \frac{1}{2r_1}\varphi_{1f}^T\varphi_{1f} + \frac{1}{2r_1}\varphi_{2f}^T\varphi_{2f} + \frac{1}{2r_2}\varphi_{1g}^T\varphi_{1g} + \frac{1}{2r_2}\varphi_{2g}^T\varphi_{2g} + \frac{1}{2r_3}\varphi_{1h}^T\varphi_{1h} + \frac{1}{2r_3}\varphi_{2h}^T\varphi_{2h} \tag{13}$$

where r_1, r_2 and r_3 are positive constants, it follows that

$$\begin{aligned}\dot{V} &= s\dot{s} + \tfrac{1}{r_1}\varphi_{1f}^T\dot{\varphi}_{1f} + \tfrac{1}{r_1}\varphi_{2f}^T\dot{\varphi}_{2f} + \tfrac{1}{r_2}\varphi_{1g}^T\dot{\varphi}_{1g} + \tfrac{1}{r_2}\varphi_{2g}^T\dot{\varphi}_{2g} + \tfrac{1}{r_3}\varphi_{1h}^T\dot{\varphi}_{1h} + \tfrac{1}{r_3}\varphi_{2h}^T\dot{\varphi}_{2h}\\ &= \tfrac{1}{r_1}\varphi_{1f}^T[r_1 s\xi(X) + \dot{\varphi}_{1f}] + \tfrac{1}{r_1}\varphi_{2f}^T[Cr_1 s\xi(X) + \dot{\varphi}_{2f}] + \tfrac{1}{r_2}\varphi_{1g}^T[r_2 s\xi(X)u(t) + \dot{\varphi}_{1g}]\\ &\quad + \tfrac{1}{r_2}\varphi_{2g}^T[Cr_2 s\xi(X)u(t) + \dot{\varphi}_{2g}] + \tfrac{1}{r_3}\varphi_{1h}^T[r_3 s\phi(s) + \dot{\varphi}_{1h}] + \tfrac{1}{r_3}\varphi_{2h}^T[Cr_3 s\phi(s) + \dot{\varphi}_{2h}]\\ &\quad + sd(t) + sw - s(D+\eta)sgn(s)\end{aligned} \tag{14}$$

where

$$\dot{\varphi}_{1f} = -\dot{\theta}_{1f},\quad \dot{\varphi}_{2f} = -\dot{\theta}_{2f},\quad \dot{\varphi}_{1g} = -\dot{\theta}_{1g},\quad \dot{\varphi}_{2g} = -\dot{\theta}_{2g},\quad \dot{\varphi}_{1h} = -\dot{\theta}_{1h},\quad \dot{\varphi}_{2h} = -\dot{\theta}_{2h}. \tag{15}$$

Introducing (8), (9), (10) and (15) in (14) leads to

$$\dot{V} = sd(t) + sw - s(D+\eta)sgn(s) \le sw - \eta\,|s| \tag{16}$$

According to the fuzzy approximation theorem, the fuzzy system based on biological adaption strategies can realize the approximation error w should be very small. So, we can state that all the signals in this system are uniformly ultimately bounded. For $s = -ke$, the boundedness of $e(0)$ ensures the the boundedness of $e(t)$. Obviously, the boundedness of the command signal $X_d(t)$ leads to the boundedness of $X_d(t)$. In order to complete the theorem proving and get the result $\lim_{t\to\infty}|e(t)| = 0$, we only need to prove $\lim_{t\to\infty}|s(t)| = 0$. Suppose that $|s| = \eta_s$, (16) becomes

$$\dot{V} \leq |s|\,|w| - \eta\,|s| \leq -\eta\,|s| + \eta_s\,|w| \tag{17}$$

Integrating (17) over $[0,t]$, it follows that

$$\int_0^t |s(t)|\,dt \leq \frac{1}{\eta}\left[|V(0)| + |V(t)|\right] + \frac{\eta_s}{\eta}\int_0^t |w|\,dt \tag{18}$$

If $w \in L_1$, one can get $s \in L_1$ from (18). And from (17), it knows that s is bounded, so $s \in L_\infty$. According to (12), it also can hold that $\dot{s} \in L_\infty$. Applying the Barbalat Lemma (if $s \in L_\infty$, $\dot{s} \in L_\infty$ and $s \in L_p$, $p \in [1,\infty]$, then $\lim_{t\to\infty} |s(t)| = 0$), we get the result $\lim_{t\to\infty} |s(t)| = 0$, so $\lim_{t\to\infty} |e(t)| = 0$.

This completes the proof.

6 Simulation example

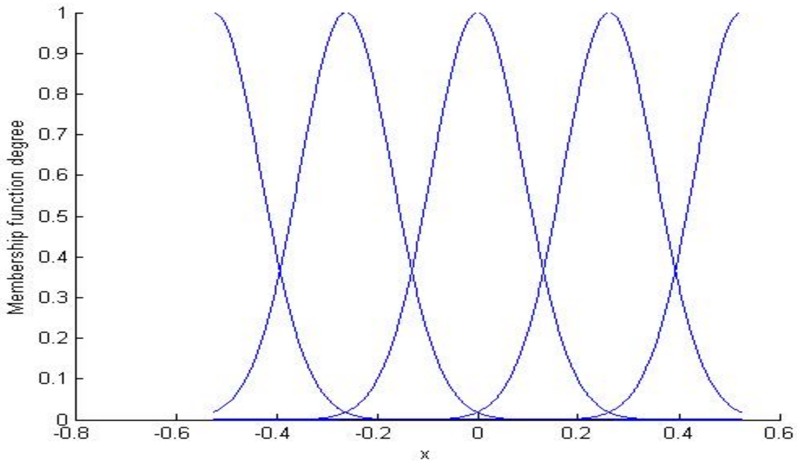

Figure 2: Membership function of x_i

Consider the benchmark control problem of the inverted pendulum as the following dynamics

$$\begin{cases} \dot{x}_1 = x_2, \\ \dot{x}_2 = \frac{g\sin x_1 - mlx_2^2\cos x_1\sin x_1/(m_c+m)}{l[4/3 - m\cos^2 x_1/(m_c+m)]} + \frac{\cos x_1/(m_c+m)}{l[4/3 - m\cos^2 x_1/(m_c+m)]}u + d(t), \end{cases}$$

where x_1 and x_2 are swinging angle and swinging velocity of the pole, respectively. $g = 9.8m/s^2$ is the acceleration due to gravity. m_c is the mass of the cart, $m_c = 1kg$. m is the mass of the pole, $m = 0.1kg$; l is half-length of the pole, $l = 0.5m$. $u$is the input of the control. $d(t)$ is the external disturbance, $d(t) = 0.1\sin(t)$. $X_d(t) = 0.1\sin(\pi t)$ is the inference signal. the switching function is $s = -k_1 e - \dot{e}$, $k_1 = 1$.

Adopt the following fuzzy membership functions

$\mu_{NM}(x_i) = \exp\left[-\left(\frac{x_i+\pi/6}{\pi/24}\right)^2\right]$, $\mu_{NS}(x_i) = \exp\left[-\left(\frac{x_i+\pi/12}{\pi/24}\right)^2\right]$, $\mu_{ZO}(x_i) = \exp\left[-\left(\frac{x_i}{\pi/24}\right)^2\right]$,

$\mu_{PS}(x_i) = \exp\left[-\left(\frac{x_i-\pi/12}{\pi/24}\right)^2\right]$, $\mu_{PM}(x_i) = \exp\left[-\left(\frac{x_i-\pi/6}{\pi/24}\right)^2\right]$.

Define the membership function of $s(t)$

$$\mu_{NM}(s) = \frac{1}{1+\exp(5(s+3))}, \quad \mu_{ZO}(s) = \exp(-s^2), \quad \mu_{PM}(s) = \frac{1}{1+\exp(5(s-3))}.$$

Let the initial values of the consequent parameters θ_f^T, θ_g^T and θ_h^T are all 0.10. The initial state of the inverted pendulum is $[\pi/60, 0]$. The adaption parameters is set as $r_1 = 5$, $r_2 = 1$, $r_3 = 10$. The simulation results are shown in the following figures (see fig. 2-4).

Using the above 5 membership function to fuzzifier, there are 25 rules used to approximate f and g. The membership function of x_i is shown as fig.2.

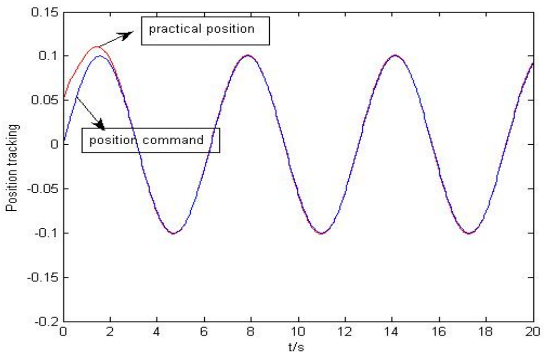

Figure 3: Position tracking with disturbance under the traditional fuzzy sliding mode control, red line denotes the system output and blue line denotes the expected output

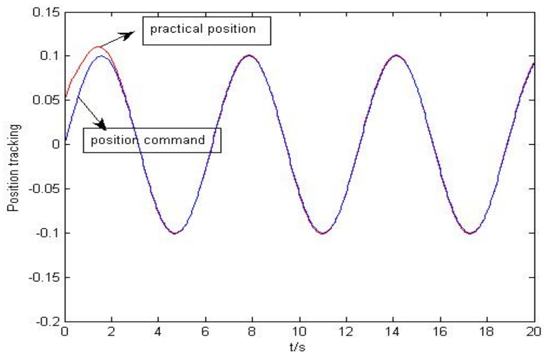

Figure 4: Position tracking with disturbance under the bionic fuzzy sliding mode control, red line denotes the system output and blue line denotes the expected output

By comparing Fig.3 and Fig.4, it can be seen that the tracking performance in Fig.4 is better. It indicate that the bionic controller has better resistance to the external disturbance. This controller can realize the synchronization of the state variables and the given inference signals under the external disturbance. This shows that the biological adaptation strategies not only has the adaptive ability, but also has the ability of initiative developing and using the environment.

7 Conclusion

To a class of nonlinear system with uncertainties, a fuzzy sliding mode control method integrated with biological adaption strategies is proposed in this article. Design controller by the using of the initiative adaptive strategy of biological individual. Achieve the continuty of the switching item through the fuzzy approximation. Thus, the system has the ability of initiative adaption to the changing external environment and disturbances, so avoid the chattering phenomenon and delete the system error. Adjusting the system state through adaptive law not only make the individuals in the system. This method can be applied in the practical engineering, such as Motor and power system control, robot control, aircraft control, etc..

Acknowledgments

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