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FUZZY DIRECT ADAPTIVE SLIDING MODE DECENTRALIZED CONTROL FOR INTERCONNECTED SYSTEMS

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Abstract: Fuzzy direct adaptive sliding mode controller is designed to realize the decentralized control for a class of nonlinear interconnected large-scale systems with unknown functions. It uses the methods of fuzzy adaptive control, fuzzy logic approximation and fuzzy sliding mode control to approximate the ideal controller. Through the adaptive process of a parameter, the affection of interconnected terms on the subsystems is counteracted. The fuzzy sliding mode control is introduced to attenuate the fuzzy approximation errors. Simultaneity, the close-loop system is stable in Lyapunov sense and the tracking error converges to a neighbourhood of zero. *Copyright © 2002 IFAC*

Keywords: fuzzy direct adaptive control; sliding-mode control; interconnected system; large-scale systems

1. INTRODUCTION[1]

Fuzzy direct adaptive control (FDAC) is referred that the fuzzy logic system in the controller is used as controller (Wang, 1994). This kind of fuzzy direct adaptive controller can directly utilize the fuzzy control rules, but not the fuzzy description information. For the fuzzy adaptive control of nonlinear unknown dynamic systems, fuzzy direct adaptive control arises as much attentions of scholars as the indirect one (Tong, and Chai, 1996, Wang, 1993, Moore and Harris, 1991). Most of these results are about the systems without interconnections (i.e., common large-scale system). But for the interconnected systems, there are few results. Furthermore, the centralized control is not easy to realize for this kind of systems because of their high-dimensions. How to design a decentralized controller such that it can guarantee the close-loop system globally stable while the interconnections satisfy certain constraint conditions?

In this paper, this kind of direct adaptive controller is designed. For the high-dimensions of it, the second kind of FDAC (Wang, 1994) is adopted. Section 2 introduces the system model, control objective, some assumptions and the specific form of the controller. The main result and its proof for stability are given in section 3. Section 4 draws a conclusion for the whole paper. The result of this paper can be applies to the two- inverted pendulum system, and the emulation result is ideal. But here we omit it.

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2. PROBLEM STATEMENT AND CONTROLLERS DESIGN

2.1 System description and control objective

Consider the nonlinear interconnected system with N subsystems:

$$y_i^{(n_i)} = a_i(x_i) + b_i(x_i)u_i + d_i(X,t) \qquad i = 1,2,\cdots,N \tag{1}$$

where $x_i = (y_i, \dot{y}_i, \cdots, y_i^{(n_i-1)}) \in R^{n_i}$ is the state vector of the ith subsystem $\sum_i$, u_i is the input, y_i is output. $a_i(x_i)$, $b_i(x_i)$ are the unknown dynamic (i.e., unknown functions). $d_i(X,t) \in R$ is the interconnection between the subsystems. They are all smooth functions, and $X = (x_1, \cdots, x_N)$.

Control objective:

Design direct adaptive fuzzy controller $u_i(x_i \mid \theta_i)$, in the case that there exist the unknown dynamics not only of the subsystems, but also of the interconnections. The controller should satisfy:
(1)The system is stable in Lyapunov sense, i.e., all the variables are bounded.
(2)The tracking error of each subsystem converges to zero or a neighborhood of zero asymptotically.

Assumption 1: (i) $|a_i(x_i)| \le M_{i0}(x_i)$

(ii) $c_i < M_{i1}(x_i) \le b_i(x_i) \le M_{i2}(x_i)$

(iii) $|(b_i^{-1})'| = |\Delta b_i^{-1}(x_i)\dot{x}_i| \le M_{i3}(x_i)$

(iv) $|d_i(X,t)| \le \sum_{k=0}^{p}\sum_{j=1}^{N} a_{ijk}\|x_j\|^k$

Where $M_{ij}(x_i)$ is a known function, c_i is a known constant. a_{ijk} is an unknown nonnegative constant obtained through adaptive process.

Let y_{im} as the reference output. Assume $y_{im}, \dot{y}_{im}, \cdots, y_{im}^{(n_i)}$ are all bounded and measurable. Then denote $x_{im} = (y_{im}, \dot{y}_{im}, \cdots, y_{im}^{(n_i-1)})$. And define the tracking error of subsystem $\sum_i$ as $e_i = y_{im} - y_i$. Let $K_i = (1, k_{i(n_i-1)}, \cdots, k_{i1})^T$. The selecting of K_i satisfies Hurwitz polynomial: $\hat{L}_i(s) = p^{(n_i-1)} + k_{i(n_i-1)}p^{(n_i-2)} + \cdots + k_{i1}$, which roots will lie in the open left half-plane.

Define the sliding hyper planes $s_i(t)$ as:

$$s_i(t) = k_{i1}e_i + k_{i2}\dot{e}_i + \cdots + k_{i(n_i-1)}e_i^{(n_i-2)} + e_i^{(n_i-1)} \tag{2}$$

If $a_i(x_i), b_i(x_i)$ and $d_i \ne 0$ are known, the ideal controller can be designed as following:

$$u_i^* = \frac{1}{b_i(x_i)}[-a_i(x_i) + \eta_i s_{i\Delta}(t) + \dot{s}_i(t) + y_{im}^{(n_i)} - e_i^{(n_i)}] \qquad \eta_i > 0 \tag{3}$$

Where $s_{i\Delta} = s_i - \phi_i sat(s_i/\phi_i)$ is the distance between the state and the border layer. $\eta_i > 0$ is a constant . $\phi_i \ge 0$ is the width of the border layer.

Here, $s_{i\Delta}$ possess the following properties:
1)if $|s_i| > \phi_i$, then $|s_{i\Delta}| = |s_i| - \phi_i$, and $\dot{s}_{i\Delta} = \dot{s}_i$
2)if $|s_i| \le \phi_i$, then $\dot{s}_{i\Delta} = \dot{s}_i = 0$

$sat(\cdot)$ is the saturation function which is defined as follows:

$$sat(x) = \begin{cases} -1 & for \quad x < -1 \\ x & for \quad |x| \le 1 \\ 1 & for \quad x > 1 \end{cases}$$

Substiting (3) into (1), it can be obtained that:

$$\dot{s}_i(t) + \eta_i s_{i\Delta}(t) = 0$$

When $t \to \infty$, there's $s_{i\Delta}(t) \to 0$, furthermore $e_i(t) \to 0$. However, in this paper $a_i(x_i), b_i(x_i)$ and $d_i \ne 0$ are unknown, thus the ideal controller u_i^* can't be realized. Then we utilize fuzzy logic system to approximate the ideal controller u_i^*.

Define bounded close-set A_{id}, A_i as following:

$$A_{id} = \{x_i \mid \|x_i - x_{i0}\|_{p,\pi} \le 1\},$$

$$A_i = \{x_i \mid \|x_i - x_{i0}\|_{p,\pi} \le 1 + \psi_i\}$$

$$\|x_i\|_{p,\pi} = \{\sum_{i=1}^{n_i}(\frac{|x_{i,n_i}|}{\pi_i})^p\}^{1/p}$$

ψ_i is the width of the transition area, x_{i0} is a fixed point in R^{n_i}. $\|x_i\|_{p,\pi}$ is a kind of P-norm, $\{\pi_i\}_{i=1}^n$ is the given power weight. For the given $\varepsilon_i > 0$, based on the approximation theory, there exists fuzzy logic system $u_i(x_i \mid \theta_i) = \theta_i^T \xi_i(x_i)$ such that for $\forall x_i \in A_i$, there's

$$|u_i^* - u_i(x_i \mid \theta_i)| \le \varepsilon_i \tag{4}$$

2.2 Controllers design

Design the decentralized fuzzy controller as:

$$u_i = (1 - m_i(t))u_{adi} - m_i(t)k_{1i}(s_i,t)u_{fsi} - k_{2i}(s_i,t)u_{fsi} \tag{5}$$

where $u_{adi} = u_i(x_i \mid \hat{\theta}_i) - \hat{\varepsilon}_i u_{fsi}$ is the adaptive part, u_{fsi} is the fuzzy sliding mode controller, $k_{1i}(s_i,t) > 0$, $k_{2i}(s_i,t) > 0$, $m_i(t)$ is a mode transformation function, and $0 \le m_i(t) \le 1$, it is defined as:

$$m_i(t) = \max\{0, sat(\frac{\|x_i - x_{i0}\|_{p,\pi} - 1}{\psi_i})\}$$

Thus, if $x_i \in A_{id}$, then $m_i(t) = 0$, i.e., the adaptive part u_{adi} takes effect. Else if $x_i \in A_i^c$, then $m_i(t) = 1$, i.e., the u_{adi} part is closed and fuzzy sliding mode controller u_{fsi} takes effect. When $x_i \in A_{id}^c \bigcap A_i$ holds, $0 < m_i(t) < 1$, the adaptive control and sliding mode control take actions simultaneously. It's clear that the mode transformation function $m_i(t)$ can keep the states of the system changing in a bounded close set.

Suppose that the fuzzy linguistic description rules of the unknown function $u_i(x_i)$ is as following form:

$R_i^{(l)}$: if x_{i1} is $F_{i1}^{(l)}$ and x_{i2} is $F_{i2}^{(l)}$, and $,\cdots,$ and x_{in} is $F_{in}^{(l)}$, then $u_i(x_i)$ is C_i^l .

Where F_{ik}^l, C_i^l and ($i=\{1,\cdots,N\}$, $k=\{1,\cdots,n\}$, $l=\{1,\cdots,p\}$) are the fuzzy set on R , their membership functions are chosen as Gaussian's form, i.e.,

$$u_i(x_i \mid \theta_i)=\frac{\sum_{l=1}^{p}\bar{y}_i^l(\prod_{j=1}^{n}\exp[-(\frac{x_{i,j}-\bar{x}_{i,j}^l}{\sigma_{i,j}^l})^2])}{\sum_{l=1}^{p}(\prod_{j=1}^{n}\exp[-(\frac{x_{i,j}-\bar{x}_{i,j}^l}{\sigma_{i,j}^l})^2])} \quad (6)$$

Where θ_i represents the set of the adjustable parameters $\bar{y}_i^l, \bar{x}_{i,j}^l$ and $\sigma_{i,j}^l$.

Using the Taylor formula yields:

$$u_i(x_i \mid \theta_i)-u_i(x_i \mid \hat{\theta}_i)$$
$$=\Phi_i^T(\frac{\partial u_i(x_i \mid \hat{\theta}_i)}{\partial \hat{\theta}_i})+O(|\Phi_i|^2)$$

Where $\Phi_i=\theta_i-\hat{\theta}_i$

Design the fuzzy sliding mode controller u_{fsi} as following (Tong and Chai, 1996):

First, define the linguistic description of s_i and u_{fsi} as following:

$$T(s_i)=\{NB,NM,ZR,PM,PB\}$$
$$=\{C_{1i},C_{2i},C_{3i},C_{4i},C_{5i}\}$$
$$T(u_{fsi})=\{NB,NM,ZR,PM,PB\}$$
$$=\{F_{1i},F_{2i},F_{3i},F_{4i},F_{5i}\}$$

Where " NB ", " NM ", " ZR ", " PM ", " PB " are labels of fuzzy sets, which express "negative big", "negative medium", "zero", "positive medium" and "positive big", respectively. They are taken to be triangle-shaped fuzzy sets: their membership functions are depicted in Fig 1.

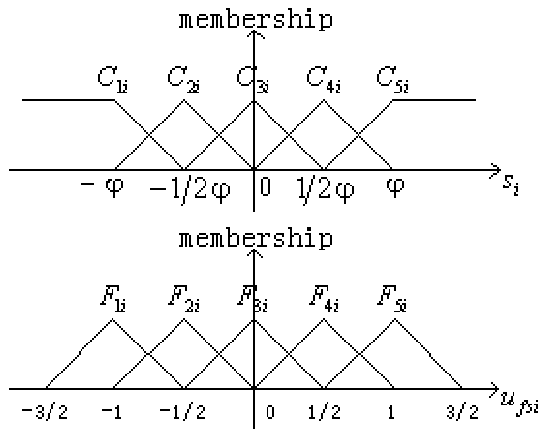

Fig 1 fuzzy membership function

Using intuitive inference, the fuzzy relationship between the tracking error s_i and the fuzzy controller u_{fsi} can be built as:

R_{ji} : if s_i is C_{ji} , then u_{fsi} is $F_{6-j,i}$

($j=1,\cdots,5$)

From the jth rule, it can be obtained that the fuzzy relation is

$$R_{ji}(s_i,u_{fsi})=C_{ji}(s_i)\bigcap F_{6-j,i}(u_{fsi})$$

Therefore, the total fuzzy relation is:

$$R_i=\bigcup_{j=1}^{5}R_{ji}$$

i.e., $$R_{ji}(s_i,u_{fsi})=\bigcup_{j=1}^{5}[C_{ji}(s_i)\bigcap F_{6-j,i}(u_{fsi})]$$

For a given input fuzzy set C_i , the output fuzzy set F_i can be calculated by singleton, max-min fuzzy reasoning:

$$F_i(u_{fsi})=\bigcup_{j=1}^{5}[C_{ji}(s_i)\bigcap F_{6-j,i}(u_{fsi})]$$

Using center-average deffuzzifier, the specific control output is:

$$u_{fsi}=\frac{\int_{-3/2}^{3/2}u_{fsi}F_i(u_{fsi})du_{fsi}}{\int_{-3/2}^{3/2}F_i(u_{fsi})du_{fsi}}$$

It's mathematical expression was derived (Kim, 1995) as follows:

$$u_{fsi}=\begin{cases}1 & x_i<-1\\ \frac{(2x_i+3)(3x_i+1)}{2(4x_i^2+6x_i+1)} & -1\le x_i<-0.5\\ \frac{x_i(2x_i+1)}{2(4x_i^2+2x_i-1)} & -0.5\le x_i<0\\ -\frac{x_i(2x_i-1)}{2(4x_i^2-2x_i-1)} & 0\le x_i<0.5\\ -\frac{(2x_i-3)(3x_i-1)}{2(4x_i^2-6x_i+1)} & 0.5\le x_i<1\\ -1 & x_i\ge 1\end{cases}$$

Where $x_i=\frac{s_i}{\phi_i}$, when $|s_i|\ge\phi_i$, it is easy to check $u_{fsi}=-\operatorname{sgn}(s_i(t))$.

From (3) and (5), the following can be obtained:

$$\dot{s}_i(t)+\eta_i s_{i\Delta}(t)=b_i(x_i)[u_i^*-u_i]-d_i(x_i,t)$$
$$=b_i(1-m_i(t))[u_i^*-u_i(x_i \mid \hat{\theta}_i)+\hat{\varepsilon}_i u_{fsi}]$$
$$+m_i b_i[u_i^*+k_{1i}u_{fsi}]+b_i k_{2i}u_{fsi}-d_i$$

$$
\begin{aligned}
&= b_i(1-m_i(t))[\Phi_i^T \frac{\partial \hat{u}_i}{\partial \hat{\theta}_i} + O(\|\Phi_i\|^2)] \\
&+ b_i k_{2i} u_{fsi} - d_i \\
&+ b_i(1-m_i(t))[u_i^* - u_i(x_i \mid \theta_i) \\
&+ \hat{\varepsilon}_i u_{fsi}] + m_i b_i [u_i^* + k_{1i} u_{fsi}] \qquad (7)
\end{aligned}
$$

Assumption 2 $O(\|\Phi_i\|^2) \le M_{i4}(x_i)$

Here choose

$$
\begin{aligned}
k_{1i}(s_i,t) &= \frac{1}{M_{i1}(x_i)}[M_{i0}(x_i) - M_{i4} \\
&+ \left|\eta_i s_{i\Delta}(t) + s_i(t) - e_i^{(n_i)} + y_{im}^{(n_i)}\right|] \qquad (8a)
\end{aligned}
$$

$$
\begin{aligned}
k_{2i}(s_i,t) &= \frac{1}{M_{i1}(x_i)} \sum_{k=0}^{p} \sum_{j=1}^{N} \hat{a}_{ijk} \|x_i\|^k \\
&+ \frac{M_{i3}|s_{i\Delta}(t)|}{2M_{i1}^2(x_i)} + M_{i4} \qquad (8b)
\end{aligned}
$$

Adopt the parameters adaptive laws as:

When $\hat{\sigma}_{i,j}^{l} = \sigma$, adopt

$$
\dot{\hat{\sigma}}_{i,j}^{l} = \begin{cases} -\eta_{i1}(1-m_i(t)) s_{i\Delta} \dfrac{\partial \hat{u}_i}{\partial \hat{\sigma}_{i,j}} \\ \cdots if \ \eta_{i1}(1-m_i(t)) s_{i\Delta} \dfrac{\partial \hat{u}_i}{\partial \hat{\sigma}_{i,j}} < 0 \\ 0 \\ \cdots if \ \eta_{i1}(1-m_i(t)) s_{i\Delta} \dfrac{\partial \hat{u}_i}{\partial \hat{\sigma}_{i,j}} \ge 0 \end{cases} \qquad (9)
$$

$$
\dot{\hat{\theta}}_i = \begin{cases} -\eta_{i1}(1-m_i(t)) s_{i\Delta} \dfrac{\partial \hat{u}_i}{\partial \hat{\theta}_i} \cdots if \ |\theta_i| < M_\theta \\ or (|\theta_i| = M_\theta \ and \ s_{i\Delta}\theta_i^T \dfrac{\partial \hat{u}_i}{\partial \hat{\theta}_i} \ge 0) \\ P_1\{-\eta_{i1}(1-m_i(t)) s_{i\Delta} \dfrac{\partial \hat{u}_i}{\partial \hat{\theta}_i}\} \cdots\cdots \\ \cdots if \ |\theta_i| = M_\theta \ and \ s_{i\Delta}\theta_i^T \dfrac{\partial \hat{u}_i}{\partial \hat{\theta}_i} < 0 \end{cases} \qquad (10)
$$

Where the projection $P_1\{*\}$ is defined as:

$$
\begin{aligned}
&P_1\{-\eta_{1i}(1-m_i(t)) s_{i\Delta} \frac{\partial \hat{u}_i}{\partial \hat{\theta}_i}\} \\
&= -\eta_{i1}(1-m_i(t)) s_{i\Delta} \frac{\partial \hat{u}_i}{\partial \hat{\theta}_i} \\
&+ \eta_{i1}(1-m_i(t)) s_{i\Delta} \frac{\theta_i \theta_i^T \dfrac{\partial \hat{u}_i}{\partial \hat{\theta}_i}}{|\theta_i|^2}
\end{aligned}
$$

$$
\dot{\hat{\varepsilon}}_i = \eta_{i2}(1-m_i(t)) s_{i\Delta} \qquad (11)
$$

$$
\dot{\hat{a}}_{ijk} = \eta_{i3} |s_{i\Delta}(t)| \|x_i\|^k \quad \hat{a}_{ijk}(0) \ge 0 \qquad (12)
$$

3. ANALYSIS FOR SYSTEMS STABILITY

Theorem 1 Consider the nonlinear interconnected system (1), if the assumption 1 and 2 are satisfied, adopt the decentralized fuzzy control scheme (5) and adaptive laws of parameters and control-gains (8)-(11), then the following properties can be obtained:

(i) $|\hat{\theta}_i| \le M_i$, $x_i, u_i \in L_\infty$

(ii) $e_i(t)$ converges to a neighborhood of zero.

Proof: The proof of (i) can be referenced to [3]. In the following, the other results will be proved.

Choose Lyapunov function as:

$$
\begin{aligned}
V = \sum_{i=1}^{N} V_i &= \sum_{i=1}^{N} [\frac{1}{2}\frac{s_{i\Delta}^2}{b_i(x_i)} + \frac{1}{2\eta_{i1}} \Phi_i^T \Phi_i \\
&+ \frac{1}{2\eta_{i2}} \tilde{\varepsilon}_i^2 + \frac{1}{2\eta_{i3}} \sum_{k=0}^{p}\sum_{j=1}^{N} \tilde{a}_{ijk}^2]
\end{aligned}
$$

Taking the derivative of V_i, yields:

$$
\begin{aligned}
\dot{V}_i &= \frac{s_{i\Delta}\dot{s}_{i\Delta}}{b_i(x_i)} - \frac{\dot{b}_i(x_i) s_{i\Delta}^2}{2b_i^2(x_i)} + \frac{1}{\eta_{i1}} \Phi_i^T \dot{\Phi}_i \\
&+ \frac{1}{\eta_{i2}} \dot{\tilde{\varepsilon}}_i \tilde{\varepsilon}_i + \frac{1}{\eta_{i3}} \sum_{k=0}^{p}\sum_{j=1}^{N} \tilde{a}_{ijk} \dot{\tilde{a}}_{ijk}
\end{aligned}
$$

If $|s_i| > \varphi_i$, since $\dot{s}_{i\Delta} = \dot{s}_i$, $u_{fsi} = -\mathrm{sgn}(s_i)$ and (12), then

$$
\begin{aligned}
\dot{V}_i(t) &\le -\eta_i \frac{s_{i\Delta}^2}{b_i(x_i)} + s_{i\Delta}(1-m_i(t)) \\
&[\Phi_i^T \frac{\partial \hat{u}_i}{\partial \hat{\theta}_i} + O(\|\Phi_i\|^2) + \hat{\varepsilon}_i u_{fsi}] \\
&+ s_{i\Delta} m_i [u_i^* + k_{1i} u_{fsi}] \\
&+ s_{i\Delta}[k_{2i} u_{fsi} - \frac{d_i}{b_i}] \\
&- \frac{\dot{b}_i(x_i) s_{i\Delta}^2}{2b_i^2(x_i)} + \frac{1}{\eta_{i1}} \Phi_i^T \dot{\Phi}_i \\
&+ \frac{1}{\eta_{i2}} \dot{\tilde{\varepsilon}}_i^T \tilde{\varepsilon}_i + \frac{1}{\eta_{i3}} \sum_{k=0}^{p}\sum_{j=1}^{N} \tilde{a}_{ijk}^T \dot{\tilde{a}}_{ijk} \\
\le -\eta_i \frac{s_{i\Delta}^2}{M_{i1}} &+ s_{i\Delta}(1-m_i(t)) \Phi_i^T \frac{\partial \hat{u}_i}{\partial \hat{\theta}_i} + \frac{1}{\eta_{i1}} \Phi_i^T \dot{\Phi}_i \\
&+ |s_{i\Delta}(t)|(1-m_i(t)) \tilde{\varepsilon}_i + \frac{1}{\eta_{i2}} \dot{\tilde{\varepsilon}}_i^T \tilde{\varepsilon}_i \\
&+ |s_{i\Delta}(t)| m_i(t) (|u_i^*| - M_{i4} - k_{1i}) \\
&+ |s_{i\Delta}(t)| (\frac{M_{i3}|s_{i\Delta}|}{2M_{i1}^2} - k_{2i} + \frac{1}{M_{i1}} \sum_{k=0}^{p}\sum_{j=1}^{N} \hat{a}_{ijk} \|x_i\|^k] \\
+ M_{i4}) &+ |s_{i\Delta}(t)| \sum_{k=0}^{p}\sum_{j=1}^{N} \tilde{a}_{ijk} \|x_i\|^k + \frac{1}{\eta_{i3}} \sum_{k=0}^{p}\sum_{j=1}^{N} \tilde{a}_{ijk}^T \dot{\tilde{a}}_{ijk}
\end{aligned}
$$

Moreover, from the adaptive control laws (8)-(11), it can be obtained that:

$$\dot{V}_i(t) \le -\eta_i \frac{s_{i\Delta}^2}{M_{i1}} + I_i s_{i\Delta}(t)$$

$$(1 - m_i(t)) s_{i\Delta} \frac{\theta_i \Phi_i \theta_i^T \frac{\partial \hat{u}_i}{\partial \hat{\theta}_i}}{|\theta_i|^2} \qquad (13)$$

Here in $P_1(*)$, I_i is defined as: If the first condition of (10) is true, then $I_i = 0$; If the second one is true, then $I_i = 1$. Consulting reference [1] yields:

$$I_i s_{i\Delta}(t)(1 - m_i(t)) s_{i\Delta} \frac{\theta_i \Phi_i \theta_i^T \frac{\partial \hat{u}_i}{\partial \hat{\theta}_i}}{|\theta_i|^2} \le 0 \qquad (14)$$

Thus, (13) can be written as

$$\dot{V}_i(t) \le -\eta_i \frac{s_{i\Delta}^2}{M_{i1}} \le -\eta_i \frac{s_{i\Delta}^2}{c_i} < 0$$

$$\dot{V}(t) \le -\sum_{i=1}^{N} \eta_i \frac{s_{i\Delta}^2}{c_i} < 0 \qquad (15)$$

From above, we know that $V \in L_\infty$, and $\hat{a}_{ijk}, \hat{\varepsilon}_i, s_{i\Delta} \in L_\infty$. Moreover, by using (2), it can be obtained $e_i \in L_\infty$, thus $x_i \in L_\infty$. By (15) and $V = \sum_{i=1}^{N} V_i$, it is known that V is decreased monotonously and inferior bounded. So $\lim_{t\to\infty} V(t) = V(\infty)$ exists.

Integrating (15) yields:

$$\int_0^\infty \dot{V}(t)dt \le V(0) - V(\infty) < 0$$

The above inequation means $s_{i\Delta} \in L_2$. Since $\dot{s}_{i\Delta} \in L_\infty$, and by Barbalet lemma, i.e., it can be obtained that $\lim_{t\to\infty} s_{i\Delta} = 0$, moreover, it can be deduced $|s_i| \le \varphi_i$, i.e., $e_i(t)$ converges to a neighborhood of zero. By using (5), it's easy to prove that u_i is bounded.

4. CONCLUSION

In this paper, a new form of the second class of fuzzy direct sliding mode controller is provided. The controller has the following properties: (1) There's no need to know the specific mathematic model of the control objective; (2) the fuzzy control rules can be directly utilized; (3) In the meaning that all signals are bounded, the close-loop system is guaranteed to be globally stable. At the same time, this paper provides a new method to deal with unknown interconnections. The using of fuzzy sliding mode control replaces the "supervisor control" (Wang, 1994). From the designing process of the controllers, it can be seen that the decentralized controller scheme is easy to be realize in engineering. How to utilize not only the fuzzy control rules but also the fuzzy description information to design a more "intelligence" adaptive controller is the next task to be focused on.

REFERENCE

Wang L. X. (1994) Adaptive fuzzy systems and control-design and stability analysis. Englewood Cliffs, NJ:Prentice-Hall.

Tong S C, Chai T Y. (1996). Stable fuzzy direct adaptive control for nonlinear systems. *International Journal of Control for Advance System Science and Application*.

Wang L X. (1993). Stable adaptive fuzzy control of nonlinear systems. *IEEE Trans on Fuzzy System*, Vol**(1)**: 146-155

Moore C G, Harris C J. (1991). Indirect adaptive fuzzy control. *International Journal of Control*, Vol**56(2)**; 441-468

Kim S W. (1995). Fuzzy logic based sliding mode control. *Fuzzy Sets and Systems*, Vol71:359-367