Abstract: Based on fuzzy T-S model and variable structure control technique, adaptive output tracking control problem for fuzzy time-delay systems in the existence of parameter perturbations is developed. Firstly, the sliding mode was chosen by variable structure control theory. By applying the Lyapunov stability theory, the design method of adaptive variable structure control is proposed. The use of adaptive technique is to overcome the unknown upper bound of perturbation so that the reaching condition can be satisfied. The method guaranteed the trajectory of system to arrive the slide surface in finite time interval and be kept here thereafter. Secondly, the sufficient condition for globally bound of the state is presented by using ISS theory and LMI method. Finally, simulation example is employed to illustrate the validity and effectiveness of the proposed method.

Keywords: Output tracking control; T-S fuzzy model; Adaptive control; Variable structure control; Robust control

INTRODUCTION

The robust stabilization and tracking control of nonlinear systems are important topics in the field of control theory and many approaches have been introduced to treat control problems in the past few decades. In general, tracking problems are more difficult than stabilization problems especially for nonlinear systems. For nonlinear system design, various control schemes are introduced including exact feedback linearization, adaptive control, sliding model control and fuzzy control. The technique of exact feedback linearization needs perfect knowledge of the nonlinear system and uses that knowledge to cancel the nonlinearities of the system. However, as pointed out in [Ying H (1999)], the controller derived by feedback linearization may not be bounded, i.e. the controller is not guaranteed to be stable for no minimum phase systems. Since perfect knowledge of the system is impossible, exact feedback linearization seems impractical for nonlinear systems with uncertainty [Khalil H K, (1996, Slotine J J E (1992)]. Recently, based on feedback linearization technique, H∞ adaptive fuzzy control schemes have been introduced to deal with nonlinear systems [Chen B S (1996), Chen B S (1998)]. However, the complicated parameter update law and control algorithm make this control scheme impractical. Especially in the case of considering the projection algorithm for the parameter update law can avoid the singularity of feedback linearization control. Variable structure system (VSS) control scheme has been developed as a popular robust strategy to treat uncertain control systems (see, for example, [Feng G (1995), Utkin V I (1978), Yoo D S. (1992)]. The main feature of such VSS control is its ability to deal with external disturbances, quickly varying parameters and unmodeled dynamics. However, it can’t avoid displaying chattering phenomena and exciting high-frequency unmodeled dynamics. So a conservative design may be obtained since the VSS control algorithm should be designed to treat the worst situation of uncertainties. On the other hand, Fuzzy control has recently found extensive applications for a wide variety of industrial systems and consumer products. It has attracted the attention of many control researchers due to its model free approach...
According to the universal approximation theorem, the T–S fuzzy model has been proved to be a very good representation for a certain class of nonlinear dynamic systems [Wang W J (1999)]. In their studies, a nonlinear plant was represented by a set of linear fuzzy models interpolated by membership functions and then a model-based fuzzy controller was developed to stabilize the T–S fuzzy model. Currently, the stabilization problem for the system represented in T-S fuzzy model have been well addressed [Takagi T, (1985), Wang H O, (1996), Wang W J (1999)], but the studies concerning with tracking controller design based on T-S fuzzy model are relatively few. [Tseng C S, (2001)] proposed fuzzy tracking design for nonlinear dynamic systems via T-S fuzzy model. However their work did only concern on the tracking control of nominal T-S fuzzy model without time delay and uncertainty. So the robustness of the whole tracking control system can’t be guaranteed. In addition, dynamic systems with time delay are common in chemical processes and long transmission lines in pneumatic, hydraulic, or rolling mill systems. Nonlinear systems with time delay constitute basic mathematical models of real phenomena in biology, mechanics, economics, etc. Generally speaking, the dynamic behaviors of systems with delays are more complicated than that of systems without any delay. Fuzzy time-delay systems of T–S model provide a method of using local linear delayed systems combined with fuzzy linguistic descriptions to achieve nonlinearity.

Motivated by the aforementioned concerns, adaptive output tracking control problems for fuzzy time-delay systems in the existence of parameter perturbations was developed based on the combination of sliding mode control and fuzzy control techniques. The method conquers the deficiency of LMI theory and H∞ theory on this problem. Furthermore, fuzzy control techniques can weaken inmanent chattering phenomenon in the sliding mode control.

2. FUZZY TIME-DELAY SYSTEM FORMATION

A fuzzy dynamic model has been proposed by Takagi and Sugeno [Takagi T (1985)] to represent a nonlinear system. The T-S fuzzy model is a piecewise interpolation of several linear models through membership functions. The fuzzy model is described by fuzzy If-Then rules and will be employed here to deal with the control design problem for nonlinear time-delay systems. The i-th rule of the fuzzy model for nonlinear systems is of the following form:

**Plant Rule i:**
If \( \theta_i(t) \) is \( \mu_{\theta_i} \) and...and \( \theta_j(t) \) is \( \mu_{\theta_j} \), Then
\[
\dot{x}(t) = (A_{ij} + \Delta A_{ij})x(t) + (A_{ii} + \Delta A_{ii})x(t - \tau(t)) + Bu(t)
\]
(1)
\[
y = C \dot{x}(t), \quad (i = 1,2,...r)
\]
(2)

where \( \mu_{\theta_i} \) denotes fuzzy set; \( x(t) \in \mathbb{R}^n \) denotes state vector; \( u(t) \in \mathbb{R}^m \) denotes the control input; \( A_{ii}, A_{jj} \) denotes some constant matrices of compatible dimensions; \( \tau(t) \) is time-delay in the state. It is assumed that \( 0 \leq \tau \leq \tau_d \), \( \tau(t) \leq \tau_d \) where \( \tau_d \) denote a constant; \( \Delta A_{ij} \), \( \Delta A_{ii} \) denote the perturbations of system. It is assumed that the premise variables are independent of the input variables \( u(t) \).

The overall fuzzy system is achieved by fuzzy blending of each individual rule as follows:
\[
\dot{x}(t) = \sum_{i=1}^{r} h_i(\theta(t))[(A_{ij} + \Delta A_{ij})x(t) + (A_{ii} + \Delta A_{ii})x(t - \tau(t)) + Bu(t)]
\]
(3)
\[
y = C \dot{x}(t)
\]
(4)

where \( \theta_i(t) \) (i=1,2,...p) are the premise variables;
\[
\theta(t) = [\theta_1(t), \theta_2(t), \ldots, \theta_p(t)], \quad w_i(\theta(t)) = \prod_{t \neq j} v_{ij}(\theta(t)),
\]
\[
h_i(\theta(t)) = w_i(\theta(t)) \quad v_{ij}(\theta(t)) \quad \text{denotes the grade of membership of } \theta_j(t).
\]

The following assumptions are made.

**Assumption 1:** The matrix \( CB \) is nonsingular.

**Assumption 2:** All the perturbations \( \Delta A_{ij}, \Delta A_{ii} \) satisfy the following matching condition, there exist \( \| \Delta A_i \|, \| \Delta A_{ii} \| \leq M_{Ak}, \) such that
\[
\Delta A_{ii}(x) = B \Delta A_{ij}, \Delta A_{ij}(x) = B \Delta A_{ii},
\]
where \( M_{Ak} \), \( M_{Ak} \) is known number.

**Assumption 3:** [Chou C H (2001)]: There exists unknown positive constant \( q_i, q_t \), such that
\[
\| x(t - \tau(t)) \| \leq q_i + q_t \| x(t) \|
\]
for \( \tau(t) \in [0, \tau_d] \), \( \tau_d \) is a constant.

The object in this paper is to find a variable structure controller such that the output \( y(t) \) of (3) will track a desired reference trajectory \( y_r(t) \).

3. OUTPUT TRACKING CONTROL

In the following, we introduce the definition of ISS and a necessary and sufficient condition for ISS. Consider the general nonlinear system
\[
\dot{x} = f(x,u)
\]
(5)
where \( x(t) \in \mathbb{R}^n, u(t) \in \mathbb{R}^m, f: \mathbb{R}^n \times \mathbb{R}^m \rightarrow \mathbb{R}^n \) is continuous and satisfies \( f(0,0) = 0 \). According to [9], we have

**Lemma 1:** System (5) is ISS if and only if there is a smooth function \( V: \mathbb{R}^n \rightarrow \mathbb{R}^+ \) such that there exist \( K_v \), function \( v_1, v_2 \) and \( K \) function \( v_3, v_4 \) such that
\[
v_1(\| \| \leq f(\xi) \leq v_2(\| \|) \quad \forall \xi \in \mathbb{R}^n
\]
\[
V(\xi) \leq -v_3(\|\|) + v_4(\|\|), \quad \text{so that } V(\xi) \geq v_3(\|\|)
\]
A function \( \gamma : \mathbb{R} \to \mathbb{R} \) is called a \( K \) function if it is continuous, strictly increasing and \( \gamma(0) = 0 \); if \( \gamma \) further satisfies \( \lim_{t \to \infty} \gamma(t) = \infty \), it is called a \( K_\infty \) function.

The sliding mode was selected for system (3) by variable structure control theory:

\[
s(t) = (CB)^{-1}(y(t) - y_r(t))
\]

Defining tracking error

\[
e(t) = y(t) - y_r(t)
\]

Then, the following variable structure controller is:

\[
u(t) = -\sum_{i=1}^{n} h_i(\theta(t))(CB)^{-1}CA_i x(t) - \sum_{i=1}^{n} \hat{h}_i(CB)^{-1}CA_i \\|x(t)\| + \hat{\theta}_i(M_{\Delta_{\alpha}} + M_{\Delta_{\alpha}})\|x(t)\| + \hat{\theta}_i(M_{\Delta_{\alpha}}) \text{sgn} s - \alpha_1 s - \alpha_2 \text{sgn} s + (CB)^{-1} \dot{y}_r(t)
\]

where \( \alpha_1, \alpha_2 \) are two positive numbers, the parameter adaptive laws are designed as

\[
\hat{\theta}_i(t) = \sum_{i=1}^{n} h_i(\theta(t))(CB)^{-1}CA_i \|x(t)\|,
\]

\[
\dot{\theta}_i(t) = \sum_{i=1}^{n} h_i(\theta(t))(CB)^{-1}CA_i x(t)
\]

(7)

Substituting the controller (6) into (3), yields

\[
\dot{x}(t) = \sum_{i=1}^{n} h_i(\theta(t))[A_i - B(CB)^{-1}CA_i] x(t) + A_i x(t - \tau) + B(\Delta_{\alpha_{\Delta}} x(t) + \Delta_{\Delta_{\alpha}} x(t - \tau)) - B[\sum_{i=1}^{n} \hat{h}_i(CB)^{-1}CA_i] + \sum_{i=1}^{n} \hat{\theta}_i(M_{\Delta_{\alpha}} + M_{\Delta_{\alpha}})\|x(t)\| + \hat{\theta}_i(M_{\Delta_{\alpha}}) \text{sgn} s + \alpha_1 s - \alpha_2 \text{sgn} s + (CB)^{-1} \dot{y}_r(t)
\]

(8)

Since matrix \( C \) is of full row rank, a nonsingular matrix \( T \) can be found such that

\[
CT = [0 \ C_2] = \bar{C},
\]

where \( C_2 \) is nonsingular. Let \( T_0^{-1} = \begin{bmatrix} \bar{B}_1 & \bar{B}_2 \end{bmatrix}^{-1} = \bar{B} \), where \( \bar{B}_i \in R^{(n+m) \times n} \), \( \bar{B}_2 \in R^{m \times m} \), since \( CB = \bar{C} \), it follows that matrix \( \bar{B} \) is nonsingular. Define

\[
T_z = \begin{bmatrix} I & -B \bar{B}^{-1} \bar{C} \end{bmatrix}, T_0 = T_z T_1 = T_0, \quad \bar{B}_0 = \begin{bmatrix} 0 & \bar{C} \end{bmatrix}
\]

where

\[
T_0 = \begin{bmatrix} I & -B \bar{B}^{-1} \bar{C} \end{bmatrix} T_1, \quad T_0 = \begin{bmatrix} 0 & \bar{C} \end{bmatrix} T_1.
\]

It shows that \( T_0 = C, T_0 B = 0 \). Let \( T_0^{-1} = \begin{bmatrix} T_{01} & T_{02} \end{bmatrix} \), where \( T_{01} \in R^{n \times n+m} \) and \( T_{02} \in R^{m \times m} \). For closed-loop system (8), we can obtain that

**Theorem 1:** Consider (3) satisfy assumptions 1-3, suppose that there are positive-definite matrix \( P \) and \( R \), such that the following:

\[
\begin{bmatrix}
PN_{00} + N_{00} P + \int_{t_0}^{t} R \quad PT_0 A_i T_{01} \\
T_{01}^T A_{\Delta_{\alpha}}^T T_{01}^T & -R
\end{bmatrix} < 0
\]

holds, where \( N_{00} = T_{00} A_i T_{01} \), the variable structure controller(6) with the adaptive laws(7) will make output of the closed-loop system (8) track reference signal \( y_r(t) \).

**Proof:** the proof is divided into two parts. In part a), we show that output of (3) can follow exactly the desired signal \( y_r(t) \) after a finite time interval and obtain adaptive laws. In part b), we show that the state of (3) is bounded globally.

a) The derivative of \( s(t) \) along the trajectory of closed-loop system (7) is

\[
\dot{s}(t) = (CB)^{-1} \dot{C} x(t) - (CB)^{-1} \dot{y}_r(t)
\]

\[
= \sum_{i=1}^{n} h_i(\theta(t))(CB)^{-1} \dot{A}_i x(t) + A_i x(t - \tau) + B(\Delta_{\alpha_{\Delta}} x(t) + \Delta_{\Delta_{\alpha}} x(t - \tau)) - (CB)^{-1} \dot{y}_r(t)
\]

\[
= \sum_{i=1}^{n} h_i(\theta(t))(CB)^{-1} A_i x(t - \tau) - \sum_{i=1}^{n} h_i(\theta(t))(CB)^{-1} CA_i x(t) + \sum_{i=1}^{n} \hat{\theta}_i(M_{\Delta_{\alpha}} + M_{\Delta_{\alpha}})\|x(t)\| + \hat{\theta}_i(M_{\Delta_{\alpha}}) \text{sgn} s + \alpha_1 s - \alpha_2 \text{sgn} s
\]

\[
= \sum_{i=1}^{n} h_i(\theta(t))(CB)^{-1} A_i x(t - \tau) - \sum_{i=1}^{n} h_i(\theta(t))(CB)^{-1} CA_i x(t) + \sum_{i=1}^{n} \hat{\theta}_i(M_{\Delta_{\alpha}} + M_{\Delta_{\alpha}})\|x(t)\| + \hat{\theta}_i(M_{\Delta_{\alpha}}) \text{sgn} s + \alpha_1 s - \alpha_2 \text{sgn} s
\]

If \( s(t) > 0 \), we hold

\[
\dot{s} = -\alpha_1 s - \alpha_2 - M_{\Delta_{\alpha}} \|x(t)\| - M_{\Delta_{\alpha}} \|x(t - \tau)\|
\]

\[
+ \sum_{i=1}^{n} h_i(\theta(t))(\Delta_{\alpha_{\Delta}} x(t) + \Delta_{\Delta_{\alpha}} x(t - \tau))
\]

\[
\leq -\alpha_1 s - \alpha_2 - M_{\Delta_{\alpha}} \|x(t)\| - M_{\Delta_{\alpha}} \|x(t - \tau)\|
\]

\[
+ \sum_{i=1}^{n} h_i(\theta(t))(\Delta_{\alpha_{\Delta}} x(t) + \Delta_{\Delta_{\alpha}} x(t - \tau))
\]

\[
\leq -\alpha_1 s - \alpha_2 - M_{\Delta_{\alpha}} \|x(t)\| - M_{\Delta_{\alpha}} \|x(t - \tau)\|
\]

\[
+ \sum_{i=1}^{n} h_i(\theta(t))(\Delta_{\alpha_{\Delta}} x(t) + \Delta_{\Delta_{\alpha}} x(t - \tau))
\]

\[
= -\alpha_1 s - \alpha_2
\]

If \( s(t) < 0 \), we hold \( \dot{s} \geq -\alpha_1 s - \alpha_2 \). From above, it can be seen that all \( s(t) \) will arrive at zero in finite time interval and keep here thereafter.

The adaptation error of each gain is defined as

\[
\hat{\theta}_i(t) = \hat{\theta}_i(t) - \hat{\theta}_i(t) = \hat{\theta}_i(t) - \hat{\theta}_i(t)
\]

Consider a Lypunov candidate function given by

\[
V(t) = \gamma(s^T s + \hat{\theta}_i^2(t) + \hat{\theta}_i^2(t))
\]

The derivative of \( V(t) \) along the trajectory of system (8) is
\[ \dot{V}(t) = s^T \dot{s} + \hat{g}_0(t) \dot{\hat{g}}_0(t) + \hat{g}_1(t) \dot{\hat{g}}_1(t) \leq \left| \frac{1}{2} \overset{n}{\sum} h_i(\theta(t)) \left( CB \right)^{-1} C A_2 \left( \overset{n}{\sum} \left| \dot{s}_i \right| - |s|^2 \right) \right| - \left( \overset{n}{\sum} h_i \left( CB \right)^{-1} C A_2 \left( \overset{n}{\sum} \left| \dot{s}_i \right| - |s|^2 \right) \right) - M_{\lambda\alpha} x(t) \right] + \left( \overset{n}{\sum} h_i(\theta(t)) \left( CB \right)^{-1} C A_2 \left( \overset{n}{\sum} \left| \dot{s}_i \right| - |s|^2 \right) \right) + \left( \overset{n}{\sum} h_i(\theta(t)) \left( CB \right)^{-1} C A_2 \left( \overset{n}{\sum} \left| \dot{s}_i \right| - |s|^2 \right) \right) + M_{\lambda\alpha} \left| x(t) \right| | | | | | \left| x(t) \right| + \left( \overset{n}{\sum} h_i(\theta(t)) \left( CB \right)^{-1} C A_2 \left( \overset{n}{\sum} \left| \dot{s}_i \right| - |s|^2 \right) \right) + M_{\lambda\alpha} \left| x(t) \right| | | | | \left| x(t) \right| + \left( \overset{n}{\sum} h_i(\theta(t)) \left( CB \right)^{-1} C A_2 \left( \overset{n}{\sum} \left| \dot{s}_i \right| - |s|^2 \right) \right) + M_{\lambda\alpha} \left| x(t) \right| | | | | \left| x(t) \right| \]

from (7), we obtain

\[ V(t) \leq -\overset{n}{\sum} h_i(\theta(t)) \left( CB \right)^{-1} C A_2 \left( \overset{n}{\sum} \left| \dot{s}_i \right| - |s|^2 \right) \leq 0 \]

from above, we show that output of (3) can follow exactly the desired signal \( y_d(t) \) after a finite time interval and obtain adaptive laws simultaneously.

b) The state of system (3) is bounded globally.

Under the following state transformation:

\[ z = \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} = \begin{bmatrix} T_{x0} & \dot{x} \\ T_{z0} & \dot{z} \end{bmatrix} \]

we obtain

\[ \dot{z}_1(t) = \overset{n}{\sum} h_i(\theta(t)) T_{01} A_1 T_{t01} z_1(t) + T_{01} A_1 T_{t01} z_2(t) + T_{01} A_2 T_{t01} z_2(t - \tau) + T_{02} A_2 T_{t02} z_2(t - \tau) \]

\[ \dot{z}_2(t) = \overset{n}{\sum} h_i(\theta(t)) \left( CB \Delta A_2, x(t) + \Delta A_2, x(t - \tau) \right) - CB[a, s + \alpha, \sgn] s + M_{\lambda\alpha} \left| x(t) \right| + M_{\lambda\alpha} \left| x(t) \right| | | | | \left| x(t) \right| + M_{\lambda\alpha} \left| x(t) \right| | | | | \left| x(t) \right| \]

Since \( z_2 = T_{x0} x = C x = y \), notice that in the previous argument, when \( t \geq t_0 \), \( y(t) = y_d(t) \). So our attention can be concentrated in (9).

Now view \( z_2(t) \) as the input of (9) and choose an ISS-Lyapunov function candidate as

\[ V(z_2(t)) = s^T \dot{s} + \gamma z_2(t) \]

The derivative of \( V(z_2(t)) \) along the trajectory of system (9) is

\[ \dot{V}(z_2(t)) = \overset{n}{\sum} h_i(\theta(t)) z_i(t) P z_i(t) + \overset{n}{\sum} h_i(\theta(t)) z_i(t) x(t - \tau(t)) \]

\[ -z_i(t) \left| x(t) \right|^2 R z_i(t) \]

where

\[ \gamma = \frac{C}{\lambda} \exp\left( \frac{-E}{RT(t)} \right) \]

4. SIMULATION EXAMPLE

Consider a continuous stirred tank reactor (CSTR), according to [Cao Y Y (2000)], the material and energy balance equation are

\[ V \frac{dA}{dt} = \lambda q A_0 + q(1 - \lambda) A(t - \alpha) - q A(t) - V K_0 \exp\left( \frac{-E}{RT(t)} \right) A(t) \]

\[ V C_r \frac{dA}{dt} = q C \left[ T A_0 + (1 - \lambda) T(t - \alpha) - T(t) \right] - V \left( \Delta H \right) K_0 \exp\left( \frac{-E}{RT(t)} \right) A(t) - U(T(t) - T_0) \]

By transformation, we have

\[ \dot{x}_2(t) = f_2(x) + \left( \frac{1}{\lambda} - 1 \right) x_2(t - \tau(t)) \]

where

\[ x_2(t) = \frac{T(t) - T_0}{T_0} \left( \frac{-E}{RT(t)} \right), \quad \theta(t) = \frac{A_0}{A_0} = \frac{\phi(t)}{\phi(t)} \]

\[ \gamma = \frac{E}{RT(t)} \]

Thus, we obtain adaptive laws simultaneously.
\[ f_1(x) = -\sqrt{\lambda} x(t) + \frac{x_2(t)}{1 + x_2(t)/\gamma_o}, \]
\[ f_2(x) = -\left(\frac{1}{\lambda} + \beta\right) x_2(t) + \frac{HD_\delta(1 - x_2(t))}{1 + x_2(t)/\gamma_o}. \]

The parameters are given as \( \gamma_o = 20; H = 8; \beta = 0.3; D_o = 0.072; \lambda = 0.8; \tau = 2. \)

Choose a steady-state as \( x_i(t) = [0.1440; 0.8862], \)
defining a new state variable
\[ \delta x_i = x_i - x_i(1), \quad \delta x_2 = x_2 - x_i(2) \]
As in [Cao Y Y (2000)], we present the following fuzzy control law

**Rule 1:** If \( \delta x_i \) is small (i.e. \( \delta x_i \) is -1) Then
\[ \delta \dot{x}(t) = (A_1 + \Delta A_1) \delta x_i(t) + (A_2 + \Delta A_2) \delta x_2(t - \tau(t)) + B \delta u \]

**Rule 2:** If \( \delta x_i \) is middle (i.e. \( \delta x_i \) is 0) Then
\[ \delta \dot{x}(t) = (A_1 + \Delta A_1) \delta x_i(t) + (A_2 + \Delta A_2) \delta x_2(t - \tau(t)) + B \delta u \]

**Rule 3:** If \( \delta x_i \) is large (i.e. \( \delta x_i \) is 1) Then
\[ \delta \dot{x}(t) = (A_1 + \Delta A_1) \delta x_i(t) + (A_2 + \Delta A_2) \delta x_2(t - \tau(t)) + B \delta u \]

where
\[ B = \begin{bmatrix} 0 & \beta \\ \end{bmatrix}, \quad A_i = \begin{bmatrix} a_{ij} & a_{ij} \\ \end{bmatrix}, \]
\[ a_{ij} = \frac{\partial f_i(\delta x_i) - (\delta x_i) \frac{\partial f_i(\delta x_i)}{\partial \delta x_i}}{\partial \delta x_j} \delta x_j \]
\[ (i = 1, 2), \quad (j = 1, 2, 3) \]

From above, we obtain
\[ A_1 = \begin{bmatrix} -1.4274 & 0.0757 \\ -1.4189 & -0.9442 \end{bmatrix}, \quad A_2 = \begin{bmatrix} -2.0508 & 0.3958 \\ -6.4066 & 1.6168 \end{bmatrix}, \]
\[ A_3 = \begin{bmatrix} -4.5279 & 0.3167 \\ -26.2228 & 0.9837 \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ 0.3 \end{bmatrix}, \]
\[ A_{21} = A_{22} = A_3 = \begin{bmatrix} 0.25 & 0 \\ 0 & 0.25 \end{bmatrix}, \quad C = \begin{bmatrix} 0 & 1 \end{bmatrix} \]

\[ \Delta A_1 = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}, \quad \Delta A_2 = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}, \quad \Delta A_3 = \begin{bmatrix} -1.4189 & -0.9442 \\ 0 & 0 \end{bmatrix}. \]
\[ \Delta A_1 = \Delta A_2 = \Delta A_3 = \begin{bmatrix} 0 & 0 \\ 0 & 0.25 \end{bmatrix}. \]

The membership function are selected as
\[ \alpha_i = \frac{\exp(-\theta x_i)}{\exp(-\theta x_i) + \exp(-\theta x_i) + \exp(-\theta x_i)}, \]
\[ \alpha_2 = \frac{\exp(-\theta x_i)}{\exp(-\theta x_i) + \exp(-\theta x_i) + \exp(-\theta x_i)}, \]
\[ \alpha_3 = \frac{\exp(-\theta x_i)}{\exp(-\theta x_i) + \exp(-\theta x_i) + \exp(-\theta x_i)}. \]

Let \( y(t) = \sin(t) \), \( \delta x(0) = [1 \quad 1]' \), the trajectory of system are shown in Fig1.
From Fig 1, it can be seen that the control techniques proposed in this paper guarantee globally bound of the state and the output of this system possesses well tracking performance. Comparing Fig 1 with Fig 2, our control techniques can track the reference signal more accurately and weaken chattering phenomenon more effectively than conventional control technique.

5. CONCLUSION

Based on fuzzy T-S model and variable structure control technique, adaptive output tracking control problem for fuzzy time-delay systems in the existence of parameter perturbations was developed. The method conquers the deficiency of LMI theory and $H_\infty$ theory in this field. Furthermore, fuzzy control techniques can weaken immanent chattering phenomenon in the sliding mode control.

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