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Finite time non-fragile dissipative control for uncertain TS fuzzy system with time-varying delay ☆

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ABSTRACT

In this paper, the problem of finite time non-fragile dissipative control for uncertain TS fuzzy time-varying delay system is investigated. Considering the time-varying delay and using of a new lemma, delay-dependent conditions are obtained. The closed-loop system is not only finite-time bounded but also satisfies the dissipative control index for all uncertainties under the obtained conditions. Then, the desired non-fragile dissipative controller can be obtained by solving the linear matrix inequalities (LMIs). Finally, simulation results demonstrate the feasibility of the proposed method.

1. Introduction

Over the past two decades, due to their industrial applications, T-S fuzzy systems have been studied extensively. And a great number of significant results on analysis and synthesis problems of T-S systems can be available [1–5]. Uncertain TS fuzzy model was discussed in [6,7]. It has been shown that the existence of time-delays is often one of the main causes of instability and poor performance in a system. Therefore, it has received considerable attention on TS fuzzy time-delay system [2,6–8]. On the other hand, since perturbations often appear in the controller gain, which may result from either the actuator degradations or the requirements for readjustment of controller gains. The non-fragile control concept is how to design a feedback control that will be insensitive to some error in gains of feedback control [9–14]. Non-fragile robust H_∞ [10] and non-fragile passive controller [11] were discussed. However, the uncertain parameter in B_i was ignored in [10,11] and many other articles on non-fragile control. In practice, it is necessary to consider the uncertainty.

Compared with passivity and H_∞ performance, dissipative is a more general criterion, which was introduced by Willems in [15]. However, for nonlinear control system, the design of an efficient dissipative controller is not an easy case. Using the TS fuzzy model, the dissipative design of the nonlinear system is effective and feasible. Hence, the problem of fuzzy dissipative control is significant. H. Gassara et al. obtained the observer based $(Q,V,R)-\alpha-$ dissipative control for T-S fuzzy descriptor systems with time delay in [16]. In [17] and [18], under dissipative conditions, the problem of fuzzy differential equations were discussed. Global robust dissipativity analysis for T-S fuzzy neural networks was demonstrated via LMI approach by Muralisankar et al. [19]. In [20], the problem of fuzzy dissipative control for nonlinear Markovian jump systems via retarded feedback was investigated.

In the aforementioned references, the stability analysis and control synthesis on fuzzy system focus on Lyapunov asymptotic stability, which is defined over an infinite time interval. However, in some practical engineering applications, the finite time control is of practical significance. Finite time stability admits that the state does not exceed a certain bound during a fixed finite time interval, see for example, [21–29]. Among them, Shen et al. discussed the problem of finite-time reliable L_2-L_∞/H_∞ control for Takagi-Sugeno fuzzy systems with actuator faults without considering time-delay in [21]. In [22], finite-time H_∞ fuzzy control of nonlinear jump systems with time delay via dynamic observer-based state feedback was studied, in which, the time-delay is constant. Non-fragile finite-time filter was designed for time-delayed Markovian jumping systems via T-S fuzzy model approach in [27]. To the best knowledge of our author, there are

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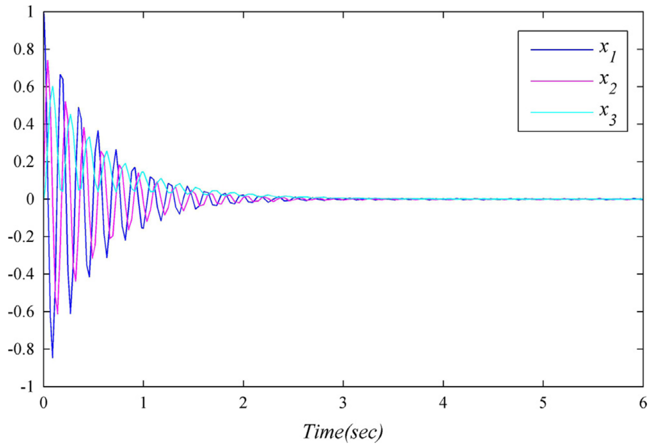

Fig. 1. State response of the closed-loop system (PDC).

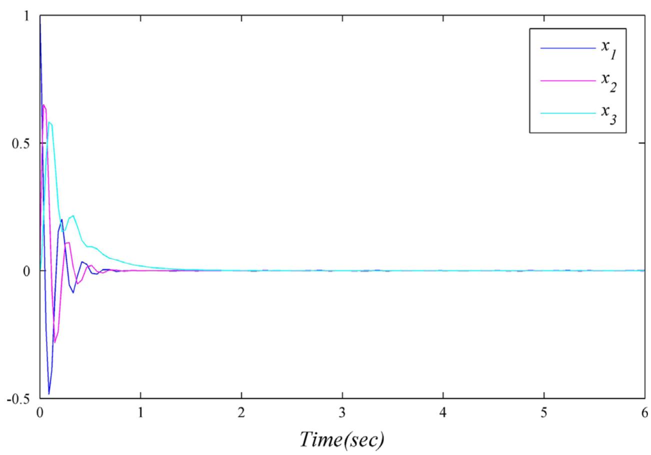

Fig. 2. State response of the closed-loop systemnon-fragile.

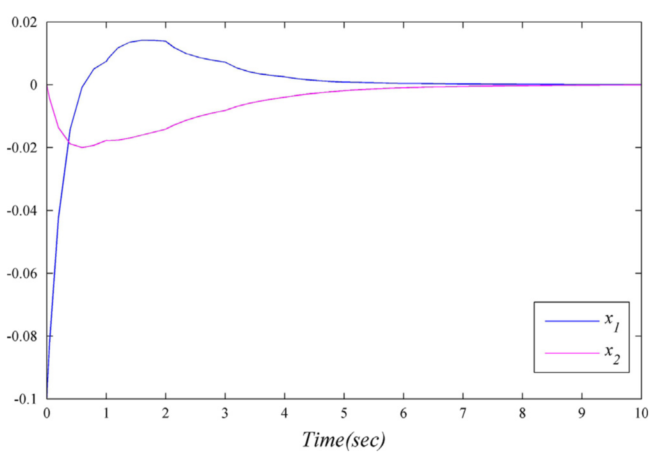

Fig. 3. State response of the closed-loop system.

few articles on finite time non-fragile dissipative control for uncertain TS fuzzy system with time-varying delay.

Motivated by the above discussion, in this paper, we consider the problem of finite time non-fragile control for uncertain TS fuzzy system with time-varying delay subject to $(Q, V, R)-\alpha-$ dissipative. The main contributions of this paper are summarized as follows: (1) a new integral inequality is introduced to solve the integral in the derivation of the Lyapunov function; (2) sufficient conditions were obtained to ensure that the closed-loop system is finite time bounded and dissipative; (3) the non-fragile dissipative controller can be obtained by solving the LMIs; (4) the dissipativity can be seen from Fig. 4 directly; (5) the simulation results demonstrate the feasibility of the method.

Notation: Throughout this paper, R^n denotes the -dimensional Euclidean space, and $\mathrm{R}^{n\times m}$ is the set of real matrices. For $A\in\mathrm{R}^{n\times m}$, A^{-1} and A^{T} denote the matrix inverse and matrix transpose respectively. $\lambda(A)$ means the eigenvalue of A. For a real symmetric matrix $A\in\mathrm{R}^{n\times n}, A>0 (A\geq 0)$ means that A is positive defined (positive semi-defined). The symbol $*$ means the symmetric term in a symmetric matrix.

2. Problem formulation

Consider a nonlinear system, and it can be presented as the following TS fuzzy model: Plant rule i: IF $\varepsilon_1(t)$ is M_{i1} and $\varepsilon_2(t)$ is $M_{i2}\ldots\varepsilon_p(t)$ is M_{ip}, THEN

$$\begin{aligned}
&\dot{x}(t)=\overline{A}_i x(t)+\overline{A}_{di}x(t-d(t))+\overline{B}_i u(t)+\overline{B}_{\omega i}\omega(t),\\
&z(t)=\overline{C}_i x(t)+\overline{C}_{di}x(t-d(t))+\overline{D}_i u(t)+\overline{D}_{\omega i}\omega(t),\\
&x(t)=\phi(t), t\in[-d,0],
\end{aligned}\tag{1}$$

where $i\in\Re{:=}\{1,2\ldots r\}, r$ is the number of IF-THEN rules. $\varepsilon(t)=\begin{bmatrix}\varepsilon_1(t) & \varepsilon_2(t) & \ldots & \varepsilon_p(t)\end{bmatrix}^{\mathrm{T}}$ is premise variable, $M_{ik}(i=1,2\ldots r, k=1,2\ldots p)$ is the fuzzy set. $x(t)\in\mathrm{R}^n$ is the state vector, $\omega(t)\in\mathrm{R}^q$ is the disturbance input which belongs to $L_2[0,\infty)$. $z(t)\in\mathrm{R}^p$ is the control output, $\phi(t)$ is the initial condition of the system. $d(t)$ is a time-varying continuous function that satisfies $0\leq d(t)\leq d$ and $\dot{d}(t)\leq h, h<1$. $u(t)\in\mathrm{R}^l$ is the control input, and for a positive scalar b and time scalar T_c, $\int_0^{T_c}\omega^{\mathrm{T}}(t)\omega(t)\leq b$. $\overline{A}_i=A_i+\Delta A_i, \overline{A}_{di}=A_{di}+\Delta A_{di}$, $\overline{B}_i=B_i+\Delta B_i, \overline{B}_{\omega i}=B_{\omega i}+\Delta B_{\omega i}, \overline{C}_i=C_i+\Delta C_i, \overline{C}_{di}=C_{di}+\Delta C_{di}, \overline{D}_i=D_i+\Delta D_i, \overline{D}_{\omega i}=D_{\omega i}+\Delta D_{\omega i}$. And $A_i, A_{di}, B_i, B_{\omega i}, C_i, C_{di}, D_i, D_{\omega i}$ are known real constant matrices with appropriate dimensions; $\Delta A_i, \Delta A_{di}, \Delta B_i, \Delta B_{\omega i}, \Delta C_i, \Delta C_{di}, \Delta D_i, \Delta D_{\omega i}$ are unknown matrices representing norm-bounded parametric uncertainties and are assumed to be of the form:

$$\begin{bmatrix}\Delta A_i & \Delta A_{di} & \Delta B_i & \Delta B_{\omega i}\\ \Delta C_i & \Delta C_{di} & \Delta D_i & \Delta D_{\omega i}\end{bmatrix}=\begin{bmatrix}H_{1i}\\ H_{2i}\end{bmatrix}\Delta\begin{bmatrix}E_{1i} & E_{2i} & E_{3i} & E_{4i}\end{bmatrix},\tag{2}$$

where $H_{1i}, H_{2i}, E_{1i}, E_{2i}, E_{3i}, E_{4i}$ are known real constant matrices with appropriate dimensions and Δ is unknown real and possibly time-varying matrices satisfying $\Delta^{\mathrm{T}}\Delta\leq I$.

Using singleton fuzzifier, product inference, and center-average defuzzifier, the global dynamics of the TS system (1) is described

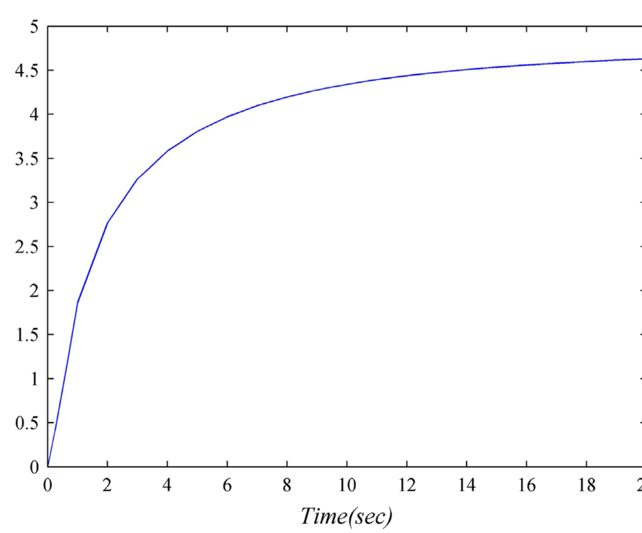

Fig. 4. The simulation of $\Gamma(t)$.