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Hybrid-triggered H∞ Fault Detection for Distributed Time-delay Systems with Communication Quantization Based on T-S Fuzzy Model

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Abstract: In the network environment, the time-triggered mechanism wastes limited bandwidth resources due to the transmission of all sampled data to the network. The event-triggered mechanism may increase system errors due to ignoring factors such as changes in network utilization. In order to reduce the design conservatism, this paper studies the design of a hybrid-triggered H∞ fault detection filter for a class of nonlinear networked control systems described by Takagi-Sugeno (T-S) fuzzy model, and applies quantization techniques in the communication channel. Using the Lyapunov-Krasovskii functional and integral inequality methods, new results on the stability and H∞ performance of fuzzy fault detection systems are presented. In particular, the designed fault detection filter has a specific H∞ noise attenuation level γ. The final simulation results verify the effectiveness of the design.

Keywords: H∞ performance, Fault detection, Hybrid trigger mechanism, Networked system, T-S fuzzy model, Communication quantification.

1. Introduction

The Takagi-Sugeno (T-S) fuzzy model provides a general system framework for describing nonlinear objects, enabling mature linear system theory to be applied to the study of complex nonlinear systems. Reference [1-2] presents the design method of the fault detection filter for the nonlinear nonlinear networked control system under the event-triggered scheme. Most of the existing literature, nonlinear network control, filtering, and fault detection problems are implemented using a single-time-triggered scheme or an event-triggered scheme. However, event-triggered schemes may increase system errors by ignoring factors such as changes in network utilization. Therefore, how to combine the advantages of the two sampling schemes to explore the dependence of the time/event-triggered hybrid sampling scheme on the performance of nonlinear networked control systems has become a research topic with application prospects and scientific significance. To address the constraints of information transmission and communication bandwidth resources in difficult systems related to control systems, researchers propose a method called quantization. In [3-5], the authors studied NCSs where the control input was quantized. Different application fields of quantization technology under different network frameworks.

2. Problem Description

Consider the T-S fuzzy model with distributed delay described as follows:

Rule: IF $\theta_1(t)$ is F_{i1}, $\theta_2(t)$ is F_{i2} $\cdots$ $\theta_n(t)$ and F_{in}, THEN

$$\begin{cases} \dot{x}(t) = A_i x(t) + A_{di} \int_{t-d}^{t} x(s)ds + B_{1i} w(t) + B_{2i} f(t) \\ y(t) = C_i x(t) \end{cases} \tag{1}$$

where, $\theta_1(t)$, $\theta_2(t) \cdots$, $\theta_n(t)$ is a measurable antecedent variable; the fuzzy $F_{ij}\,(j=1,2,\cdots,n)$ sets that make up T-S; , r is the number of fuzzy rules. $x(t)$ and $y(t)$ are the state vector and the output vector respectively, $z(t)$ are the signal to be estimated, $w(t)$ are the disturbance input and belong to $L_2[0,\infty)$, $f(t)$ represent the system failure, $d>0$ and are the distributed time delay time constant. A_i, A_{di}, B_i and C_i are given matrices of appropriate dimensions.

Applying single-point fuzzification, product inference, and weighted average to defuzzify system (1), we get

$$\begin{cases} \dot{x}(t) = A(t)x(t) + A_d(t) \int_{t-d}^{t} x(s)ds + B_1(t)w(t) + B_2(t)f(t) \\ y(t) = C(t)x(t) \end{cases} \tag{2}$$

A fuzzy fault detection filter is constructed in the following form:

Rule: IF $\theta_1(t)$ is F_{i1}, $\theta_2(t)$ is F_{i2} $\cdots$ $\theta_n(t)$ and F_{in}, THEN

$$\begin{cases} \dot{x}_f(t) = A_{fi} x_f(t) + B_{fi} \hat{y}(t) \\ r(t) = C_{fi} x_f(t) \end{cases} \tag{3}$$

According to the parallel distributed compensation technique, the defuzzification output of (3) is

$$\begin{cases} \dot{x}_f(t) = A_f(t) x_f(t) + B_f(t) \hat{y}(t) \\ r(t) = C_f(t) x_f(t) \end{cases} \tag{4}$$

Based on the limited transmission capacity, in order to reduce the number of data transmitted by the communication channel, the BCQ quantization mode is selected in this chapter for the characteristics that the network communication quality is seriously affected under high quantization density, and important packet information is lost under low quantization density. The quantizer can be expressed as

$$h(y) = (I + \Delta h)y \tag{5}$$

Combined with the proposed design scheme of the hybrid trigger filter, the measured output of the fault detection filter under the hybrid trigger scheme can be expressed as:

$$\begin{aligned}\hat{y}(t) &= \delta(t)y_1(t) + (1-\delta(t))y_2(t) \\ &= \delta(t)(I+\Delta h)C(t)x(t-\tau(t)) + (1-\delta(t))(I+\Delta h)[C(t)x(t-\eta(t)) + v_k(t)]\end{aligned} \tag{6}$$

In order to improve the sensitivity of the fuzzy fault detection system, a weighted fault model is added, its state space form is as follows:

$$\begin{cases}\dot{x}_w(t) = A_w x_w(t) + B_w f(t) \\ f_w(t) = C_w x_w(t)\end{cases} \tag{7}$$

Combining (2), (11) and (12), the fuzzy fault detection system can be obtained:

$$\begin{cases}\dot{\xi}(t) = \bar{A}(t)\xi(t) + \bar{A}_d(t)\int_{t-d}^{t}\xi(s)ds + \delta(t)\bar{A}_1(t)\xi(t-\tau(t)) \\ \quad +(1-\delta(t))\bar{A}_1(t)\xi(t-\eta(t)) + (1-\delta(t))\bar{A}_2(t)Gv_k(t) + \bar{B}(t)v(t) \\ e(t) = \bar{C}(t)\xi(t)\end{cases} \tag{8}$$

3. Hybrid Trigger H∞ Performance Analysis

In this section, we present a complete proof of the H∞ performance criterion for the fuzzy fault detection system under the hybrid triggering scheme, the following theorem plays an important role in the design of the H∞ fault detection filter.

Theorem 1: Given a constant $\bar{\delta}$, d, τ_M, η_M, σ, τ_1, η_1, for all $i, j, k = 1, 2, \cdots, r$, under the mixed trigger mechanism, if there are matrix $P > 0$, $Q_{1i} > 0$, $Q_{2i} > 0$, $Q_{3i} > 0$, $R_{1i} > 0$, $R_{2i} > 0$, $R_{3i} > 0$, $Q_{1k} > 0$, $Q_{2k} > 0$, $Q_{3k} > 0$ satisfies

$$\Xi = \begin{bmatrix}\Sigma_1 & \Sigma_2 \\ * & \Sigma_3\end{bmatrix} < 0 \tag{9}$$

Then the fuzzy fault detection filtering error system is mean square asymptotically stable and has H∞ interference suppression level γ.

Where

$$\Sigma_1 = \begin{bmatrix}\Phi_{11} & \Phi_{12} & 0 & \Phi_{14} & 0 & 0 & P\bar{A}_{di} & (1-\bar{\delta})P\bar{A}_{2i} & P\bar{B}_i & \bar{C}_i^T \\ * & -2R_{1i} & R_{1i} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ * & * & -Q_{1k}-R_{1i} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ * & * & * & \Phi_{44} & R_{2i} & 0 & 0 & 0 & 0 & 0 \\ * & * & * & * & -Q_{2k}-R_{2i} & 0 & 0 & 0 & 0 & 0 \\ * & * & * & * & * & -Q_{3k} & 0 & 0 & 0 & 0 \\ * & * & * & * & * & * & -dR_{3i} & 0 & 0 & 0 \\ * & * & * & * & * & * & * & -\Omega & 0 & 0 \\ * & * & * & * & * & * & * & * & -\gamma^2 I & 0 \\ * & * & * & * & * & * & * & * & * & -I\end{bmatrix},$$

$\Phi_{11} = P\bar{A}_{ij} + \bar{A}_{ij}^T P + Q_{1i} + Q_{2i} + Q_{3i} - R_{1i} - R_{2i} + dR_{3i}$, $\Phi_{12} = \bar{\delta}P\bar{A}_{1i} + R_{1i}$,

$\Phi_{14} = (1-\bar{\delta})P\bar{A}_{1i} + R_{2i}$, $\Phi_{44} = -2R_{1i} + \sigma C_i^T \Omega C$,

$\Sigma_3 = diag\{-PR_{1i}^{-1}P, -PR_{2i}^{-1}P, -PR_{1i}^{-1}P, -PR_{2i}^{-1}P\}$,

$$\Sigma_2 = \begin{bmatrix}\tau_M\bar{A}_{ij}^T P & \eta_M\bar{A}_{ij}^T P & 0 & 0 \\ \tau_M\bar{\delta}\bar{A}_{1ij}^T P & \eta_M\bar{\delta}\bar{A}_{1ij}^T P & \tau_M\lambda\bar{A}_{1ij}^T P & \eta_M\lambda\bar{A}_{1ij}^T P \\ 0 & 0 & 0 & 0 \\ \tau_M(1-\bar{\delta})\bar{A}_{1ij}^T P & \eta_M(1-\bar{\delta})\bar{A}_{1ij}^T P & \tau_M\lambda\bar{A}_{2ij}^T P & \eta_M\bar{A}_{2ij}^T P \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \tau_M\bar{A}_{dij}^T P & \eta_M\bar{A}_{dij}^T P & 0 & 0 \\ \tau_M(1-\bar{\delta})G^T\bar{A}_{2ij}^T P & \eta_M(1-\bar{\delta})G^T\bar{A}_{2ij}^T P & \tau_M G^T\bar{A}_{2ij}^T P & \eta_M G^T\bar{A}_{2ij}^T P \\ \tau_M\bar{B}_{ij}^T P & \eta_M\bar{B}_{ij}^T P & 0 & 0 \\ 0 & 0 & 0 & 0\end{bmatrix}.$$

Proof: Construct a Lyapunov-Krasovskii functional of the form:

$$V(t) = V_1(t) + V_2(t) + V_3(t) \tag{10}$$

where,

$V_1(t) = x^T(t)Px(t)$,

$V_2(t) = \int_{t-\tau_M}^{t} x^T(s)Q_1(s)x(s)ds + \int_{t-\eta_M}^{t} x^T(s)Q_2(s)x(s)ds + \int_{t-d}^{t} x^T(s)Q_3(s)x(s)ds$,

$$V_3(t) = \tau_M\int_{t-\tau_M}^{t}\int_s^t \dot{x}^T(v)R_2(v)\dot{x}(v)dvds + \eta_M\int_{t-\eta_M}^{t}\int_s^t \dot{x}^T(v)R_2(v)\dot{x}(v)dvds + \int_{t-d}^{t}\int_s^t x^T(v)R_3(v)x(v)dvds,$$

According to the definition, the infinitesimal operator operation is performed on the above Lyapunov function, and we get:

$$\begin{aligned}\ell\dot{V}(t) &= 2E\left\{x^T(t)P\dot{x}(t)\right\} + x^T(t)(Q_1(t)+Q_2(t)+Q_3(t))x(t) + dx^T(t)R_3(t)x(t) + x^T(t-\tau_M) \\ &Q_2(t-\tau_M)x(t-\tau_M) + x^T(t-\eta_M)Q_4(t-\eta_M)x(t-\eta_M) + x^T(t-d)Q_5(t-d)x(t-d) \\ &+\tau_M^2 E\{\dot{x}^T(t)R_1(t)\dot{x}(t)\} + \eta_M^2 E\{\dot{x}^T(t)R_2(t)\dot{x}(t)\} + \tau_M\int_{t-\tau_M}^{t}\dot{x}^T(s)R_1(t)\dot{x}(s)ds \\ &+\eta_M\int_{t-\eta_M}^{t}\dot{x}^T(s)R_2(t)\dot{x}(s)ds - \int_{t-d}^{t}\dot{x}^T(s)R_3(t)\dot{x}(s)ds\end{aligned}$$

It can be obtained by derivation,

$$\begin{aligned}\ell\dot{V}(t) &< 2x^T(t)P\bar{H} + x^T(t)(Q_1(t)+Q_2(t)+Q_3(t))x(t) + dx^T(t)R_3(t)x(t) + x^T(t-\tau_M) \\ &Q_2(t-\tau_M)x(t-\tau_M) + x^T(t-\eta_M)Q_4(t-\eta_M)x(t-\eta_M) + x^T(t-d)Q_5(t-d)x(t-d) \\ &+\bar{H}^T\bar{R}\bar{H} + \lambda^2\bar{H}_1^T\bar{R}\bar{H}_1 - [\xi(t)-\xi(t-\tau(t))]^T R_1(t)[\xi(t)-\xi(t-\tau(t))] - [\xi(t-\tau(t)) \\ &-\xi(t-\tau_M)]^T R_1(t)[\xi(t-\tau(t))-\xi(t-\tau_M)] - [\xi(t)-\xi(t-\eta(t))]^T R_2(t)[\xi(t)-\xi(t-\eta(t))] \\ &-[\xi(t-\eta(t))-\xi(t-\eta_M)]^T R_2(t)[\xi(t-\eta(t))-\xi(t-\eta_M)] + \sigma x^T(t-\eta(t))\Omega x(t-\eta(t)) \\ &-v_k^T(t)\Omega v_k(t) - d^{-1}(\int_{t-d}^{t}x(s)ds)^T R_3(t)\int_{t-d}^{t}x(s)ds\end{aligned}$$

Using Schur's complement lemma to simplify the above formula, (9) in Theorem 1 can be obtained, and at the same time, it can be obtained. To sum up, inequality (9) guarantees the mean square asymptotic stability of the fuzzy fault detection filtering error system and satisfies the known H∞ noise suppression level. Theorem is proven.

4. Hybrid Trigger H∞ Fuzzy Fault Detection Filter Design

Theorem 2: Given constant $\bar{\delta}$, d, τ_M, η_M, σ, τ_1, η_1, for all $i, j, k = 1, 2, \cdots, r$, under the hybrid trigger mechanism, the fuzzy fault detection filtering error system (14) is mean square asymptotically stable and has H∞ interference suppression level γ, if there is a matrix, $Z > 0$, $U_1 > 0$, $U_2 > 0$, $V_1 > 0$, $\bar{Q}_{1i} > 0$, $\bar{Q}_{2i} > 0$, $\bar{Q}_{3i} > 0$, $\bar{R}_{1i} > 0$, $\bar{R}_{2i} > 0$, $\bar{R}_{3i} > 0$, $\bar{Q}_{1k} > 0$, $\bar{Q}_{2k} > 0$, $\bar{Q}_{3k} > 0$, $\bar{A}_{fj}$, $\bar{B}_{fj}$ and $\bar{C}_{fj}$, so that the following inequalities hold

$$\Xi = \begin{bmatrix} \bar{\Sigma}_1 & \bar{\Sigma}_2 \\ * & \bar{\Sigma}_3 \end{bmatrix} < 0 \qquad (11)$$

Then the fuzzy hybrid trigger H∞ fault detection filter parameters are

$$A_{fj} = V_1^{-1} \bar{A}_{fj} Z^{-1} W^{-T},\ B_{fj} = V_1^{-1} \bar{B}_{fj},\ C_{fj} = V_1^{-1} \bar{C}_{fj}$$

where,

$$\bar{\Sigma}_1 = \begin{bmatrix} \bar{\Phi}_{11} & \bar{\Phi}_{12} & 0 & \bar{\Phi}_{14} & 0 & 0 & \bar{\Phi}_{17} & \bar{\Phi}_{18} & \bar{\Phi}_{19} & \bar{\Phi}_{10} \\ * & -2\bar{R}_{1i} & \bar{R}_{1i} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ * & * & -\bar{Q}_{1k} - \bar{R}_{1i} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ * & * & * & \bar{\Phi}_{44} & \bar{R}_{2i} & 0 & 0 & 0 & 0 & 0 \\ * & * & * & * & -\bar{Q}_{2k} - \bar{R}_{2i} & 0 & 0 & 0 & 0 & 0 \\ * & * & * & * & * & -\bar{Q}_{3k} & 0 & 0 & 0 & 0 \\ * & * & * & * & * & * & -d\bar{R}_{3i} & 0 & 0 & 0 \\ * & * & * & * & * & * & * & -\bar{\Omega} & 0 & 0 \\ * & * & * & * & * & * & * & * & -\gamma^2 I & 0 \\ * & * & * & * & * & * & * & * & * & -I \end{bmatrix},$$

$$\bar{\Phi}_{11} = \Pi_{11} + \bar{Q}_{1i} + \bar{Q}_{2i} + \bar{Q}_{3i} - \bar{R}_{1i} - \bar{R}_{2i} + d\bar{R}_{3i},$$

$$\bar{\Phi}_{12} = \bar{\delta}\Pi_{12} + \bar{R}_{1i},\quad \bar{\Phi}_{14} = (1-\bar{\delta})\Pi_{14} + \bar{R}_{2i},$$

$$\bar{\Phi}_{44} = -2\bar{R}_{1i} + \sigma C_i^T \Omega C_i,\quad \bar{\Phi}_{18} = (1-\bar{\delta})\Pi_{18},$$

$$\Gamma_2 = \bar{\delta}\Pi_{12}^T,\ \Gamma_3 = \bar{\Phi}_{17}^T,\ \Gamma_4 = \bar{\delta}\Pi_{14}^T,\ \Gamma_5 = \bar{\Phi}_{18}^T,$$

$$\Pi_{11} = \begin{bmatrix} ZA_i + A_i^T Z & ZA_i + A_i^T U_1 + \bar{A}_{fj}^T & 0 \\ * & U_1 A_i + A_i^T U_1 & 0 \\ * & * & U_2 A_w + A_w^T U_2 \end{bmatrix},$$

$$\Pi_{12} = \begin{bmatrix} 0 & 0 & 0 \\ \bar{B}_{fj} C_i & \bar{B}_{fj} C_i & 0 \\ 0 & 0 & 0 \end{bmatrix},$$

$$\Pi_{14} = \begin{bmatrix} 0 & 0 & 0 \\ \bar{B}_{fj} C_i & \bar{B}_{fj} C_i & 0 \\ 0 & 0 & 0 \end{bmatrix},$$

$$\bar{\Phi}_{17} = \begin{bmatrix} ZA_{di} & U_1 ZA_{di} & 0 \\ U_1 A_{di} & U_1 A_{di} & 0 \\ 0 & 0 & 0 \end{bmatrix},\ \Pi_{18} = \begin{bmatrix} 0 & 0 & 0 \\ \bar{B}_{fj} & \bar{B}_{fj} & 0 \\ 0 & 0 & 0 \end{bmatrix},$$

$$\bar{\Sigma}_2 = \begin{bmatrix} \tau_M\Gamma_1 & \eta_M\Gamma_1 & 0 & 0 & \Gamma_5 & 0 & 0 & 0 \\ \tau_M\Gamma_2 & \eta_M\Gamma_1 & \tau_M\lambda\Gamma_2 & \eta_M\lambda\Gamma_2 & 0 & \Gamma_8 & 0 & \Gamma_{13} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \tau_M\Gamma_2 & \eta_M\Gamma_2 & \tau_M\lambda\Gamma_2 & \eta_M\lambda\Gamma_2 & 0 & \Gamma_9 & 0 & \Gamma_{14} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \tau_M\Gamma_3 & \eta_M\Gamma_3 & 0 & 0 & 0 & 0 & 0 & 0 \\ \tau_M\Gamma_4 & \eta_M\Gamma_4 & \tau_M\lambda\Gamma_4 & \eta_M\lambda\Gamma_4 & 0 & \Gamma_{10} & 0 & \Gamma_{15} \\ \tau_M\Gamma_5 & \eta_M\Gamma_5 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$\bar{\Sigma}_3 = \begin{bmatrix} \Xi_1 & 0 & 0 & 0 & \Gamma_6 & 0 & 0 & 0 \\ * & \Xi_2 & 0 & 0 & \Gamma_7 & 0 & 0 & 0 \\ * & * & \Xi_1 & 0 & 0 & 0 & \Gamma_{11} & 0 \\ * & * & * & \Xi_2 & 0 & 0 & \Gamma_{12} & 0 \\ * & * & * & * & -m_1 I & 0 & 0 & 0 \\ * & * & * & * & * & -m_2 I & 0 & 0 \\ * & * & * & * & * & * & -n_1 I & 0 \\ * & * & * & * & * & * & * & -n_2 I \end{bmatrix},$$

$$\bar{\Phi}_{19} = \begin{bmatrix} ZB_{1i} & ZB_{1i} \\ U_1 B_{2i} & V_1 B_{2i} \\ 0 & U_2 B_w \end{bmatrix},\quad \bar{\Phi}_{10} = \begin{bmatrix} 0 \\ \bar{C}_{fj}^T \\ -U_2 C_w^T \end{bmatrix},$$

$$\Gamma_1 = \begin{bmatrix} A_i^T Z & A_i^T U_1 + \bar{A}_{fj}^T & 0 \\ A_i^T Z & A_i^T U_1 & 0 \\ 0 & 0 & A_w^T U_2 \end{bmatrix},\quad n_2 = \frac{1}{n_1},$$

$$\Gamma_5 = \begin{bmatrix} \bar{B}_{fj} \\ 0 \\ 0 \end{bmatrix},\quad \Gamma_6 = \begin{bmatrix} 0 \\ \tau_M \bar{B}_{fj} \\ 0 \end{bmatrix},\quad \Gamma_7 = \begin{bmatrix} 0 \\ \eta_M \bar{B}_{fj} \\ 0 \end{bmatrix},$$

$$\Gamma_8 = \begin{bmatrix} \bar{\delta} C_i^T \\ \bar{\delta} C_i^T \\ 0 \end{bmatrix},\quad \Gamma_9 = \begin{bmatrix} (1-\bar{\delta}) C_i^T \\ (1-\bar{\delta}) C_i^T \\ 0 \end{bmatrix},\quad \Gamma_{10} = \begin{bmatrix} (1-\bar{\delta}) G^T \\ (1-\bar{\delta}) G^T \\ 0 \end{bmatrix},$$

$$\Gamma_{11} = \begin{bmatrix} 0 \\ \tau_M \bar{B}_{fj} \\ 0 \end{bmatrix},\quad \Gamma_{12} = \begin{bmatrix} 0 \\ \eta_M \bar{B}_{fj} \\ 0 \end{bmatrix},\quad \Gamma_{13} = \begin{bmatrix} \lambda C_i^T \\ \lambda C_i^T \\ 0 \end{bmatrix},$$

$$\Gamma_{14} = \begin{bmatrix} \lambda C_i^T \\ \lambda C_i^T \\ 0 \end{bmatrix},\quad \Gamma_{15} = \begin{bmatrix} \lambda G^T \\ \lambda G^T \\ 0 \end{bmatrix},\quad \Xi_1 = -2\mu_1 \bar{P} + \mu_1^2 \bar{R}_1,$$

$$\Xi_2 = -2\mu_2 \bar{P} + \mu_2^2 \bar{R}_2,\quad \lambda = \bar{\delta}(1-\bar{\delta}),\quad m_2 = \frac{1}{m_1}.$$

Proof: First, the following equation is obtained:

$$\Xi = \Xi_1 + sym\{H_B^T \Delta_h H_K\} + sym\{H_C^T \Delta_h H_J\} < 0 \qquad (12)$$

Define the following matrix:

$$P=\begin{bmatrix} U_1 & V_1 & 0 \\ V_1^T & V_2 & 0 \\ 0 & 0 & U_2 \end{bmatrix},\quad T_1=\begin{bmatrix} I & I & 0 \\ W^T Z & 0 & 0 \\ 0 & 0 & I \end{bmatrix},$$

$$T_2=\begin{bmatrix} Z & U_1 & 0 \\ 0 & V_1^T & 0 \\ 0 & 0 & U_2 \end{bmatrix}$$

Available $PT_1=T_2$, Using $\Lambda=diag\{T_1,T_1,T_1,T_1,T_1,T_1,T_1,T_1,I,I,T_1,T_1,T_1,T_1,I,I,I,I\}$ congruent transformation to (16), and variable substitution, $\bar{P}=T_1^T P T_1$, $\bar{Q}_{li}=T_1^T Q_{li} T_1$, $\bar{R}_{li}=T_1^T R_{li} T_1 (l=1,2,3)$, $\bar{A}_{fj}=V_1 A_{fj} W^T Z$, $\bar{B}_{fj}=V_1 B_{fj}$, $\bar{C}_{fj}=C_{fj} V_1^T$, therefore, it is easy to obtain inequality (11), and the theorem is proved.

5. Numerical Simulation

Consider a T-S fuzzy fault detection filtering error system with distributed delay and quantization, and its coefficient matrix as follows:

$$A_1=\begin{bmatrix} -3 & 0.2 & 0.4 \\ 0.3 & -1.7 & 0.2 \\ 0 & 0.5 & -2.5 \end{bmatrix},$$

$$A_2=\begin{bmatrix} -2.7 & 0.3 & 0.6 \\ 0.2 & -1.5 & 0.8 \\ 0.3 & 0.4 & -2.4 \end{bmatrix},$$

$$A_{d1}=\begin{bmatrix} 0.2 & 0.4 & 0.7 \\ 0.9 & 0.5 & 0.8 \\ 0.1 & -0.9 & 0.3 \end{bmatrix},$$

$$A_{d2}=\begin{bmatrix} 0.2 & 0.6 & 0.1 \\ 0.2 & 0.4 & 0.8 \\ 0.4 & -0.1 & 0.6 \end{bmatrix},\quad B_{11}=\begin{bmatrix} 0.5 \\ 0.8 \\ 0.6 \end{bmatrix},$$

$$B_{21}=\begin{bmatrix} 0.3 \\ 0.4 \\ 0.4 \end{bmatrix},\quad B_{12}=\begin{bmatrix} 0.4 \\ 0.5 \\ 0.4 \end{bmatrix},\quad B_{22}=\begin{bmatrix} -0.1 \\ 0.7 \\ 0.9 \end{bmatrix},$$

$$C_1=\begin{bmatrix} 1 & 0.1 & 0.2 \end{bmatrix},\quad C_2=\begin{bmatrix} 1.2 & -0.9 & 0.2 \end{bmatrix}.$$

The residual evaluation function and threshold are shown in Figure 1, and the residual error signal is shown in Figure 2. The detection threshold obtained by the residual evaluation function and the threshold formula is $J_{th}=0.3675$, when the fault occurs at the moment, $J(30)=0.7613>J_{th}$. Therefore, the fault detection filter can accurately detect the fault.

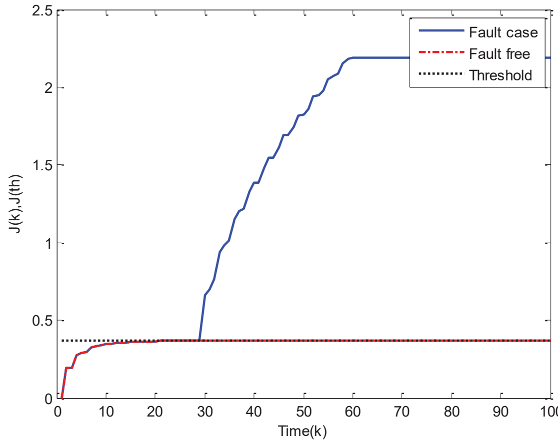

Figure 1. Residual evaluation function and threshold

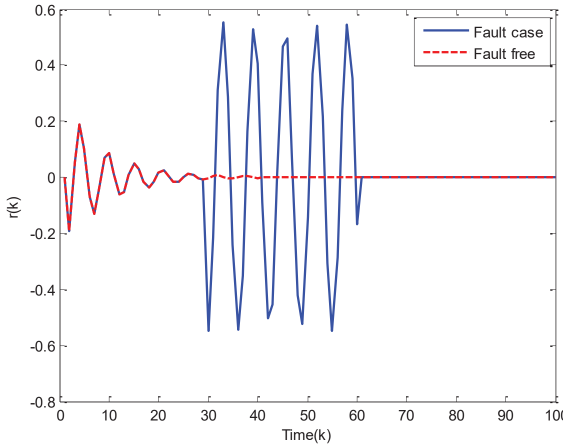

Figure 2. Residual error signal

6. Conclusion

This paper studies the H∞ fuzzy fault detection problem of a class of nonlinear systems under a hybrid triggering scheme consisting of time-triggered and event-triggered schemes. A random variable satisfying Bernoulli distribution is used to describe the random switching between the two triggering schemes. In particular, by designing a filter to generate the residual signal, the fault detection problem is transformed into a filter design problem, and the mean square asymptotic stability of the fuzzy fault detection system is guaranteed. The gain of the fault detection filter in the hybrid triggering scheme is obtained.

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