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Robust Fault Detection for Continuous-Time Networked Control System

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ABSTRACT *- This paper focus on continuous-time and discrete-time networked control systems. A full order fault filter and observer-based fault detection scheme are introduced to generate the residual signal. New models for continuous-time or discrete-time with faults are established correspondingly, and design the controller and fault detection filter at the same time, because it will improve the detectability of the fault and the reliability of the fault detection. The designed residue generator could ensure the sensitivity of the residual to fault and simultaneously guarantee the robustness of residual signal to the disturbance signal, and can also detect the occurrence of faults in time. At last, some examples are given to illustrate the approaches are feasible.*

KEYWORDS: *Networked control systems; fault detection; communication constraint; delay; packet dropout; convex analysis.*

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I INTRODUCTION

Networked Control System (NCS) is a control system composed of sensors, controllers and actuators and other components connected through a network [1]. For NCS, failures are inevitable. The occurrence of failure will reduce the performance of the system and even make the system unstable. Detecting the occurrence of failures in a timely and accurate manner is crucial to improve the security and stability of the system [2]. In recent years, NCS fault detection has received more and more attention. For example, [3] studied a class of network-based robust fault detection problems for uncertain discrete-time T-S fuzzy systems with random mixed delay and continuous packet loss. For a networked predictive control system with random network induced delay and clock asynchrony, [4] proposed a fault detection and compensation method. In [5], a robust fault detection problem based on full-order filters is studied for discrete systems with norm bounded uncertainties and state delays. Literature [6] studies the problem of fault detection in network control systems with uncertain network induced delays. Literature [7] discusses the problem of fault detection in networked control systems for discrete-time systems.

Because of its simple installation and maintenance, low cost, high reliability and other advantages, the network control system has been widely concerned. Its complexity and degree of automation have become higher and higher with the continuous development of science and technology. This will increase the production efficiency and reduce the production cost. At the same time, it will increase the possibility of system failure. The reliability, maintainability and safety of these large-scale systems are extremely important. Fault detection technology has opened up a new path for improving system maintainability and reliability. However, due to the intervention of the network, traditional fault detection methods cannot be directly applied to the research of network control system fault detection. This is a challenge and opportunity for network control system research [8].

In addition, in many existing network control systems, due to the limitation of communication bandwidth and nodes, only some actuators and sensors can obtain communication authority. Literature [9] considers the problem of communication restrictions in discrete-time network control systems. For the fault detection problem of continuous-time network control systems, how to improve the sensitivity of the fault detection system to fault signals considering the communication limitations is another starting point of this paper.

Considering sensor-to-controller network induced delays and data loss, as well as controller-to-actuator communication constraints, this paper studies the design of fault detection filters for continuous-time network control systems. By defining suitable Lyapunov functionals and using convex analysis methods, a new design criterion for fault detection filters is proposed.

This section focuses on continuous-time network control systems with network-induced delays, data loss, and communication limitations. It investigates the problem of data loss and delay between sensors and controllers and communication limitations between controllers and actuators. Stick fault detection problem. Firstly, a control system model with corresponding network characteristics is established, an observer-based fault detection filter is constructed to generate a residual signal, and a corresponding continuous-time residual dynamic system is established. By defining suitable Lyapunov functionals and using convex analysis methods, a new design rule for fault detection filters is proposed. Theoretical analysis shows that the proposed fault detection filter design criteria are less conservative. The designed fault detection filter not only ensures the residual system's sensitivity to faults, but also guarantees the robustness of the external disturbance input to the system. Numerical examples verify that the method proposed in this section is feasible.

II PROBLEM FORMULATION

In this paper: R^n denotes an n -dimensional Euclidean space; $R^{n\times m}$ denotes an $n \times$ m real matrix; I and 0 denotes an identity matrix and a zero matrix with appropriate dimensions, respectively; * denotes an item that is omitted from the symmetrical part of the matrix.

Consider the following continuous-time controlled objects

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu_p(t) + E_1 d(t) + E_2 f(t) \\ y_p(t) = Cx(t) \end{cases} \tag{1}$$

where $x(t)\epsilon R^n$, $u_p(t)\ \epsilon R^r$, $y_p(t)\epsilon R^m$, the system status, control input, and measurement output are $d(t)\epsilon R^p$ for system disturbances and $d(t)\epsilon L_2[0,\infty)$, $f(t)\epsilon R^s$ fault signal, A, B, C, E_1, E_2 it is a known real matrix with appropriate dimensions.

A typical closed-loop network control system is shown in Figure 1. Due to network congestion and other unpredictable network conditions, network-induced delay, data loss, and communication restrictions may exist at the same time. Therefore, this section investigates the network-induced delay and data packet loss between the sensor and the controller, as well as the problem of communication restrictions between the controller and the actuator. Below, several assumptions about the network are given:

Assumption 1. The sensor is clocked and the sampling period is h. The controller and actuator are event driven.

Assumption 2. The network-induced delay between sensor-to-controller is τ_k which is time-varying and bounded (can exceed the length of one sampling period). The upper bound of the number of continuous packet loss is δ.

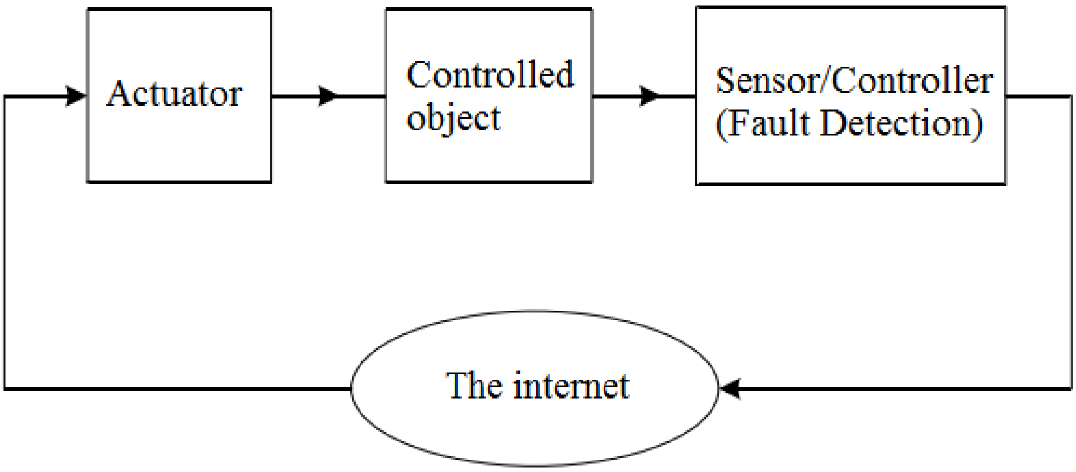

Figure 1. The illustration of fault detection for NCSs

The modeling of the system is described as follows: For the system (Figure 1), if the time delay and packet loss of the sensor-to-controller and controller-to-actuator networks are taken into account as well as the sensor-to-controller communication restrictions, the residuals Producing a model of the system can become quite complex [10]. Therefore, this section only considers the sensor-to-controller network-induced delay and data loss, as well as the controller-to-actuator communication constraints.

First, consider the sensor to the controller of the network-induced delay and data packet loss.

It is assumed in $t_k, t_{k+1}, \dots, (k = 0,1,2, \dots)$, $y_p(t)$ been successfully sampled and transmitted to the fault detection filter, and in the t_k and t_{k+1} between the sampling data in the event of packet loss. In t, assume that the sensor sampling of the measurement output signal transmitted through the network to the fault detection filter time required for τ_k, wherein $\tau_k \epsilon [\tau_m, \tau_M)$. Then, in $t \epsilon [t_k + \tau_k, t_{k+1} + \tau_{k+1})$

$$y_p(t) = y_p(t_k) = Cx(t_k) \tag{2}$$

Definition $\tau(t) = t - t_k$, then $\tau(t) \epsilon [\tau_m, \tau_1), \tau_1 = (\delta + 1)\hbar + \tau_M$, wherein δ for continuous packet loss the number of upper bound, $\hbar$ is the sampling period length. Then, when $t \epsilon [t_k + \tau_k, t_{k+1} + \tau_{k+1})$

$$y_p(t) = y_p(t_k) = y_p\big(t - \tau(t)\big) \tag{3}$$

For the above considered system (1), an observer-based continuous-time fault detection filter is constructed as follows.

$$\begin{cases} \dot{\hat{x}}(t) = A\hat{x}(t) + B\tilde{u}(t) + L\left(y_p(t) - \hat{y}(t)\right) \\ \hat{y}(t) = C\hat{x}(t) \\ \tilde{u}(t) = K\hat{x}(t) \\ r(t) = V\left(y_p(t) - \hat{y}(t)\right) \end{cases} \tag{4}$$

where $\hat{x}(t)$, $\tilde{u}(t)$, $\hat{y}(t)$ respectively, for the fault detection filter of the state, control input and measurement output; L, V is to design the fault detection filter gain matrix; K is to design The controller gain matrix; $r(t)$ for the residual signal.

Considering $y_p(t)$ is sampled and transmitted over the network to the fault detection filter. So when $t\epsilon[t_k +$ *τk, tk+1+τk+1* time, formula (4) in *ypt=ypt−τt.*

Consider the following network control system controller-to-actuator communication constraints [11].

When there is a communication restriction between the controller and the actuator, assume that the shared communication medium can provide $W_\alpha (1 \le W_\alpha \le r)$ controller to actuator communication channel. At any time, $\tilde{u}(t)$ only in W_α the amount of control can be transmitted over the communication channel, the rest of the components that do not have communication rights are discarded. Define binary variable $\theta_i (i = 1,2, \dots, r)$ for $\tilde{u}(t)$ in the first i one of the elements of the medium access status, that $\theta_i \epsilon \{0,1\}$, wherein *'1'* indicates successful transmission, *'0'* indicates the failed transmission. When $\theta_i = 0$, the actuator will be ignored $\tilde{u}(t)$ in the first i elements, and with *'0'* instead of the first i one of the elements of the value. At this time

$$u_p(t) = W_\theta \tilde{u}(t) = W_\theta K\hat{x}(t) \tag{5}$$

in the formula $W_\theta = diag(\theta_1, \theta_2, \dots, \theta_r)$, wherein $\theta_i = 0$ or $\theta_i = 1, (i = 1,2, \dots, r)$.

Define the state error $e(t) = x(t) - \hat{x}(t)$, residual error $r_e(t) = r(t) - f(t)$, then by the formula (1)-(5) to obtain the augmented system.

$$\begin{cases} \dot{\xi}(t) = \tilde{A}\xi(t) + \tilde{B}\xi\big(t - \tau(t)\big) + \tilde{E}\omega(t) \\ r_e(t) = \tilde{C}\xi(t) + \tilde{D}\xi\big(t - \tau(t)\big) + \tilde{F}\omega(t) \end{cases} \tag{6}$$

The formula

$$\xi(t) = [e^T(t) \;\; x^T(t)]^T, \quad \omega(t) = [d^T(t) \;\; f^T(t)]^T$$

$$\tilde{A} = \begin{bmatrix} A - LC - BW_\theta K + BK & LC + BW_\theta K - BK \\ -BW_\theta K & A + BW_\theta K \end{bmatrix}$$

$$\tilde{B} = \begin{bmatrix} 0 & -LC \\ 0 & 0 \end{bmatrix}, \quad \tilde{E} = \begin{bmatrix} E_1 & E_2 \\ E_1 & E_2 \end{bmatrix}, \quad \tilde{C} = [VC \;\; -VC],$$

$$\tilde{D} = [0 \;\; VC], \quad \tilde{F} = [0 \;\; -I]$$

The robust fault detection filter designed in this section can be solved by transforming it into the following problem: Under zero initial conditions, the filter constructed by equation (4) above is to make the augmented system (1) asymptotically stable. , and meet the performance criteria shown in formula (6):

$$\|r_e(t)\|_2 < \gamma \|\omega(t)\|_2 \tag{7}$$

Is given by the following residual evaluation function and threshold value for fault detection.

Based on the designed residual production system, the following residual evaluation function is defined:

$$J(r) \triangleq \left(\int_0^t r^T(s) r(s) ds\right)^{\frac{1}{2}} \tag{8}$$

Select the following threshold function [12]

$$J_{th} = \sup_{\omega(t) \in L_2, f(t)=0} J(r) \tag{9}$$

The fault detection logic is as follows

$$\begin{aligned} J(r) > J_{t\hbar} &\Rightarrow fault \\ J(r) \le J_{t\hbar} &\Rightarrow no\ fault \end{aligned} \tag{10}$$

III MAIN RESULTS

In this section, a new fault detection filter design criterion is given by defining an appropriate Lyapunov functional and using convex analysis methods.

Theorem 1. for a given scalar τ_m, τ_M, δ and $\hbar$, a sufficient condition for the augmented system (1) to be asymptotically stable and has an H_∞ performance index γ is the existence of a symmetric positive definite matrix W, $\tilde{Q}_1$, $\tilde{Q}_2$, $\tilde{R}_1$, $\tilde{R}_2$, matrix $\bar{K}, \bar{L}, \bar{V}$, make the following formula true.

$$\begin{bmatrix} \tilde{\Pi}_{11}^i & \tilde{\Pi}_{12} \\ * & \tilde{\Pi}_{22} \end{bmatrix} < 0 \qquad (11)$$

$$WC^T = C^T N \qquad (12)$$

wherein

$$\tilde{\Pi}_{11}^i = \tilde{\Pi} - \tilde{\beta}_i, \ i = 1,2, \ \tilde{\Pi}_{12} = [\tilde{\Delta}_1 \quad \tilde{\Delta}_1 \quad \tilde{\Delta}_2],$$
$$\tilde{\Pi}_{22} = diag\{\tau_m^{-2}(\tilde{R}_1 - 2\gamma), \ (\tau_1 - \tau_m)^{-2}(\tilde{R}_2 - 2\gamma), -\gamma I\}$$

and

$$\tilde{\Pi} = \begin{bmatrix} \tilde{\Omega}_{11} & \tilde{R}_1 & H_2^T & 0 & \tilde{E} \\ * & \tilde{\Omega}_{22} & \tilde{R}_2 & 0 & 0 \\ * & * & \tilde{\Omega}_{33} & \tilde{R}_2 & 0 \\ * & * & * & \tilde{\Omega}_{44} & 0 \\ * & * & * & * & -\gamma I \end{bmatrix}$$

$$\tilde{\beta}_1 = J_1^T \tilde{R}_2 J_1, \ \tilde{\beta}_2 = J_2^T \tilde{R}_2 J_2,$$
$$\tilde{\Delta}_1 = [H_1^T \quad 0 \quad H_2^T \quad 0 \quad \tilde{E}]^T$$
$$\tilde{\Delta}_2 = [H_3^T \quad 0 \quad H_4^T \quad 0 \quad \tilde{F}]^T$$

and

$$\tilde{\Omega}_{11} = H_1 + H_1^T + \tilde{Q}_1 + \tilde{Q}_2 - \tilde{R}_1, \ \tilde{\Omega}_{22} = -\tilde{Q}_1 - \tilde{R}_1 - \tilde{R}_2,$$
$$\tilde{\Omega}_{33} = -2\tilde{R}_2, \ \tilde{\Omega}_{44} = -\tilde{Q}_2 - \tilde{R}_2,$$
$$J_1 = [0 \quad 0 \quad I \quad -I \quad 0], \ J_2 = [0 \quad I \quad -I \quad 0 \quad 0],$$
$$H_1 = \begin{bmatrix} WA^T - C^T\bar{L} - \bar{K}W_\theta^T B^T + \bar{K}B^T & -\bar{K}W_\theta^T B^T \\ C^T\bar{L} + \bar{K}W_\theta^T B^T - \bar{K}B^T & WA^T + \bar{K}W_\theta^T B^T \end{bmatrix}$$
$$H_2 = \begin{bmatrix} -C^T\bar{L} & 0 \\ 0 & 0 \end{bmatrix}, \ H_3 = \begin{bmatrix} C^T\bar{V} \\ -C^T\bar{V} \end{bmatrix}, \ H_4 = \begin{bmatrix} 0 \\ C^T\bar{V} \end{bmatrix}, \gamma = \begin{bmatrix} W & 0 \\ 0 & W \end{bmatrix}$$

And the filter gain matrix $L = \bar{L}^T N^{-T}$, $V = \bar{V}^T N^{-T}$, controller gain matrix $K = \bar{K}^T W^{-T}$.

Prove: Construct the following Lyapunov functional

$$V(t,\xi_t) = \sum_{i=1}^{3} V_i(t,\xi_t) \qquad (13)$$

wherein

$$V_1(t,\xi_t) = \xi^T(t)P\xi(t)$$
$$V_2(t,\xi_t) = \int_{t-\tau_m}^{t} \xi^T(s)Q_1\xi(s)ds + \int_{t-\tau_1}^{t} \xi^T(s)Q_2\xi(s)ds$$
$$V_3(t,\xi_t) = \tau_m \int_{-\tau_m}^{0}\int_{t+s}^{t} \bar{\xi}^T(\theta)R_1\bar{\xi}(\theta)d\theta ds + (\tau_1 + \tau_m)\int_{-\tau_1}^{-\tau_m}\int_{t+s}^{t} \bar{\xi}^T(\theta)R_2\bar{\xi}(\theta)d\theta ds$$

P, Q_1, Q_2, R_1, R_2 it is a symmetrical positive definite matrix with proper dimensions. For the system (1), $V(t,\xi_t)$ the time derivative is

$$V_1(t,\xi_t) = 2\xi^T(t)P\bar{\xi}(t) = 2\xi^T(t)P\tilde{A}\xi(t) + 2\xi^T(t)P\tilde{B}\xi(t-\tau(t)) + 2\xi^T(t)P\tilde{E}\omega(t)$$
$$V_2(t,\xi_t) = \xi^T(t)(Q_1 + Q_2)\xi(t) - \xi^T(t-\tau_m)Q_1\xi(t-\tau_m) - \xi^T(t-\tau_1)Q_2\xi(t-\tau_1)$$
$$V_3(t,\xi_t) = \bar{\xi}^T(t)\Theta\bar{\xi}(t) - \tau_m \int_{t-\tau_m}^{t} \bar{\xi}^T(\theta)R_1\bar{\xi}(\theta)d\theta - (\tau_1 - \tau_m)\int_{t-\tau_1}^{t-\tau_m} \bar{\xi}^T(\theta)R_2\bar{\xi}(\theta)d\theta$$

wherein $\Theta = \tau_m^2 R_1 + (\tau_1 - \tau_m)^2 R_2$.

Available from Jensen inequality [13]

$$-\tau_m \int_{t-\tau_m}^{t} \bar{\xi}^T(\theta)R_1\bar{\xi}(\theta)d\theta \le -[\xi(t) - \xi(t-\tau_m)]^T R_1[\xi(t) - \xi(t-\tau_m)] -$$

$$-(\tau_1 - \tau_m)\int_{t-\tau_1}^{t-\tau_m} \bar{\xi}^T(\theta)R_2\bar{\xi}(\theta)d\theta = -(\tau_1 - \tau(t))\int_{t-\tau(t)}^{t-\tau_m} \bar{\xi}^T(\theta)R_2\bar{\xi}(\theta)d\theta$$
$$-(\tau(t) - \tau_m)\int_{t-\tau(t)}^{t-\tau_m} \bar{\xi}^T(\theta)R_2\bar{\xi}(\theta)d\theta$$

$$-\big(\tau_1-\tau(t)\big)\int_{t-\tau_1}^{t-\tau(t)}\bar{\xi}^T(\theta)R_2\bar{\xi}(\theta)d\theta$$
$$-(\tau(t){-}\tau_m)\int_{t-\tau_1)}^{t-\tau(t)}\bar{\xi}^T(\theta)R_2\bar{\xi}(\theta)d\theta$$

Define scalar $\rho=(\tau(t){-}\tau_m)/(\tau_1-\tau_m)$, the above formula is simplified to

$$-(\tau(t){-}\tau_m)\int_{t-\tau_1)}^{t-\tau(t)}\bar{\xi}^T(\theta)R_2\bar{\xi}(\theta)d\theta\le-\rho\tilde{\xi}^T(t)J_1^TR_2J_1\tilde{\xi}(t) \tag{14}$$
$$-\big(\tau_1-\tau(t)\big)\int_{t-\tau(t)}^{t-\tau_m}\bar{\xi}^T(\theta)R_2\bar{\xi}(\theta)d\theta\le-(1-\rho)\tilde{\xi}^T(t)J_2^TR_2J_2\tilde{\xi}(t) \tag{15}$$

And

$$-\big(\tau_1-\tau(t)\big)\int_{t-\tau_1}^{t-\tau(t)}\bar{\xi}^T(\theta)R_2\bar{\xi}(\theta)d\theta\le-\tilde{\xi}^T(t)J_1^TR_2J_1\tilde{\xi}(t) \tag{16}$$
$$-(\tau(t){-}\tau_m)\int_{t-\tau(t)}^{t-\tau_m}\bar{\xi}^T(\theta)R_2\bar{\xi}(\theta)d\theta\le-\tilde{\xi}^T(t)J_2^TR_2J_2\tilde{\xi}(t) \tag{17}$$

Where $\tilde{\xi}(t)$ is the same as in (18), and
$J_1=[0\quad 0\quad I\quad -I\quad 0]$, $\quad J_2=[0\quad I\quad -I\quad 0\quad 0]$,
Consider the system(1) and $V(t,\xi_t)$ the time derivative, can be obtained

$$\dot{V}(t,\xi_t)+\gamma^{-1}r_e^T(t)r_e(t)-\gamma\omega^T(t)\omega(t)\le\tilde{\xi}^T(t)[\rho\kappa_1+(1-\rho)\kappa_2]\tilde{\xi}(t) \tag{18}$$

Wherein

$$\tilde{\xi}(t)=[\xi^T(t)\quad \xi^T(t-\tau_m)\quad \xi^T(t-\tau(t))\quad \xi^T(t-\tau_1)\quad \omega^T(t)]^T$$
$$\kappa_1=(\Pi+\Xi)-\beta_1,\qquad \kappa_2=(\Pi+\Xi)-\beta_2$$

and

$$\Pi=\begin{bmatrix}\Omega_{11} & R_1 & P\tilde{B} & 0 & P\tilde{E}\\ * & \Omega_{22} & R_2 & 0 & 0\\ * & * & \Omega_{33} & R_2 & 0\\ * & * & * & \Omega_{44} & 0\\ * & * & * & * & -\gamma I\end{bmatrix}$$

$\Xi=\Phi_1^T\Theta\Phi_1+\gamma^{-1}\Phi_2^T\Phi_2$, $\beta_1=J_1^TR_2J_1$, $\beta_2=J_2^TR_2J_2$,
$\Omega_{11}=\tilde{A}^TP+P\tilde{A}+Q_1+Q_2-R_1$, $\Omega_{22}=-Q_1-R_1-R_2$, $\Omega_{33}=-2R_2$, $\Omega_{44}=-Q_2-R_2$

$$\Phi_1=[\tilde{A}\quad 0\quad \tilde{B}\quad 0\quad \tilde{E}],\qquad \Phi_2=[\tilde{C}\quad 0\quad \tilde{D}\quad 0\quad \tilde{F}],$$
$$J_1=[0\quad 0\quad I\quad -I\quad 0],\qquad J_2=[0\quad I\quad -I\quad 0\quad 0],$$

By a scalar ρ the definition shows that $\rho\epsilon[0,1)$. Convex analysis method, $\rho\kappa_1+(1-\rho)\kappa_2$ is convex, when $\kappa_1<0,\kappa_2<0$, we can get $\rho\kappa_1+(1-\rho)\kappa_2<0$, this ensures that

$$V(t,\xi_t)+\gamma^{-1}r_e^T(t)r_e(t)-\gamma\omega^T(t)\omega(t)<0 \tag{19}$$

In addition $\kappa_1<0,\kappa_2<0$ is equivalent to the following inequality group

$$\begin{cases}\Pi+\Xi-\beta_1<0\\ \Pi+\Xi-\beta_2<0\end{cases} \tag{20}$$

The schur complement theorem, formula (19) can be equivalently described as

$$\begin{bmatrix}\Pi_{11}^i & \Pi_{12}\\ * & \Pi_{22}\end{bmatrix}<0 \tag{21}$$

Wherein

$$\Pi_{11}^i=\Pi-\beta_i,\qquad i=1,2$$
$$\Pi_{12}=[\Delta_1\quad \Delta_1\quad \Delta_2]$$
$$\Pi_{22}=diag\{-\tau_m^{-2}R_1^{-1},\quad -(\tau_1-\tau_m)^{-2}R_2^{-1},\quad -\gamma I\}$$

Matrix Π, θ_i with the previously defined matrix is the same, and

$$\Delta_1=[\tilde{A}\quad 0\quad \tilde{B}\quad 0\quad \tilde{E}]^{\mathrm{T}},\qquad \Delta_2=[\tilde{C}\quad 0\quad \tilde{D}\quad 0\quad \tilde{F}]^{\mathrm{T}}$$

Assumed $P=\begin{bmatrix}S & 0\\ 0 & S\end{bmatrix}$, $P^{-1}=\begin{bmatrix}S^{-1} & 0\\ 0 & S^{-1}\end{bmatrix}$, and there is a matrix N that satisfies $S^{-1}C^T=C^TN$. Respectively, the formula (21) the left multiplication, right multiplication matrix $diag\Big\{\underbrace{P^{-1},\dots,P^{-1}}_{4},\underbrace{I,\dots,I}_{4}\Big\}$ and its transposition.

Definition $S^{-1}=W,P^{-1}Q_iP^{-1}=\tilde{Q}_i,P^{-1}R_iP^{-1}=\tilde{R}_i$,
$WK^T=\bar{K}$, $NL^T=\bar{L}$, $NV^T=\bar{V}$. Considering $-R_i^{-1}\le P^{-1}R_iP^{-1}-2P^{-1}$, we can conclude that when the formula (11) and (12) holds, $\Pi+\Xi-\beta_i<0$ also true, this also ensures that formula (19) holds.

By H_∞ performance definition, when $\omega(t)=0$, theorem 1 the fault detection filter guidelines to ensure that the system (1) asymptotically stable, when $\omega(t)\ne0,\|r_e(t)\|_2<\gamma\|\omega(t)\|_2$. Therefore, when the formula (11) and (12) are satisfied at the same time, system (1) is asymptotically stable and has an H_∞ performance index γ. Theorem 1 is proved.

Notes 1. Using the convex analysis method, Theorem 1 proposes a new design criterion for fault detection filters. The literature [14] proved that the convex analysis method can guarantee less conservativeness. Therefore, compared with the results without considering the convex analysis method, the design criteria of the fault detection filter proposed in this section are less conservative.

IV NUMERICAL EXAMPLE

This section will illustrate the effectiveness of the proposed method through simulation examples. Consider the continuous-time system (1) with a parameter matrix of

$$A = \begin{bmatrix} 0.4 & -0.5 \\ 0.1 & -0.2 \end{bmatrix}, \quad B = \begin{bmatrix} 0.5 & 0 \\ 0.2 & -0.2 \end{bmatrix},$$
$$C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \quad E_1 = \begin{bmatrix} 0.7 \\ 0.3 \end{bmatrix}, \quad E_2 = \begin{bmatrix} -0.1 \\ 0.2 \end{bmatrix}$$

Suppose $h = 1s, t_m = 0.05s, t_M = 0.3s, \delta = 3,$ controller to the actuator between the presence of communication limitations, we assume that the W_θ will be at $W_{\theta 1} = diag(1,0)$ and $W_{\theta 2} = diag(0,1)$ between the random switch. Use this section to propose a to design robust fault detection filter, get a Filter parameter matrix as follows:

when $W_{\theta 1} = diag(1,0)$ time, $\gamma_{min} = 1.0188,$

$$K_1 = \begin{bmatrix} -6.6069 & 3.5843 \\ -1.9660 & 0.5656 \end{bmatrix}, \quad L_1 = \begin{bmatrix} 0.6069 & 0.0689 \\ 0.1441 & 0.2374 \end{bmatrix},$$
$$V_1 = [-0.0053 \quad 0.0010]$$

when $W_{\theta 2} = diag(0,1)$ time, $\gamma_{min} = 1.0327,$

$$K_2 = \begin{bmatrix} -1.5865 & 1.8787 \\ -13.9012 & 14.9379 \end{bmatrix}, \quad L_2 = \begin{bmatrix} 0.0907 & -0.1243 \\ 0.1648 & -0.0715 \end{bmatrix},$$
$$V_2 = [0.0020 \quad 0.0000]$$

Assume that the initial state of the augmentation system (1) is $\xi(0)=[0.3 \;\; -0.3 \;\; 0.8 \;\; 1]^T$, within a limited time interval [0,3], external disturbance signal is taken as a sine wave signal with amplitude 1 (Figure 2), assume that the system fails between 0.5s and 1.5s, and the fault signal is Gaussian white noise (Figure 3).

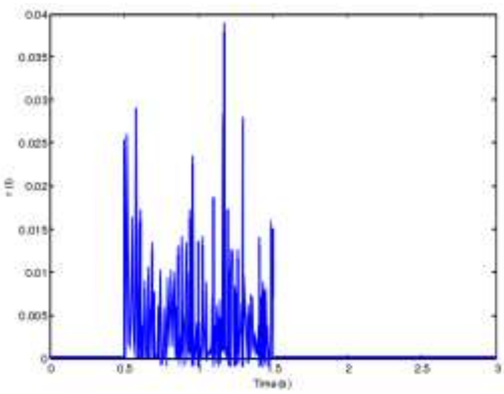

Figure 2. Residual signal

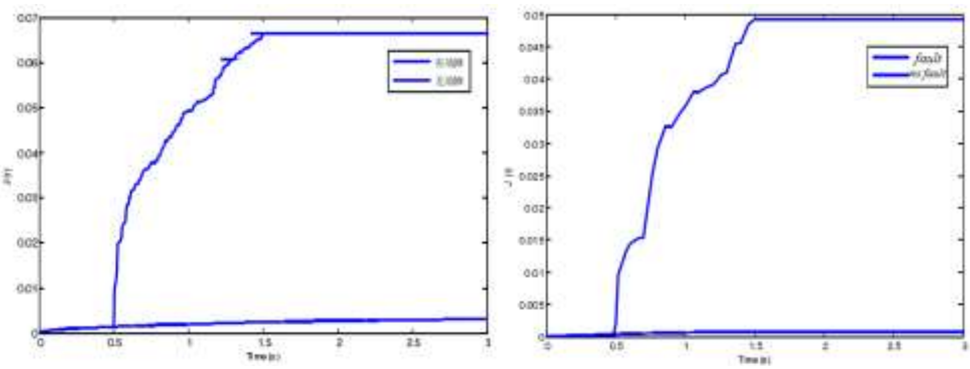

Figure 3. Residual evaluation function

Figure 2 shows the output of the residual error detection filter when there is a fault signal. Figure 3 shows the variation curve of the residual error evaluation function when there is a fault and no fault. As can be seen from figure (3), the fault detection filter designed in this section can quickly detect the occurrence of a fault and has good robustness to external disturbances.

V CONCLUSION

This paper addresses the problem of fault detection for a continuous-time network control system where the sensor-to-controller network-induced delay and data packet loss and controller-to-actuator communication limitations exist. On the basis of fully considering the network-induced characteristics, an observer-based fault detection filter is used to generate a residual signal. Based on this, a fault detection model of a continuous-time network control system is established. Using convex analysis method, a new design rule for fault detection filter is proposed. The designed fault detection system not only ensures the residual's sensitivity to the fault, but also ensures the robustness of the disturbance input to the system. A numerical example verifies that the fault detection method proposed in this section is effective.

REFERENCES

[1]. J. Liu and D. Yue, Event-based fault detection for networked systems with communication delay and nonlinear perturbation, Journal of the Franklin Institute, 2013, 350(9): 2791–2807.

[2]. Z. Mao, B. Jiang, P Shi. H_∞ Fault detection filter design for networked control systems modelled by discrete Markovian jump systems. IET Control Theory and Application, 2007, 1(5): 1336-1343.

[3]. X. He, Z. D. Wang, D. H. Zhou. Robust fault detection of networked systems with communication delay and data missing. Automatica, 2009, 45(11): 2634-2639.

[4]. X. He, Z. D. Wang, Y. D. Ji, et al. Robust Fault Detection of Networked Systerms with Distributed Sensors [J]. IEEE Transactions on Aerospace and Electronic Systems, 2011, 47(1): 166-177.

[5]. X. M. Qi, C. J. Zhang. Robust H_∞ fault detection filter for networked control system with network-induced uncertainties.Proceeding of the IEEE International Conference on Automation and Logistics, Zhengzhou, 2012: 172-177.

[6]. Y. Q. Wang, H. Ye, G. Z. Wang. Fault detection of NCS based on eigendecomposition, adaptive evaluation and adaptive threshold [J]. International Journal of Control, 2007, 80(12): 1903-1911.

[7]. H. Ye, R. He, H. Liu, et al. A new approach for fault detection of networked control systems [C]. Proceedings of 14th Symposium on System Identification. Newcastle, Australia: IFAC, 2006: 654 -659.

[8]. Y. L. Wang, Q. L. Han. Observer-based continuous-time networked control system design [C]. Proceedings of the American Control Conference. Piscataway, NJ, USA: IEEE, 2012: 5694-5699.

[9]. K. Gu, J. Chen, V. L. Kharitonov. Stability of time-delay systems [M]. Berlin: Springer, 2003.

[10]. P. M. Frank, X. Ding. Survey of robust residual generation and evaluation methods in observer-based fault detection systems [J]. Journal of Process Control, 1997, 7(6): 403-424.

[11]. Y. L. Wang, G. H. Yang. Robust H_∞ model reference tracking control for networked control systems with communication constraints [J]. International Journal of Control, Automation and Systems, 2009, 7(6): 992-1000.

[12]. Y. L. Wang, Q. L. Han. Modelling and observer-based H_∞ controller design for networked control systems [J]. IET Control Theory & Applications, 2014, 8(15): 1478-1486.

[13]. W. Jiang, C. Dong, E.Niu and Q. Wang. Observer-Based Robust Fault Detection Filter Design and Optimization for Networked Control Systems [J]. Mathematical Problems in Engineering, 2015, 9(6): 147-152.

[14]. X. Wan, H. Fang, and S. Fu. Observer-based fault detection for networked discrete-time infinite-distributed delay systems with packet dropouts. Applied Mathematical Modelling. Simulation and Computation for Engineering and Environmental Systems, 2012, 36(1): 270–278.

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