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The Study for Guaranteed Cost Fault Tolerant Control of the Networked Control Systems

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***Abstract*—In this paper, the problem of guaranteed cost fault-tolerant control for networked control systems (NCSs) is discussed based on Lyapunov stability theory and Linear Matrix Inequality (LMI). The sufficient conditions possessing robust integrity against actuator failures are given by adopting memory state feedback control law, which can meet a cost function for closed-loop networked control systems, and the robust fault-tolerant controller is designed .At last, the numerical example is given, which can demonstrate the effectiveness and feasibility of the proposed approach.**

***Index Terms* − guaranteed cost control, robust fault-tolerant control, networked control systems, LMI**

I. INTRODUCTION

With the development of the technology about computer and network, the reduction of the cost of hardware and software, the structure of control systems trend towards the networked, open and intelligent direction gradually. The feedback control systems wherein the control loops are closed through a real-time network called networked control systems (NCSs) [1]. The outstanding feature of the NCSs is the character of sharing resources among the control nodes, which it compared with the traditional control system has more advantages, such as remote operation and easy controlling, fault diagnosis, and simple installation and maintenance and so on[2][3]. However，the issues such as the time delay, packet dropout, congestion, which exist in the NCSs, bring new challenge to the conventional control theory, so the analysis and synthesis of NCSs is necessary to explore take into account a balance between control performance and network services new ways of performance.

Networked control systems have been widely used in aerospace, large-scale transport, production and processing of complicated control systems [4], and such systems require the higher security and reliability and therefore the NCSs which has a fault tolerant ability performance indicators is no longer a system of additional requirements, which have begun to attract a high degree of attention in academic circle [5-7]. Reference [8] was a class of random time delay of networked control systems with Markov modeling for the delay characteristics of the discrete jump linear systems, and studied the problem of random time delay for NCSs against actuator failure with hopping theory and the idea of fault tolerant control. Reference [9] studied the robust fault-tolerant control for the uncertrain NCSs based on the Lyapunov stability theory, and gave the sufficient conditions of robust fault-tolerant control for the NCSs against actuator or sensor failure, Reference [10] studied the problem of guaranteed cost fault-tolerant control for uncertain networked control systems based on the CAN bus protocol by adopting the state feedback control law, but it didn’t consider the system components failures. Reference [11,12]studied the problem of robust fault-tolerant control for the NCSs whether exist uncertainty disturbance, and the sufficient conditions for closed-loop NCSs possessing robust integrity against sensor or actuator failures are given, but the higher performance requirement of NCSs against sensor or actuator failures isn’t considered .

In this paper, aiming at uncertain networked control systems, the sufficient conditions which can meet a cost function for closed-loop networked control systems possessing robust integrity against actuator failures are given based on Lyapunov stability theory and Linear Matrix Inequality by adopting memory state feedback control law, and the robust fault-tolerant controller is designed. Finally, the numerical example is given to demonstrate the effectiveness and feasibility of the proposed approach.

II. SYSTEM STATEMENT

A. Networked Time-delay

As the bandwidth is limited in the NCSs and there are lots of information sources, these make delay appear in data transmission inevitably. Delay in the NCSs consists of: Time delay for data transmission between the plant and controller(τ_3);Time delay in controllers (τ_4);Time delay for command transmission

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between the plant and controller(τ_1,τ_5);Time delay from receiving command to executive command for the plant(τ_2,τ_6);In order to facilitate the analysis of time-delay, assuming that the controller and actuator are event-driven, the sensor are time-driven .We set that the sampling period is h, The distribution of delay in networked control systems is shown in Fig.1.

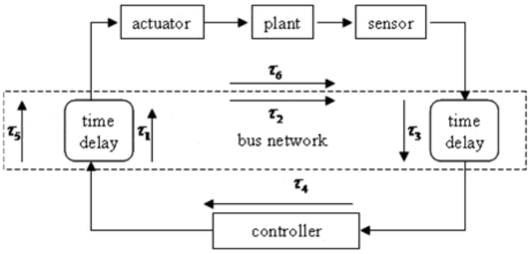


Fig. 1The distribution of delay in networked control systems

Networked control systems as a result of the above-mentioned time delay , therefore the controller sends the executive order at $\tau^{'}$ .We assume that $\tau^{'} \succ \tau_1+\tau_2+\tau_3+\tau_4$, and the controller sends the executive order at $kh+\tau^{'}$, which is good to eliminate the effect of the uncertainty of $\tau_1 \sim \tau_4$,the uncertainty of τ_5 and τ_6 are still unknown at present. But the asynchronism between the controller and the controlled plant is introduced into the NCSs at the same time.

B. The mathematical Statement of the NCSs

Consider the following controlled plant with parameter uncertainty:

$$\dot{x} = (A+\Delta A)x+(B+\Delta B)u \\ z = Cx \tag{1}$$

Where: $x \in R^n$, $u \in R^m$, $z \in R^l$ are the state, the control input, the uncertain disturbance and the system output respectively; A,B,C are real constant matrices with appropriate dimension, ΔA, ΔB are uncertain matrices of system parameters.

According to the reference [13] and considering the above mentioned network delay, asynchronism between the controller and the controlled plant, we have the discretization state Eq:

$$x(k+1)=(A_0+\Delta A_0)x(k)+(B_0+\Delta B_0)u(k) \\ +(B_1+\Delta B_1)u(k-1) \tag{2}$$
$$z(k)=Cx(k)$$

Where: $x(k)\in R^n$, $u(k)\in R^m$, A_0 , B_0 , B_1 and C are matrices with appropriate dimension, $\Delta A_0,\Delta B_0$ and ΔB_1 are matrices with appropriate dimension determined by parameter uncertainty and time delay uncertainty.

Assuming parameter uncertainty is norm-bounded, and according to the construction of $\Delta A_0,\Delta B_0,\Delta B_1$, there exist $E\in R^{n\times n}$, $G_0 \in R^{n\times n}$, $G_1\in R^{n\times m}$, $G_2\in R^{n\times m}$ and $F\in R^{n\times n}$ is an unknown and time-varying real value matrix function with Lebesgue measurable elements satisfying $F^TF\le I$, we have:

$$\left[\mathbf{\Delta A_0},\mathbf{\Delta B_0},\mathbf{\Delta B_1}\right]=\mathbf{EF}\left[\mathbf{G_0},\mathbf{G_1},\mathbf{G_2}\right] \tag{3}$$

Considering the control delay in the NCSs, and assuming $(A_0,B_i), i=0,1$ can be controlled, we adopt memory state feedback control law:

$$u(k)=Kx(k-\tau) \tag{4}$$

Then the closed-loop control system is described as:

$$x(k+1)=(A_0+\Delta A_0)x(k)+(B_0+\Delta B_0)Kx(k-\tau) \\ +(B_1+\Delta B_1)x(k-\tau-1) \tag{5}$$

Where:

assumption of the delay τ satisfying $0\le\tau\le l,\tau,l$ are positive integers.

C. The Object of Fault-tolerant Control in NCSs

Considering possible actuator failure faults, we can introduce a switch matrix L, and lay the matrix L between input matrix and feedback gain matrix, the form as follows:

$$L=diag(l_1,l_2,\cdots l_m)$$

Where: $l_i=\begin{cases}1,\ \text{the } i\text{th actuator normal}\\ 0,\ \text{the } i\text{th actuator failure}\end{cases}$

$L\in\Omega$, where Ω is a set which consists of all possible actuator failure faults switch matrix L which elements take 0 or 1 any various combinations of the collection of diagonal matrices.

The networked closed-loop fault system (NCFS) becomes:

$$x(k+1)=(A_0+\Delta A_0)x(k)+(B_0+\Delta B_0)LKx(k-\tau) \\ +(B_1+\Delta B_1)LKx(k-\tau-1) \\ =\bar{A}x(k)+\bar{B}_0x(k-\tau)+\bar{B}_1x(k-\tau-1) \tag{6}$$

Where:

$$\bar{A}=A_0+\Delta A_0,\ \bar{B}_0=(B_0+\Delta B_0)LK,\ \bar{B}_1=(B_1+\Delta B_1)LK$$

Assuming the objective function of system is:

$$J=\sum_{k=0}^{\infty}\left[x^T(k)R_1x(k)+u^T(k)R_2u(k)\right] \\ =\sum_{k=0}^{\infty}x^T(k,\tau)Rx(k,\tau) \tag{7}$$

Where:

$$x^T(k,\tau)=\left[x^T(k),x^T(k-\tau),x^T(k-\tau-1)\right]$$
$$R=diag\left\{R_1,K^TR_2K,0\right\}$$

The object of guaranteed cost fault-tolerant control for NCSs with uncertainty against actuator failures is to find state feedback matrix K, the NCSs system is guaranteed cost asymptotically stable with $L \in \Omega$, where Ω is a set which consists of all possible actuator failure faults switch matrix L.

III. MAIN RESULTS

Given three matrix Z_1, Z_2 and Z_3 by Lemma [14], if there exit $Z_1 + \in^{-1} Z_3 Z_3^T + \in Z_2^T Z_2 < 0$, $\exists \in > 0$, if and only if $Z_1 + Z_3 \Delta_k Z_2 + Z_2^T \Delta_k^T Z_3^T < 0$, where $\forall \Delta_k^T \Delta_k \le I$.

Lemma 1 Considering any possible actuator failures $L \in \Omega$, matrix K and positive definite symmetric P, S and T, make matrix inequality

$$\begin{bmatrix} \Pi_1 & \bar{A}^T P \bar{B}_0 & \bar{A}^T P \bar{B}_1 \\ \bar{B}_0^T P \bar{A} & \Pi_2 & \bar{B}_0^T P \bar{B}_1 \\ \bar{B}_1^T P \bar{A} & \bar{B}_1^T P \bar{B}_0 & \Pi_3 \end{bmatrix} < 0 \tag{8}$$

For an acceptable uncertainty are established. Fault closed-loop system (6) is asymptotically stable under the conditions of satisfying certain performance indicator (7), and the state feedback $u(k) = Kx(k-\tau)$ is a guaranteed cost fault-tolerant control law of the system.

Where: $\Pi_1 = \bar{A}^T P \bar{A} - P + S + R_1$, $\Pi_3 = \bar{B}_1^T P \bar{B}_1 - T$

$\Pi_2 = \bar{B}_0^T P \bar{B}_0 - S + T + K^T R_2 K$,

Demonstrate:

Considering the Lyapunov function of system (6) is:

$$V(k) = x^T(k) P x(k) + \sum_{i=1}^{\tau} x^T(k-i) S x(k-i) + x^T(k-\tau-1) T x(k-\tau-1)$$

Where P, S, T is positive definite symmetric matrix, the difference of Lyapunov function along the system（6） is:

$$\begin{aligned} \Delta V(k) &= V(k+1) - V(k) = x^T(k+1) P x(k+1) \\ &+ \sum_{i=1}^{\tau} x^T(k+1-i) S x(k+1-i) \\ &+ x^T(k-\tau) T x(k-\tau) - x^T(k) P x(k) \\ &- \sum_{i=1}^{\tau} x^T(k-i) S x(k-i) \\ &- x^T(k-\tau-1) T x(k-\tau-1) \\ &= x^T(k+1) P x(k+1) - x^T(k) P x(k) \\ &+ x^T(k) S x(k) - x^T(k-\tau) S x(k-\tau) \\ &+ x^T(k-\tau) T x(k-\tau) - x^T(k-\tau-1) T x(k-\tau-1) \end{aligned} \tag{9}$$

Substituting the expression $x(k+1) = \bar{A}x(k) + \bar{B}_0 x(k-\tau) + \bar{B}_1 x(k-\tau-1)$ into（9）,we obtain:

$$\begin{bmatrix} x^T(k), & x^T(k-\tau) & x^T(k-\tau-1) \end{bmatrix} \Theta \begin{bmatrix} x(k) \\ x(k-\tau) \\ x(k-\tau-1) \end{bmatrix} \tag{10}$$

Where $\Theta = \begin{bmatrix} \Pi_1 - R_1 & \bar{A}^T P \bar{B}_0 & \bar{A}^T P \bar{B}_1 \\ \bar{B}_0^T P \bar{A} & \Pi_2 - K^T R_2 K & \bar{B}_0^T P \bar{B}_1 \\ \bar{B}_1^T P \bar{A} & \bar{B}_1^T P \bar{B}_0 & \Pi_3 \end{bmatrix}$

According to Theorem 1, we obtain by combining inequality (8) with formula (10):

$$\Theta + \begin{bmatrix} R_1 & 0 & 0 \\ 0 & K^T R_2 K & 0 \\ 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} \Pi_1 & \bar{A}^T P \bar{B}_0 & \bar{A}^T P \bar{B}_1 \\ \bar{B}_0^T P \bar{A} & \Pi_2 & \bar{B}_0^T P \bar{B}_1 \\ \bar{B}_1 P \bar{A} & \bar{B}_1 P \bar{B}_0 & \Pi_3 \end{bmatrix} < 0$$

That is $\Delta V(k) + x^T(k,\tau) R x(k,\tau) < 0$

Because of

$$\Delta V(k) < -x^T(k,\tau) R x(k,\tau) \le -\lambda_{\min}(R) \| x(k,\tau) \| \tag{11}$$

According to the Lyapunov stability theory, the closed-loop system (6) is asymptotically stable.

Further transforming（11）,we have:

$$-\Delta V(k) > x^T(k,\tau) R x(k,\tau) \tag{12}$$

Accumulating k of formula（12）at both ends, where k is from 0 to ∞, there is:

$$J \le x^T(0) P x(0) + \sum_{i=1}^{\tau} x^T(-i) P x(-i) + x^T(-\tau-1) T x(-\tau-1)$$

Therefore, $u(k) = Kx(k-\tau)$ is a guaranteed cost fault-tolerant control law of the system (6), the proof is completed.

In order to facilitate the solution of the above matrix inequality and controller design, the following further processing will convert non-linear matrix inequality into linear matrix inequality, the formula (8) of theorem 1 is equivalent to the next formula:

$$\begin{bmatrix} \bar{A}^T \\ \bar{B}_0^T \\ \bar{B}_1^T \end{bmatrix} P \begin{bmatrix} \bar{A} & \bar{B}_0 & \bar{B}_1 \end{bmatrix} + \begin{bmatrix} -P + S + R_1 & 0 & 0 \\ 0 & -S + T + K^T R_2 K & 0 \\ 0 & 0 & -T \end{bmatrix} < 0 \tag{13}$$

Schur lemma can be completed by formula (13) is equivalent to formula (14):

$$\begin{bmatrix} -P^{-1} & \bar{A} & \bar{B}_0 & \bar{B}_1 \\ \bar{A}^T & -P+S+R_1 & 0 & 0 \\ \bar{B}_0^T & 0 & -S+T+K^TR_2K & 0 \\ \bar{B}_1^T & 0 & 0 & -T \end{bmatrix} < 0 \quad (14)$$

Substituting the expression $\bar{A}$, $\bar{B}_0$, $\bar{B}_1$, ΔA_0, ΔB_0, ΔB_1 to (14) , we have formula (15):

$$\begin{bmatrix} -P^{-1} & A_0 & B_0LK & B_1LK \\ A_0^T & -P+S+R_1 & 0 & 0 \\ (B_0LK)^T & 0 & -S+T+K^TR_2K & 0 \\ (B_1LK)^T & 0 & 0 & -T \end{bmatrix} + \bar{E}F\bar{G} + (\bar{E}F\bar{G})^T < 0 \quad (15)$$

Where: $\bar{E} = \begin{bmatrix} E^T & 0 & 0 & 0 \end{bmatrix}^T$

$$\bar{G} = \begin{bmatrix} 0 & G_0 & G_1LK & G_2LK \end{bmatrix}$$

Available by the lemma: the existence of formula (15) is equivalent to formula (16):

$$\begin{bmatrix} -P^{-1} & A_0 & B_0LK & B_1LK \\ A_0^T & -P+S+R_1 & 0 & 0 \\ (B_0LK)^T & 0 & -S+T+K^TR_2K & 0 \\ (B_1LK)^T & 0 & 0 & -T \end{bmatrix} + \in\bar{E}\bar{E}^T + \in^{-1}\bar{G}^T\bar{G} < 0 \quad (16)$$

Pre-and post-multiplying (16) by $diag\{I, X, X, X\}$, We obtain (17)

$$\begin{bmatrix} -X+\in EE^T & A_0X & B_0LY & B_1LY \\ (A_0X)^T & -X+\hat{S}+X^TR_1X+\Gamma & \Omega_1 & \Omega_2 \\ (B_0LY)^T & \in^{-1}(G_1LY)^TG_0X & \Omega_3 & \Omega_4 \\ (B_1LY)^T & \in^{-1}(G_2LY)^TG_0X & \Omega_5 & \Omega_6 \end{bmatrix} < 0 \quad (17)$$

Where:

$\Gamma = \in^{-1} XG_0^TG_0X$, $H = \in^{-1} X(G_1LK)^T(G_1LK)X$

$\Omega_1 = \in^{-1}(G_0X)^T(G_1LY)$, $\Omega_2 = \in^{-1}(G_0X)^T(G_2LY)$

$\Omega_3 = -\hat{S} + \hat{T} + Y^TR_2Y + H$, $\Omega_4 = \in^{-1}(G_1LY)^T(G_2LY)$

$\Omega_5 = \in^{-1}(G_2LY)^T(G_1LY)$, $\Omega_6 = -\hat{T} + (G_2LY)^T(G_2LY)$

$X = P^{-1}$, $Y = KX$, $\hat{S} = X^TSX$, $\hat{T} = XTX$

Applying lemma 1 again, we have (18):

$$\begin{bmatrix} \Omega_7 & \Omega_8 & B_1LY & 0 & 0 & 0 \\ \Omega_8^T & -X+\hat{Q} & 0 & \Omega_9 & X^T & 0 \\ (B_1LY)^T & 0 & -\hat{Q} & (G_2LY)^T & 0 & Y^T \\ 0 & \Omega_8^T & G_2LY & -\in I & 0 & 0 \\ 0 & X & 0 & 0 & -R_1^{-1} & 0 \\ 0 & 0 & Y & 0 & 0 & -R_2^{-1}I \end{bmatrix} < 0 \quad (18)$$

Where:

$\Omega_7 = -X + \in EE^T$, $\Omega_8 = (A_0X + B_0LY)$, $\Omega_9 = (G_0X + G_1LY)^T$

Lemma 2 : Considering any possible actuator failures $L \in \Omega$, if the existence of positive definite symmetric matrix $X, \hat{T}, \hat{S}$ and the matrix Y, and positive constant $\in$ to make the networked closed fault system with uncertainty(6) satisfy the linear matrix inequalities (18), $u(k) = Kx(k-\tau)$ is a guaranteed cost control law of the system, and the controller can be obtained by $K = YX^{-1}$.

IV. Mathematical Simulation

Considering the networked control system (6), where:

$$A_0 = \begin{pmatrix} 0.36 & 0.32 \\ 0.23 & 0.20 \end{pmatrix} \; B_2 = \begin{pmatrix} 0.15 & 0.25 \\ 0.16 & 0.06 \end{pmatrix} \; C = \begin{pmatrix} 0 & 0.5 \\ 0.2 & 0.4 \end{pmatrix}$$

$$E = \begin{pmatrix} 0.15 & 0 \\ 0 & 0.15 \end{pmatrix} \; F = \begin{pmatrix} \sin(0.01t) & 0 \\ 0 & \cos(0.01t) \end{pmatrix}$$

$$G_0 = \begin{pmatrix} 0.15 & 0.3 \\ 0.2 & 0.15 \end{pmatrix} \; G_1 = \begin{pmatrix} 0.25 & 0.2 \\ 0.4 & 0.25 \end{pmatrix} \; R_1 = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$R_2 = 0.1 \; G_2 = \begin{pmatrix} 0.1 & 0.15 \\ 0.2 & 0.25 \end{pmatrix} \; B_1 = \begin{pmatrix} 0.12 & 0.20 \\ 0.15 & 0 \end{pmatrix}$$

Setting memory state feedback delay τ with the upper bound $l = 2$, and the state of the initial value is:

$$x(0) = x(-1) = x(-2) = x(-3) = (0.1 \quad 0.1)^T$$

In cases of actuator normal and possible failures, the switch matrices $L_0 = diag(1,1)$, $L_1 = diag(0,1)$ and $L_2 = diag(1,0)$ indicate actuator normal and actuator 1,2failure, respectively.

We can introduce memory state feedback control law $u(k) = Kx(k-\tau)$ into the NCSs. According to the formula (8) of lemma 2 and taking $\in = 1$, we can obtain by solving linear matrix inequalities:

$$X = \begin{pmatrix} 0.4243 & -0.1185 \\ -0.1185 & 0.4194 \end{pmatrix} \; \hat{S} = \begin{pmatrix} 0.1139 & -0.0455 \\ -0.0455 & 0.1231 \end{pmatrix}$$

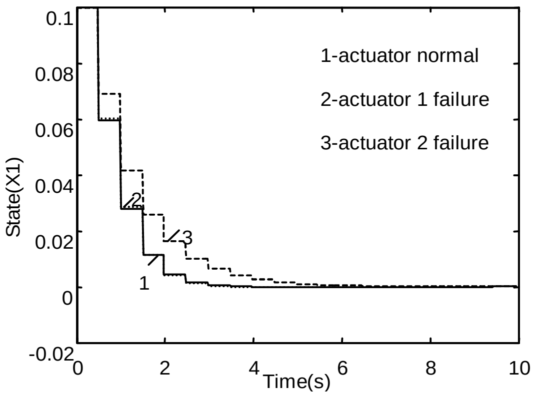
$$\hat{T} = \begin{pmatrix} 0.0567 & -0.0226 \\ -0.0226 & 0.0614 \end{pmatrix} \; Y = \begin{pmatrix} 0.0401 & -0.0292 \\ -0.0312 & -0.0324 \end{pmatrix}$$

Finally, we have a state feedback control law:

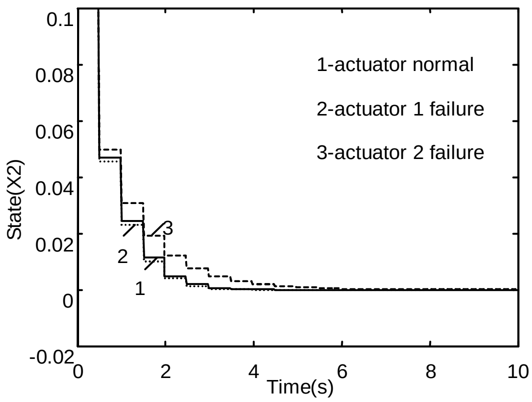
$$u(k) = \begin{pmatrix} 0.0815 & -0.0466 \\ -0.1033 & -0.1064 \end{pmatrix} x(k-\tau)$$

Performance function $J \le 0.0629$

When $\tau = 1$,in the cases of L_0, L_1, L_2 indicating actuator normal and actuator failure, zero-input response of state x_1, x_2 are shown in Fig.2 :



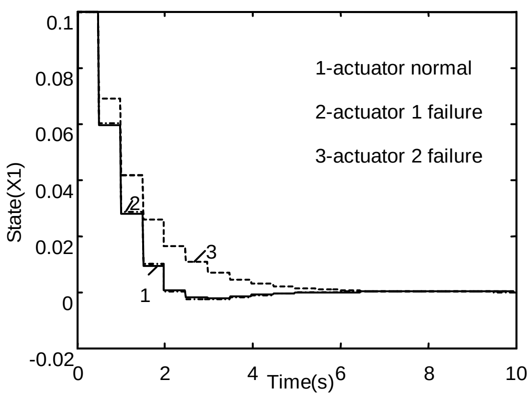
a. Zero-input response of state x_1



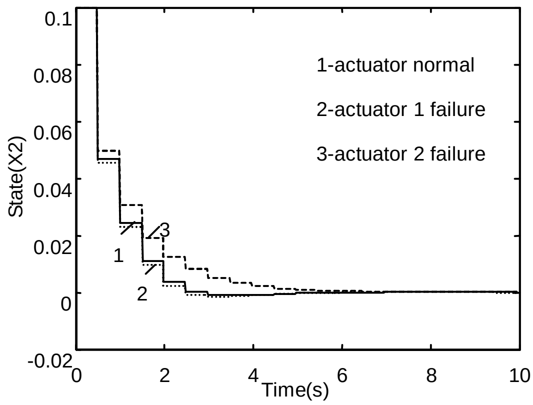
b. Zero-input response of state x_2

Fig.2. Zero-input response of actuator normal and actuator failure

When $\tau = 2$,in the cases of L_0, L_1, L_2 indicating actuator normal and actuator failure, zero-input response of state x_1, x_2 are shown in Fig.3 :



a. Zero-input response of state x_1



b. Zero-input response of state x_2

Fig.3. Zero-input response of actuator normal and actuator failure

By the simulation results, the presented method makes the networked control system with uncertainty against actuator failures possess good control performance by adopting memory state feedback control law.

V. CONCLUSION

Based on Lyapunove stability theory and linear matrix inequality (LMI), the problem of guaranteed cost control for the NCSs with uncertain disturbance is investigated in this paper. According to lemma 2, the networked control systems with parameter uncertainty against actuator failures, we can obtain robust fault-tolerant controller guaranteeing certain performance indicators by solving the linear matrix inequalities directly. The advantage of the presented method is that solving simple and no need to adjust other parameters. The mathematical simulation further demonstrates effectiveness and feasibility of the proposed approach.

REFERENCES

[1] Huajjing Fang, Hao Ye, Maiying Zhong, Fault Diagnosis of Networked Control Systems,[C]//In: proceedings of the 6 IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes. 2206: 1-12

[2] Wang Feiyue, Wang Chenghong, On Some Basic Issues in Network-Based Direct Control Systems[J], Acta Automatica Sinica, 2002 (S1)：171 -176

[3] Ray, Yoram Halevi. Integrated Communication and Control Systems: Part II - Design Considerations[J]. Dynamic Systems, Measurement, and Control, 1988, 110:.374～ 381

[4] Yingwei Zhang, Fuli Wang ,Joe Qin S etal,. Fault Detection for MIMO Networked Control System[C]//In: proceedings of the 6 IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes. 2006 1141-1146

[5] Zheng Ying, Huanjing Fang, Hua Wang and Linbo xie. Fault Detection Approach for Networked Control System based on a memoryless reduced-order observer [J]..ACTA AUTOMATICA SINICA , 2003, 29(4):559-566.

[6] Zhang P., S.X. Ding, P. M. Frank and M. Sader. Fault Detection of Networked Control Systems with Missing Measurements[C]//In: Proceedings of the Asian Control Conference, 2004.:1257-1262

[7] C Kambhampti, C Perkgoz, R J Patton, and W Ahamed. An Interaction Predictive Approach to Fault-tolerant Control in Network Control Systems[C]//In Proc. IMechE Part 1: Systems and Control Engineering, 2007:885-894

[8] Huo Zhihong, Fang Huajing, Fault-tolerant Control of Networked Control Systems with Random Time-delays[J], Information and control，2006，35(5):.584～587

[9] Zheng ying, Fang jinghua, Robust Fault Tolerant Control of Networked Control System with Time-Varying Delays[J], Journal of xi'an jiaotong university, 2004,38(8):pp.804～807

[10] Junbo Wang, Bugong Xu,Qingyang Wang.Guaranteed Cost Control Analysis of a Class of Networked Control Systems[C]//In: proceedings of the 6th world Congress on intelligent control and automation, 2006:4561-4565

[11] Li wei, Li yajie, Liu weirong, Robust Fault Tolerant Control of Networked Control System Based on LMI Method[J], Journal of air force engineering university, 2007 ,4(8):pp.27-31

[12] Li wei , Li yajie , Liu weirong. Robust Fault Tolerant Control for Networked Control Systems with Uncertain Disturbance[C]//In: proceedings of the 2007 IEEE International Conference on Mechatronics and Automation, 2007:.2813~2818

[13] Jiang peigang, Jiang xiefu, Li chunwen, ect,Robust H∞ control for the networked control systems based on LMI[J], control and decision, 2004,19(1):17-21

[14] Mahmoud M.S. Robust H∞ Control of Discrete Systems with Uncertain Parameters and Unknown Delay[J]. Automatica, 2000.,.36(.4): pp. 627-635