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Fault tolerant synchronization of chaotic systems with time delay based on the double event-triggered sampled control☆

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ABSTRACT

This paper is concerned with the fault tolerant synchronization of the master-slave chaotic system. Based on the double event-triggered scheme, the sampled controller, which yellow includes the fault compensator and state feedback controller, is designed to achieve the fault tolerant synchronization. When the fault exceeds the threshold value, the fault compensator can eliminate its effect in synchronized chaotic system. The double event-triggered scheme is composed of the system trigger and fault trigger, which can judge whether or not the newly sampled signal should be transmitted to the fault compensator and state feedback controller. It can make more appropriate use of network resources and increase the robustness of synchronized chaotic system. Based on the input delay method, the solution of the controller is converted to guarantee the stability of chaotic errors system. By constructing the Lyapunov–Krasovskii functional and employing the Wirtinger-brk inequality, sufficient conditions for asymptotical stability of the chaotic error system are derived for achieving the fault tolerant synchronization through linear matrix inequality approach. Finally, a numerical simulation example is discussed to prove the practical utility of this method.

1. Introduction

Considerable attention is focused on the synchronization since its wide range of application in practical systems. The last decades have witnessed significant progress in our understanding of master-slave synchronization in coupled chaotic systems [1]. Hence, the master-slave synchronization is becoming more and more important in industrial process control due to its important theoretical value within chaotic theory and its practical applications in many fields such as secure communication [2,3], signal processing [4] and image processing [5].

At present, a great number of control strategies have been proposed to achieve master-slave synchronization, such as feedback control [6–8], LMI optimization approach [9–11], adaptive control [12], sliding mode control [13], switching synchronization [14,15], etc. However, most strategies on master-slave synchronization are on account of time-triggered scheme(or periodic-triggered scheme) [16–18]. The main disadvantage of the time-triggered scheme is waste of the communication resources and reduction of the controller's life. Unlike the time-triggered scheme, the event-triggered scheme can

☆ Fully documented templates are available in the elsarticle package on CTAN.

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immensely reduce the load of the network and save computation resources. Many literatures have researched the event-triggered scheme in various systems, including multi-agent system [19,20], network control system [21–24,24], fuzzy system [25,26], electric power system [27], etc. The event-triggered scheme has also been used to achieve master-slave synchronization in [28–30]. These literatures combine the event-triggered scheme with sampled control, which can reduce the network load pressure and also adapt to the rapid developments of high-performance computing technology and modern digital communication technique. However, the above control methods haven't considered the effect of the fault, which may lead to a bad control performance or even a failing control.

In fact, the fault is usually inevitable in a real system, such as the component failure in a circuit or the changes in model parameters caused by malfunctions in sensors. Therefore, in order to ensure the system performance, it is necessary to detect and isolate fault quickly. So the fault-tolerant control has been an active research topic for enhancing the safety and reliability of the considered systems. The fault tolerant master-slave synchronization for Lur'e systems is solved by using time-delay feedback control in [31]. On the basis of [31], the fault tolerant master-slave synchronization for a class of chaotic systems with multiple time-delays is considered in [33]. The sliding mode control is used to realize the fault tolerant synchronization problem for a class of uncertain chaotic systems in [32]. These methods achieve the fault tolerant master-slave synchronization, which means whether the fault happens in the chaotic systems or not, the synchronization methods not only guarantee that the error system is globally asymptotically stable, but also satisfy a prescribed performance level. But the above methods are all time triggered, which may occupy network bandwidth and reduce actuator's life.

From the above discussion, the fault tolerant synchronization of master-slave system based on event triggered scheme is barely studied. Hence the sampled controller based on double event triggered scheme is proposed for the purpose of fault tolerant synchronization in this paper. The proposed method, which fully considers the impact of the fault influence on the system, can achieve the synchronization whether the fault happens or not in the master chaotic system. The innovations of the proposed method are as follows:

1. The sampled controller based on double event triggered scheme, which includes state feedback controller and fault compensator, is firstly proposed to achieve fault tolerant synchronization.
2. The trigger parameters can be dynamically and non-monotonically adjusted, which can change the controller's update frequency. It can improve the performance of the sampled controller and reduce utilization rate of the network.
3. The fault compensator is dynamically added into the sampled controller, which can realize the fault tolerant synchronization and also improve the robustness of the master-slave synchronized system.

This paper is organized as follows. In Section 2, the main lemmas and related assumptions are given. In Section 3, the framework of fault tolerant synchronization of master-salve chaotic systems is established and the sampled controller based on double event-triggered scheme is presented. In Section 4, the LMI-based conditions of fault tolerant synchronization are investigated to guarantee the error system stability. In Section, a numerical simulation example is discussed to illustrate the effectiveness of the proposed approach. A conclusion is drawn in Section 5.

Some main lemmas and assumptions are given to derive the main results in this section.

Lemma 1. *(Wirtinger's inequality) [34] Let $z(t) \in W[a, b)$ and $z(a) = 0$. Then for any $n \times n$ -matrix $R > 0$, the following inequality holds:*

$$\int_a^b z^T(\xi) R z(\xi) d\xi \leq \frac{4(b-a)^2}{\pi^2} \int_a^b \dot{z}^T(\xi) R \dot{z}(\xi) d\xi \tag{1}$$

Lemma 2. *(Jensen's inequality) [35] For any constant matrix $W \in R^{n\times n}, W = W^T \geq 0$, scalars $\tau_2 \geq \tau_1 \geq 0$, and vector-valued function $\dot{x} : [-\tau_2, -\tau_1] \to R^{n\times n}$, such that the following integration is well defined, it holds that:*

$$\begin{aligned} &-(\tau_2 - \tau_1) \textstyle\int_{t-\tau_2}^{t-\tau_1} \dot{x}^T(s) W \dot{x}(s) ds \\ &\leq -\begin{bmatrix} x(t-\tau_1) \\ x(t-\tau_2) \end{bmatrix}^T \begin{bmatrix} W & * \\ -W & W \end{bmatrix} \begin{bmatrix} x(t-\tau_1) \\ x(t-\tau_2) \end{bmatrix} \end{aligned} \tag{2}$$

Assumption 1. The sensors are clock-driven with a constant sampling period h, while the controller and actuator are event-driven.

Assumption 2. The Zero-order-hold (ZOH) is adopted to hold the control signal until a new control signal arrives at the actuator.

Assumption 3. The nonlinear function f: $R^n \to R^n$ satisfies the Lipschitz condition:

$$\exists l > 0, s.t., \|f(x) - f(y)\| < l\|x - y\| \tag{3}$$

for any $x, y \in R^n$.