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Combination event-triggered adaptive networked synchronization communication for nonlinear uncertain fractional-order chaotic systems

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A B S T R A C T

In this paper, the networked synchronization communication for nonlinear uncertain fractional-order chaotic systems is investigated. Notice that the network transmission capacity is limited, a novel combination event-triggered mechanism is designed. Based on the fractional Lyapunov stability criterion and adaptive control technique, an event-triggered adaptive controller is constructed and a sufficient networked synchronization condition for the above-mentioned fractional-order chaotic systems with uncertainties and disturbances is attained. The detailed theoretical derivation and specific numerical simulation demonstrate that the proposed networked synchronization strategy can reduce the burden of network bandwidth effectively without losing the desired synchronization performance. Meanwhile, Zeno phenomenon is excluded.

1. Introduction

Over the last decades, dynamics described by fractional differential equations are becoming more and more popular as the underlying facts that the fractional calculus provides more precise models of the physical systems than the regular calculus does [1–9]. An integer order differential operator is a local operator whereas the fractional order differential operator is non local in the sense that it takes into account the fact that the future state not only depends upon the present state but also upon all of the history of its previous states. That is to say, fractional calculus is an excellent mathematical tool for an exact description of memory and heredity features of many materials and processes [10]. It has been proven that fractional calculus has wide range of applications in control theory [11], viscoelasticity [12], diffusion [13–15], turbulence, electromagnetism, robotics, electrical circuit [16], signal processing [17], bioengineering [18], chaotic synchronization [19,20], and quantitative finance [21], among which the fractional chaos theory is the most attractive one due to its potential applications in secure communication and control processing.

On the other hand, in the chaos-based secure communications of analog and digital signal generator design and the development of safe and reliable cryptographic systems, to recover the message from the transmitter, the drive-response synchronization must be completely achieved. Up to now, the synchronization of integer-order chaotic systems has achieved fruitful achievements both in theory and in practice, which leads to chaotic synchronization of fractional order system

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becoming a very promising research topic. However, there still exists essential difference between fractional-order differential systems and integer-order differential ones. Most of the methods, properties, and conclusions used to deal with integer-order systems can not simply be extended to fractional cases, such as the Lyapunov direct method. Therefore, the research results on the chaotic synchronization of fractional-order system are far less than that of integer-order ones, which means this topic is still open [22].

Due to their low cost, reduced weight and power requirements, simple installation and maintenances, sharing of the resources and other excellent performances, networked control systems (NCSs) has recently received considerable attention [23–33]. Due to easy implementation and analysis, time-triggered method is preferred in many digital control tasks for dealing with NCSs. However, it has to be admitted this method has the drawback that all the sampled data is transmitted. In addition, the NCSs are often designed under limited resource constraints such as processor capacity, communication bandwidth, battery life, and the computational load imposed by the controller is proportional to the execution speed. Therefore, it becomes a valuable problem that how to reduce the network bandwidth utilization without damaging the stability and desired control performance of NCSs. To solve this problem, event-triggered communication scheme has emerged for nonlinear NCSs. The basic idea of the method is the sampled data being transmitted only when an event is triggered, i.e., some predefined condition is violated, which ensures that less network sampled data is transmitted and the burden of network bandwidth occupation is relieved [34–44].

So far, there are two types of event-triggered conditions in the existing literatures on integer-order system. The most classic one is expressed by the inequality $(x(t)-x(t_k))^T\Psi(x(t)-x(t_k)) < \rho x^T(t)\Psi x(t),\ t\in[t_k,t_{k+1})$, where $x(t)$ is state vector, Ψ is a positive matrix, and the pre-set constant $\rho\in(0,1)$ determines the average transmission frequency of the sampled data [38]. The characteristic of this method is that the threshold function is related to the norm of the current state. Using this event-triggered mechanism, the original system must be transformed into a time-delay system and then processed by Lyapunov stability theory. However, since the methods currently used to deal with fractional time-delay systems are very limited, it is still a formidable problem to develop the above event-triggered mechanism directly to fractional NCSs. The other typical event-triggered condition $\|x(t)-x(t_k)\|^2 < \kappa e^{-\epsilon t},\ \kappa>0,\ \epsilon>0,\ t\in[t_k,t_{k+1})$ is often used to deal with the consensus of multi-agent systems, in which the threshold function is an exponentially decreasing function. The advantage of this method is that Zeno behavior can be avoided while the disadvantage is that the threshold function has nothing to do with the current state, which means the ability to filter the sampled data is poor when the error of the state is large.

As far as I know, there is only one literature has been published on the event-driven control of fractional-order systems [45]. In [45], the exponential event-triggered mechanism has been applied to deal with the consensus of fractional-order multi-agent system. However, the study on event-triggered synchronization of fractional-order chaotic systems has not been found yet. In the fractional-order case, scanty theoretical tools become the biggest obstacle. Thus, it is meaningful and challenging to combine the two traditional event-triggered mechanisms and maximize their strengths and circumvent their weaknesses, or to design a better one than this two to deal with the synchronization of fractional chaotic systems.

Moreover, in practical applications, the accurate dynamics of the systems are not available due to the limit of physical devices, the effect of interference and the presence of variable changes, unknown parameters and unmodeled dynamics. To cope with the uncertainties and perturbations, many robust control techniques have been presented, among which the adaptive control strategy is considered as an efficient one owing to its significant features such as fast response, robustness against perturbations, good transient performance, and easy implementation in real applications [46–52].

Motivated by the above discussions, in this paper we investigate the adaptive networked synchronization communication for nonlinear uncertain fractional-order chaotic systems based on a novel combination event-triggered mechanism. the main contributions making our proposed method attractive can be summarized as follows. First, the problem of network synchronization for fractional-order chaotic system based on event-triggered mechanism is discussed for the first time. Second, the combination event-triggered mechanism is first presented. This method combines the advantages of the two traditional event-triggered mechanisms which are popular in integer-order systems, and does not need to be transformed into fractional-order time-delay system. Third, a fractional-order parameter estimate law is well designed to cope with the uncertainties and perturbations.

The rest of this paper is organized as follows. In Section 2, some basic definitions, properties of fractional calculus and some useful lemmas are introduced, and then system model and problem under investigated are proposed. In Section 3, a novel combination event-triggered mechanism is designed and then an adaptive networked synchronization is constructed to reduce the burden of network bandwidth and avoid Zeno behavior. In Section 4, a simulation is provided to verify the effectiveness of the proposed synchronization strategy. Finally the conclusion is drawn in Section 5.

2. Preliminaries and system description

In this section, we first present some basic definitions and properties of fractional calculus, and then introduce some useful lemmas which are necessary for controller design.

2.1. Caputo fractional derivative

Fractional-order calculus operator is the generalization of integer order calculus operator. As same as the integer order, the fractional calculus plays an important role in various fields of applied sciences and engineering. There are three