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On designing of an adaptive event-triggered communication scheme for nonlinear networked interconnected control systems

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ABSTRACT

This paper is concerned with the design of adaptive event-triggered scheme for networked nonlinear interconnected systems via T-S fuzzy models. The transmission of control signals is based on a novel adaptive event-triggered communication scheme, where the adaptive threshold is dependent on a dynamic error of the system rather than a predetermined constant as the one in the existing results. The amount of the releasing data is regulated with the adaptive threshold that plays a crucial role in decision of whether releasing the sampled data or not. This technique reflects an inherent dynamic balance between the control performance and the utilization of the network resource. A corresponding Lyapunov function is constructed to achieve sufficient conditions of stability and stabilization. Finally, a simulation example is given to show the effectiveness of the proposed theoretic results.

1. Introduction

Many real-world systems such as economic models, spacecraft dynamics, power systems, industrial processes, and transportation networks can be modeled as interconnected systems [6,24,30,38]. Compared with the linear interconnected systems, it is more difficult to analyze the nonlinear interconnected systems due to its complex nonlinear processing. During the past several decades, there has been rapidly growing interest in the fuzzy control of nonlinear systems by using the Takagi–Sugeno (T–S) fuzzy model [4,14,16,20,26,27]. Communication network is necessary for large scale nonlinear control systems to transmit the control signals owing to the networked control systems (NCSs) with advantages of lower cost, easier maintenance and higher reliability of the closed-loop systems [2,9,18]. However, in this framework, a gap remains between the decentralized control and the network, for example, the output of the controller is a piecewise continuous-time function due to the system receiving discrete data-packets; The data can not be updated in real time on account of the network with a limited bandwidth, which decreases the control performance of the system with a network communication.

In recent years, much effort has been devoted to improve the efficiency of data releasing for NCSs, especially for wireless NCSs, such as, the NCS with Bluetooth, wireless HART and ZigBee etc., to alleviate the burden of the network-bandwidth. Periodic sampling and transmission in conventional NCSs may lead to a redundant data releasing on the grounds that the dynamical characteristics of the system is not considered in control designing. It implies that the limited resource of the

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communication and computation will be occupied by some unnecessary data. Moreover, it increases the energy consumption in the implementation of data-transmission as well. For these purposes, event-based data communication scheme provides an inspiring opportunity for reducing the amount of data releasing over the network within the prescribed time period. The event of data-transmission, under this scheme, is triggered by a well-designed condition instead of a certain period of time. Less data packets are needed to transmit over the network in achieving a desired control performance compared with the time-triggered scheme.

A new task of data-transmission is generated when the state error exceeds a predetermined constant under the event-triggered scheme (ETS) . The authors in [33] designed a time-continuous ETS for distributed NCSs. The authors explored applications of self-triggered technique to distributed linear/nonlinear state feedback controllers in [1,19]. ETMs for the implementation of the observer and the output feedback controller of sampled-data systems are developed in [28]. The output feedback control of linear time invariant systems with ETS is reported in [8], where the event-triggered control system is modeled as an impulsive system. Based on passivity theory, the authors in [35] developed an event-triggering condition for the output feedback stabilizing controllers. However the aforementioned literature is based on an assumption that the controllers are known in prior. Additionally, if the error of the state varies fast, then the hardware can not reach the requirement of high-speed sampling, since the event-triggered implementation is dependent on the continuous-time state.

To solve the above mentioned problem, discrete event-triggering communication schemes for NCSs were developed in [13,21,25,31,34,36], and references therein. Under the schemes, the authors proposed some approaches to co-design both the controllers and the parameters of event-triggering. The problem of over-sampling can be avoided due to the implementation of the designed event depending on the state at discrete sampling instant. The controllers can be designed as well by using an approach of transferring the hybrid system into a delay system.

It is noted that the threshold in ETS plays a remarkable role in the decision of whether releasing the sampling data or not. Some results were given in [21,31,36] on this issue, for example, if the threshold tends to zero, the case turns to be a conventional time-triggered data releasing scheme, that is to say, the threshold taking different value may result in a distinguish difference to the amount of the data releasing. However, it is hard to predetermine a proper fixed threshold for the system in whole control process. The authors in [22,39] did some preliminary study on this issue. However, these results only depend on the upper-bound of the threshold. It is known that the adaptive control is a control method used by a controller that can adapt to the controlled system with parameters variation or uncertainty [3,7,32]. An adaptive law is needed to adapt such changing condition. Borrowing this ideas, the threshold will be regulated with the variation of external conditions by using the adaptive way. However, it is still an open and challenging issue by using an adaptive method for nonlinear interconnected systems in selecting the proper threshold. This motivates the current study.

In this paper, we proposed an adaptive event-triggered scheme (AETS) for a nonlinear networked interconnected control system. Under the proposed scheme, the releasing rate of the sampling data is dramatically reduced, by which the limited resource of the communication and computation can be allocated the other components according to the necessity of the controlled system dynamically. The main contribution of this work is as follows: Firstly, an adaptive ETS for nonlinear networked interconnected control system is proposed. The threshold of AETS is regulated on-line, which mainly depends on the dynamic error of the system. It is a result of inherent trade-off rather than a predetermined constant. Secondly, a new Lyapunov function is constructed to address the problem of nonlinearity arisen from the proposed adaptive law. Finally, sufficient conditions are derived to co-design the controllers and the parameters of AETS.

The rest of the paper is organized as follows. Section 2 presents an adaptive ETS and a unified T-S fuzzy model of nonlinear networked interconnected system under AETS. Stability analysis of the networked nonlinear interconnected systems based on AETS is provided in Section 3. Section 4 is devoted to co-design the controllers and the parameters of AETS. A simulation example is given in Section 5 to demonstrate the advantage of our adaptive event-triggering scheme. Finally, the paper is concluded in Section 6.

Notation 1. $\mathbb{R}^n$ denotes the n-dimensional Euclidean space, $\mathbb{R}^{n\times m}$ is the set of real $n\times m$ matrices, I is the identity matrix of appropriate dimensions, $\|\cdot\|$ stands for the Euclidean vector norm or spectral norm as appropriate. The notation $X>0$ (respectively, $X<0$), for $X\in\mathbb{R}^{n\times n}$ means that the matrix X is a real symmetric positive definite (respectively, negative definite). The asterisk $*$ in a matrix is used to denote term that is induced by symmetry, Matrices, if they are not explicitly stated, are assumed to have compatible dimensions.

2. Problem formulation

In this section, we will develop a framework of network-based nonlinear interconnected control systems. A novel AETS for reducing the amount of the releasing data within a given period will be proposed to mitigate the burden of the network bandwidth. Under the proposed AETS, the stability and stabilization of the networked nonlinear interconnected control system will be discussed.

2.1. The system description

Suppose a nonlinear interconnected system with time-varying coupled delay is composed of N subsystems $\mathbf{S_i}$, $i\in\{i|i=1,2,\dots,n_s\}\triangleq\mathscr{N}$. The T-S fuzzy model of subsystem $\mathbf{S_i}$ for rule j is shown as: