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Exponential synchronization of chaotic neural networks with time-varying delay via intermittent output feedback approach

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ABSTRACT

This paper is dealt with the problem of exponential synchronization for chaotic neural networks with time-varying delay by using intermittent output feedback control. Based on the Lyapunov–Krasovskii functional method and the lower bound lemma for reciprocally convex technique, a novel criterion for existence of the controller is first established to ensure synchronization between the master and slave systems. Moreover, from the delay point of view, the derived criterion is extended to the relaxed case because of introducing an adjustable parameter in the Lyapunov–Krasovskii functional. Finally, a numerical simulation is carried out to demonstrate the effectiveness of the proposed synchronization law.

1. Introduction

Since Pecora and Carroll [1] first proposed the master–slave concept to achieve the synchronization for two identical chaotic systems with different initial conditions, chaos synchronization has been extensively investigated due to its potential applications in secure communication and cryptography, harmonic oscillation generation, and some other nonlinear fields [2–4]. In fact, as special complex networks, neural networks such as Hopfield neural networks, recurrent neural networks and BP neural networks have also been found to exhibit complicated dynamic characteristics and even chaotic behavior. Therefore, the study of stability analysis and control for neural networks has become a hot topic in the past decades [5–14]. Up to now, numerous papers on the subject have been published. And then, a number of synchronization and control schemes have been put forward, for example, sampled-data control [15–17], impulsive control [18,19], output feedback control [20,21], and intermittent control [22–26].

In recent years, intermittent control has become a key control strategy due to its broad potential applications in engineering fields and the special role in explaining the mechanism of human physiological and imitating human behavior [27–29]. In comparison with impulsive control, intermittent control is more easily implemented in practical application since it is not activated instantaneously. On the other hand, compared with the continuous control, intermittent control is more economical because the control signal is reset intermittently. Therefore, intermittent control can be regarded as a link between impulsive and continuous feedback control and integrates those merits. Until now, many papers on intermittently controlled systems have been carried out, for example, see [22–25,30–33] and references therein.

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In addition, time delay, especially time-varying delay is inevitable in modeling realistic neural networks due to various reasons, such as the signal transmission speed among the neurons, finite speed of information processing and the finite switching speed of amplifier circuits. It is well known that the existence of time delay also causes poor performance or even chaotic behavior. Therefore, it is very important not only in theory but also in practical applications to study intermittent control systems with time-varying delay. In the available intermittent control literatures, the Lyapunov function method and the Lyapunov–Krasovskii functional method are often introduced to analyze the stabilization and synchronization of the considered systems. Especially, the latter can provide more useful state information and delay information, which has attracted a lot of interests. Meanwhile, some approaches are developed to reduce the possible conservativeness of the Lyapunov–Krasovskii functional method, such as free-weighting matrices method [35], delay-partitioning scheme [36,37] and some integral inequalities technique [39–44]. It should be pointed out that for the derivation upper bound of time-varying delay, many scholars often assume that it is less than 1, that is, the results reported in the existing literature are only applicable to the case of slow time-varying delays, see [15,30,32,33,45,46].

In the framework of intermittent control, some types of the intermittent controllers have been designed to achieve the synchronization and stabilization problems for various dynamic systems, for example, the adaptive intermittent controller [47], the intermittent predictive controller [48], the intermittent pinning controller [49,50], the periodically intermittent feedback controller [33,34,51,52], and the delayed intermittent feedback controller [30,31,53]. It is easy to see that the controllers designed in the above references are based on intermittent state-feedback, in other words, all state information must be known. However, in most real control situations, the system state cannot be fully captured, or the cost of obtaining some state information is huge. Therefore, there is a strong need to design an intermittent output feedback controller instead of an intermittent state-feedback controller for the sake of obtaining a better performance and dynamical behavior of the state response. To the best of our knowledge, no results on synchronization for chaotic neural networks with time-varying delay via intermittent output feedback control have been reported in the literature.

Motivated by the preceding discussions, in this paper, we will investigate the problem of exponential synchronization for chaotic neural networks with time-varying delay. First, the intermittent output feedback controller is presented. Second, by constructing a novel Lyapunov–Krasovskii functional and employing the lower bound lemma for reciprocally convex approach, linear transformation technique and linear matrix equality formulation, a novel criterion for existence of the controller is first derived in terms of linear matrix equalities and linear matrix equality, which can guarantee the master system to synchronize with the slave system. Additionally, the traditional assumption that the delay-derivation upper bound of time-varying delay is restricted to be smaller than 1 is removed in this paper. Finally, a simulation example is given to demonstrate the effectiveness and the benefits of the proposed methods.

This paper is organized as follows. In Section 2, model description and preliminaries are given. Some new criteria are obtained in Section 3 to ensure the exponential synchronization for chaotic neural networks with time-varying delay. In Section 4, the effectiveness of the theoretical results is shown by a numerical example.

Throughout this paper, the superscripts '-1' and 'T' stand for the inverse and transpose of a matrix, respectively; $\Re^n$ denotes the n-dimensional Euclidean space; $\Re^{p\times q}$ is the set of all $p\times q$ real matrices; $P>0(<0,\ \leq 0,\ \geq 0)$ means that the matrix is symmetric positive(negative, semi-negative, semi-positive) definite matrix; P symmetric terms in a symmetric matrix are denoted by '*' ; 'I' is an appropriately dimensioned identity matrix; $\lambda_{\min}(P)$ strands for the minimum eigenvalue of the matrix P; $\mathrm{Sym}\{X\}=X+X^T$.

2. Problem formulation and preliminaries

Consider the following chaotic neural networks with time-varying delay

$$\begin{cases}\dot{x}_m(t)=-Ax_m(t)+Df(x_m(t))+Eg(x_m(t-\tau(t)))+\nu(t),\ \ t>0\\ y_m(t)=Cx_m(t)\\ x_m(t)=\psi(t),\quad \forall t\in[-d,0]\end{cases}\tag{1}$$

where $x_m(t)\in\Re^n$ is the state vector of the master system associated with n neutrons; $y_m(t)\in\Re^p$ is the output of the master system; $\nu(t)$ is an external input vector; $f(\cdot)$, $g(\cdot)$: $\Re^n\to\Re^n$, represent the neutron activation functions with respect to the current state $x_m(t)$ and delayed state $x_m(t-\tau(t))$, respectively; $A\in\Re^{n\times n}$ is the self-feedback term; $C\in\Re^{p\times n}$, $D\in\Re^{n\times n}$ and $E\in\Re^{n\times n}$ are known connection weight matrices; with loss of generality, one can assume that $\mathrm{rank}\{C\}=p$.The initial condition of the master system, $\psi(t)$, denotes a continuous vector-valued function on the interval $[-d,0]$. The interval time-varying delay $\tau(t)$ satisfies

$$0\leq\tau(t)\leq d,\quad \dot{\tau}(t)\leq\mu<\infty\tag{2}$$

where d and μ are constants.

Remark 1. It is worth noting that the derivative upper bound of the time-varying delay, μ, plays a key role in analyzing the exponential stability and synchronization of time-varying-delayed systems. Generally, μ is restricted to be less than 1 (see [15,30,33,34], etc.), and such constraint in some papers is not given directly in their conditions, for example, [32,45,46], however, the obtained results can only be used to deal with the case. In this paper, the derivative upper bound is more general since μ may be less or more than 1, namely, the system considered may be slow or fast time-varying delay system. Thus, the criterion to be developed in this paper has the wider range in comparison with the previous ones.