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Exponential synchronization of Markovian jumping chaotic neural networks with sampled-data and saturating actuators

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ABSTRACT

This paper deals with the problem of exponential synchronization of Markovian jumping chaotic neural networks with saturating actuators using a sampled-data controller. By constructing a proper Lyapunov–Krasovskii functional (LKF) with triple integral terms, and employing Jensen's inequality, some new sufficient conditions for the exponential synchronization of considered chaotic neural networks are derived in terms of linear matrix inequalities (LMIs). The obtained LMIs can be easily solved by any of the available software. Finally, the numerical examples are provided to demonstrate the effectiveness of our theoretical results.

1. Introduction

Over the past few decades, there has been a fervent support to neural networks due to their wide applications in various fields, such as pattern recognition, static image processing, combinatorial optimization [1–3]. A number of important and interesting results have been developed for neural networks, for example, [4–11]. On the other hand, the communication time of neurons may induce time delays in the interaction between the neurons when the neural networks are implemented by very large-scale integrated electronic circuits. It has been shown that time delay is an important reason for oscillation, divergence and instability in systems [12,13]. The large variety of methods are used to study the time delay. Among them, the linear matrix inequality (LMI) technique has been successfully used to deal with problems for neural networks with time delays [14–16]. Therefore, the stability analysis of delayed neural networks has been focused by the researchers in recent years.

Markovian jump systems are a special class of hybrid systems, which is specified by two components, the first component which refers to the mode, which is described by a continuous time finite state Markovian process and the second one which refers to the state which is represented by a system of differential equation. Also, Markovian jump systems can be defined as a special class of dynamical systems with finite mode operation due to random changes in their structure, such as component failures or repairs, sudden environmental disturbance, changing subsystems inter connections, and so on. The application of the Markovian jump system can be found in economic systems, modeling production system, network

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control systems, manufacturing systems, communication systems, and so on. Stability analysis results about Markovian jump neural networks can be found in [17–22]. Moreover, the problems of $\mathcal{H}_\infty$ finite-time boundedness and finite-time $\mathcal{H}_\infty$ state feedback stabilization for Markov jump systems partially known transition probabilities were discussed in [23]. The authors in [24] have studied about the stabilization and synchronization control of Markovian jumping neural networks with mode-dependent mixed delays subject to quantization and packet dropout. The adaptive synchronization for stochastic neural networks of neutral-type with mixed delays was studied in [25].

Also, it is well known that the chaotic neural networks have complex dynamical behaviors that possess some special features [26]. Chaotic systems possess a typical characteristic due to small changes in their initial conditions. Over the past two decades, the synchronization problem of chaotic systems has been widely analyzed due to its applications in biology, chemistry, cryptography and some other nonlinear fields. Many useful approaches have been established for the synchronization of chaotic systems, which include time-delay feedback control, adaptive control, impulsive control, sampled-data control, manifold-based method, and so on. Since the synchronization concept introduced by Pecora and Carroll in the pioneering work [27], an increasing interest has been devoted to the master–slave synchronization of chaotic neural networks with delays. The authors in [28], have studied the synchronization problem of chaotic neural networks with time delays, where controllers have been designed to achieve the synchronization of the considered neural networks. In [29], the synchronization problem of stochastic neural networks with time delays has been considered by using the LMI method and sufficient conditions have been derived to ensure that the master system synchronizes with the slave system.

On the other hand, the sampled-data control system has been studied extensively over the past few years. The analysis of linear control systems is based on the fact that the signals at various points in the system are continuous with respect to time. However, in some applications it is convenient to use one or more control signals at discrete time intervals. The control systems using one or more signals at discrete time intervals are known as sampled-data control systems. In a sampled-data control method the signal at any one or more places is sampled and appears in the form of a pulse at periodic intervals. Also, in sampled data control systems, choosing proper sampling interval is more important for designing suitable controllers (see [30–32] for instance). The use of sampled-data control systems enables time sharing between different input signals using the same control equipment. Different input signals can be sampled periodically by staggering sampling time, and thus over the same control equipment number of inputs can be used. This arrangement of control reduces the cost of control equipment. The sampled-data control theory has received much attention due to the powerful application in the field of engineering. For example, the authors discussed robust sample-data control for uncertain dynamic systems in the presence of missing data in [33], here the sample-data controller is presented in the form of linear matrix inequality. The authors in [34], studied the uncertain nonlinear chaotic systems through a stochastic sample-data control to ensure the robust synchronization. In [35], the authors have discussed the problem of exponential synchronization of neural networks with mixed delays using sampled-data feedback control. The authors have discussed the sampled-data synchronization problem of neural networks with discrete and distributed delays under variable sampling in the framework of input delay in approach in [30].

Also, actuator saturation is inevitable in feedback control systems. If it is ignored in the design, a controller may wind up the actuator, possibly in degraded performance or instability. A classical approach to avoiding such undesirable behaviors is to add an anti-windup compensator to the original controller. On the other hand, higher performance may be expected if a controller is designed a priori considering the saturation effect. The nonlinearity saturation is described by bounded sector [36–41]. The authors have discussed the stabilization problem for sampled and saturated controlled systems in [42]. The synchronization problem has been considered for sampled and saturating actuators in [43], where the time-dependent Lyapunov function has been constructed for synchronization of the master and slave neural networks.

Inspired by the above works, in this paper we study the exponential synchronization problem for Markovian jumping chaotic neural networks with sample-data and saturating actuators. We emphasize that the sample-data with respect to actuator saturation in presence of Markovian jumping and time varying delay for a chaotic neural networks undergoes exponential synchronization with help of derived criteria by skillfully choosing the Lyapunov functional, which makes the condition in this paper more effective than in [43]. Finally, numerical simulations are also exploited to demonstrate the effectiveness and validity of the theoretical results.

The main improvements of this paper compared to [43,44] are as follows: (1) Although the importance of actuator saturation has been widely recognized there is no related results have been established for exponential synchronization in the presence of actuator saturation with sample data. In [43] only the local synchronization of the chaotic systems has been investigated. (2) In order to over come the disturbance we improvised our work by including the Markovian jump term to the proposed system which is not done in past research [43,44].

The rest of the paper is organized as follows. In Section 2, preliminaries and problem formulation is given. In Section 3, we analyze the exponential synchronization problem for Markovian jumping chaotic neural networks with sample-data and saturating actuators. Numerical simulations are given to verify our theoretical results in Section 4. Concluding remarks are drawn in Section 5.

Notations: Throughout this section, $\mathbb{R}^n$ and $\mathbb{R}^{m\times n}$ denote the n-dimensional Euclidean space and the set of all $m \times n$ real matrices respectively. The notation $X > Y (X \geq Y)$, where X and Y are symmetric matrices, means that $X - Y$ is positive definite(positive semi-definite). $\lambda_{\max}(Q)$ $(\lambda_{\min}(Q))$ denotes the maximum (minimum) of the eigenvalue of real symmetric matrix Q. I and O represent the identity matrix and zero matrix. Let $\mathcal{C}([-d_2, 0]; \mathbb{R}^n)$ denote the family of continuously differentiable functions φ from $[-d_2, 0]$ to $\mathbb{R}^n$. The superscript "T" represents the transpose and diag$\{\ldots\}$ stands for a