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Finite-time synchronization for fuzzy cellular neural networks with time-varying delays

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Abstract

In this paper, finite-time synchronization for a class of fuzzy cellular neural networks with time-varying delays is investigated based on the finite-time stability theory. By applying the inequality technique and the analysis method, some new and useful criteria of finite-time synchronization for the addressed network are derived in terms of p-norm. Finally, two examples with their numerical simulations are given to show the feasibility and effectiveness of the developed synchronization method.

Keywords: Fuzzy cellular neural network; Finite-time synchronization; Time-varying delay

1. Introduction

Since first proposed by Chua and Yang in 1988 [1,2], cellular neural networks (CNNs) have been widely studied due to their extensive applications in many fields such as image processing, associative memories, classification of patterns, quadratic optimization and so on. One special group of fundamental neural networks, fuzzy cellular neural network (FCNN), which integrates fuzzy logic into the structure of traditional CNN and maintains local connectedness among cells, has been introduced by Yang and Yang [3,4]. Unlike previous CNN structures, FCNN has fuzzy logic between its template and input and/or output besides the "sum of product" operation. Meanwhile, many studies have been revealed that FCNN is a useful paradigm for image processing problems, which is a cornerstone in image processing and pattern recognition. Therefore, it is of great importance to analyze the dynamical behaviors of FCNNs both in theory and applications.

In the implementation of neural networks, such as in the process of moving images, time delays unavoidably exist in the neural processing and signal transmission due to the finite switching speed of neurons and amplifiers, which will affect the stability of the neural system and may lead to some complex dynamic behaviors, such as instability, chaos, oscillation or other performance of the neural network. As a result, the dynamical behavior analysis of delayed neural

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networks has attracted more and more attention of researchers and many results have been reported in the literature [5–12].

During the last three decades, chaos has been intensively investigated in the context of several specific problems arising in physics, mathematics, engineering science, secure communication, etc. Synchronization means two or more systems which are either chaotic or periodic sharing a common dynamical behavior and it has been shown that this common behavior can be induced by coupling or by external force. Due to this property, chaos synchronization has been successfully applied in a variety of fields including secure communication, chemical and biological systems, human heartbeat regulation, information science, image processing, and harmonic oscillation generation [13,14]. Up to now, a wide variety of approaches have been proposed for synchronization of chaotic systems, such as adaptive control [8,13], impulsive control [15], fuzzy control [16], periodically intermittent control [17], observer-based control [18], and so on.

In view of the significance of the control for delayed FCNNs, we see that there have been many important works, for example, [8–12]. In [8], the synchronization for delayed FCNNs with unknown parameters was investigated by using well-known Lyapunov–Lasall principle and some synchronization criteria were obtained. By employing the Lyapunov-like stability theory of impulsive functional differential equations, some criteria for global exponential synchronization of delayed FCNNs with impulsive effects were derived in [9]. In [10], with the help of the nonlinear measure method, the authors concerned the synchronization of coupled FCNNs with time-varying delays. By designing a sliding mode controller, the asymptotical synchronization problem of non-identical chaotic FCNNs with time-varying delays was investigated in [11]. In [12], the synchronization for a class of coupled identical Yang–Yang type FCNNs with time-varying delays was studied by using adaptive control method.

However, most of the methods mentioned above, have been used to guarantee the asymptotic stability or exponential stability of the synchronization error dynamics. This means that the trajectories of the response system can reach to the trajectories of the drive system over the infinite horizon. In the practical engineering process, however, it is more reasonable that synchronization objective is realized in a finite horizon. To achieve faster synchronization in control systems, an effective method is using finite-time control techniques. Finite-time synchronization means the optimality in convergence time. Moreover, the finite-time control techniques have demonstrated better robustness and disturbance rejection properties [19,20]. In [21], by introducing nonsingular terminal sliding surface and designing adaptive controller, the authors studied the finite-time chaos synchronization problem between two different chaotic systems with unknown parameters. In [22], the finite time stability of periodic solution for Hopfield neural networks with discontinuous activations was investigated. In [23], based on the finite-time stability theory and by designing adaptive feedback controllers, the authors concerned the finite-time synchronization problem between two chaotic CNNs with constant delays. However, to the best of our knowledge, till now, there are very few or even no studies on the problem of finite-time synchronization for the chaotic FCNNs with time-varying delays.

Motivated by the above discussions, in this paper, we study the finite-time synchronization for the delayed FCNNs by designing a suitable finite-time controller. Based on the finite-time convergence theory, we establish some new and useful sufficient conditions on the finite-time synchronization of addressed model.

The rest of the paper is organized as follows. In Section 2, the drive system and the response system are introduced. In addition some assumptions and definitions together with some useful lemmas needed in this paper are presented. Section 3 is devoted to investigating the finite-time synchronization between two chaotic FCNNs with time-varying delays. In Section 4, two examples with their numerical simulations are given to illustrate the effectiveness of the obtained results. Finally, some general conclusions are drawn in Section 5.

2. Preliminaries

In this paper, we consider the following n-dimensional FCNNs with time-varying delays

$$\begin{aligned}\dot{x}_i(t) = {} & -c_i x_i(t) + \sum_{j=1}^{n} a_{ij} f_j(x_j(t)) + \sum_{j=1}^{n} b_{ij} f_j(x_j(t-\tau_j(t))) + \sum_{j=1}^{n} d_{ij} v_j + \bigwedge_{j=1}^{n} T_{ij} v_j \\ & + \bigwedge_{j=1}^{n} \alpha_{ij} f_j\left(x_j(t-\tau_j(t))\right) + \bigvee_{j=1}^{n} \beta_{ij} f_j\left(x_j(t-\tau_j(t))\right) + \bigvee_{j=1}^{n} S_{ij} v_j + I_i, \qquad (1)\end{aligned}$$