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Finite-time synchronization for a class of fuzzy cellular neural networks with time-varying coefficients and proportional delays ☆

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Abstract

Based on the finite-time stability theory, this paper deals with finite-time synchronization for a class of fuzzy cellular neural networks with time-varying coefficients and proportional delays. Using differential inequality techniques and the analysis approach, we derive some new and useful sufficient conditions of finite-time synchronization for the addressed systems. Finally, an illustrative example with its numerical simulations is given to show the effectiveness of main results.

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

1. Introduction

In order to consider fuzzy logic and local connectedness and extend cellular neural networks (CNNs) those proposed by Chua and Yang [1,2], Yang and Yang [3,4] have pioneered fuzzy cellular neural networks (FCNNs) in 1996. Recently, many researchers have found that FCNNs are so useful in psychophysics, speech, perception, robotics, adaptive pattern recognition, vision, and image processing (see [5–8]) that abundant results on stability, periodicity and synchronization of FCNNs [9–18] have appeared. Although delays are involved in those FCNNs models, coefficients are often constant and delays are bounded. In real world, coefficients of FCNNs usually vary with environment and delays may be proportional, i.e., the proportional delay function $\tau(t) = t - qt$ is monotonically increasing function with the increase of time t, where $q \in (0, 1)$ is a constant.

In view of the control for delayed FCNNs, finite-time synchronization is very significant since it means that two or more dynamic systems converge to a desired target (in general referring to the origin) within a finite time. The authors of [19,20] investigated the finite-time chaos synchronization problem between two different chaotic systems

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with unknown parameters and the finite-time stability of periodic solution for Hopfield neural networks with discontinuous activations respectively. In [21], Mei et al. investigated the finite-time synchronization problem between two chaotic CNNs with constant delays. Earlier this year, authors of [5,22,23] considered the finite-time and exponential synchronization for FCNNs with constant coefficients and bounded delays. However, as far as we know there is no result on the finite-time synchronization of FCNNs with time-varying coefficients and proportional delays, except Jia [24] who studied a special finite-time and exponential synchronization for a single FCNNs system.

Inspired by the above discussions, we consider the finite-time synchronization for the following FCNNs with time-varying coefficients and proportional delays:

$$\begin{aligned} x_i'(t) &= -c_i(t)x_i(t) + \sum_{j=1}^{n} a_{ij}(t)f_j(x_j(t)) + \sum_{j=1}^{n} b_{ij}(t)f_j(x_j(q_{ij}t)) + \sum_{j=1}^{n} d_{ij}(t)v_j(t) \\ &+ \bigwedge_{j=1}^{n} T_{ij}(t)v_j(t) + \bigwedge_{j=1}^{n} \alpha_{ij}(t)f_j(x_j(q_{ij}t)) + \bigvee_{j=1}^{n} \beta_{ij}(t)f_j(x_j(q_{ij}t)) \\ &+ \bigvee_{j=1}^{n} S_{ij}(t)v_j(t) + I_i(t), t \geq t_0 > 0, i \in J = \{1, 2, \cdots, n\}, \end{aligned} \tag{1.1}$$

$$\begin{aligned} y_i'(t) &= -c_i(t)y_i(t) + \sum_{j=1}^{n} a_{ij}(t)f_j(y_j(t)) + \sum_{j=1}^{n} b_{ij}(t)f_j(y_j(q_{ij}t)) + \sum_{j=1}^{n} d_{ij}(t)v_j(t) \\ &+ \bigwedge_{j=1}^{n} T_{ij}(t)v_j(t) + \bigwedge_{j=1}^{n} \alpha_{ij}(t)f_j(y_j(q_{ij}t)) + \bigvee_{j=1}^{n} \beta_{ij}(t)f_j(y_j(q_{ij}t)) \\ &+ \bigvee_{j=1}^{n} S_{ij}(t)v_j(t) + I_i(t) + u_i(t), t \geq t_0 > 0, i \in J. \end{aligned} \tag{1.2}$$

Models (1.1) and (1.2) are so-called drive–response systems, where $q_{ij} \in (0, 1]$ is proportional delay factor, and $q_{ij}t = t - \tau_{ij}(t)$, in which $\tau_{ij}(t) = (1 - q_{ij})t$ is a transmission delay function, and $\tau_{ij}(t) \to \infty$ as $q_{ij} \neq 1$, $t \to \infty$; $x_i(t)$ and $y_i(t)$ correspond to the state variable of the ith unit of drive system and response system respectively; $c_i(t)$ represents the passive decay rate to the state of ith unit; $a_{ij}(t)$ and $b_{ij}(t)$ are elements of feedback templates and $d_{ij}(t)$ is feed-forward template; $\alpha_{ij}(t)$, $\beta_{ij}(t)$, $T_{ij}(t)$ and $S_{ij}(t)$ are elements of the fuzzy feedback MIN template, fuzzy feedback MAX template, fuzzy feed-forward MIN template and fuzzy feed-forward MAX template, respectively; $\bigwedge$ and $\bigvee$ denote the fuzzy AND and fuzzy OR operation, respectively; $v_i(t)$, $I_i(t)$ and $u_i(t)$ denote the input, the bias of the ith neuron and the control input respectively; f_i is an activation function.

Assume that the systems (1.1) and (1.2) are associated with the following initial conditions:

$$x_i(s) = \varphi_i(s), \quad s \in [\rho_i t_0, t_0], \ i \in J, \tag{1.3}$$

$$y_i(s) = \phi_i(s), \quad s \in [\rho_i t_0, t_0], \ i \in J. \tag{1.4}$$

Here, $\rho_i = \min_{1 \leq j \leq n} \{q_{ij}\}$ and $\varphi_i, \phi_i \in C[\rho_i t_0, t_0]$, $i \in J$.

The main goal of this paper is to design and implement a suitable controller $u_i(t)$ for the response system (1.2) such that the controlled response system (1.2) could be synchronous with the drive system (1.1) in a finite time. It is worthy to mentioned that models of [5,22,23] are special FCNNs of this paper when coefficients of (1.1) and (1.2) are constant.

The rest of this paper is organized as follows. In Section 2, we give some basic definitions, assumptions and useful lemmas, which play an important role in Section 3 to derive sufficient conditions on the finite-time synchronous between two chaotic FCNNs with time-varying coefficients and proportional delays. Finally, Section 4 provides an example and its numerical simulations to show the effectiveness of obtained results.

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