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Adaptive synchronization for stochastic competitive neural networks with mixed time-varying delays ☆

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This paper deals with the synchronization problem for competitive neural networks with different time scales, as well as mixed time-varying delays (both discrete and distributed time-varying delays) and stochastic disturbance. By using stochastic analysis approaches and constructing a novel Lyapunov–Krasovskii functional, an adaptive feedback controller is proposed to guarantee the exponential synchronization of proposed competitive neural networks in terms of p-norm. The synchronization results presented in this paper generalize and improve many known results. This paper also presents an illustrative example and uses simulated results of this example to show the feasibility and effectiveness of the theoretical results.

1. Introduction

In the past decade, there has been a great interest in neural networks due to their wide range of applications, such as associative memory, pattern recognition, signal processing, image processing, fault diagnosis, automatic control engineering, combinatorial optimization, and so on. In fact, time delays are unavoidably in the information processing of neurons due to various reasons. For example, time delays can be caused by the finite switching speed of amplifier circuits in neural networks or deliberately introduced to achieve tasks of dealing with motion-related problems, such as moving image processing. In addition, the axonal transmission delays in neural networks are often time-varying [13,28,29,37]. Meanwhile, a neural network usually has a spatial nature due to the presence of an amount of parallel pathways of a variety of axon sizes and lengths, it is desired to model them by introducing distributed delays. Therefore, both discrete and distributed delays, especially both discrete and distributed time-varying delays, should be taken into account when modeling realistic neural networks [14,17,31,32,34,35].

In 1983, Cohen and Grossberg [4] proposed competitive neural networks. Recently, Meyer-Bäse et al. [21–23] proposed the so called competitive neural networks with different time scales, which can be seen as the extension of Hopfield neural networks [11,12], Grossberg's shunting network [7] and Amari's model for primitive neuronal competition [1]. In the competitive neural networks model, there are two types of state variables: the short-term memory (STM) variable describing the fast neural activity, and the long-term memory (LTM) variable describing the slow unsupervised synaptic modifications. Therefore, there are two time scales in the competitive neural networks model, one of which corresponds to the fast change of the state, and the other to the slow change of the synapse by external stimuli. Recently, many scientific and technical

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workers have been joining the study fields with great interest, and various interesting results for competitive neural networks with different time scales have been reported in [9,19,24,25].

It was found in [3] that some delayed neural networks can exhibit chaotic dynamics. As special complex networks, delayed competitive neural networks with different time scales have been found to exhibit complex and unpredictable behaviors including stable equilibria, periodic oscillations, bifurcation and chaotic attractors. Therefore, some works dealing with chaos synchronization phenomena in delayed competitive neural networks with different time scales have also been published in [6,18]. Gan et al. [6] investigated the adaptive synchronization problem of competitive neural networks with different time scales, discrete constant delays and unknown parameters by utilizing Lyapunov stability theory and parameter identification technique, and they also demonstrated the effectiveness of application of the proposed adaptive feedback scheme in secure communication. Without assuming the active functions to be differentiable and bounded, some delay-independent or delay-dependent criteria for the exponential synchronization problem of a class of competitive neural networks with different time scales and time-varying delays were derived and the controller gain matrix was designed by using Lyapunov functionals, free-weighting matrix approach, linear matrix inequality approach and Leibniz–Newton formula in [18].

Actually, the synaptic transmission in real neural networks can be viewed as a noisy process introduced by random fluctuations from the release of neurotransmitters and other probabilistic causes [10,40]. Hence, noise is unavoidable and should be taken into consideration in modeling. Hence, considerable attention has been paid on the study of stochastic neural networks theory and various interesting results have been reported in [2,8,15,27,26,30,33,38,39]. Especially, Gu [8] proposed an adaptive feedback controller to achieve complete synchronization of coupled competitive neural networks with different time scales, discrete constant delays and stochastic perturbations by using LaSalle-type invariance principle for stochastic differential delay equation. In [38], Yang et al. investigated the problem of lag synchronization for a kind of competitive neural networks with different time scales, discrete and distributed constant delays, as well as uncertain nonlinear external and stochastic perturbations by designing a simple but robust adaptive controller. In [39], the problem of exponential synchronization of switched stochastic competitive neural networks with different time scales, both interval time-varying delays and distributed delays was studied based on multiple Lyapunov–Krasovkii functionals, the free-weighting matrix method, Newton–Leibniz formulation, as well as the invariance principle of stochastic differential equations, where distributed delays were unbounded or bounded, the stochastic disturbance was of the form of multi-dimensional Brownian motion, and the networks were governed by switching signals with average dwell time. Based on the Lyapunov second method and LMI (linear matrix inequality) optimization approach, Park et al. [30] proposed a dynamic feedback controller to guarantee the asymptotical mean-square synchronization of two identical delayed discrete-time complex networks with stochastic disturbances.

From the above analysis, we know that the mixed time-varying delays and stochastic noise disturbance on the dynamic behaviors of competitive neural networks with different time scales cannot be neglected in modeling. As is pointed out in [13], there are few results, or even no results concerning the synchronization schemes for complex networks, in particular stochastic complex networks based on p-norm. The issues of integrating mixed time-varying delays and stochastic noise disturbance into the study of synchronization for competitive neural networks with different time scales require more complicated analysis. Therefore, it is interesting to study this problem both in theory and in applications, and there exist open room for further improvement. This situation motivates our present investigation. This paper is concerned with the exponential synchronization of competitive neural networks with different time scales, mixed time-varying delays and stochastic perturbations under the adaptive control in terms of p-norm is investigated in this paper. By introducing a novel Lyapunov–Krasovskii functional with the idea of delay partitioning, employing stochastic analysis approaches, an adaptive controller is proposed for the considered competitive neural networks. Our results are more general and they effectually complement or improve the previously known results.

The organization of this paper is as follows: in the next section, problem statement and preliminaries are presented; in Section 3, an adaptive controller is proposed to ensure the exponential synchronization for competitive neural networks with different time scales, mixed time-varying delays and stochastic perturbations in terms of p-norm; a numerical example will be given in Section 4 to demonstrate the effectiveness and feasibility of our theoretical results. Finally, conclusions are drawn in Section 5.

Notation: Throughout this paper, $\mathbf{R}^n$ and $\mathbf{R}^{n\times m}$ denote the n dimensional Euclidean space and the set of all $n \times m$ real matrices, respectively; $(\Omega, \mathcal{F}, \mathcal{P})$ is a complete probability space, where Ω is the sample space, $\mathcal{F}$ is the σ-algebra of subsets of the sample space and $\mathcal{P}$ is the probability measure on $\mathcal{F}$; $\mathbb{E}\{\cdot\}$ stands for the mathematical expectation operator with respect to the given probability measure $\mathcal{P}$; "sgn" is the sign function defined in Filippov sense [5].

2. Modeling and preliminary

Motivated by the discussions in the above section, in this paper, we consider the competitive neural networks with different time scales and mixed time-varying delays described by:

$$\mathrm{STM}: \quad \varepsilon\dot{x}_i(t) = -a_i x_i(t) + \sum_{k=1}^{N} D_{ik} f_k(x_k(t)) + \sum_{k=1}^{N} D_{ik}^{\tau} f_k(x_k(t-\tau(t))) + \sum_{k=1}^{N} D_{ik}^{\sigma} \int_{t-\sigma(t)}^{t} f_k(x_k(s))\mathrm{d}s + B_i \sum_{j=1}^{P} m_{ij} w_j, \tag{2.1}$$