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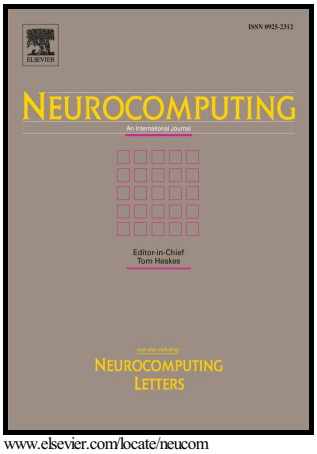

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Synchronization of coupled neural networks with time-varying delay

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Abstract

This paper addresses the synchronization problem for a class of neural networks with time-varying delay and hybrid couplings. By using a Lyapunov-Krasovskii functional (LKF) containing a triple integral term, applying the theory of Kronecker product of matrices, the Wirtinger-based inequality, the method of reciprocally convex combination and the technique of linear matrix inequality (LMI) to estimate the derivative of the LKF, the delay-dependent synchronization criteria in terms of LMIs are newly obtained. And a numerical example is given to illustrate the effectiveness of proposed results.

Key words: coupled neural networks (CNNs), time-varying delay, synchronization

1. Introduction

In the last two decades, complex dynamical networks have been received considerable attention due to their theoretical importance and potential applications in various areas of science and engineering such as transportation networks, biological networks, social networks, wireless communication, electric power grid, the World Wide Web, global economic markets [1, 2, 3, 4]. Since Watts and Strogatz introduced the 'small-world' networks [5], the asymptotic behavior of interconnected oscillatory nodes on the structural properties of complex dynamical networks has been widely investigated. Many interesting behaviors have been observed from complex dynamical networks such as synchronization, consensus and so on. Synchronization, one of the most important collective behaviors of complex dynamical networks, has drawn significant research interest very recently [6, 7, 8, 9, 10, 11].

Coupled neural networks (CNNs), as a special class of complex networks, have been found to exhibit more complicated and unpredictable behaviors than a single neural network [12]. Synchronization in CNNs has been a hot research topic because of its wide applications in many areas such as harmonic oscillation generation, information science, secure communication and chaos generation design [12, 13]. On the other hand, in the applications of neural networks, time delays unavoidably occur in neural networks due to the network traffic jam and the finite speed of signal transmission over the links, which can cause divergence, oscillation and instability such that the performances of the networks are degraded [14]. The analysis and control of synchronization in CNNs with time delays have become a hot topic. To mention a few, the synchronization problem for arrays of delayed neural networks with constant and delayed coupling was investigated in [15]. And the cluster synchronization condition was derived for an array of hybrid coupled neural networks with delay in [16]. In [17], the globally exponential synchronization in an array of linearly CNNs with delayed coupling was studied. Park et al. [18] obtained the delay-dependent synchronization criteria for CNNs with interval time-varying delays and leakage delay. Du et al. [12] presented the globally exponential synchronization criteria for an array of hybrid coupled neural networks with leakage delay, time-varying discrete and distributed delays. In [19], the synchronization analysis was investigated for an array of hybrid coupled neural networks with discrete time-varying delays, distributed time-varying delays and nonlinear coupling. By introducing an augmented Lyapunov-Krasovskii functional (LKF), the sufficient conditions in terms of linear matrix inequalities (LMIs) for global synchronization of hybrid coupled neural networks with interval delay were obtained in [20]. In order to deal with a large number of highly interconnected dynamical units in CNNs, Huang et al. [13], Zhang et al. [20], Gong et al. [21] and Wang et al. [22] propose a new method to construct an appropriate LKF by using the Kronecker product of matrices. In recent years, some new techniques are also used to derive less conservative criteria, such as triple integral terms contained in the LKF [23], Jensen's inequality [24] or Wirtinger-based inequality [25]. And a less conservative criterion was obtained by using Wirtinger-based inequality and a triple integral term in [23]. How to better the results has still attracted much attention. Constructing better LKFs and reducing the enlargement of the derivative of LKF are the main topics of this problem.

Motivated by the above discussions, the problem of synchronization for a class of neural networks with time-varying delay and hybrid couplings is further studied in this paper. Inspired by the work in [13, 20, 21] and [23], not only the Kronecker product of matrices but also a triple integral term is introduced to the LKF. Different from [20, 21], the introduced LKF is not augmented, which implies that there are less matrix variables in our obtained synchronization criteria. And Jensen's inequality, Wirtinger-based inequality, recipro-

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