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Adaptive observer-based projective synchronization for chaotic neural networks with mixed time delays

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ABSTRACT

This paper addresses adaptive projective synchronization of chaotic neural networks with mixed time delays based on an observer-based design strategy. For this, the idea of designing nonlinear state observers is used, and a novel adaptive observer-based controller is given to provide projective synchronization between the master and the slave chaotic systems. Lyapunov theorem is also utilized to obtain the adaptation laws for tuning the controller when the parameters of the master system are unknown. The proposed control scheme is successfully applied for projective synchronization of two chaotic neural networks with mixed delays. The simulation results demonstrate the feasibility and efficiency of the presented method.

1. Introduction

Biological and artificial neural networks contain inherently time delays due to the existence of time delay in the information processing of neurons. Time delays may lead to many inevitable effects and some complex dynamical behaviors such as oscillation, instability, bifurcation and chaos in neural networks. Since Aihara et al. offered the first modeling of single chaotic neuron in 1990 [1], several types of chaotic neural networks such as Hopfield, bidirectional associative memory, Lotka–Volterra and cellular neural networks have been investigated by many researchers [2–6].

Nowadays, an increasing attention has been attracted by researchers to study the dynamical behavior of delayed chaotic neural network and also synchronization of such neural networks due to their potential applications in crucial fields such as information processing, secure communication, pattern recognition and model identification, image processing and restoration, combinational optimization, motion related problems, chemical and biological systems, human heart beat regulation, social science, power system protection and so on [7–14].

The primitive study on chaos synchronization has been carried out by Pecora and Carroll in 1990 for two identical chaotic systems with different initial conditions [15]. Since then, diverse types of master-slave synchronization methods have been presented such as non-identical synchronization [14,16,17], generalized synchronization [18–20], lag synchronization [21,22], projective synchronization [23], exponential synchronization [24,25]. Amongst these types of chaos synchronization, projective synchronization has drawn increasing attention by many scientists because of its proportional features and subsequently faster communication [26].

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Projective synchronization concept has been proposed by Gonzalez-Miranda [27]. It also presented by Mainieri and Rehacek for two identical systems using a scaling factor and clarified in a tree-dimensional system [28]. Subsequently, projective synchronization has been extended as generalized projective synchronization by some researchers [29–31].

The previous methods are often based on identical projective synchronization with the same dynamical structure and parameters of the master and the slave systems or usually by considering a constant delays in the neural networks and there have been very few results on the project synchronization for neural networks with mixed delays [32,33]. Thus, it is interesting to further study the project synchronization of different neural networks by considering mixed time delays in the dynamics of neural networks.

In addition, in the existing works, synchronization methods are often based on Lyapunov theory. For instance, in Ref. [23] projective synchronization of the delayed chaotic neural networks is explained by designing the integral sliding mode control (SMC) method based on Lyapunov-Krasovskii theory and linear matrix inequality (LMI) technique. However, such synchronization procedures need to calculate the Lyapunov functions and this have limited the use of such methods. Thus, it is important to use simple synchronization techniques which have not any special requirement on the structure of the system for delayed chaotic neural networks [26,32].

On the other hand, the existing synchronizations are generally designed by considering the conditions in which the parameters of the systems are known and constant. However, due to the complications in real world applications, the parameters of the systems may be unknown and such uncertainties may impress the dynamical behavior of the systems or even destroy the mechanism of synchronization. Accordingly, tackling the uncertainties in the parameters is a significant and challenging task in the synchronizing methods which can be achieved using adaptive controller schemes [34].

To consider the above-mentioned problems, in the present endeavor, we firstly propose a new projective synchronization scheme for two non-identical chaotic neural networks with both discrete and distribute time delay. The proposed method is a simple generalized projective synchronization method based on a nonlinear observer design technique. The method is not a LMI-based method and thereby there is not special requirement for the structure of the system. Therefore, the proposed synchronization method has fewer limitations. In the second step, by assuming that the master system contains unknown parameters, the adaptive controller is also designed for adjusting the control parameters. The proposed adaptive controller can effectively provide projective synchronization of delayed chaotic neural networks, where the parameters of the master system are unknown. Eventually, an example with numerical simulations is provided to show the feasibility and effectiveness of the proposed method.

The main contributions of this paper are listed as follows: (i) The proposed method is developed for the first time for project synchronizing between two non-identical delayed chaotic neural network by considering mixed time delays; (ii) By utilizing a simple observer-based design technique, the project synchronization problem is investigated without any need to LMI and its limitations; (iii) Using an adaptive law extracted based a Lyapunov-based technique, the effects of unknown parameter variations in the master system can be overcome successfully.

The paper is organized as follows: In Section 2, general description of chaotic neural network with mixed time delays and basic definitions are given. The observer-based synchronization method is presented in Section 3. In Section 4, an adaptive law is obtained for adjusting the observer-based controller. Section 5 gives the simulation results to verify the efficiency of the proposed method as a generalized projective synchronization method. Finally conclusion remarks are drawn in the last section.

2. Problem formulation

A chaotic neural network with mixed time delays is considered as:

$$\dot{x}(t) = -Cx(t) + Af_1(x(t)) + Bf_2(x(t-\tau_1)) + D\int_{t-\tau_2}^{t} f_3(x(s))ds + J_1 \tag{1}$$

where $x(t) = [x_1(t), x_2(t), ...x_n(t)]^T \in \Re^n$ represents the n-dimensional state vector of chaotic neural network;$f_i(x(t)) = [f_{i1}(x(t)), f_{i2}(x(t)), ...f_{in}(x(t))]^T$ for $i = 1, 2, 3$ refer to the activation vector functions; $C = diag(c_1, c_2, ..., c_n)$ is the state feedback coefficient matrix which is a positive diagonal matrix, i.e., $c_i > 0$ for $i = 1, 2, \ldots, n$; $A = [a_{ij}]_{n\times n}$, $B = [b_{ij}]_{n\times n}$ and $D = [d_{ij}]_{n\times n}$ for $i, j = 1, 2, \ldots, n$ are the connection weight matrix, the time-delayed weight matrix and the distributed time-delayed weight matrix respectively;$J_1 = [J_{11}, J_{12}, ..J_{1n}]^T$ is the external input and also τ_1 and τ_2 correspond to the transmission delays, where $\tau_i \geq 0$ for $i = 1, 2$.

In this paper, the chaotic neural network (1) is used as the master system. In additional, the slave system is considered in the following form:

$$\dot{y}(t) = -Ny(t) + Rg_1(y(t)) + Lg_2(y(t-\tau_1)) + M\int_{t-\tau_2}^{t} g_3(y(s))ds + J_2 + u(t) \tag{2}$$