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Projective synchronization adaptive control for different chaotic neural networks with mixed time delays

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ABSTRACT

An adaptive control schemes is presented to the projective synchronization of different chaotic neural networks with mixed time delays. The adaptive controller is designed by a linear matrix inequality approach. The proposed approach in this paper gives the flexibility to construct one adaptive control law, and the merit of the adaptive controller with one parameter is that projective synchronization errors can be reached zero field at fast speed. Finally, numerical simulation results are given to validate the design method.

1. Introduction

Over the past decade, neural networks have been extensively investigated due to that neural networks have successful applications in a variety of areas such as pattern recognition, static image processing, and signal processing [1–3]. In many application engineers, time delays exhibits as a typical characteristic in the processing of neurons and becomes one of the main sources to cause instability and poor performances, or lead to some dynamic behaviors such as chaos, instability, divergence, and others [4–8]. Therefore, time-delay neural networks have been an important subject of research in the past decades.

It is noted that the chaos phenomenon often appears in neural networks [9], and thus the drive–response (or master–slave) synchronization of two identical chaotic systems proposed with different initial conditions [10], which has attracted considerable attention. For example, in [9,11], sampled-data controllers are proposed for the synchronization of drive–response systems with time-delays. A projective synchronization was reported in [12], and a scaling factor α is introduced to be synchronized between two identical systems in [13]. Based on these pioneer works, many of works in the projective synchronization of chaotic delayed neural networks are presented [14–16]. The disadvantage of these works is that the drive–response systems have the same parameters and identical dynamic structure. However, the drive and response systems are different in many practical situations, so these design methods will be invalided if they be used in these systems. So it is necessary to find another design projective synchronization method such that it is not only utilized in the drive–response systems has the same parameters and identical dynamic structure but also suit to the nonidentical drive and response systems. For the hybrid projective of fractional order chaotic systems with time-delay, a nonlinear controller is designed in [17]. An integral sliding mode control approach is presented to investigate the projective synchronization of nonidentical chaotic neural networks with mixed time delays in [18]. The projective-anticipatory, projective and projective-lag synchronization of two different variable time-delayed systems is discussed based on Krasovskii–Lyapunov stability in [19]. However, this method takes another problem is that the projective synchronization cost is large, because it is well known that the synchronization cost is an important quality index in judging control method for the synchronization of drive and response systems. For this purpose, we consider adaptive control design method in order to decrease the projective synchronization cost. Based on analysis of the Lyapunov–Krasovskii functional and the linear matrix inequality, a sufficient condition which can be eliminated the projective synchronization cost and error of the different chaotic neural networks with mixed time delays.

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The paper is organized as follows. In Section 2, some problem descriptions are given. In Section 3, the methodology of Projective synchronization by adaptive control method is developed. Numerical example is used to demonstrate the effectiveness of proposed schemes in Section 4. Section 5 gives the conclusions of this paper.

2. Problem descriptions

The following drive system of neural network model is considered:

$$\dot{x}(t) = -C_1x(t) + A_1f_1(x(t)) + B_1f_2(x(t-\tau_1)) + D_1\int_{t-\tau_2}^{t} f_3(x(s))ds + J_1 \tag{1}$$

where $x(t) = (x_1(t), x_2(t), \ldots, x_n(t))^T \in R^n$ is an n-dimensional state vector of the drive system; $C_1 = diag(c_1^1, c_2^1, \ldots, c_n^1)$ is the state feedback coefficient matrix; $A_1 = (a_{ij}^1)_{n\times n}$ is the connection weight matrix, $B_1 = (b_{ij}^1)_{n\times n}$ is the discretely delayed connection weight matrix, and $D_1 = (d_{ij}^1)_{n\times n}$ distributive delayed connection weight matrix. J_1 denotes the external input vector; $\tau_1 > 0$, $\tau_2 > 0$ are transmission delay; $f_i(x(t)) = (f_{i1}x(t), f_{i2}x(t), \ldots, f_{in}x(t))^T$ $(i = 1, 2, 3)$ denote the neuron activation functions. $x_i(t) = \mu_i(t) \in C([-\tau_{\max}, 0], R)$ is the initial conditions of system (1), where $C([-\tau_{\max}, 0], R)$ denotes the set of all continuous functions from $[-\tau_{\max}, 0]$ to R, $\tau_{\max} = \max[\tau_1, \tau_2]$.

The response system is described as:

$$\dot{z}(t) = -C_2z(t) + A_2g_1(z(t)) + B_2g_2(z(t-\tau_1)) + D_2\int_{t-\tau_2}^{t} g_3(z(s))ds + u(t) + J_2 \tag{2}$$

where $z(t) \in R^n$ is the state vector of the response system, $g_i(z(t))$ denotes the neuron activation function, and $u(t)$ is the controller to be designed.

Definition 1. The projective synchronization error between drive system (1) and response system (2) is defined as $e(t) = z(t) - \alpha x(t), \alpha \neq 0$ is called a scaling factor.

According to the analysis of Definition 1, the error dynamic system can be obtained as follows:

$$\dot{e}(t) = -C_2e(t) + A_2\varphi_1(e(t)) + B_2\varphi_2(e(t-\tau_1)) + D_2\int_{t-\tau_2}^{t} \varphi_3(e(s))ds + u(t) + \omega_1 \tag{3}$$

where $\omega_1 = \alpha[A_2g_1(x(t)) - A_1f_1(x(t))] + \alpha[B_2g_2(x(t-\tau_1)) - B_1f_2(x(t-\tau_1))]$

$$+\alpha(C_1 - C_2)x(t) + \alpha[D_2\int_{t-\tau_2}^{t} g_3(x(s))ds - D_1\int_{t-\tau_2}^{t} f_3(x(s))ds],\ \varphi_i(e(t)) = g_i(z(t)) - \alpha g_i(x(t))$$

Assumption 1. There exist positive constants F_{1i}, F_{2i}, F_{3i} such that the activation function f_i satisfies the following conditions:

$$0 \le \frac{f_{1i}(y_i) - f_{1i}(\bar{y}_i)}{y_i - \bar{y}_i} \le F_{1i}, \quad 0 \le \frac{f_{2i}(y_i) - f_{2i}(\bar{y}_i)}{y_i - \bar{y}_i} \le F_{2i}, \quad 0 \le \frac{f_{3i}(y_i) - f_{3i}(\bar{y}_i)}{y_i - \bar{y}_i} \le F_{3i} \tag{4}$$

where $y_i, \bar{y}_i \in R$.

Lemma 1 ([20]). For any positive definite matrix $D \in R^{n\times n}$, a scalar $\rho > 0$, vector function ω: $[0, \rho] \to R^n$ such that the integration concerned is well defined, then the following inequality is hold:

$$\left(\int_0^{\rho} \omega(x)ds\right)^T D\left(\int_0^{\rho} \omega(x)ds\right) \le \rho\int_0^{\rho} \omega(x)D\omega(x)ds \tag{5}$$

The control goal in this paper is to design an adaptive controller $u(t)$ such that

$$\lim_{t\to\infty} \left\|e(t)\right\| = \lim_{t\to\infty} \left\|z(t) - \alpha x(t)\right\| = 0 \tag{6}$$

where $\|\cdot\|$ denotes the Euclidean norm of a vector. Projective synchronization between drive system (1) and response system (2) with (6) has been obtained.

3. Projective synchronization based on adaptive controller design

The adaptive control with time-delay

$$u(t) = -K_1\beta e(t) - K_2\beta e(t-\tau_1) - K_3\beta e(t-\tau_2) \tag{7}$$