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Short communication

A novel adaptive synchronization control of a class of master–slave large-scale systems with unknown channel time-delay

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ABSTRACT

The paper addresses a practical issue for adaptive synchronization in master–slave large-scale systems with constant channel time-delay., and a novel adaptive synchronization control scheme is proposed to guarantee the synchronization errors asymptotically converge to the origin, in which the matching condition as in the related literatures is not necessary. The real value of channel time-delay can be estimated online by a proper adaptation mechanism, which removes the conditions that the channel time-delay should be known exactly as in existing works. Finally, simulation results demonstrate the effectiveness of the approach.

1. Introduction

Time-delays are often encountered in practical systems, such as chemical systems, distributed networks and systems with transmission lines. The existence of the time-delay may cause instability or bad performances in dynamic systems. Hence, stability control for time-delayed systems has attracted wide attention of researchers in different fields and fruitful results have been obtained, see for example [1,2]. Recently, time-delayed systems have become an attractive research field [3–20]. However, in most of existing works, just state time-delays were considered. Nevertheless, channel time delay or signal propagation delay is unavoidable in typical master–slave synchronization schemes or model-reference control systems due to the distance between the remote systems. However, the literature considering such delays is not abundant. In [3], where the signal propagation delay is called the phase sensitivity, it was reported that the existence of a time-delay can destroy the synchronization. In [4], synchronization and bifurcation phenomena were studied on two chaotic circuits coupled by a delay line. Experimental confirmation of synchronization of two chaotic circuits with time-delay was also reported in [5]. In order to provide some theoretical analysis of this problem, [6] further studied the time-delay effect on the master–slave type of synchronization of Luré systems. Notice that, the above results require that the time delay must be known beforehand in order to design the control input. However, in a practical environment with signal propagation delays, this is not realistic. As pointed out in [7,8], this is convenient for mathematical analysis but does not describe the real physical situation properly.

This paper studies the adaptive synchronization control of master–slave large-scale systems with channel time-delay. In such context, a novel adaptive delay-dependent control scheme is proposed. The following main contributions are worth to

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be emphasized: (i) differing from [6–8,15], the channel time-delay is unknown, whose real value can be estimated online; (ii) compared with [6], the scheme removes the restrictive matching condition; and (iii) in contrast with [6–8,15–19], based on a proper Lyapunov–Krasovskii function, a novel delay-dependent control criterion is derived. By theoretical analysis, it is shown that the synchronization errors asymptotically converge to the origin.

The organization of this paper is as follows. Preliminaries and systems description are presented in Section 2. Design of adaptive synchronization controllers and stability analysis are given in Section 3. Simulations are presented in Section 4. Finally, Section 5 draws the conclusions.

2. Preliminaries and systems description

The uncertain interconnected local slave nonlinear system Ξ with time-delay in the interconnections, is composed of N linked subsystems Ξ_i. Each subsystem Ξ_i is given as follows

$$\Xi_i : \begin{cases} \dot{x}_i(t) = A_i x_i(t) + B_i u_i(t) + \sum_{j\neq i}^{N} A_{ij} x_j(t-d_{ij}) + B_i f_i(x_i(t), x_j(t-d_{ij}), p_i; t) \\ x_i(t) = \phi_i(t), \quad t \in [-\bar{d}_i, 0] \end{cases}, \quad i = 1, \dots, N \tag{1}$$

where $x_i = [x_{i1}, \dot{x}_{i1}, \dots, x_{i1}^{(n_i-1)}]^T = [x_{i1}, x_{i2}, \dots, x_{in_i}]^T \in R^{n_i}$ and $u_i \in R$ denote the state variable and input of the ith local subsystem, respectively; $f_i(x_i(t), x_j(t-d_{ij}), p_i; t) \in R$ denotes the lumped uncertainties of the ith subsystem, including model uncertainties, parameters variations and external disturbances; p_i represents the uncertain parameters; $\sum_{j\neq i}^{N} A_{ij} x_i(t-d_{ij})$ represents the interconnection between the ith and jth subsystems; d_{ij}, $\forall i, j$, $i \neq j$ denotes the nonnegative time-delay presented in the interconnection; $\phi_i(t)$ is an arbitrarily known continuous function that specifies the values of state x_i on the time window $[-\bar{d}_i, 0]$, $\bar{d}$ is a known constant; state matrix A_i, input matrix B_i, and interconnection matrix A_{ij} are of appropriate dimensions.

Let define $n = \sum_{i=1}^{N} n_i$ the dimension of the global state vector of Ξ.

The ith local master subsystem Ω_i for the ith subsystem Ξ_i is described as follows:

$$\Omega_i : \dot{y}_i(t) = A_{mi} y_i(t) + B_{mi} v_i \tag{2}$$

where $y_i = [y_{i1}, \dot{y}_{i1}, \dots, y_{i1}^{(n_i-1)}]^T = [y_{i1}, y_{i2}, \dots, y_{in_i}]^T \in R^{n_i}$ and $v_i \in R$ denote the state variable and local bounded reference input of the ith master subsystem, respectively; A_{mi}, B_{mi} are the known constant matrices with appropriate dimensions.

The control objective is, taking the channel time-delay into account, to design the proper controller $u_i(t)$, such that the state of the local slave subsystem at time t is asymptotically synchronized with the state of the local master subsystem at time $t - \tau_i$, namely,

$$\lim_{t\to\infty} \|x_i(t) - y_i(t-\tau_i)\| = 0$$

where $\tau_i > 0$ is channel time-delay assuming being an unknown real constant; $||\bullet||$ represents the Euclidean norm when $\bullet$ is a vector, or the induced norm when $\bullet$ is a matrix.

Define the tracking error signal as follows

$$e_i(t, \tau_i) = x_i(t) - y_i(t-\tau_i) \tag{3}$$

It follows from (2) that

$$\dot{y}_i(t-\tau_i) = A_{mi} y_i(t-\tau_i) + B_{mi} v_i(t-\tau_i) \tag{4}$$

By using (3) and (4), it yields

$$\begin{aligned} \dot{e}_i(t, \tau_i) &= A_i x_i(t) + B_i u_i(t) + \sum_{j\neq i}^{N} A_{ij} x_j(t-d_{ij}) + B_i f_i(x_i, x_j, p_i; t) - A_{mi} y_i(t-\tau_i) - B_{mi} v_i(t-\tau_i) \\ &= A_{mi} e_i(t, \tau_i) + (A_i - A_{mi}) x_i(t) - B_{mi} v_i(t-\tau_i) + \sum_{j\neq i}^{N} A_{ij} x_j(t-d_{ij}) + B_i f_i(x_i, x_j, p_i; t) + B_i u_i(t) \end{aligned} \tag{5}$$

Synchronization requires that, the following control input $u_i(t)$

$$u_i(t) = h(x_i(t), y_i(t-\hat{\tau}_i)) \tag{6}$$

is designed, such that $\|\tau_i - \hat{\tau}_i\| \to 0$ and $||e_i(t, \tau_i)|| \to 0$ as $t \to \infty$, where $\hat{\tau}_i$ is the estimate of the time delay constant τ_i at time t, $h(\cdot,\cdot)$ is the control input function to be designed to achieve synchronization.

To design appropriate controller for systems (1) and (2), several assumptions are made in the following.

Assumption 1. (A_i, B_i), $i = 1, 2, \dots, N$ are controllable pairs.