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Adaptive sliding mode fault-tolerant control for nonlinearly chaotic systems against network faults and time-delays ☆

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Abstract

The robust fault-tolerant control (FTC) problem against network faults and time-delays of a class of nonlinearly coupled chaotic systems is addressed in this paper. Two kinds of faults on networks, that is, network deterioration and signal attenuations, and a perturbation caused by general nonlinear couplings and time-varying bounded delays are considered in the FTC chaotic system designs. A sliding mode control strategy is proposed, guaranteeing the compensation of the faulted and perturbed couplings by means of adaptive estimations of unknown controller parameters. It is shown that, through Lyapunov stability theory, the proposed adaptive sliding mode controllers are successful in ensuring the achievement of asymptotic synchronization of chaotic systems even in the case of faulted and perturbed couplings. The proposed controller is tested by simulation on a unified chaotic system.

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1. Introduction

During the past several years, considerable attention has been paid to the robust synchronization analysis and synthesis problems of dynamical chaotic systems (please see [1] and references therein). As various unexpected factors will disturb the systems in practical applications, many efforts have been made to obtain the synchronization of systems in the cases of time-delays [2–9], deteriorated couplings [10–13], nonlinear couplings [14–22], uncertainties and disturbances [23–31], etc.

For the sake of eliminating the effects of those factors for synchronization of dynamical chaotic systems, the controlled synchronization has become a rather significant topic nowadays. There are several approaches to obtain controller gains such as linear matrix inequality (LMI) approach [2–5,16,11–13,18–21], adaptive approach [6,11–13,18–21], backstepping approach [25], slide-mode approach [26–35]. As the ability of robustness and insensitivity to withstand certain types external disturbances and model uncertainties, the slide-mode control method has been implemented successfully by many studies to solve the robust synchronization problem of chaotic systems [26–31]. Indeed, some of studies designed slide-mode controllers relying on adaptive technique, which has properties of quick and automatic response for estimating of unknown parameters at each instant. An adaptive sliding-mode observer design method was proposed to synchronize chaotic systems with known bound perturbations in [26]. The adaptive sliding-mode technique was also utilized in [27] to ensure that the slave chaotic systems with uncertainties can synchronize with the master system accurately. The paper [28] presented an adaptive terminal sliding mode control method for synchronization subject to input nonlinearities between two identical attractors.

It should be noted that the fault-tolerant control (FTC) problem has not been seriously considered in the existing chaotic system designs. In the traditional designs of FTC systems, actuator and sensor faults have been usually addressed in the linear or nonlinear multi-inputs and multi-outputs systems (see for example [36–38]). However, in the networked chaotic systems, beyond considering the actuator and sensor faults, an especial FTC design for the faults of coupled networks should be rigorously attended. There are several network faults in the couplings such as random link failures (like package loss) [39], network deterioration [10–13] and the fault of losing effectiveness in the process of networked transmission which named as signal attenuations [40,41]. Note that the above mentioned network faults are broadly existed in secure communications, formation of unmanned aerial vehicle (UAV) team, the world wide web (WWW). However, few efforts have been made to consider the synchronization behavior of networked chaotic systems with signal attenuations and network deterioration. The related studies about signal attenuations can be found in the designs of large scale interconnected systems. Lossy interconnection links (signal attenuations) were considered in [40] of distributed systems by using LMI-based methods. The recent paper [41] proposed an indirect adaptive method to deal with the asymptotic synchronization problem of master–slave large-scale systems with bias actuators and network attenuations of communications. But the method proposed in [41] utilizes large computational resource for estimating many control parameters by using adaptive laws. Thus, more effectively methods for asymptotic synchronization of chaotic systems against signal attenuations need to be further studied.

For the case of network deterioration, the recent paper [10] proposed a discrete-time consensus protocol to deal with the convergence speed problem of switching random networks.