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A note on chaotic synchronization of time-delay secure communication systems

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Abstract

In a real world, the signals are often transmitted through a hostile environment, and therefore the secure communication system has attracted considerable research interests. In this paper, the observer-based chaotic synchronization problem is studied for a class of time-delay secure communication systems. The system under consideration is subject to delayed state and nonlinear disturbances. The time-delay is allowed to be time-varying, and the nonlinearities are assumed to satisfy global Lipschitz conditions. The problem addressed is the design of a synchronization scheme such that, for the admissible time-delay as well as nonlinear disturbances, the response system can globally synchronize the driving system. An effective algebraic matrix inequality approach is developed to solve the chaotic synchronization problem. A numerical example is presented to show the effectiveness and efficiency of the proposed secure communication scheme.

1. Introduction

In the past few decades, chaos synchronization has attracted a great deal of research interest [1,2,8,10–12,14,22–25]. Both the theoretical analysis and laboratory realisations have demonstrated the pivotal role of this phenomenon in secure communications. In their seminal paper, Pecora and Carroll [14] addressed this synchronization problem by using a drive-response concept. The idea is to use the output of the driving system to control the response system such that both systems oscillate in a synchronized manner. So far, many synchronization schemes have been developed. Among them, we mention the inverse system [10], observer design [8] and the system decomposition [11,14] approaches. It should be pointed out that, recently, several investigations have linked observer-based concepts to chaos synchronization, where the whole state information can be reconstructed from only the transmitted signal [1,8,12]. Furthermore, in light of sliding mode control theory, a method has been proposed in [3] such that the response system can synchronize the driving system globally, and the hidden message can be approximately recovered in the least mean square sense.

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It is now well recognised that the dynamical behaviors of many communication processes contains inherent time delays. Time delays may result from the distributed nature of the communication system, information transitions, or from the time required to measure some of the signals. It is known that processes with time delays are inherently difficult to analyse and control [9], in the sense that it is difficult to achieve satisfactory performance. Therefore, analysis and design of time-delay systems with various types of disturbances has been a subject of great practical importance for several decades, see [4–7,16–21,26–29] and the references therein. Unfortunately, so far, the observer-based chaotic synchronization problem for time-delay secure communication systems has yet to be fully investigated, which helps motivate our current study.

In this paper, inspired by previous works in [3,16], we deal with the observer-based chaotic synchronization problem for a class of time-delay secure communication systems. The system under consideration is subject to delayed state and nonlinear disturbances. The time delay is allowed to be time varying, and the nonlinearities are assumed to satisfy global Lipschitz conditions. The problem addressed is the design of a synchronization scheme such that, for the admissible time delay as well as nonlinear disturbances, the response system can synchronize the driving system globally. An effective algebraic matrix inequality approach is developed to solve the chaotic synchronization problem. A numerical example is presented to show the effectiveness and efficiency of the proposed secure communication scheme.

The remainder of the paper is arranged as follows. The chaotic system problem is formulated and some preliminaries are presented in Section 2 for continuous time-delay systems. In Section 3, the conditions are derived under which the desired nonlinear observers exist, the global synchronization scheme is also described for secure communication systems with constant or time-varying delays. A numerical example is provided in Section 4 to demonstrate the validity and applicability of the proposed theory. Finally, some concluding remarks are drawn in Section 5.

2. Problem formulation and preliminaries

The secure communication system involves the development of a signal that contains the information that is to remain undetectable by others within a carrier signal. We can ensure the security of this information by inserting it into a chaotic signal that is transmitted to a prescribed receiver who would then be able to detect and recover the information from the chaotic signal. The technique takes the information and modulates one parameter of a nonlinear signal that is generated by a chaotic signal generator. The resulting signal is transmitted through the hostile environment to a receiver. The receiver consists of a chaotic signal generator of the type that was used in the chaotic transmitter and additive terms. This will permit the demodulation of the received signal and the recovery of the information. As the signal is transmitted through the hostile environment, it is secure since it is required that an interloper possesses an identical chaotic signal generator and additive terms in order to intercept the information correctly. In this paper, we try to apply this idea to design the secure communication problem.

Consider the following form of chaotic systems:

$$\dot{x}(t) = Ax(t) + A_d x(t-\tau) + Bf(x(t)) + Bg(x(t))s(t) \tag{1}$$

$$y(t) = Cx(t) \tag{2}$$

where $x \in R^n$ is the state vector, τ is the state delay, $y \in R^p$ is the output vector, $s \in R$ is an unknown parameter which can be considered as a signal to be reconstructed in the receiver, $f : R^n \to R^q$ and $g : R^n \to R^q$ are nonlinear vector valued functions, and A, A_d, B and C are constant known matrices with appropriate dimensions. Generally speaking, only partial states of system (1) can be measured in a real communication system. Therefore, without loss of generality, the matrix C can be represented by $C = [I_p, 0] \in R^{p\times n}$.

Remark 1. Note that many chaotic systems are already in the form of (1), e.g., Lur'e systems, Rössler system, Lorenz system, almost all forced chaotic oscillators, etc.

In order to recover the message $s(t)$, we need to make the following assumptions:

Assumption 1. The nonlinear function $f(x)$ and $g(x)$ satisfy the following Lipschitz conditions:

$$\|f(x) - f(\hat{x})\| \leqslant k_f \|x - \hat{x}\| \tag{3}$$

$$\|g(x) - g(\hat{x})\| \leqslant k_g \|x - \hat{x}\| \tag{4}$$

where k_f, k_g are appropriate positive constants, $\|W\|$ represents the Euclidean norm when W is a vector or the induced norm when W is a matrix.