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Hyperchaotic secure communication via generalized function projective synchronization

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ABSTRACT

This paper presents two different hyperchaotic secure communication schemes by using generalized function projective synchronization (GFPS), where the drive and response systems could be synchronized up to a desired scaling function matrix. The unpredictability of the scaling functions can additionally enhance the security of communication. First, a hyperchaotic secure communication scheme applying GFPS of the uncertain Chen hyperchaotic system is proposed. The transmitted information signal is modulated into the parameter of the Chen hyperchaotic system in the transmitter and it is assumed that the parameter of the receiver system is unknown. Based on the Lyapunov stability theory and the adaptive control technique, the controllers are designed to make two identical Chen hyperchaotic systems with unknown parameter asymptotically synchronized; thus, the uncertain parameter of the receiver system is identified. The information signal can be recovered accurately by the estimated parameter. Secondly, another secure communication scheme by the coupled GFPS of the Chen hyperchaotic system is introduced. The information signal transmitted can be extracted exactly through simple operation in the receiver. The corresponding theoretical proofs and numerical simulations demonstrate the validity and feasibility of the proposed hyperchaotic secure communication schemes.

1. Introduction

Since the pioneering work by Pecora and Carroll [1], synchronization and control chaotic systems have attracted a great deal of interest among researchers from various fields. Along this line of research, it should be noted that an even broader problem of synchronization of nonlinear oscillations has already had a long history with a great variety of applications in ecological systems, physical systems, modelling brain activity, system identification and pattern recognition phenomena, secure communications, etc. [2–7].

Many different types of synchronization phenomena [3,8–12] have been revealed to investigate chaos synchronization. Amongst all kinds of chaos synchronization, projective synchronization, which was first reported by Mainieri and Rehacek [13], has been extensively investigated in recent years because it can obtain faster communication with its proportional feature [14–21]. However, most of research efforts mentioned above have concentrated on considering the constant scaling factor. More recently, a novel synchronization phenomenon, called function projective synchronization (FPS) [22–26], has been observed. In FPS, the drive and response systems can synchronize up to a desired scaling function.

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Setting the scaling function to constant or unity will obtain projective synchronization (PS) or complete synchronization (CS), respectively. So FPS is a more general definition of PS. As compared with PS, FPS means that the drive (master) and response (slave) systems could be synchronized up to a scaling function, but not a constant. Because the unpredictability of the scaling function in function projective synchronization can additionally strengthen the security of communication, this feature could be applied to get more secure communication in application to secure communications.

In recent years, chaos synchronization has been widely investigated for applications in secure communication [2–6,17,18,25,26]. The idea is that the chaotic signal can be used as a carrier and transmitted together with an information signal to a receiver. In the receiver, chaos synchronization is employed to recover the information signal. In the existing secure communication methods, the useful information signal is directly injected to the input of chaotic systems. The magnitude of the transmitted signals is required to be sufficiently small; otherwise, it may induce the instability of the whole system. On the other hand, the hyperchaotic systems, characterized as a chaotic attractor with more than one positive Lyapunov exponents, are widely used for cryptography and secure communication because the presence of more than one Lyapunov exponent clearly improves the security of communication schemes by generating more complex dynamics [27–29].

Secure communication can be implemented through many ways. Actually, three main message encoding schemes were developed: chaotic shift keying [4], chaotic modulation [5,6] and chaotic masking [17,18]. In chaotic masking, the information signal is added to a much stronger chaotic signal and the combined signal is then transmitted to the receiver. Under certain conditions, the information signal may be recovered in the receiver. Chaotic shift keying refers that the transmitted signal is obtained by switching between N chaotic generators according to the information level of an N-ary signal. In chaotic modulation, the information signal modifies the states or the parameters of the chaotic system through an invertible procedure; thus, the generated chaotic signal inherently contains the information of the transmitted signal. Although these schemes have been successfully demonstrated in simulations, performance of the communication schemes was usually quantified by assuming the identical chaos synchronization based on the exact knowledge of the system parameters [5,30], which may impose some limitations to the applicability of these techniques. But in real situation, some or all of the parameters are unknown and the noise exists. The effect of these uncertainties and noise will destroy the synchronization and even break it. As a consequence, secure communication via parameter modulation in chaotic systems in the presence of unknown parameters is an important issue.

Inspired by the above discussions, in this paper, we consider two nonidentical hyperchaotic secure communication schemes by applying GFPS. In the GFPS method, the responses of the synchronized dynamical states synchronize up to a function matrix. It is obvious that the unpredictability of the scaling functions can additionally strengthen the security of communication, which could be employed to get more secure communications. The contributions of this paper are twofold. First of all, a novel secure communication scheme based on GFPS of the Chen hyperchaotic system with an unknown parameter is proposed. The information signal is modulated into the parameter of the Chen hyperchaotic system and the resulting system is still chaotic. The information signal can be selected arbitrarily. The adaptive control technique is adopted to synchronize two identical hyperchaotic systems embedded in the transmitter and the receiver. We assume that the parameter of the receiver system is uncertain. By the Lyapunov stability theory, we derive the controllers and a parameter update rule to ensure that GFPS of uncertain Chen hyperchaotic systems is obtained and the parameter of the receiver system is estimated. Then, the recovery of the information signal in the receiver is achieved successfully on the basis of the estimated parameter. Next, another hyperchaotic secure communication method by the coupled GFPS of the Chen hyperchaotic system is presented. The coupled GFPS is a general scheme of FPS in the coupled partially linear chaotic systems. In this secure communication scheme, the information signal can be transmitted in a form of any function pre-designed between a transmitter and a receiver, and recovered accurately. Since the function is arbitrary and the scaling function in the coupled GFPS is unpredictable, it is hard for an interceptor to extract the information from the transmitted signal. The corresponding theoretical proofs and numerical simulations are performed to validate the effectiveness and feasibility of the presented two hyperchaotic secure communication schemes.

The layout of this paper is as follows. In Section 2, the Chen hyperchaotic system is introduced and some necessary preliminaries are also given. In Section 3, a hyperchaotic secure communication scheme based on GFPS of the uncertain Chen hyperchaotic system is illustrated. On the basis of the Lyapunov stability theory and the adaptive control method, the controllers and the parameter update rule for GFPS between two identical Chen hyperchaotic systems with unknown parameters are designed and theoretically analyzed. Numerical simulations are used to show this process. In Section 4, another hyperchaotic secure communication scheme by applying the coupled GFPS of the Chen hyperchaotic system is presented and investigated in detail based on the Lyapunov stability theory. Numerical simulations are employed to demonstrate this process. The conclusions are finally drawn in Section 5.

2. System description and preliminaries

2.1. System description

Recently, by introducing a feedback controller w to the first equation of the Chen system [31], Li et al. [32] presented a novel hyperchaotic system, called the Chen hyperchaotic system, which is described by