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An improved secure communication scheme based passive synchronization of hyperchaotic complex nonlinear system

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ABSTRACT

In this paper, an improved secure communication scheme is proposed based on passive synchronization of hyperchaotic complex nonlinear system. The hyperchaotic complex Lü system is employed to encrypt the emitted signal. Comparing with the existing approaches, the useful information in our work can be unbounded. In the transmitter, the original information signal is modulated into one parameter of hyperchaotic complex Lü system and it is assumed that the parameter of the receiver system is unknown. In the receiver, based on the passivity theory, the controllers and corresponding parameter update rule are designed to make two identical hyperchaotic complex Lü systems asymptotically synchronized, and identify the unknown parameter simultaneously. The information signal can be recovered accurately by the estimated parameter. Corresponding theoretical proofs and numerical simulations demonstrate the feasibility and effectiveness of the proposed method. It is also shown that the presented secure communication scheme is robust against different channel noise.

1. Introduction

In the past two decades, synchronization of chaotic systems with real variables has become an active research topic in nonlinear science since the seminal work of Pecora and Carroll [1], and due to its potential applications in physics [2], chemistry and ecological science [3,4], neural networks [5] and secure communications [6–16], etc. To date, various control techniques and methods have been proposed for achieving chaos synchronization, such as linear and nonlinear feedback control [17,18], adaptive control [19,20], active control [21], passive control [22–25], and so forth. In recent years, secure communication based on chaos has received a significant attention [26]. The idea of chaotic secure communication is that chaotic signal can be employed as a carrier, and transmitted together with an information signal through a public channel, which may be perturbed by noise, to a receiver. In the receiver side, chaos synchronization is applied to recover the information signal. The information signal can be transmitted using chaotic systems in various ways. Generally speaking, three main approaches, i.e., chaotic masking [6–10,14], chaos modulation [11–14] and chaotic shift keying [15,16], are frequently introduced to implement secure communications. In the current researches, the magnitude of the information signal to be transmitted is usually required to be sufficiently small, otherwise it may induce the instability of the whole system, which may

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result in failing to recover the information signal [6–10,14]. On the other hand, if the information signal is large, the upper and lower bounds of the information signal must be known or determined beforehand [11–16]. However, in practical situations, the upper and/or lower bound(s) of some information signals always cannot be obtained, such as $e^t, t\sin(t), t^3+3t^2-2$ etc., $t<\infty$. The existing chaotic secure communication schemes will be invalid when the information signal is unbounded. This motivates the research on devising a secure communication approach for the transmission of the unbounded messages.

In 1982, Fowler et al. introduced the complex Lorenz equations [27]. After that, many chaotic or hyperchaotic complex systems, such as the chaotic complex Chen system [28], the chaotic complex Lü system [29], the hyperchaotic complex Lorenz system [30,31], the hyperchaotic complex Lü system [32] etc, were introduced and their dynamical properties were studied. These nonlinear systems involving complex variables can elegantly describe disk dynamos, rotating fluids, electronic circuits, the physics of a detuned laser and particle beam dynamics in high energy accelerators. Furthermore, various synchronization phenomena in chaotic complex systems have been reported in the literature [33–45]. For instance, by using adaptive control method, complete synchronization (CS) of two identical n-dimensional chaotic complex systems was investigated in [33]. Phase synchronization and anti-phase synchronization of two identical hyperchaotic complex nonlinear systems were realized in [34] by means of an active control technique and Lyapunov stability analysis. Projective synchronization (PS) of chaotic complex systems was studied in [35–38]. Lag synchronization (LS) and anti-lag synchronization (ALS) of two identical or different hyperchaotic complex nonlinear systems were discussed in [39,40]. Complex projective synchronization [41] and complex complete synchronization [42] were performed on chaotic complex nonlinear systems, where both modulus synchronization and phase synchronization of their oscillations can be observed simultaneously. Since doubling the number of variables increases the content and security of the transmitted information, chaotic complex systems can be efficiently applied for secure communications [36,38,43]. In [36], PS of hyperchaotic complex Lorenz system and its application in secure communications were studied based on the passivity theory. More than one large or bounded message can be transmitted from the transmitter to the receiver by means of the presented scheme. The effect of channel noise on secure communication is not considered yet. However, noise is omnipresent in nature and man-made systems, and secure communication by chaos synchronization may be damaged by channel noise [8]. Therefore, in our work, we will investigate secure communication for the unbounded messages in presence of channel noise. In [38], the authors realized PS of two identical or non-identical chaotic complex nonlinear systems with uncertain parameters using adaptive control technique. Then a secure communication method regardless of channel noise was given based on the presented synchronization scheme and chaotic masking technique, where the transmitted information signal must be small and bounded. Assuming that the channel is disturbed by stochastic Gaussian noise, Liu and Zhang [43] developed a secure communication approach via complex function projective synchronization (CFPS) of complex chaotic systems and chaotic masking. But the designed controllers in [43] are very complex and the control cost is high, which make the controllers difficult to implement. In addition, the presented method is only applicable to transmit the bounded and small information signals. Contrasting to the results in [38,43], in our work, passive control method is introduced to achieve synchronization of uncertain hyperchaotic complex nonlinear system and identify the unknown parameter. Our designed controllers are simple and convenient to implement in practice. Further, considering the existence of channel noise, combining the proposed synchronization method with chaotic modulation, a secure communication scheme is constructed to transmit the unbounded messages.

The passivity theory is universally acknowledged as a nice tool in several areas such as complexity, signal processing, stability, synchronization, fuzzy control and chaos control [22–25,46–50]. The main idea of passivity theory is that the system is rendered passive by designing suitable controller, which can make the system internally stable. Due to the advantages of passive control such as clear physical interpretation, controller simplicity and robustness, the passivity theory is popularly utilized for control and synchronization of chaotic systems with real variables [24,25,49,50] and complex variables [36,44,45] in recent years. Many results on passive synchronization of chaotic systems are derived under the assumption of knowing the exact knowledge of the system parameters in advance and without noise disturbance [49,50]. However, in real-world applications, the system parameters are often unknown and may change from time to time. The effect of these uncertainties and noise will destroy the synchronization and even break it [19]. Up to now, little attention has been paid to passive synchronization of chaotic complex systems with uncertain parameters and noise. So it is essential to investigate synchronization of uncertain hyperchaotic complex systems using passive control and its application in secure communication via chaotic modulation in presence of channel noise.

Motivated by the above discussions, in this paper, we propose an improved secure communication scheme using the synchronization technique of two uncertain hyperchaotic complex nonlinear systems based on the passive control theory. The hyperchaotic complex Lü system is employed to encrypt the useful information. Different from the existing secure communication methods, the information signal can be very large and even unbounded. In the transmitter side, the emitted signal is modulated into one parameter of the hyperchaotic complex Lü system and the resulting system is still hyperchaotic. And the resulting transmitted signal consists of the information hidden in the signal from the hyperchaotic complex Lü system. Suppose that the parameter of the receiver system is uncertain. In the receiver end, by the passivity theory, the passive controllers and corresponding parameter update rule are constructed to synchronize two identical hyperchaotic complex Lü systems with unknown parameter and identify the unknown parameter simultaneously. According to the estimated parameter, the recovery of the information can be achieved with an appropriate demodulator which is described in this work. We also show that the proposed scheme is robust with respect to channel noise. The illustrative example of the hyperchaotic