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Secure communication based on a four-wing chaotic system subject to disturbance inputs

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ABSTRACT

In this paper, a two-input two-output secure communication scheme based on a four-wing four-dimensional chaotic system with disturbance inputs is discussed. Based on parameter modulation theory and Lyapunov stability theory, synchronization and secure communication between transmitter and receiver are achieved and two message signals are recovered via a convenient robust high-order sliding mode adaptative controller. In addition, the gains of the receiver system can be adjusted continually, the unknown parameters can be identified precisely and the disturbance inputs can be suppressed simultaneously by the proposed adaptative controller. Synchronization under the effect of noise is also considered. Computer simulations are done to verify the proposed methods and the numerical results show that the obtained theoretic results are feasible and efficient.

1. Introduction

Since the pioneering work by Pecora and Carrol [1], synchronization of chaotic systems and its potential application to secure communication have received a lot of attentions. The idea of synchronization is to use the output of the drive system to control the response system so that the output of the response system follows the output of the drive system asymptotically [2]. In the past decades, a variety of many methods and techniques for handling chaos control and synchronization of various chaotic systems have been developed, such as OGY method [3], backstepping technique [4], active control method [5], sliding mode control method [6–8], adaptive control method [9,10], linear and nonlinear feedback control method [11,12], inverse control method [13], H_∞ technique [14], etc. Recently, a new chaos synchronization control method, high-order sliding mode technique, which has been actively researched [15–17], consider a fractional power of the absolute value of the tracking error coupled with the sign function. The signal encryption scheme by using this technique lends itself to cheap implementation and can therefore be used effectively for ensuring security and privacy in commercial consumer electronics products [17]. Compared with the general kind of sliding-mode structures, this structure provides several advantages such as simplification of the control law, higher accuracy and chattering prevention [15]. However, most of these research results are realized without any disturbance inputs [15–17]. It is well known that the noise disturbance is inevitable in the practical situations. So synchronization and secure communication of concrete models is unavoidably subject to internal and external noise disturbance. And a major problem in designing chaos-based secure communication systems can be stated as how to send a secret message from the transmitter to the receiver in the practical situations while achieving security, maintaining privacy, and providing good noise rejection [18]. Therefore investigation of synchronization and

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secure communication for the chaotic systems by the impact of disturbance inputs and channel noise has become an important research topic.

Meanwhile, many different types of chaos-based secure communication schemes have been proposed and generally categorized into four different generations. For a recent survey one can refer to [19]. The first generation generally called chaotic masking [20], an addition method was based on simply adding the secret message to one of the chaotic states of the transmitter and then the composite signal was sent to the receiver, provided that the message strength was much weaker than that of the chaotic state [21]. Due to its sensitivity to channel noise and parameters mismatch between the transmitter and the receiver, this technique was impractical and have been proved to have poor security [22]. In order to improve the security, a multistage chaos synchronized system that was applied to secure communication through chaotic masking was discussed in [23]. Another method that was aimed at digital information signals, called chaotic switching or chaotic shift keying, was developed a shift keying technique for the coding/decoding of binary signals where the carrier signal was chaotic [24]. Although chaotic switching was more robust against noise than chaotic masking, it suffered from a lower information transmission rate. Chaotic parameter modulation [25] was called the second generation, where the information signal was used to modulate one of the parameters of the chaotic transmitter. At the receiver, some adaptive control methods were applied to synchronize the system in the receiver with the chaotic system in the transmitter and hence to recover the message from the adaptation rules [26]. In [27], an observer was presented to identify the unknown parameter of Liu chaotic system. Recently, another variant to this method, based on generalized function projective synchronization, was introduced in [28]. In this method, the responses of the synchronized dynamical states synchronize up to a function matrix. The unpredictability of the scaling functions can additionally strengthen the security of communication, which could be employed to get more secure communications. Combined the advantages of chaos and cryptography, a new chaos encryption technology called chaotic cryptosystems [29], was belonged to the third generation, which has very high safety performance. In this method, many nonlinear encryption methods were used to scramble the secure message at the transmitter side, while using an inverse operation at the receiver side that can effectively recover the original message, provided that synchronization was achieved [18,21]. A versatile combination of the parameter modulation technique and cryptography was proposed in [18]. Based on the impulsive synchronization, new techniques of chaotic communication were belonged to the fourth generation [30]. These systems have the advantage of reducing the information redundancy in the transmitted signal as only synchronization impulses sent to the driven system, which could increase the bandwidth utilization.

Inspired by the above discussions, in this paper, we consider a two-input two-output secure communication scheme based on a four-wing four-dimensional (4D) chaotic system via a robust high order sliding mode adaptative controller, and investigate the identification of the four-wing system with partly uncertain parameters and disturbance inputs, and an application in secure communications via chaotic parameter modulation. By utilizing parameter modulation theory and Lyapunov stability theory, synchronization and secure communication between transmitter and receiver is achieved and two message signals are recovered accurately. In addition, the gains of the receiver system can be adjusted continually, the unknown parameters can be identified precisely and the disturbance inputs can be suppressed simultaneously by the adaptative controller. The corresponding theoretical proofs and numerical simulations are performed to validate the effectiveness and feasibility of the presented secure communication scheme.

2. Four-wing 4D chaotic system and its dynamics

Consider a four-wing 4D chaotic system:

$$\begin{cases} \dot{x} = -ax + yz, \\ \dot{y} = by - xz, \\ \dot{z} = xy - cz + dw, \\ \dot{w} = xy - ew, \end{cases} \tag{1}$$

where a, b, c, d, e are system parameters, x, y, z, w are the state variables. When $a = 10$, $b = 12$, $c = 60$, $d = 2$ and $e = 3$, the Lyapunov exponents of system (1) are found to be $l_1 = 2.6692$, $l_2 = 0$, $l_3 = -3.7703$ and $l_4 = -57.7174$. It can be seen that there is a larger positive Lyapunov exponent that means system (1) can exhibit extremely rich dynamics. A four-wing chaotic attractor from system (1) is shown in Fig. 1 while the arbitrary initial conditions are selected as $[2, 1, 2, 2]^T$. From Fig. 1, we can see that in any three-dimensional (3D) spaces, the chaotic attractor can display a four-wing type.

Obviously that the system is asymmetric about $(x, y, z, w) \to (\pm x, \mp y, -z, -w)$, which persists for all values of the system parameters. Note that $\nabla V = (\partial\dot{x}/\partial x) + (\partial\dot{y}/\partial y) + (\partial\dot{z}/\partial z) + (\partial\dot{w}/\partial w) = -a + b - c - e$, so the system is dissipative as long as $-a + b - c - e < 0$. That means a volume element V_0 is contracted by the flow into a volume element $V_0{}^{-a+b-c-e}$ in time t. When the parameters $a = 10$, $b = 12$, $c = 60$, $e = 3$ are fixed while d varies on the closed interval $[-5, 15]$. Figs. 2 and 3 show the bifurcation diagram of the state X and the corresponding Lyapunov exponent spectrum versus increasing d respectively. From Figs. 2 and 3, it can be seen that the bifurcation diagram well coincides with the spectrum of the Lyapunov exponents. Interestingly, this chaotic system can display one-, two-, three- and four-wing attractors by varying one single parameter d while the others are fixed. The corresponding

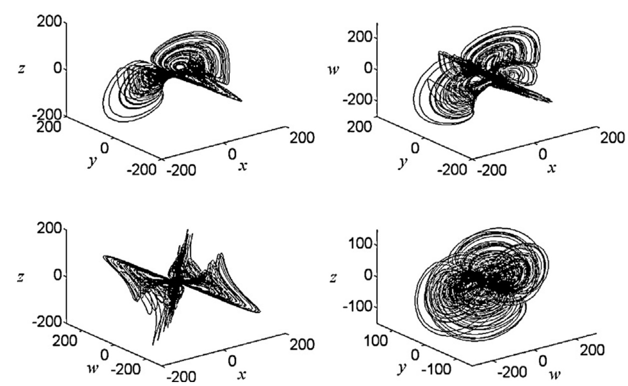

Fig. 1. Four-wing chaotic attractors of system (1) in 3D spaces.

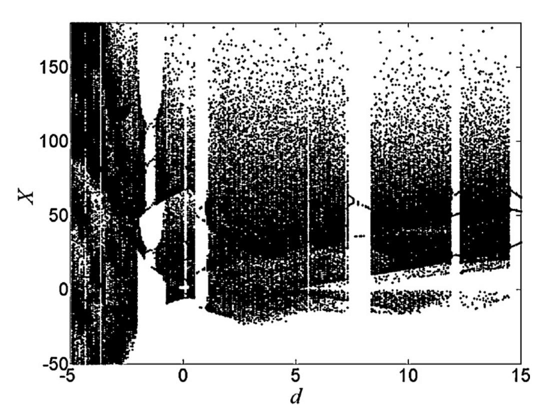

Fig. 2. Bifurcation diagram for increasing parameter d.