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Fast synchronization of non-identical chaotic modulation-based secure systems using a modified sliding mode controller

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ABSTRACT

In this paper, a secure communication scheme based on chaotic modulation is proposed using a reversible process and a robust controller with efficient cost and complexity to synchronize two different chaotic systems. In the controller design, a sliding mode control with an adaptive rule is used for non-linear inputs. The adaptive rule is applied to ensure the synchronization when uncertainties, non-modeled dynamics or external distortions are at work. The message signal is recovered at the receiver using a recursive process at the end. The effectiveness of the proposed algorithm is confirmed via the simulation results for the synchronization of the transmitted signal modulated by Chen chaotic system at the transmitter and Genesio chaotic system at the receiver, and those for the information recovery process.

1. Introduction

Synchronization is one of critical issues for the validity control of the received signals in communication systems. Recently, chaotic systems have attracted growing interest for the synchronization of the communication systems. Yamada and Fujisaka in 1983 proposed a method for the synchronization of the chaotic systems [1]. However, the interest in this field increased when Pecora et al. discussed the synchronization of the chaotic systems in the telecommunication problems [2]. They stated that the chaotic systems with sub-Lyapanov exponents laid at the left half-plane could be synchronized.

In the literature, there are many research projects studying secure communication systems based on chaos theory [3–6]. Because of some specifications of chaotic systems such as non-linearity, there are some common aspects between secure communication and chaotic systems. On the other hand, the demolishing narrow-band effects such as frequency-selective fading and narrow-band distortion can be handled thanks to the spread spectrum property of the telecommunication signals and the noise-like wide band spectrum of the chaos. The number of system components can be decreased and the maximum gain of the carrier power can be achieved with the help of chaotic systems. In spite of their deterministic nature, the chaotic systems exhibit many features of a stochastic process very critical for the spread spectrum communication such as being bounded, aperiodic, uncorrelated output and the autocorrelation function with its peak in zero and rapidly decreasing tails [7,8]. Furthermore, an appropriate feature which can be added to this list is their significant dependence on the initial condition. This principal property of the chaotic systems means that even with the least modifications in the initial state, the intermediate states and

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subsequently the output of such systems undergo considerable changes. This property makes them very unpredictable and appropriate for the application in the secure communications [7].

Based on specifications of chaotic systems, several techniques have been proposed for chaos based telecommunication systems such as chaotic masking [9,10], chaotic shift keying or chaotic switching [11], and chaotic modulation [12]. Extensive supplementary research has been conducted on each of the above-mentioned methods. In chaotic masking systems which can be considered as conventional methods, the information signal is added to one of the varying states of the chaotic system in the transmitter, and is recovered at the receiver synchronized with the transmitter by applying the subtraction to the pseudo-noise signal received after passing the public channel [13]. The information signal is switched between two or N chaotic systems in chaotic switching. This method is very effective against noise but the security level is lowered in the case of non-identical chaos systems in the transmitter and receiver [13]. In the chaotic modulation systems, the task of modulation of the information is addressed by the parameters or the states of the chaotic systems using a reversible process. This approach elevates the security level compared with the chaotic masking method [13].

In the conventional chaos based telecommunications, two chaotic systems known as drive or master, and response or slave are connected by a public communication channel. Due to the high sensitivity of the chaotic systems to the initial condition and the importance of bit error rate (BER), the synchronization of two systems is critical to achieve a precise long-term prediction. In order to achieve the appropriate synchronization, a controller is required. Since the chaotic systems are intrinsically non-linear, the application of the controller with the non-linear input and low cost and complexity is inevitable. Several methods are proposed for the synchronization of the chaotic systems, such as feedback control [14,15], adaptive control [16–20], optimal control [21,22], intermittent control [23,24], digital redesign control [25], back-stepping control [26,27], linear state feedback by linear matrix inequalities (LMI) technique [28], H-inf based control [29], passive control [30], active control [31], fuzzy control [32–34], neural-based control [35–37], and sliding mode control [38,39]. Since the unknown parameters, uncertainties, and external distortions may cause severe problems or failure in the synchronization process, their effect must be carefully considered in the design of chaos based synchronization.

Up to now, studies have been conducted on sliding mode control by considering the adaptive version. This adaptive rule helps ensure the synchronization at the presence of the unknown bounded parameters, external distortions and bounded uncertainties. Moreover, a reliable secure modulation plan can improve the communication security. Previous works, to the best of our knowledge have not considered the chaotic secure modulation in the presence of all the aforementioned destructive factors and are mainly focused on simple masking and modulations with a few or none of these factors. For example, the study on the adaptive synchronization of Rossler and Chen chaotic systems was performed considering unknown time-varying parameters in [40]. As another instance, an adaptive sliding mode controller for the synchronization of the master–slave chaotic systems at the presence of the uncertainties was proposed in [38]. Moreover, a secure communication scheme using hyper-chaos synchronization and chaotic masking at the presence of uncertainties and distortions was suggested in [9]. Another important point that is less considered in such studies is that the chaotic nature which is the basis of the desired security must be preserved.

This study presents a chaotic secure communication scheme with the aid of two different chaotic systems, highly secure modulation, fast and accurate synchronization of the two chaotic systems by an improved sliding mode controller with nonlinear input. In this scheme, the message will be hidden at the heart of chaotic system dynamics using an innovative way in two steps: chaos modulation as the first step and mapping as the second. Besides contributing to the establishment of the system structure, this mapping also increases the security level. After transmission over the channel and considering the uncertainty problem in the receiver, the resultant signal with a high level of security is synchronized with the transmitter by the improved sliding mode controller. Eventually, using a specific algorithm, the message signal will be extracted in the receiver. We also employed an adaptive law in the design of the controller. This guarantees the synchronization of two different chaotic systems in the presence of bounded uncertainties, external disturbances, and bounded unknown parameters. The high speed and accuracy of controller in synchronizing the transmitter and receiver systems made the accurate and low error message extraction possible. This means a lower bit error rate (BER) and, accordingly, a higher string length. Totally, in the suggested scheme, it is attempted to develop a method for chaotic secure modulation and also a controller design that leads to a secure communication system which, in addition to simplicity and low complexity, is highly secure and entails a low cost in practical implementation. Therefore, given the structure of the proposed system, it can be implemented using simple processors which enable us to develop rapid and economic systems compared to conventional systems. Meanwhile, exploiting two different chaotic systems results in secure and easy implementation of a secure communication system in comparison with two similar chaotic systems.

The rest of the paper is organized as follows. The problem formulation and the proposed method are given in Section 2. Simulation results of the proposed scheme are presented in Section 3. Section 4 discusses the advantages and disadvantages of the proposed method, while Section 5 concludes the paper.

2. Proposed method

In this section, the generic design of the proposed method is introduced. Then, the problem definition including chaotic modulation equations for the input signal, design of the controller and the synchronization of the received signal are discussed. Finally, the demodulation