Neurocomputing xx (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

Secure communication based on the synchronous control of hysteretic chaotic neuron

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ARTICLE INFO

Keywords:
Hysteretic chaotic neuron
Sliding mode control
Chaos masking
Secure communication

ABSTRACT

In order to improve the physical realization of the chaotic secure communication, a chaos masking encoding method based on the synchronous control of chaotic neurons with different structure is proposed. The conventional chaotic neuron is set as the transmitting system, and the hysteretic chaotic neuron is set as the receiving system. Hysteretic parameters have creep characteristic which make the hysteretic chaotic neuron have uncertainty. Sliding mode control is used to perform the synchronous control, and fuzzy inference is used to reduce the chattering of the sliding mode control. Simulation results prove the effectiveness of the method.

1. Introduction

Chaos is an important interesting phenomenon in the nonlinear dynamical systems. Many scholars study chaos over the last four decades. Chaotic systems can show the complex and unpredictable behavior. Especially, chaotic systems are sensitive respect to the initial conditions. Therefore, chaotic theory can be used to resolve many engineering problem.

Along with the rapid development of network and communication, the secure communication becomes a hot issue [1–3]. Studies on the chaos theory show that chaos can exhibit special advantage on secure communications because of its nonlinear complexity and unpredictability [4–6]. As well as, chaotic synchronous control provides the theoretical basis for chaotic application in secure communications [7–10]. That is, chaotic secure communication is generally based on the synchronization of chaotic dynamical systems. The transmitter system can produce chaotic signals, the useful information signals are embedded in the chaotic signals and sent to the receiving terminal, and the useful information is recovered by the receiving system. Some early methods, such as the additive chaos masking approach [11], the chaotic shift keying or the chaotic switching approach [12], and chaotic parameter modulation method [13], have shown good performance. However, some novel chaotic systems and new synchronization methods are introduced and used for secure communication [14,15]. Therefore, it is still a hot spot issue to construct a new chaotic synchronization system to perform the secure communication.

The synchronization of chaotic systems has been studied for many years. Many control methods, such as adaptive control, impulsive control, active control and nonlinear control, can be used to achieve chaos synchronization. Synchronous control for the chaotic systems with the same structures is investigated for several decades [16–18]. However, it is difficult to ensure the parameters to keep the same in practical application, and some disturbance on the system parameters may destroy the synchronization of the systems. Therefore, synchronous control for chaotic systems with different structures has a better application prospect [19–21].

Chaotic neural network is composed of many chaotic neurons, so it has complex coupling characteristic. Based on the conventional chaotic neural network, hysteretic chaotic neuron and neural network are proposed by changing their activation functions [22,23]. The control of the hysteretic chaotic neural network are further studied [24], and good application effects, such as associative memory and optimal computation are got.

Furthermore, creep characteristic is considered to add into the hysteretic chaotic neuron [24,25]. Thus, its complex nonlinear characteristics make the model have robust chaotic characteristics and uncertainty. Just right, the sliding mode control which has good robustness to the uncertainties of the internal parameters as well as the external disturbances becomes an ideal control method for the nonlinear system with uncertainty. Therefore, a new secure communication method based on the synchronous control for hysteretic chaotic neuron with different structure and creep characteristic is proposed in this paper.

2. Synchronous control of hysteretic chaotic neuron

Chaos synchronous control is a special chaos control. It is to achieve a certain relationship among the motion trajectories of two (or more)

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http://dx.doi.org/10.1016/j.neucom.2016.08.100
Received 28 March 2016; Received in revised form 27 July 2016; Accepted 6 August 2016
Available online xxxx
0925-2312/

chaotic systems with the same or different structures. That is, the response system is controlled by the output of the drive system to follow to the drive system, and the tracking error is controlled to approach to zero.

A discrete chaotic neuron model can be described as [24]:

$$x(k) = f[y(k)] \tag{1}$$

$$y(k+1) = \lambda y(k) - \alpha[x(k) - I_0] \tag{2}$$

where, $x(k)$ and $y(k)$ are the output of neuron and the inner state of neuron at discrete time k, I_0 is the input bias of neuron, and α is the self-feedback gain coefficient. The function $f()$ is the activation function. The conventional activation function is Sigmoid function as follows [24]:

$$f(z) = (1 + \exp(-c \cdot z))^{-1} \tag{3}$$

where, c is the shape parameters.

The activation function in the hysteretic chaotic neuron model is a hysteretic function which can be described as [24]:

$$f_c(z) = \begin{cases} (1 + \exp[-c(z - a)])^{-1}, & \dot{z}(t - \delta t) > 0 \\ (1 + \exp[-c(z + b)])^{-1}, & \dot{z}(t - \delta t) < 0 \end{cases} \tag{4}$$

$$\dot{z}(t - \delta t) = \lim_{\delta t \to 0} [z(t) - z(t - \delta t)]/\delta t \tag{5}$$

where, the parameters a and b are the hysteretic parameters. The parameter c determine the steepness of the activation function. The activation function has two response branches which form a hysteretic loop in the interval $(-\infty, +\infty)$.

In practice, the parameters in the neuron have creep characteristics. Considering the hysteretic creep characteristics, the activation function can be described as:

$$f_{cr}(z, \Delta r) = \begin{cases} (1 + \exp[-c(z - a + \Delta r)])^{-1}, & \dot{z}(t - \delta t) > 0 \\ (1 + \exp[-c(z + b + \Delta r)])^{-1}, & \dot{z}(t - \delta t) < 0 \end{cases} \tag{6}$$

When the parameters are set properly, for instance, k=1.0, a=b=0.8, I=0.86, c=250, the bifurcation diagram and the Lyapunov exponent diagram of the neuron are shown in Fig. 1.

Set α=0.098 and a=b, the Lyapunov exponent diagrams with different hysteretic parameters can be shown in Fig. 2.

From the Fig. 2 above, the characteristic of the hysteretic chaotic neuron are sensitive to many parameters, for instance, hysteretic parameters. Therefore, the hysteretic chaotic neuron has more complex dynamic behaviors.

Furthermore, the hysteretic creep characteristics cause a uncertainty $d = f(z, \Delta r) - f(z)$ which has a upper bound D, that is $|d| \le D$.

In the real system, parameters of all the components in the circuit distribute in some range because of the temperature-drift, which can cause to the uncertainty in the physical systems. Therefore, the uncertainty is represented by the creep characteristics.

The uncertainty caused by the hysteretic creep characteristics in the hysteretic chaotic neuron increases the complexity of the system.

Similarly, the internal state of the conventional chaotic neuron can be described as:

$$y(k+1) = \lambda y(k) - \alpha[f(y(k)) - I_0] \tag{7}$$

The controlled internal state of the hysteretic chaotic neuron can be described as:

$$Y(k+1) = \lambda Y(k) - \alpha[f_{cr}(Y(k), \Delta r) - I_0] + u(k) \tag{8}$$

The aims of the synchronous control of hysteretic chaotic neuron with different structures is to design a control law $u(k)$ to drive the internal state of the hysteretic chaotic neuron Y to follow to the internal state of the conventional chaotic neuron y. That is,

$$\lim_{k \to +\infty} |y(k) - Y(k)| = 0 \tag{9}$$

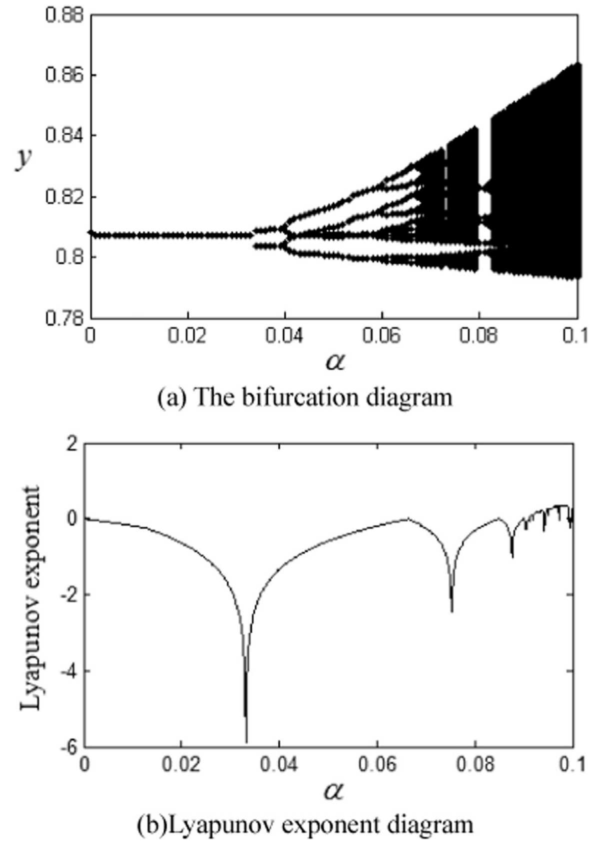

Fig. 1. The bifurcation diagram and Lyapunov exponent diagram of neuron (a) The bifurcation diagram (b) Lyapunov exponent diagram.

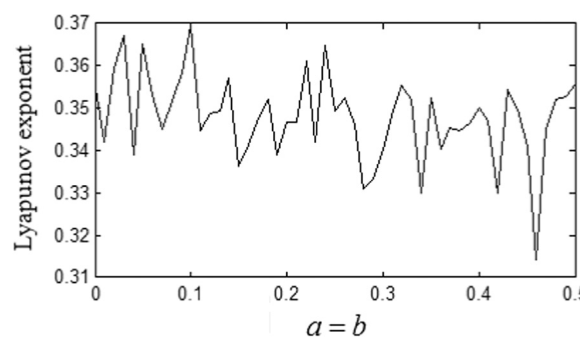

Fig. 2. Lyapunov exponent with different hysteretic parameter.

Because hysteretic creep characteristics can cause the uncertainty of the output of the neuron, sliding mode control strategy is used to perform the control.

Theorem 1. For the systems described by Eqs. (7) and (8), in order to drive the internal state of the hysteretic chaotic neuron Y to follow the internal state of the conventional chaotic neuron y, the sliding mode control law $u(k)$ can be designed as:

$$u(k) = \lambda \cdot e(k) - \alpha \cdot \varphi[e(k)] - e(k) - \frac{de(k)}{(h + 1/t_s)} + (D + \eta)\operatorname{sgn}(s(k)) \tag{10}$$

where, t_s is sampling time, $e(k)$ is the error signal defined as:

$$e(k) = y(k) - Y(k) \tag{11}$$

The parameter $h > 0$ meets the Hurwitz conditions, and the parameter η is set as: