Design and Application of Chaotic System Based on Memristor

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Keywords: Memristor; Chaotic system; Design and application

Abstract. The information age makes information transmission more convenient, but the confidentiality and effectiveness of information transmission is a topic of high controversy and the focus of technology development. The chaotic system based on memristor has rich dynamic behavior, and the chaotic signal generated by it has better pseudo-random characteristics compared with the traditional chaotic system, which effectively guarantees the validity and confidentiality of information transmission. In this paper, the design and application of chaotic system based on memristor are studied to promote the development of information technology.

The memristor is a fourth circuit component except the three circuit components of inductance, resistance and capacitance. It is mainly used to indicate the relationship between charge and magnetic flux. It has nano-scale, non-volatile, and switching, having a wide application prospect in the fields of nonlinear systems and circuits and neural networks. It is difficult for traditional information processing to meet the needs of the rapid development of the information society. Strengthening research on information processing and promoting the development of information processing in the direction of intelligence, high security, and low power consumption have become the main problems that need to be solved. Chaotic system is a common means to ensure information security, image processing and climate prediction. The memristor with low energy consumption and low space occupation is used in chaotic systems to construct a chaotic system based on memristor and to be applied to information processing to improve the efficiency and confidentiality of information processing.

1. The Development and Research Status of Memristor

Cai Shaotang put forward the concept of memristor in the 1970s. The earliest physical model of memristor was developed by HP Laboratory. Nature, a foreign magazine, pointed out that the memristor satisfied the characteristics of the new basic circuit elements proposed by Cai Shaotang. With the emergence of the earliest physical model of memristors, people have unprecedented interest in the research of memristors, and more and more memristors have been developed. At present, the widely used memristor models include HP model, Spin model, Simmons tunnel memristor model and Threshold adaptive model. And many scholars have begun to try to prepare practical memristor physical models. The research results show that materials such as metal oxides and semiconductor thin films are the best materials for the preparation of memristors. Because of its low cost and good compatibility, it is the preferred material for preparing memristor physical model at present, such as ZnO, NiO and MgO.

There are many studies on memristors abroad. HP Laboratory, Imperial University of Technology, and University of California all have memristor research rooms. HP research team points out that memristors not only have storage function, but also have the ability of logical operation. Considering the memory characteristics of memristor, it has certain application value in the breakthrough of artificial neurons. In 2013, researchers at the University of Bilefield designed a learning memristor model. In 2015, researchers at the University of California used memristors to classify images.

Tsinghua University, Southwest University and Hong Kong University all have research teams of memristors. The HP memristor model is the most widely studied model in China. Wang Lidan et al. deduced the HP memristor model and developed magnetic and charge controlled memristor model,

  DOI: 10.25236/ciais.2019.033

and the two memristor models are applied to the chaotic system, and a chaotic system based on memristor is fabricated, which has achieved remarkable application effects. Duan Meitao and Wang Xiaodong also designed a memristor synapse circuit to process the image. In recent years, there have been more and more researches on memristors in China, and they have practical value in non-volatile memory, chaotic systems and neural networks.

2. Characteristics of Memristor

2.1 Nanometer Size

Metal oxides, thin film materials and fixed electrolytes are the commonly used materials for the preparation of memristors, the most widely used of which are metal metal oxides. The process of using a metal oxide to prepare a memristor is similar to the COMS process. It does not require a large chip area. HP Labs has now developed a memristor fabrication process to a thickness of 3 nm, making it possible for memristors to be highly integrated.

2.2 Memory Characteristics

The well-known memristor is a non-linear element with a storage function that reflects the relationship between magnetic flux and charge, but the memristor also has a memory characteristic that can "remember" the amount of current flowing through it. In recent years, domestic and foreign scholars have studied the memory characteristics of the memristor and analyzed the non-volatility of power failure of the memristive model, and finally the researches have confirmed the memory characteristics of the memristor.

2.3 Non-volatility of Power Failure

Non-volatility of power failure is the biggest feature of memristor. Unlike inductance and capacitance, inductance and capacitance can also store data, but after power off, the stored data will disappear rapidly. The memristor will still store the charge before power off. Therefore, the memristor has a unique function and is suitable for use in an instant-on computer.

2.4 Logic Function

Crossbar Latch, a foreign scholar, has also pointed out that three kinds of logical relations can be realized by using grid to realize the operations of addition and subtraction.

2.5 Compatible with CMOS Process

The materials and processes of memristors are mostly combined with CMOS. Therefore, memristors can be connected with general circuits to improve signal bandwidth and reduce energy consumption by adjusting the spacing.

2.6 Low Power Consumption

Comparing the servers equipped with memristor chips with ordinary servers, the servers equipped with memristor chips have higher computing functions and smaller size, and consumes only 1.25% of the power consumption of ordinary servers. They have the advantages of intelligence, energy saving and high speed.

3. Design of Chaotic System based on Memristor

As a non-linear controllable device, memristor can produce chaotic signals. Nowadays, more and more people pay attention to the non-linear characteristics of memristor, and its controllable characteristics are often neglected. In this study, a memristor chaotic system is designed. First of all, the basic dynamic behavior of memristor chaotic system is summarized, the effect of parameters on its basic dynamic behavior is studied, and then the simulation test is carried out with the help of relevant experimental tools.

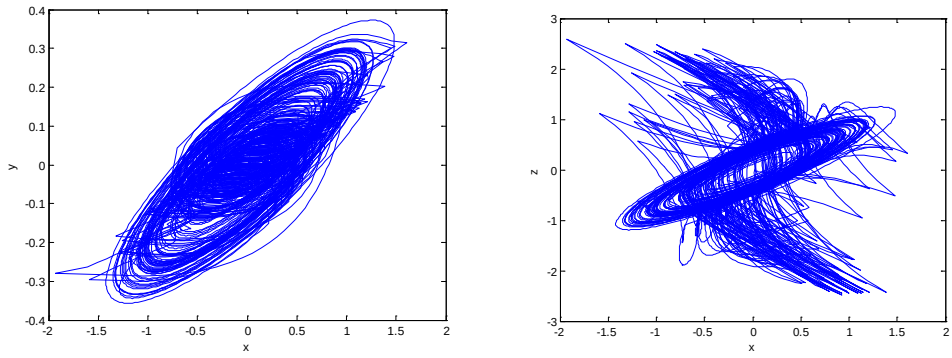
The new memristive chaotic system model is presented as follow

$$\begin{cases} \dot{x} = (\alpha - \bar{W}(\phi))x - \beta y + \bar{W}(\phi)z \\ \dot{y} = \kappa x - \delta y \\ \dot{z} = \bar{W}(\phi)(x - z) - v \\ \dot{v} = z \\ \dot{w} = x - z \end{cases}$$

Where $\bar{W}(\phi)$is the memristor model such that

$$\bar{W}(\phi) = \begin{cases} A, |\phi| \le 1, and |x| < E \\ B, |\phi| > 1, and |x| < E \\ C, |\phi| \le 1, and |x| \ge E \\ D, |\phi| > 1, and |x| \ge E \end{cases}$$

Let $\alpha = 0.5, \beta = 0.5$，$\kappa = 0.3$，$\delta = 1$； A=-0.4, B=1.65, C=-1.5, D=3, E=1.56。then, the memristive circuit will show the complicated dynamical behavior as Fig. 1.



(a) Phase diagram of x-y (b) Phase diagram of x-z

Fig. 1. Phase diagram of the memristive chaotic system.

In the process of designing a chaotic system based on memristor, we must pay attention to the analysis of dynamic characteristics, that is, the dissipativeness and existence, balance point and stability of attractors. The stability of the equilibrium point of the memristor chaotic system will vary with the change of the system parameters, that is, the influence of various parameters of the memristor chaotic system on its basic dynamics, so the parameter change system will also be in different states. Tools such as bifurcation diagrams, maximum Lyapunov exponent spectra, and phase diagrams can be used to reflect changes in the parameter change system.

Fig. 2 shows the Lyapunov exponent spectra of the new memristive chaotic system. Fig. 3 shows the bifurcation diagram of the new memristive chaotic system. It can be seen that when $\beta \in$ (0, 1.22), the new memristive system will be in chaotic state with one positive Lyapunov exponent.

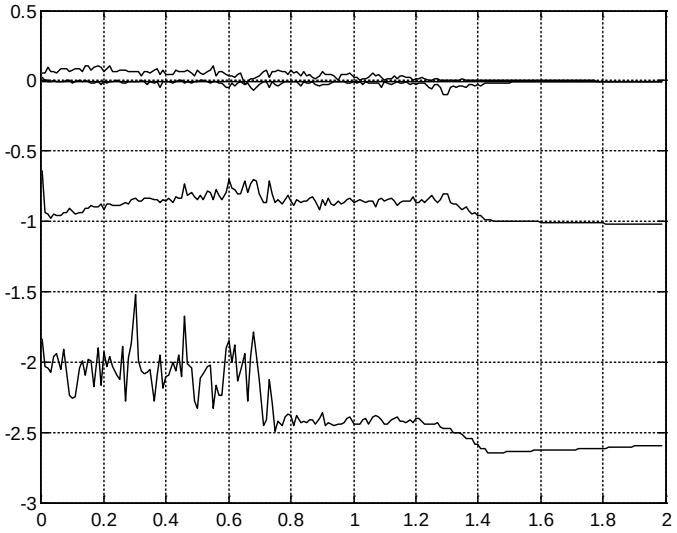


Fig. 2. Lyapunov exponent spectra of the new memristive chaotic system.

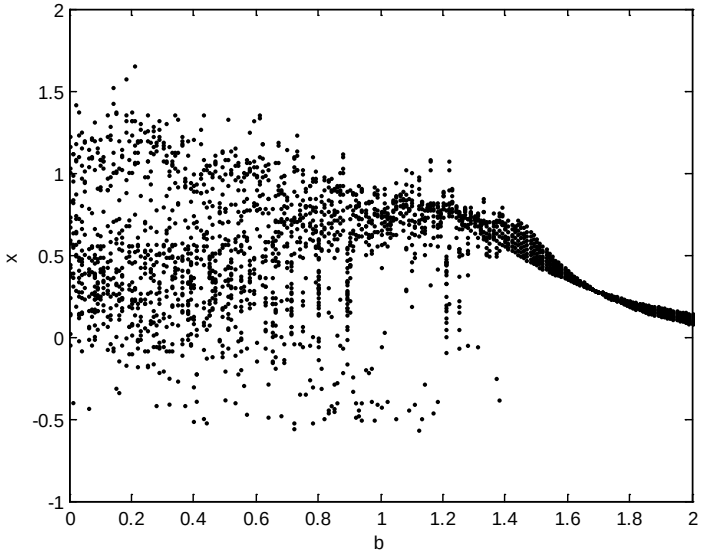


Fig. 3. Bifurcation diagram of the new memristive chaotic system

4. Application and Prospect of Memristor

Considering the characteristics of the memristor, it can be applied to the life sciences and information engineering industry to promote the research of artificial neural networks. Compared with the traditional cellular neural network, the cellular neural network completed by the memristor has simpler circuit and weight change conditions, and its circuit size and operation efficiency are significantly higher. It can be said that the cellular neural network completed by the memristor is more suitable for large-scale integrated circuits. Some studies have shown that the application of memristors as synapses in the field of artificial neural networks can achieve de-weighting operations, and the image processing effect is better, which can effectively promote the further implementation of artificial neural networks.

However, the research on memristor does not stop there. Researchers should insist on exploring the relevant characteristics of memristor, pay attention to the intersection with other disciplines, apply the characteristics of memristor to other fields, and fully exert the value of memristor. The research ideas of memristors are summarized as follows:

(1) The research direction of memristors focuses on intellectualization to study how to apply the characteristics of memristors in the internal structure and working mechanism of products.

(2) Previous studies have shown that memristors have good application effect in the field of neural networks, so it is necessary to focus on the combination of memristors and neural networks, and use mathematical tools for fault tolerance and stability analysis.

(3) A large-scale neural network circuit based on memristor is constructed, which enlarges the function of memristor to enhance the image processing effect infinitely and promotes the development of science and technology better.

Summary

With the continuous development of information technology, security and information processing have become the focus of research. Intelligence and efficiency have become the development goals of science and technology. Memristors have good characteristics. Strengthening the research on memristors and giving full play to their value will accelerate the arrival of intelligent society. This paper studies the chaotic system based on memristor, summarizes the related application advantages of chaotic system based on memristor, and proves the realizability and feasibility of chaotic system based on memristor. However, the research on the related characteristics of memristor is endless, and we need to explore constantly to better play the value of memristor.

Acknowledgment

Project: Aba Teachers College Research Fund Project, project number ASC19-24.

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