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Experimental confirmation of a new reversed butterfly-shaped attractor

Liu Ling(刘 凌)[a)], Su Yan-Chen(苏燕辰)[a)], and Liu Chong-Xin(刘崇新)[b)]

[a)] *College of Mechanical Engineering, Southwest Jiaotong University, Chengdu* 610031, *China*

[b)] *College of Electrical Engineering, Xi'an Jiaotong University, Xi'an* 710049, *China*

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This paper reports a new reverse butterfly-shaped chaotic attractor and its experimental confirmation. Some basic dynamical properties, and chaotic behaviours of this new reverse butterfly attractor are studied. Simulation results support brief theoretical derivations. Furthermore, the system is experimentally confirmed by a simple electronic circuit.

Keywords: chaotic system, experimental confirmation, reverse butterfly attractor
PACC: 0545

1. Introduction

A novel reverse butterfly-shaped chaotic attractor is reported in this paper. It is also a three-dimensional autonomous system.[1−4] The chaotic attractor obtained from this new system according to the detailed numerical as well as theoretical analysis is the butterfly-shaped attractor, exhibiting the abundant and complex chaotic dynamics, but it is a reverse butterfly attractor.[5−7] This paper has briefly studied and analysed its dynamical properties and behaviours. Numerical simulation results support brief theoretical derivations, otherwise, the system is experimentally confirmed by an electronic circuit. Experimental results also verify the effectiveness of the designed circuitry.[8]

2. Novel reverses butterfly-shaped chaotic attractor

The novel reverse butterfly-shaped chaotic attractor is described by

$$\begin{cases} \dot{x} = a(y - x), \\ \dot{y} = bx + kxz, \\ \dot{z} = -cz - hxy. \end{cases} \tag{1}$$

Here, let

$$a = 10, \quad b = 40,$$
$$c = 2.5, \quad h = 1, \quad k = 16.$$

For this novel attractor we use MATLAB program complete the numerical simulation, and the initial values of the system are selected as (2.2, 2.2, 0). This nonlinear system exhibits also the complex and abundant chaotic dynamical behaviour, the strange attractors are shown in Figs.1 and 2. Apparently, the strange attractors in this nonlinear-system are different from Lorenz system in topological structure, so, it is a reverse butterfly-shaped attractor, its spectrum is continuous as shown in Fig.3. Poincaré mapping yields those points of the confusion as shown in Fig.4.[9,10]

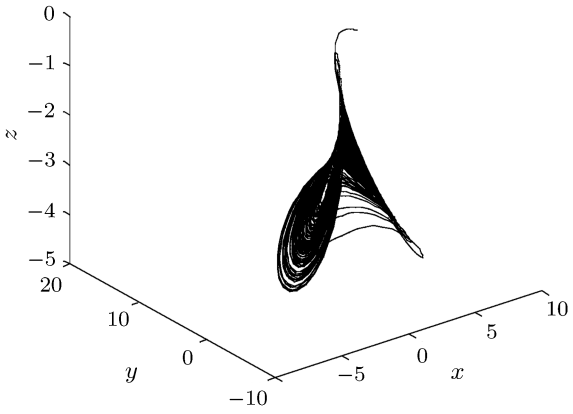


Fig.1. Three-dimensional view.

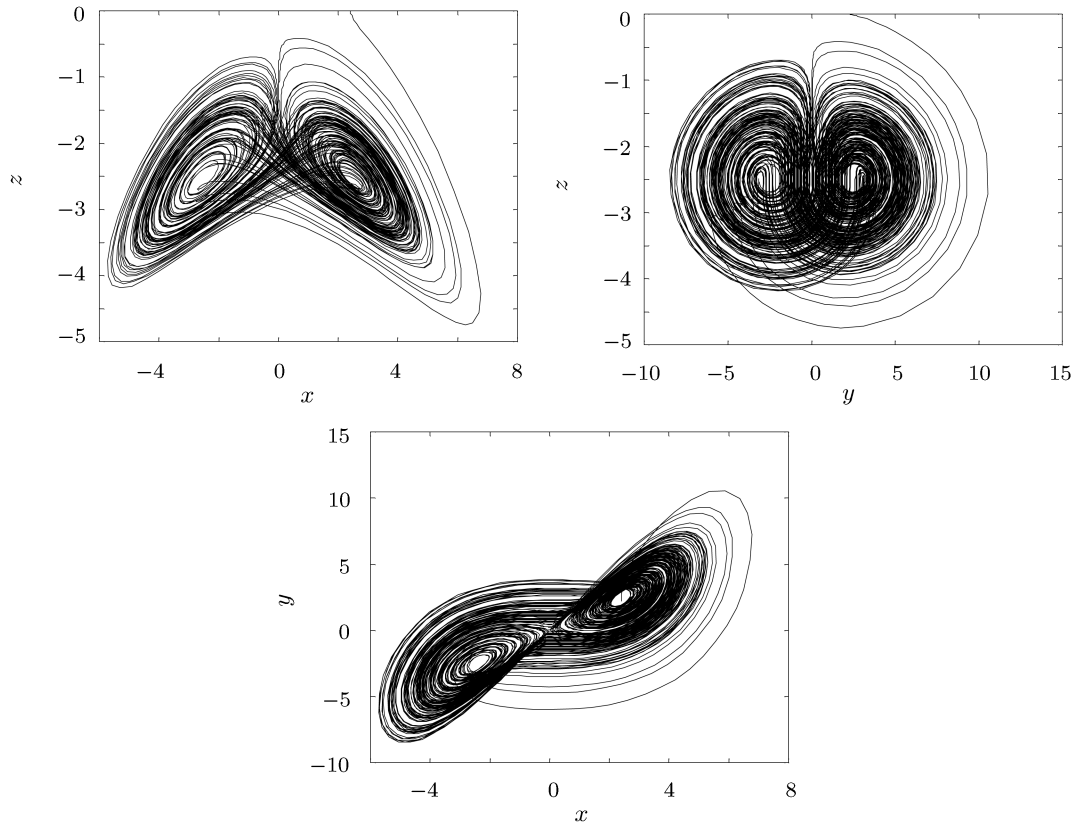


Fig.2. (a) $x-z$ phase plane strange attractors. (b) $y-z$ phase plane strange attractors. (c) $x-y$ phase plane strange attractors.

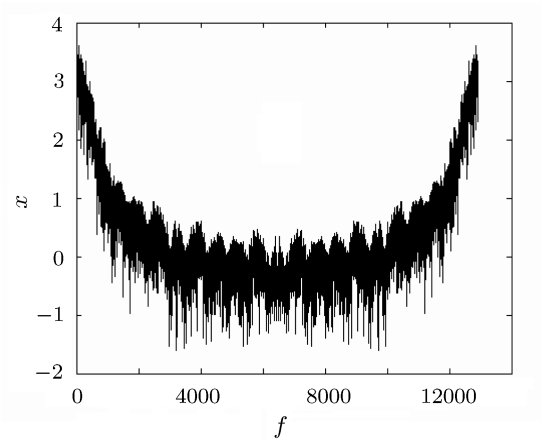


Fig.3. Spectrum of $|x|$.

The largest value of positive Lyapunov exponents of this system is obtained as $\lambda_{\mathrm{L}1} = 1.20464$.

Another Lyapunov exponent is $\lambda_{\mathrm{L}2} = 0$.

Negative Lyapunov exponent is $\lambda_{\mathrm{L}3} = -13.7051$.

The Lyapunov dimension of chaotic attractors of this nonlinear-system is also of fractional dimension, it is described as

$$\begin{aligned} D_{\mathrm{L}} &= j + \frac{1}{|\lambda_{\mathrm{L}\,j+1}|}\sum_{i=1}^{j}\lambda_{\mathrm{L}\,i} \\ &= 2 + \frac{(\lambda_{\mathrm{L}1} + \lambda_{\mathrm{L}2})}{|\lambda_{\mathrm{L}3}|} \\ &= 2 + \frac{1.20464 + 0}{|-13.7051|} = 2.088. \end{aligned} \tag{2}$$

Fractional dimension surely reveals a basic chaotic dynamical property of this system.[5]

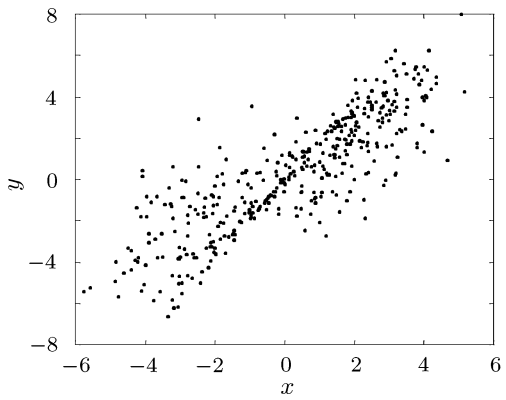


Fig.4. The Poincaré map of $x-y$ plane.

3. Circuitry implementation of this novel system

An electronic circuit is designed to realize this novel chaotic system and shown as Fig.5. The four-quadrant, analogue multiplier AD633 is adopted to realize the multiplication; some linear resistors and capacitors and operational amplifiers are used to realize the function of this chaotic system therein.[6] Three state variables, x, y and z, are obtained from the outputs of $uc1$, $uc2$ and $uc3$ respectively. The attractors can be observed from the oscilloscope, which are shown in Fig.6.

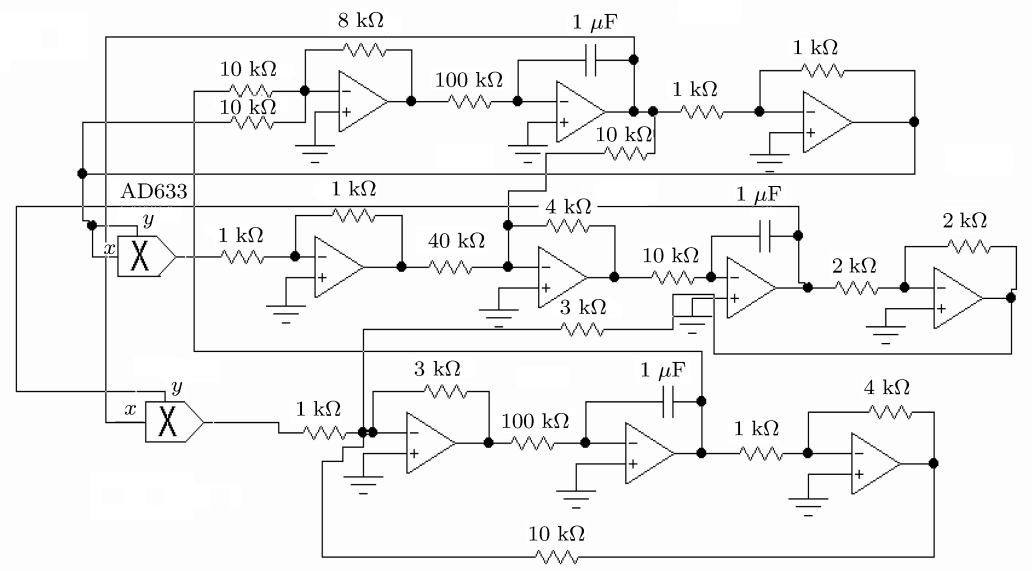


Fig.5. Electronic circuit of this novel chaotic system.

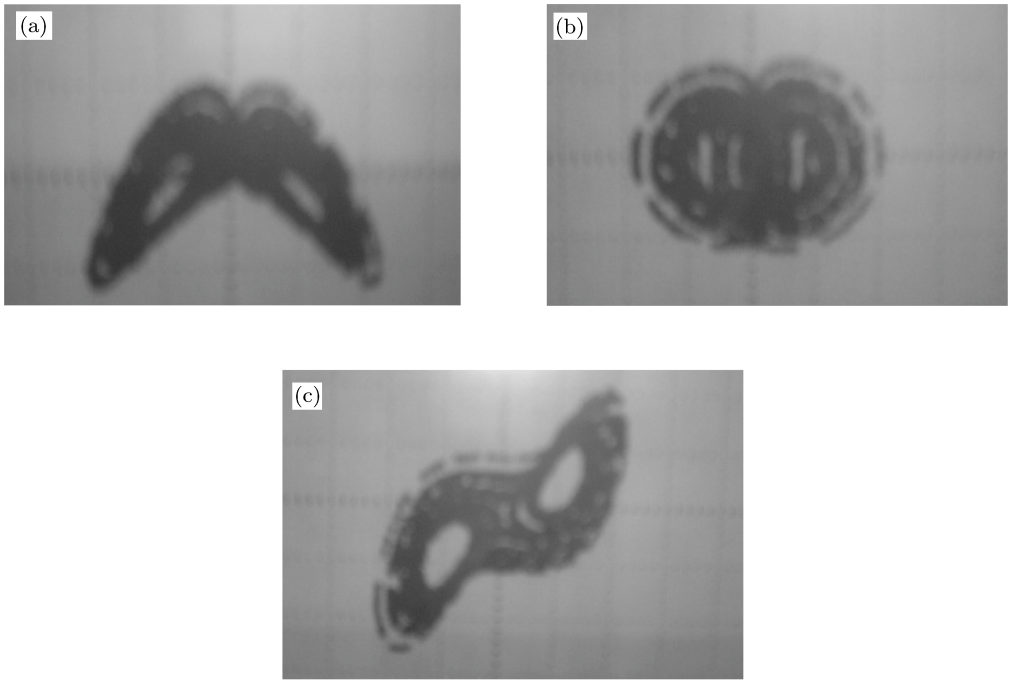


Fig.6. Oscilloscope observation for the strange attractors. (a) $x-z$ phase plane (0.15 V/div, 0.12 V/div); (b) $y-z$ phase plane (0.15 V/div, 0.12 V/div); (c) $x-y$ phase plane (0.15 V/div, 0.12 V/div).

4. Conclusions

In this paper, a novel reverse butterfly-shaped attractor and its electronic circuitry are proposed. Numerical simulation and experimental results verify the chaotic dynamical behaviour of this system and effectiveness of this electronic circuitry designed. This chaotic system has great potential for communication and electronics, it deserves further investigation in the near future.

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