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A novel chaotic attractor and its weak signal detection application

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ABSTRACT

In this paper, we present a new sinusoidal chaotic attractor and its weak signal detection application. This new system has a simple structure, parametric variety and high applicability. Its dynamic characteristics are studied in detailed. Firstly, the relationship between the system state and the amplitude of the forcing term is defined by examining the Lyapunov exponents of the system. The chaotic system's dynamical behavior is observed by this way. Secondly, the critical threshold value of the system is determined by the bifurcation analysis. This critical value named as tangent bifurcation point is a suitable one to detect weak signal which is submerged in strong noise. Thirdly, electronic circuit of the novel chaotic attractor is designed. Finally, a weak signal detection application of the system is studied. Simulation results indicate that this system can detect weak signal with high detection accuracy and low signal to noise ratio (SNR). It can also detect weak signal in high frequency cases. Matlab-Simulink® and PSpice simulation results prove the correctness of the theoretical analysis of studied system.

1. Introduction

Chaotic systems are seemingly random and depend on the initial conditions sensitively. Besides this, they are sensitive to certain signal and immune to background noise. Because of these properties of chaotic systems, chaos theory is used in many scientific researches. In 1963, Lorenz presented a new chaotic system known as the Lorenz attractor [1]. Rössler introduced another canonical low dimensional dissipative dynamical system [2]. Sprott focused his researches on autonomous 3D chaotic systems [3]. Lü and Chen introduced a chaotic system which represented the transition between the Lorenz and Chen attractors [4]. Pehlivan and Uyaroglu introduced and analyzed a new 3D chaotic system with golden proportion equilibria [5]. Since then, chaos theory has become an interesting research topic on many chaos-based technologies and information systems [6–10].

In the last two decades, many researchers focused on weak signal detection applications. In 1992, Brix showed that chaotic systems are sensitive to certain signal but immune to noise [11]. Researchers developed the techniques both in time domain and frequency domain for weak signal detection applications [12–20]. The modified Duffing-Holmes equation to detect nV level signal has been used by Li and Yang [21]. Chunyan and Yaowu demonstrated the Melnikov method to observe the threshold value of an oscillator [22]. Additionally, they used cross-correlation method to get lower SNR threshold. But

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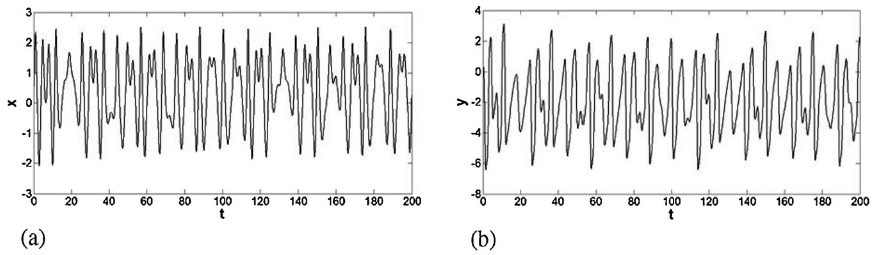

Fig. 1. Time series of the novel chaotic system for (a) x signals, (b) y signals.

the sensitivity of threshold value is low at Melnikov method. Also Melnikov function is complex [23]. On the other side, many researchers used Lyapunov exponents method to determine the threshold value [24,25]. These researches showed that Lyapunov method increased the detection accuracy.

This paper is organized as follows: Basic dynamic properties of the novel chaotic system are examined in Section 2. We used the Lyapunov exponents of the novel system to define relationship between the system state and the amplitude of the forcing term. Bifurcation analysis easily determines the critical tangent bifurcation point of the novel system. This critical point is the most suitable one to detect weak signal. In Section 3, the electronic circuit of the studied system is designed. In Section 4, a weak signal detection application is presented. Additionally, detection result comparisons with different frequencies of the studied system are given in this section. Section 5 contains the conclusions.

2. Basic dynamic properties of the novel chaotic system

2.1. The novel chaotic system

The novel chaotic system is described as follow:

$$\begin{cases} \dot{x} = y + \alpha\sin(\omega t) + a \\ \dot{y} = (-xy/b) - x^3 + c \end{cases} \tag{1}$$

where x and y are state variables, $\alpha\sin(\omega t)$ is a time-varying forcing term and a–c are constant parameters. Initial conditions $x(0) = 0$ and $y(0) = 0$. If we fix the constant parameters then as α varies from small to big, the system states may appear like a fixed point, a chaotic motion, a chaotic critical motion or a large scale periodic motion. The novel system has parametric varieties and rich dynamical behaviors. The time series of the novel chaotic system when $a = 2$, $b = 10$, $c = 1$ and $\omega = 1$ are shown in Fig. 1 for $\alpha = 1{,}5$.

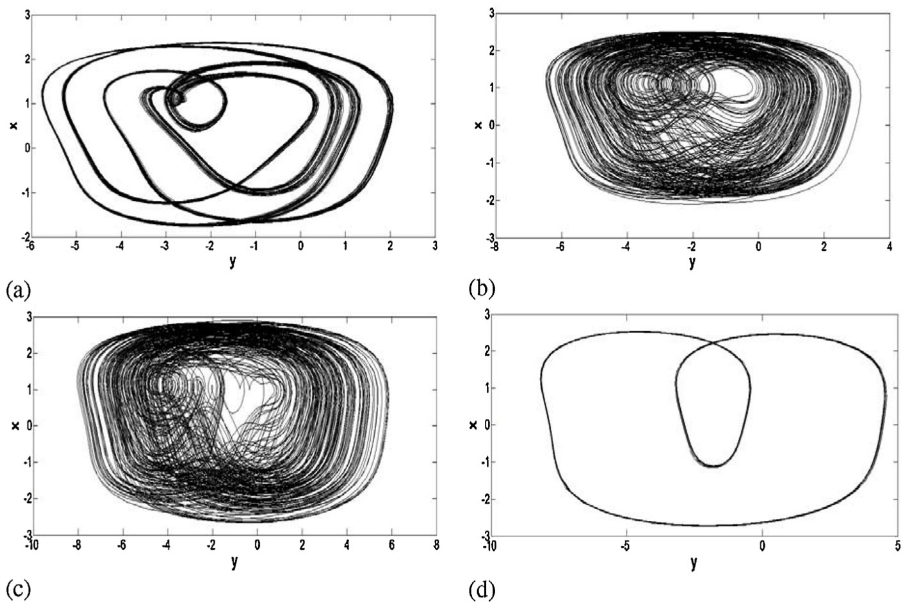

Fig. 2. x–y phase portraits of the novel chaotic system for $a = 2$, $b = 10$, $c = 1$ and (a) $\alpha = 1154$ ($t = 200$–$1000sn$) (b) $\alpha = 1{,}5$, (c) $\alpha = 2{,}55$, (d) $\alpha = 2{,}56$ ($t = 200$–$1000sn$).