membrane elasticity is closely related to the membrane proteins and cytoskeletons. This implies that we can take the mechanical property of membrane as a criterion for identification of normal and pathological cells and pathological cells before and after treatment, which is of great significance for disease diagnosis and drug screening.

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Chaotic system for the detection of periodic signals under the background of strong noise

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Abstract **We propose a method to study the chaotic system for the detection of periodic signals in the presence of strong background noise. The numerical experiments indicate that the chaotic system constructed from the modified Duffing-Holmes equation is sensitive to the weak periodic signal mixed with noise, and it has certain immunity to noise. The signal to noise ratio for the system can reach to about –91 dB.**

Keywords: chaotic system, weak periodic signal, detection, signal to noise ratio (SNR).

The periodic signal detection under the strong background noise is one of the basic issues in the fields of signal detection and signal processing, and it is extensively utilized in the fields, such as the information inception in communication engineering, radar information detection, the electronic antagonistic technology, the biomedicine signal processing, the long-distance detection of earthquake signals, and the industrial broken-down diagnosis. The study of the weak signal detection began in the 1950s, and the techniques have been developed both in time domain and frequency domain[1]. As for the methods of time domain, Birx proposed to apply the chaotic theory to the weak signal detection in 1992[2], but the author just showed the experimental results and did not investigate the principle behind. Over the past ten years, there have been very few reports about detection of weak signals using the chaotic system. It was Abarbanel et al. who pointed out that the nature of the system should be considered in which the signal to be detected is to calculate Lyapunov exponents[3], and the effects of the weak signal detection is relative to the amplitudes of the noise[4]. Researchers in China have achieved some results in the chaotic system detection of harmonic and square waves under the background of strong noise[5—7], and the SNR reached to about –60 dB. In this study we report the successful examples using the chaotic system, which is constructed from the modified Duffing-Holmes equation to detect the periodic signal under the background of strong noise.

1 Mathematic model

The idea is to use periodic signals that are detected to transform the system's chaotic state to a periodic state on a large scale. By the experimental comparison of sensitivity for the weak harmonic signals and square waves, we choose the Duffing-Holmes equation, which can construct the chaotic system, i.e.

$$\ddot{x}+k\dot{x}-x+x^3=\gamma\sin(\omega t), \qquad (1)$$

where $\gamma\sin(\omega t)$ is the forced periodic term to the equation (it is an internal signal in the system), and the term $(-x+x^3)$ is the recovery force term of the equation, and k denotes the rate of damping.

In eq. (1), when the forced periodic term $\gamma\sin(\omega t)$ is invariable, the kinematical state of the system mainly depends on the equation's recovery force term. By systematically considering the sensitivity of detecting weak periodic signal and the feasibility of the chaotic criterion, we transform the recovery force term to $(-x^3+cx^5)$, where the parameter $c=1+as_T(t)$, $a\geqslant 0$, $s_T(t)$ is a periodic signal, and then obtain a modified Duffing-Holmes equation

$$\ddot{x}+k\dot{x}-x^3+[1+as_T(t)]x^5=\gamma\sin(\omega t). \qquad (2)$$

This equation can construct the chaotic system for the detection of periodic signal. When a = 0, eq. (2) indicates that there is no periodic signal to be detected. When $a\neq 0$, the periodic signal to be detected exists in the system.

2 Numerical experiments

(i) The simulation model. We re-write eq. (2) in the following form:

$$\begin{cases}\dot{x}=y,\\ \dot{y}=\{x^3-[1+as_T(t)]x^5-ky+\gamma\sin(\omega t)\}.\end{cases} \qquad (3)$$

In the numerical experiments, we take $\omega=1\ \mathrm{rad}/s$ of the internal signal. According to eq. (3), we can construct the system's simulation model using MATLAB software (Fig. 1). In the simulation model, the two harmonic signals with different frequencies add together to give a relatively complicated signal $s_T(t)$, and we can use the new signal to simulate a periodic signal (Fig. 2).

(ii) Results

(1) a = 0, the system is in the critical periodic state (namely the margin of the chaotic state is changed to periodic state on a large scale), here γ= 0.72698980, and the projection of the phase plane ($x-\dot{x}$) corresponds to the solution of wave forms in the time domain of the system as given in Fig. 3.

(2) Merging the white-noise z_s into the system and continuously adjusting z_s, the system still keeps in the

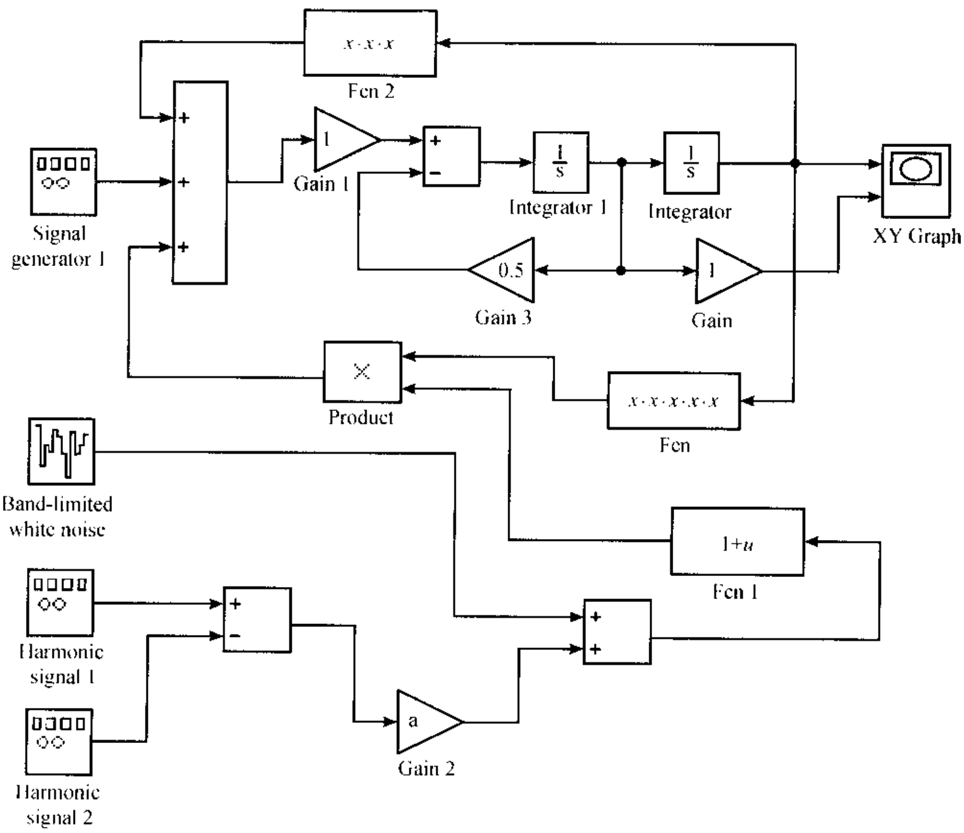

Fig. 1. The system's simulation model.

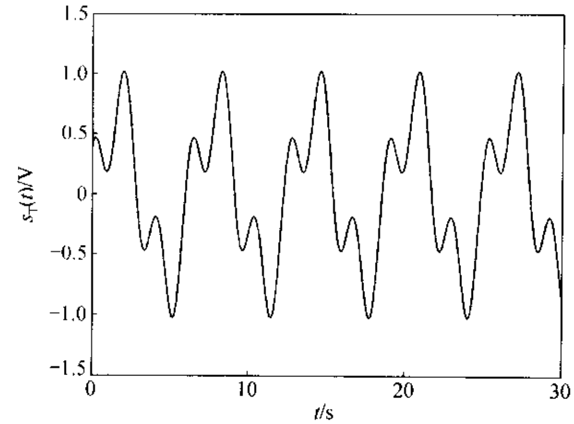

Fig. 2. The two harmonic signals with different frequencies stack to form a new periodic signal $s_T(t)$.

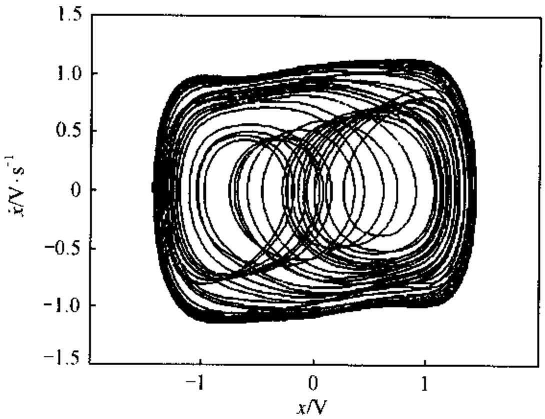

Fig. 3. The phase plane orbits in the chaotic critical state.

chaotic state; namely, although the noise is strong, the strange attractor still fetters the phase points in the projections. This indicates that the chaotic system has certain immunity to noise.

(3) Adding the mixed information $(as_T(t)+z_s)$ noise and periodic signals, we find that the system movement projections immediately change from the chaotic critical state to a periodic state in large scale (Fig. 4). The numerical calculation shows that the noise power of the optimal simulating results is 10^{-4} W, and the amplitude of the periodic signal is $a = 4 \times 10^{-7}$ V.

(iii) Results analysis. In the simulating experiments, when the power of noise is 10^{-4} W, the lowest amplitude of the detected periodic signal, i.e. the system's lowest detection limit, is 4×10^{-7} V. So the lowest detection limit of this system is 20 log $(4 \times 10^{-7}) \approx -128$ dB. The lowest limit of SNR of the signal is

$$\text{SNR}=10\log\frac{\text{Period Signal Power}}{\text{Noise Power}} \approx -91 \text{ dB}.$$

At present, in the time domain the lowest limit of SNR is only –10 dB using other signal detection methods except for the chaotic system detection[6].

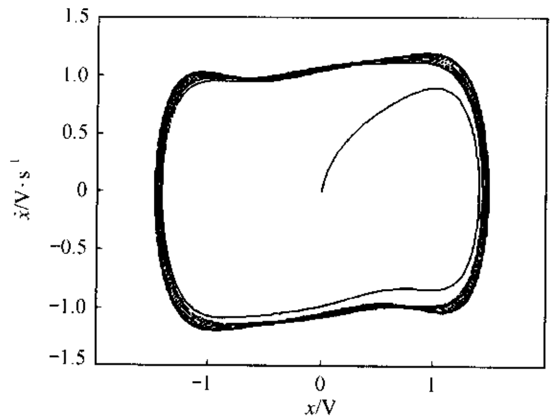

Fig. 4. The phase plane orbits in the large scale period state.

3 Conclusions

Using mathematical models and numerical experiments, we show that the chaotic system of the modified Duffing-Holmes equation is effective. Because the chaotic system studied in this report is sensitive to the weak periodic signal and has definite immunity to noise, it has a wide range of applications.

The physical mechanism of applying the chaotic system to the detection of weak periodic signal comes from the chaotic state's control existing in the system, i.e. according to the change of the given phase projection of the chaotic systems from the chaotic state to the periodic state at a large scale, the weak signal can be detected, which can be considered as a compliment of the theory for the weak signal detection, or may form a new branch of the weak signal detection theory.

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