Chaos weak signal detecting algorithm and its application in the ultrasonic Doppler bloodstream speed measuring

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Chaos weak signal detecting algorithm and its application in the ultrasonic Doppler bloodstream speed measuring [*]

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Abstract：At the present time, the ultrasonic Doppler measuring means has been extensively used in the human body's bloodstream speed measuring. The ultrasonic Doppler measuring means can achieve the measuring of liquid flux by detecting Doppler frequency shift of ultrasonic in the process of liquid spread. However, the detected sound wave is a weak signal that is flooded in the strong noise signal. The traditional measuring method depends on signal-to-noise ratio. Under the very low signal-to-noise ratio or the strong noise signal background, the signal frequency is not measured. This article studied on chaotic movement of Duffing oscillator and intermittent chaotic characteristic on chaotic oscillator of Duffing equation. In the light of the range of the bloodstream speed of human body and the principle of Doppler shift, the paper determines the frequency shift range. An oscillator array including many oscillators is designed according to it. The reflected ultrasonic frequency information can be ascertained accurately by the intermittent chaos quality of the oscillator. The signal-to-noise ratio of –26.5dB is obtained by the result of the experiment. Compared with the tradition the frequency method compare, the dependence to signal-to-noise ratio is lowered consumedly. The measuring precision of the bloodstream speed is heightened.
Keywords: chaotic oscillator, intermittent chaos, signal-to-noise ratio, Doppler shift, bloodstream speed measuring.

1. Introduction

At examining heart brain blood vessel patients with the under medical treatment, it is very important to measure the blood flowing the speed. Human body blood is a much impurity and ropy liquid. For such current containing the solid granules and air bladders, the method of measuring liquid flux with the ultrasonic Doppler measuring will be adopted preferentially. At present, it is applied abroad to the medical science to measure the brain blood flowing along the diagram with ultrasonic Doppler measurement. Its measurement principle is Ultrasonic Doppler Effect. The flowing the speed can be measured from the incidence wave and reflecting wave difference. Because the frequency of the incidence ultrasonic is fixed, the reflecting wave frequency need to measure accurately. The reflecting waves are flooded under strong noises. Consequently the method of the effective measuring frequency is requisite. Aimed at the some limit of the traditional measuring frequency，the article introduces the method measuring frequency on chaotic oscillator so that the reflecting ultrasonic frequency can be ascertained effectually.

2. The measure principle of ultrasonic Doppler

The arithmetic of the Doppler bloodstream speed measuring bases on a principle of the ultrasonic Doppler frequency shift, namely from a ultrasonic detector to blood vessels continue to shoot a fixed frequency ultrasonic and when the ultrasonic meets the solid granules and air bladders, the reflect wave frequency and the incidence wave frequency produce a excursion that is a direct proportion with the blood flowing speed. We can shoot some ultrasonic from skin to blood. The ultrasonic will occur a dispersion and produce a frequency shift that is a direct proportion with the blood cell sporting speed. Therefore, only this shift can be measured, the blood speed can be measured untouched, shown as fig 1.
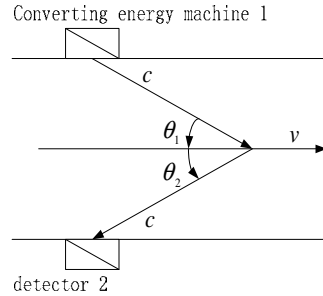
Fig.1 The measure principle of ultrasonic Doppler

Let converting energy mashine1 emits a ultrasonic with a fixed frequency f_1 and the received reflect wave frequency is expressed as f . We suppose the sport speed of the solid granules and air bladders are same as the blood speed, each one is equal to v . If the wave speed in motionless blood is v_1, the reflect wave speed is f and is given by

$$f = f_1 \frac{v_1 + v\ \cos\theta_1}{v_1 - v\ \cos\theta_2} \qquad (1)$$

Where θ_1, θ_2 is a angle between the ultrasonic emitting direction, the reflect direction and the blood speed direction respectively. When $v_1 >> v$, $\theta_1 = \theta_2 = \theta$, there is

$$f = f_1(1 + \frac{2v\ \cos\theta}{v_1}) \qquad (2)$$

Therefore, the difference value between received wave and emitted wave is $\Delta f = \dfrac{2v\ \cos\theta}{v_1} f_1$.

2. Method of measuring frequency with chaotic oscillator in the strong noise background

2.1 Intermittent chaotic mathematics equation of Duffing equation and the principle of measuring frequency

The general form of Home type Duffing system with the item of the damp and receiving the outsider period incentive is

$$\ddot{x} + \delta\dot{x} - x + x^3 = f\ cos\ \omega t \qquad (3)$$

Where δ is the damp coefficient; $f\ cos\ \omega t$ is a period incentive (reference signal) with the angle frequency ω .

In this paper, the little amplitude cyclical signal whose angular frequency is closed to the frequency of the interior driving force is used to take perturbation to the cyclical interior driving force of the equation (3). So, the equation (3) will be changed to the equation (4).

$$\ddot{x} + \delta\dot{x} - x + x^3 = f_r\ cos\ t + d\ cos((1 + \Delta\omega)t + \varphi) \qquad (4)$$

With $f_r\ cos\ t + d\ cos((1 + \Delta\omega)t + \varphi)$ is the gross driving force; $f_r\ cos\ t$ is the interior driving force signal; $d\ cos((1 + \Delta\omega)t + \varphi)$ is the outward little amplitude value disturbed signal (small signal, weak signal), It is the perturbation of the interior driving force signal; $\Delta\omega$ is the angular frequency difference between the periodic disturbed signal and interior driving force. fr is less than f_c $d << f_r$ and is secured greater than f_c. In this paper, here we take f_r=0.51 N. Formula (4) turns in brief to dynamics

equation:

$$\begin{cases} \dfrac{dx}{dt} = v \\ \dfrac{dv}{dt} = -\delta v + x - x^3 + f_r \cos(t) + d \cos[(1+\Delta\omega)t + \varphi] \end{cases} \tag{5}$$

The gross driving force of the right-hand member of the equation (5) may be converted to the equation (6):

$$
\begin{aligned}
f_r \, cos(t) + d \, cos((1+\Delta\omega)t + \varphi) \\
= f_r \, cos(t) + d \, cos(t) \cdot cos(\Delta\omega \cdot t + \varphi) - d \, sin(t) \cdot sin(\Delta\omega \cdot t + \varphi) \\
= F(t) \cdot cos[t + \theta(t)]
\end{aligned}
\tag{6}
$$

with

$$F(t) = \sqrt{f_r^2 + 2 f_r d \cos(\Delta\omega \cdot t + \varphi) + d^2} \tag{7}$$

$$\theta(t) = \arctan[\dfrac{d \sin(\Delta\omega \cdot t + \varphi)}{f_r + d \cos(\Delta\omega \cdot t + \varphi)}] \tag{8}$$

From the formula (8), because of $d \ll f_r$, $\theta(t)$ very small and its influence is extremely small and can

$$Q = \dfrac{\pi D^3}{4 \sin 2\theta} (1 + \dfrac{\pi c_2 \sin\theta}{D})^2 \cdot \Delta F \tag{3}$$

take no account of it. According to formula (7), we can conclude:

(1) When $\Delta\omega = 0$, The frequency of driving force is the same as the signal of disturbed signal. If φ satisfy the next formula:

$$\pi - \arccos\dfrac{d}{2 f_r} \leq \varphi \leq \pi + \arccos\dfrac{d}{2 f_r} \tag{9}$$

There is $F(t) \leq f_r < f_c$, the system always be placed the chaotic movement state. Only when φ is not in the scope, $F(t) > f_r$, the change of phase may happen.

(2) When $\Delta\omega \neq 0$, the amplitude $F(t)$ of the gross driving force will periodically and alternatively change between $f_r + d$ and $f_r - d$. The intermittent chaos appearance may be presented in the system. When $\Delta\omega$ is very small, the $F(t)$ will periodically be greater than or less than f_c. Its period is T_{Δ}

$$T_{\Delta} = 2\pi / \Delta\omega \tag{10}$$

The interim chaos phenomenon will appear periodic in the system. Therefore, we can acquire indirectly the frequency value of the outside perturbation signal through measuring T_{Δ}. When Δw is very small, T will be very big. An oscillator array with minute frequency difference will be designed. The interval of two oscillators whose input signal frequency difference is the smallest two when the outward signal is inputted. So, the frequency of the signal may be ascertained exactly.

The numerical value experiment indicate when $\Delta\omega > 0.04$ rad/s, the regular interim chaos phenomenon is recognized difficultly. That is because the requirement of to finish the change of phase process is enough long incitation time. The $F(t)$ will change so fast that the system can not respond very good if the value of $\Delta\omega$ is very big.

The incitation damped so fast that the periodic motion can not be kept when $F(t)$ is greater than f_c; The incitation increased so fast that the stable chaos motion can not be kept when $F(t)$ is less than f_c. So, the value of the $\Delta\omega_{max}$ will be 0.03 rad/s.

2.2. Influence for noise to signal-to-noise ratio

The signal-to-noise ratio is defined as the division between the average power of the useful signal and noise. The signal-to-noise ratio is also defined as the proportion of the amplitude of the signal and the standard deviation of the noise. Namely,

$$SNR = 20\lg\frac{d}{\sigma_N} \tag{11}$$

A perturbation will be added on the base of the disturbed signal. The equation (4) will be changed to the equation (12).

$$\ddot{x} + 0.3 \cdot \dot{x} - x + x^3 = 0.51 \cdot \cos t + d\cos((1+\Delta\omega)t + \varphi) + \sigma \cdot \text{randn}(t) \tag{12}$$

Where the randn(t) is the noise creation function which is satisfy the normal distribution. σ is the standard deviation of the noise.

3. Simulation experiment

We take a example that is the measurement human body brain artery blood flowing speed to explain the method. Human body brain artery blood flowing the speed is 150-800mm/s, v is 1570m/s. We emit the 30KHz ultrasonic to blood vessels.

According to the formula $f = f_1(v_1 + v\cos\theta_1)/(v_1 - v\cos\theta_2)$, the scope of human body blood frequency can be ascertained. In experiment, we take the incidence angle θ is 45 degree. We suppose that the variety scope of the measured signal frequency f_d is $29955 < f_d < 30068$ （Hz）, homologous the angle frequency is $1.88214\times10^5 < w_d < 1.88926\times10^5$ （rad/s）. According to w_d, we design a oscillator array with seven oscillators:
$w_1 = (1.8821 + 1\times\Delta w)\times10^5$ 、 $w_2 = (1.8821 + 2\times\Delta w)\times10^5$ ... $w_7 = (1.8821 + 7\times\Delta w)\times10^5$, where $\Delta\omega = 0.001$ rad/s. when the outside signals input, one by one in order to scan the oscillator, then compute the scanning result through the analyze software and the signal frequency can be ascertained. We take the input signal is as the equation (13)

$$x(t) = 0.032 \times \cos(1.884 \times 10^5 t) + 0.58 \times randn(t) \tag{13}$$

In the time domain, the shape of the signal $x(t)$ is shown as fig 2. we can observe the background noise is specially strong and the signal is submerged in the noise.
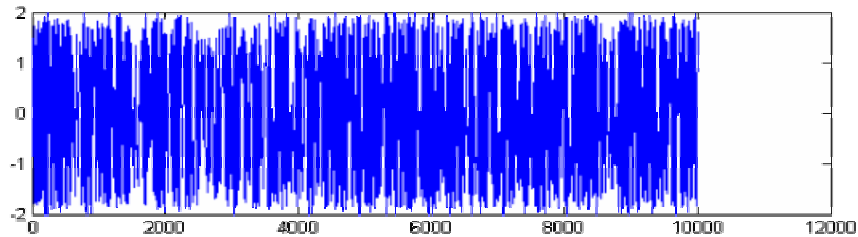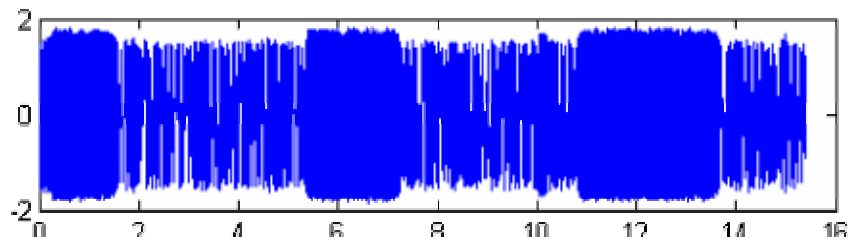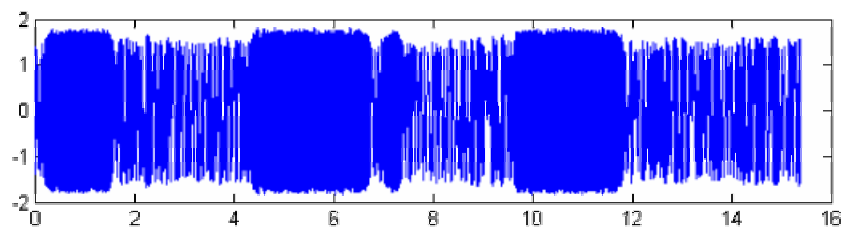

Fig.2 The time image of the input signal $x(t)$

(a)The time image of the number 2 oscillator

(b) The time image of the number 3 oscillator

Fig.3 The time image of the oscillator

In the theories, the phase transition time cycle of the number2 and the number3 oscillator is longer two when the signal $x(t)$ is inputted. It was improved by the experiment result. The sharp intermittent chaos phenomenon can be got in the Fig.3 and the face change interval is the longest. The angular frequency of the input signal can be ascertained by the algorithm finally. The value of the frequency is 1.8854×10^5. The signal-to-noise ratio can be got by the equation (14).

$$SNR = 20 \lg \frac{d}{\sigma_N} = \text{-26.5 dB} \tag{14}$$

Therefore, we can calculate the blood speed v =388.6mm/s according to formula (2)

4. Conclusion

From the experimental result, we can observe obviously that after the chaotic oscillator array measuring the frequency, the blood speed can be ascertained by use of the method of the ultrasonic Doppler. Moreover, the Signal-to-Noise Ratio can be improved greatly. This method will have the extensive foreground in the medical science realm.

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