The Weak Signal Detection Based on Chaos and Genetic Algorithms

Changjian Deng
Department of Automatic Control Engineering
Chengdu University of Information Technology
Chengdu, Sichuan, 610225, China
chenglidcj@cuit.edu.cn

Shaoquan Zhang
Department of Automatic Control Engineering
Chengdu University of Information Technology
Chengdu, Sichuan, 610225, China
zsq_euyiuhs@163.com

***Abstract*— weak signals detection using different chaos oscillators such as Duffing systems and Lorenz systems is an effective detection method in low SNR. Genetic algorithms have a lot of applications in the fields of parameters estimation and neighbor searching. Combination two methods to detect weak signal can test lower SNR signal, give a more meaningful chaos prediction and so on. In the paper, the methods of detecting weak sinusoid signal using improved chaos oscillators method is presented, and the nonlinear time series prediction using genetic algorithms is discussed .The simulation result can prove that this methods is effective in weak signal detection.** *(Abstract)*

Keywords-chaos;Lorenz system;genetic algorithms; nonlinear time series signal(key words)

I. Introduction

It is well known, deterministic chaos offers a explanation for irregular behavior and anomalies in systems which do not seem to be inherently stochastic, and the chaotic oscillator is immunity to the noise and sensitivity to certain periodic signal and is effective in weak periodic signal detection.

Also, in some environments chaos is undesired state of systems, chaos control can help to reestablish at least a regularly oscillating output at a higher rate, with judiciously applied minimal perturbations. Or, it is a quite surprising phenomenon that chaotic solutions can be destabilized and periodic solutions can be formed by small and periodic perturbations of a system [1].All are regarded as a foundation of detecting weak signal.

When considering chaotic characteristics of some kinds of noise, the chaotic noise is predicated firstly, and then general detection methods are applied to detect weak signal. For example, to find a predicable model of chaotic signals using radial basic function neural network and so on. According to the observed value of chaotic singular variable, and then subtracts the predicable chaotic noises from the received signals. And when the noise is combination the chaotic and normal noise, self-adaptive or hierarchical structures may be considered.

At a mean time, Genetic algorithms are powerful tool to make parameters estimation when to find a predicable model of chaotic noise or to undertake other steps of weak signal detection task [2].

So the weak signal detection using chaos oscillators and genetic algorithms is a meaningful work.

In part II of the paper, some theory knowledge is introduce, such as chaos oscillators and noise, concepts of dynamic systems and means to judge chaos phenomenon.

In section III, weak sinusoid signal detection using Duffing Oscillators and combining chaos critical state detection method with general detection methods is introduced. And the theoretical analysis and simulating experiments demonstrate the method has powerful ability to detect very weak signals under the background of the white noise.

In section IV, the method of nonlinear time series prediction using genetic algorithms is presented. And the algorithm is presented.

II. The Chaos Phenomenon

A. *chaos oscillators and noise*

A vector space that a point in a space specifies the state of system, and vice versa, is called a state space or phase space. As a dynamical system, the nonlinear time series (the time evolution is defined in some phase space) can exhibit deterministic chaos. The most direct link between chaos theory and real world is the analysis of time series from real systems in terns of nonlinear dynamics.

It is said that the reason that chaos oscillators can occur from some nonlinear system is its property of sensitivity to initial value. For example, the duffing systems [3]:

$$x''+f(x)=\varepsilon[h(t)-kx']=\varepsilon\cdot g(x',t) \tag{1}$$

But all experimental data are to some extent contaminated by noise, weather the noise can be separated from the clean signal depends on the nature of noise and signal. such as the signal can be predictable or not ,the noise is how different from the signal and so on. To simplify this problem, think a dynamical noise: it is a feedback process wherein the system is perturbed by a small random amount at each time step:

$$x_{n+1}=F(x_n+\eta_n) \tag{2}$$

For strongly chaotic systems, measurement and dynamical noise can be mapped onto each other.Generally; dynamical noise induces much greater problems in data processing than additive noise, since in the latter case a nearby clean trajectory of the underlying deterministic system always exists.

Chaotic systems have the property of sensitive dependence on initial conditions, which means that infinitesimally close vectors in state space give rise to two trajectories which separate exponentially fast. Let x and y be two such nearby trajectories in m-dimensional state space. Considering the dynamical system as a map, the time evolution of their distance is:

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$$y_{n+1} - x_{n+1} = F(y_n) - F(x_n) = J_n(y_n - x_n) + O(\| y_n - x_n \|^2); \tag{3}$$

The equation (3) is useful when judging chaos phenomenon's in time series.

B. The methods of judging chaos phenomenon .

The first method of judging chaos phenomenon is numeral way, that comes from the property of chaos: local (small scale) unstable and global (long and large scale) stable. The same as it, the figure of phase plane can be used to judge chaos phenomenon also.

As a addition, the Lyapunov exponents is used: In a non animus system. Its Poincare map is:

$$x_{n+1} = X(x_n, y_n)$$
$$y_{n+1} = Y(x_n, y_n) \tag{4}$$

And its Lyapunov exponents is define as

$$L_1 = \lim_{n \to \infty} \sqrt[n]{j_1^{\,n}}$$
$$L_2 = \lim_{n \to \infty} \sqrt[n]{j_2^{\,n}} \tag{5}$$

J is Jacobin matrix (Like equation 3),L1 and L2 is a reveal value of extend or decline times of axis X and axis Y. Note when L1 and L2 is below than 1,the chaos phenomenon may occurs.

Anther methods are using Melnikov function:

$$M(t_0) = \int_{-\infty}^{\infty} f(q^0(t)) \Lambda g(q^0(t), t + t_0) dt \tag{6}$$

III. WEAK SINUSOID SIGNAL DETECTION BASED ON CHAOS

Generally, for a nonlinear dynamic system, a small perturbation of system parameters may lead to the essential change of system state. Many methods utilizing the sensitivity to system parameters were put forward to detect weak periodic signal.

A. Principle

At the beginning of weak sinusoid detection, the Holmes Duffing equation (7) is chosen

$$\ddot{x} + \varepsilon \cdot k \cdot \dot{x} - \alpha \cdot x + \beta \cdot x^3 = \varepsilon \cdot \gamma \cos(\omega \cdot t) \tag{7}$$

According to paper [4], to simplify the problem, the model can be determined as below equations:

$$\ddot{x} + k \cdot \dot{x} - x^3 + x^5 = \gamma \cos(\omega \cdot t) + input \tag{8}$$

And the simulink model is figure 1.

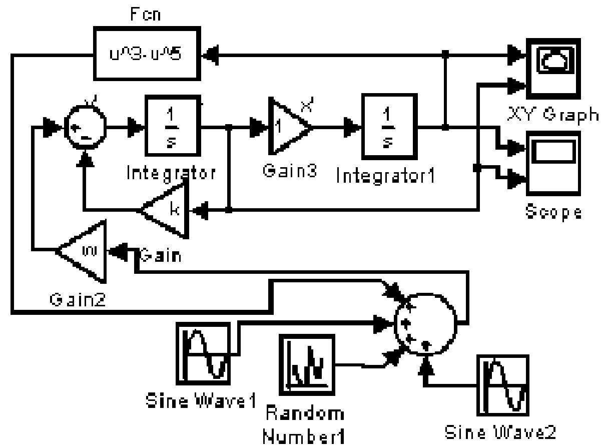

Figure.1 The simulink model of chaos system

B. The diagram of weak signal detection

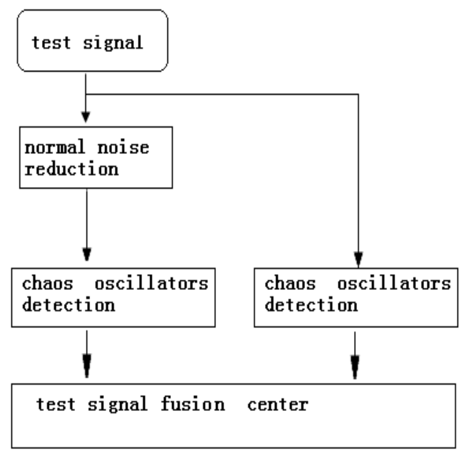

Figure.2 The improve model of chaos oscillators detection

In Figure.2, the technology of normal noise reduction include: the power spectrum and Wiener filter; the SFFT (such as: to find out all relatively obvious peaks in SFFT spectrum and estimate all frequency components associated with those peaks, and then set s range of every estimated frequency to be the estimated frequency band and scan the frequency using a small array of Duffing oscillator in the frequency band); synchronous integral; and noise Cancellation (like Figure.3), and so on.

Based on the work of other studies, the synchronous integral or noise cancellation is applied. And the synchronous integral can improve the SNR of signal that can be test as report in paper [4].

Like test signal come from different sensors, the clean signal come from different model can be fusion to improve ability of detection.(see Figure.2),Figure.4 is the results of simulation and it is similar as paper [4].

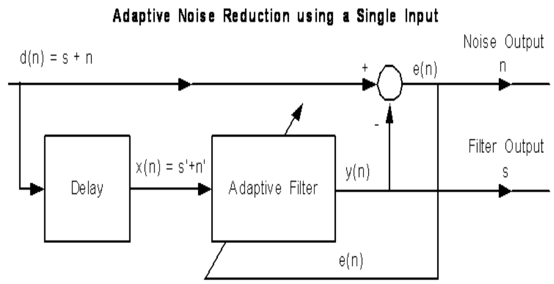

Figure.3 Adaptive noise reduction using a single input

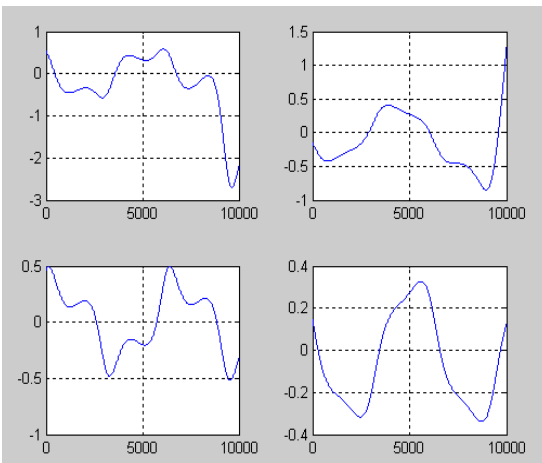

Figure.4 the results of simulation.

IV. NONLINEAR TIME SERIES PRIDICTION USING GENETIC ALGORITHMS

To analysis nonlinear time series include chaos time series, Signal processing based on Genetic Algorithm is used to proceed with target parameters estimation. Genetic algorithms are algorithms for optimization and machine learning based loosely on several features of biological evolution [5].A simple nonlinear noise reduction algorithm essentially consists of finding all neighbors closer than some distance ε in an m-dimensional embedding space. This is a efficient neighbor searching problem. There are two ways to solve this problem, one is consider a set of N vectors xn in m dimensions, for simplicity rescaled to fall into the unit cube, the problem is determine the set of indices :

$$u_n(\varepsilon)=\{n':\|x_n'-x_n\|<\varepsilon\} \qquad (9)$$

Another is box-assisted methods; divide the phase into a grid of boxes of side length ε, and then each point falls into one of these boxes. All neighbors closer than ε have to lie in either the same box or one of the adjacent boxes. Like a simple code of nonlinear noise reduction, this needs a list of the indices of all neighbors for further processing.

If a minimal number of neighbors are need rather than a neighborhood of fixed radius, it becomes another nonlinear noise reduction algorithm: neighborhoods of fixed radius are formed and the points which do not have enough neighbors within this radius is marked. These points are visited in a next sweep, where slightly larger neighborhoods are formed; repeat the procedure until all are satisfied [1].

The process is similar to intelligent searching algorithm process. The different of two algorithms is GA has mutation and crossover and another have not. Consideration of the unpredictability behaviors of chaos, using the GA algorithm to do nonlinear time series prediction is a choice. Like other predictions methods, the cross-correlations can computation.

The algorithm is described in Figure.5:

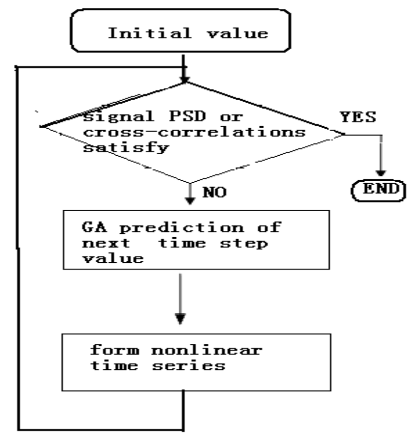

Fig.ure5 The process of the nonlinear time series pridiction .

Typical parameters of GA included: mutation probability 5%; crossover probability 30%.

A genetic algorithm operates according to the following steps:

1. Initialize the population using the initialization procedure, and evaluate each member of the initial population.

2. Reproduce until a stopping criterion is met. Reproduction consists of iterations of the following steps:

(a) Choose one or more parents to reproduce. Selection is stochastic, but the individuals with the highest evaluations are favored in the selection.

(b) Choose a genetic operator and apply it to the parents.

(c) Evaluate the children and accumulate them into a generation.

The PSD of chaos time series is plain, and signal is peak, use the method of synchronous integral is considered to judge the signal in nonlinear time series.

V. CONCLUTION

In the paper, weak sinusoid signal detection using Duffing Oscillators and combining chaos critical state detection method with general detection methods is introduced. And the method of nonlinear time series prediction using genetic algorithms is presented.

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