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Brief Papers

Hysteretic chaotic operator network and its application in wind speed series prediction

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ABSTRACT

A novel hysteretic chaotic operator network is constructed to improve the prediction performance of the wind speed series. The network is composed of three layers: the input layer, the chaotic operator layer and the hysteretic output layer. The hysteretic output can enhance the storage and memory capacity of the network, which can restrain the error change of the neuron state. Genetic algorithm is used to change the dynamic behavior of the network to follow that of the predicted system. Thus, the network can obtain the regular information contained in the training samples, and the dynamic prediction can be performed. Simulation results show that the network can be applied to perform the wind speed series prediction, and it can obtain better prediction performance than conventional methods.

1. Introduction

Nowadays, the study on the time series prediction and analysis becomes one of the hotspots in many fields [1–6]. For instance, the prediction of the wind speed series has been a bottleneck in the large-scale wind power integration [7]. Wind energy, as an ideal green and alternative energy resource, is gaining attention over the world. A main way of wind energy utilization is to perform high-power grid-connected of wind turbine. However, unlike conventional power sources, the wind power is stochastic, intermittent, low-energy-density and low-controllable [8–10]. These complex nonlinear characteristics cause to a series of big problems for the grid interconnection of wind farms. For instance, the stability and security of the electric power system will be destroyed because of the great impact caused by the wind power. If wind speed series can be accurately predicted in advance, scheduling plan can be adjusted timely to ensure power quality, the system reserve capacity can be reduced and more economic and social benefits can be acquired.

For now, there are many wind speed series prediction methods proposed based on kinds of prediction mechanisms [11–16]. Such as, ARMA, Kalman filter, gray model, etc. In fact, the prediction of the wind speed series, in essence, is to model a multiple input multiple output nonlinear system [17–21]. In view of the complex characteristics of wind speed series, neural networks show good application prospects in the wind speed series prediction because it can perform the black-box modeling [22–26]. BP neural network is one of the most common neural networks [27–31]. However, it is a static neural network which is hard to meet the modeling demands of dynamical systems. Chaotic operator network can be applied to model the dynamical system [32]. It is composed of many chaotic operator units. The dynamic characteristics of the network are determined by all of the chaotic operators. The dynamic behaviors can be changed by adjusting the control parameter of each chaotic operator unit. But its characteristics are too sensitive to those control parameters. So the prediction result obtained by the chaotic operator network may be less stable.

Moreover, some nonlinear characteristics can improve the performance of the neural network, For instance, hysteretic characteristic can enhance the storage and memory capacity. In fact, these nonlinear characteristics exist in the natural biological neural networks, and play the important role in the information processing. These characteristics can improve the performance of the network by adding appropriately into the neural network.

In this paper, a hysteretic chaotic operator network is proposed to perform the wind speed series prediction. The network is composed of the input layer, the chaotic operator layer and the hysteretic output layer. Hystertic characteristic can improve the memory ability of the network, and enhance the stability of the prediction results.

In Section 2, the dynamic characteristic of the chaotic operator is exhibited, and the hysteretic neuron model is given. Furthermore, the hysteretic chaotic operator network is constructed, and its training method is described. In Section 3, the prediction results of the wind speed series obtained by our method is compared with the conventional methods. A brief conclusion is given in Section 4.

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2. Hysteretic chaotic operator network

The chaotic system can show the complex dynamic behavior. Even a simple chaotic map can also has the complex dynamic behavior. For instance, a simple chaotic operator unit which can show complex dynamic behavior is shown in Eq. (1).

$$x_{n+1} = \sin \alpha x_n \tag{1}$$

It has a control parameter α which can change the chaotic dynamic characteristic of the map. The bifurcation process diagram with the variation of the parameters α is shown in Fig. 1.

Correspondingly, Lyapunov exponent diagram with the variation of the parameters α is shown in Fig. 2.

The map can be in the period state or chaotic state by changing the control parameter. Many such chaotic operator units can be coupled into a network which has the more complex dynamic behaviors. The change of control parameter of any chaotic operator can cause to the change of the dynamic behavior of the network. Therefore, the dynamic behavior of the prediction network can be changed to follow to that of the real system. And the dynamic characteristic of the prediction network will be consistent with the dynamic characteristic of the real system. In this way, dynamic prediction can be performed by the network.

However, the prediction result of the network is not stable enough because it is too sensitive to the control parameter. Therefore, hysteretic characteristic can be brought into the network to stabilize the prediction result.

The hysteretic neuron model can be designed as (Fig. 3).

There are n input elements $x_1(t), x_2(t), \ldots, x_n(t)$, and a threshold θ in the hysteretic neuron model. The input sum $s(t+1)$ of the neuron is calculated as:

$$s(t+1) = s(t) + \Delta s(t+1) = \sum_{i=1}^{n} w_i x_i(t) - \theta \tag{2}$$

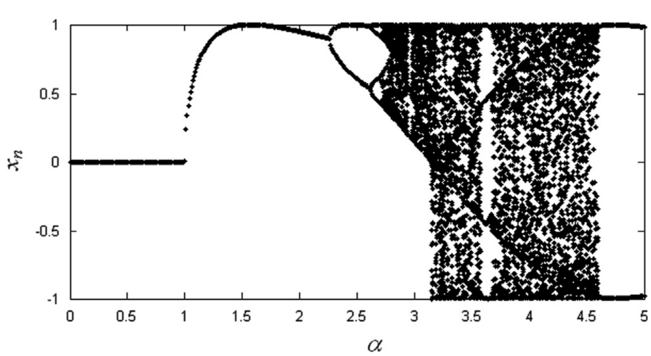

Fig. 1. The bifurcation diagram of the map.

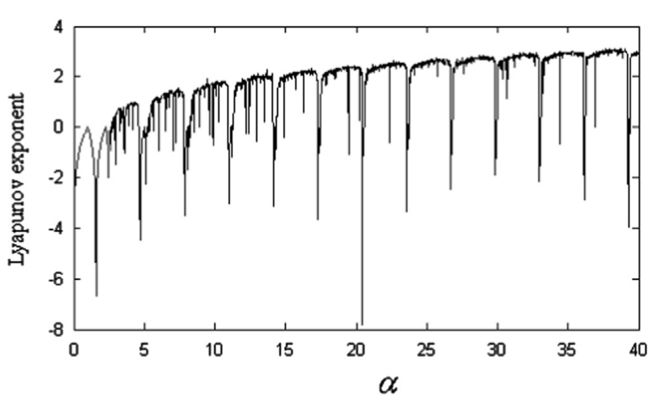

Fig. 2. Lyapunov exponent diagrams of the map.

According to Eq. (2), the increment of the input can be calculated as:

$$\Delta s(t+1) = \left[\sum_{i=1}^{n} w_i x_i(t) - \theta\right] - s(t) \tag{3}$$

The hysteretic operator response according to the increment $\Delta s(t)$ can be described as:

$$d(t+1) = \begin{cases} a, & \text{if} \quad \Delta s(t+1) > h \\ -a, & \text{if} \quad \Delta s(t+1) < -h \\ d(t), & \text{else} \end{cases} \tag{4}$$

where, $h > 0$, and $a > 0$. The output $d(t+1)$ is the key parameter of the activation function. The output of the activation function $y(t+1)$ can be calculated as:

$$y(t+1) = f(s(t+1), d(t+1)) = \frac{1}{1+\exp[-c(s-d)]} \tag{5}$$

Thus, the response of the activation function has the hysteretic characteristic. It is got by translating the Sigmoid function. It has two response branches. One is the rising branch, and the other is the falling branch. The increment $\Delta s(t+1)$ of the neuron determines which branch is selected to respond. The hysteretic characteristic can help to improve the holding original state ability of the neuron which can prevent to wrongly change the state of the neuron.

Synthesizing the two models above, a hysteretic chaotic operator network is construct as (Fig. 4).

The hysteretic chaotic operator network above contains three layers. First layer is the input layer in which neurons' activation functions are the Sigmoid functions, the second layer is the middle layer in which neurons' functions are the chaotic operators, and the third layer is the output layer in which neurons' activation are the hysteretic functions.

The structure of the network is very complex. Many parameters in the network need to be trained, such as, connection weights, chaos control parameters, and hysteretic parameters, etc. Thus, it is hard to train the network by the conventional learning algorithm based on gradient algorithm.

It is generally known that genetic algorithm based on the evolvement theory has better searching and convergence performances. Therefore, genetic algorithm is used to train the parameters in the network.

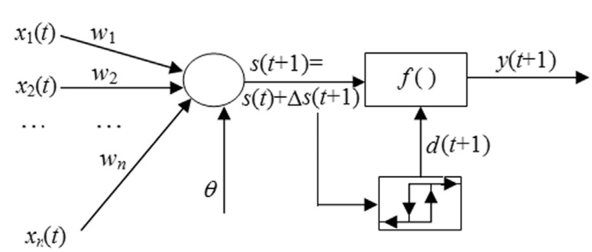

Fig. 3. The structure of the hysteretic neuron.

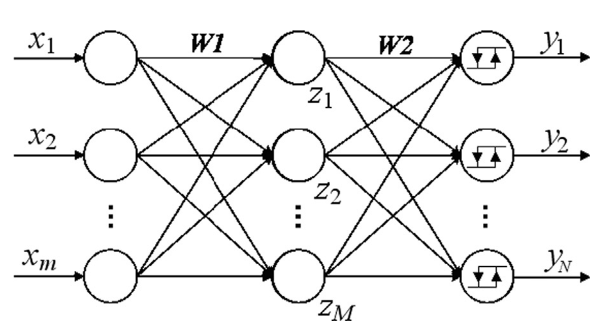

Fig. 4. The structure of the hysteretic chaotic operator network.

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