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Weak Signal Detection of Photoelectric Sensor Based on Extreme Learning Machine

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Abstract: In order to improve the accuracy of automatic detection of weak signal of photoelectric sensor, an automatic detection method of weak signal of photoelectric sensor based on neural network is proposed. Firstly, the weak signal sequence of photoelectric sensor is collected and reconstructed in phase space by mutual information method and false neighbor point method. Then, the weak signal sequence of photoelectric sensor is modeled and detected by limit learning machine. Finally, the weak signal data of photoelectric sensor is used for simulation experiment. Compared with other methods, the results show that this method can accurately reflect the chaotic characteristics of weak signal of photoelectric sensor, restrain the interference and influence of noise on useful signal, and greatly improve the detection accuracy. It can be applied to the automatic detection of weak signal of photoelectric sensor.

1. Introduction

Photoelectric sensors can collect real-time information of targets. In the process of data measurement, because the background is very complex, there are many noises in the collected data, which make the useful signals very weak, and have adverse effects on the practical application of photoelectric sensors. How to improve the detection accuracy of weak signals of photoelectric sensors, from which useful signals are obtained has aroused people's attention. Extensive attention has been paid to it.

According to related research, weak signal detection of photoelectric sensor is a modeling and prediction problem in pattern recognition. Aiming at the problem of automatic detection of weak signal of photoelectric sensor, many experts abroad and at home have carried out extensive and extensive research, and many weak signal detection methods of photoelectric sensor have appeared. The traditional weak signal detection methods of photoelectric sensors are generally modeled and detected according to statistical theory. Because the weak signal of photoelectric sensors is a kind of non-linear dynamic system and has chaotic characteristics of strong fire, it is difficult to accurately detect the weak signal of photoelectric sensors by traditional statistical theory, which affects the scope of practical application]. In recent years, with the continuous in-depth study of chaos theory, some scholars regard the weak signal of photoelectric sensor as a kind of time series. By analyzing the time relationship between the data, the weak signal can be detected automatically. This provides a new modeling idea for the weak signal detection of photoelectric sensor. At present, there are mainly local prediction and global prediction. It is very important to choose which modeling technology. The key is that it directly affects the performance of weak signal detection of photoelectric sensors. In all methods, RBF neural network is a machine learning algorithm with self-learning ability and adaptability. It is widely used in the automatic detection of weak signal of photoelectric sensors. However, the hierarchical structure of the network needs to be designed in the process of modeling of RBF neural network. If the structure is not properly set, it is easy to appear. The problem of local minimum leads to low detection accuracy of weak signal of photoelectric sensor, which limits its further application in automatic detection of weak signal of photoelectric sensor.

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Extreme Learning Machine (ELM) is a new type of neural network. It only needs to set the number of neurons in the hidden layer to solve the difficult problem of designing the hierarchical structure of RBF neural network. In order to improve the accuracy of automatic detection of weak signal of photoelectric sensor, an automatic detection method of weak signal of photoelectric sensor based on neural network is proposed in this paper. The simulation experiment is carried out. The test results show that this method can describe the change characteristics of weak signal of photoelectric sensor, and obtain high-precision detection results, which can meet the practical application requirements of weak signal of photoelectric sensor.

2. Relevant technologies

2.1 Chaos Theory

A lot of research results show that the weak signal of photoelectric sensor is a chaotic time series. By reasonably determining the delay time (τ) and embedding dimension (m), we can discover its change rule from the original data and reconstruct an equivalent state space. Therefore, for a photoelectric sensor, the weak signal sequence is: x_i,i=1,2,…,n,, it can be reconstructed into a multi-dimensional state space, as follows:

$$y_i = \{x_i, x_{i+\tau}, x_{i+2\tau}, \cdots, x_{i+(m-1)\tau}\} \tag{1}$$

In formula (1), $t = 1, 2, \ldots, n - (m+1)\tau$ [14].

According to embedding theorem, the selection of m and τ has an important effect on the estimation result of weak signal of photoelectric sensor. Because the weak signal of photoelectric sensor contains noise, the delay time should not be too long. At the same time, the length of weak signal sequence of photoelectric sensor is limited. In this paper, mutual information method and false neighbor point method are selected to determine m and τ.

2.2 Extreme Learning Machine

In 2006, A new single hidden layer neural network - Extreme Learning Machine (ELM) was proposed by Huang et al, which overcomes the shortcomings of other methods and has N training samples (x_i,t_i), in which $x_i=[x_{i1},x_{i2},\ldots,x_{in}]^T$ is the input vector, $t_i=[t_{i1},t_{i2},\ldots,t_{in}]^T$ is expected output, the ELM with M hidden layer neurons can be expressed as:

$$\sum_{i=1}^{M} \beta_i g(w_i \cdot x_i + b_i) = O_j, \ j = 1, 2, \cdots, N \tag{2}$$

In formula (2),$w_i=[w_{i1},w_{i2},\ldots,w_{im}]^T$, it is the connection weight between the input layer node and the hidden layer node, and $\beta_i=[\beta_{i1}, \beta_{i2},\ldots, \beta_{im}]^T$ is the connection weight between the hidden layer and the output layer nodes; b_i is the threshold value; $O_j=[\beta_{j1}, O_{j2},\ldots, O_{im}]^T$ is the output value; g(x) is the excitation function.

ELM can approximate training samples with zero error, that is $\sum_{i=1}^{M} \left\| O_j - t_j \right\| = 0$, there are

$$\sum_{i=1}^{M} \beta_i g(w_i \cdot x_i + b_i) = y_j, \ j = 1, 2, \cdots, N \tag{3}$$

So that we can get

$$H\beta = Y \tag{4}$$

In formula (4), H is the output matrix.

Because w_i and b_i can be selected randomly, the ELM training process is the same as the least squares solution of $\widehat{\beta}$, that is:

$$\min_{\beta}\|H\beta - Y\| \tag{5}$$

The Minimum value of formula (5) is: $\widehat{\beta} = H^{+}Y$, where H + is the Moore-Penrose generalized inverse of H.

The training process of ELM is as follows:

(1) Randomly determine w_i and b_i;

(2) Calculating the H of the hidden layer;

(3) Computation $\widehat{\beta} : \widehat{\beta} = H^{+}Y$.

3. Detection method of weak signal of photoelectric sensor based on ELM

The idea of weak signal detection of photoelectric sensor based on ELM is as follows: firstly, weak signal of photoelectric sensor is collected and denoised, then weak signal of photoelectric sensor is reconstructed in phase space after denoising. Finally, weak signal detection method of reconstructed photoelectric sensor is adopted by using extreme learning machine, and weak signal detection result of photoelectric sensor is obtained. The specific process is shown in Figure 1.

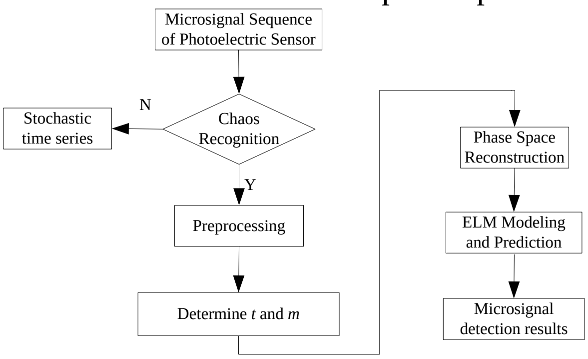
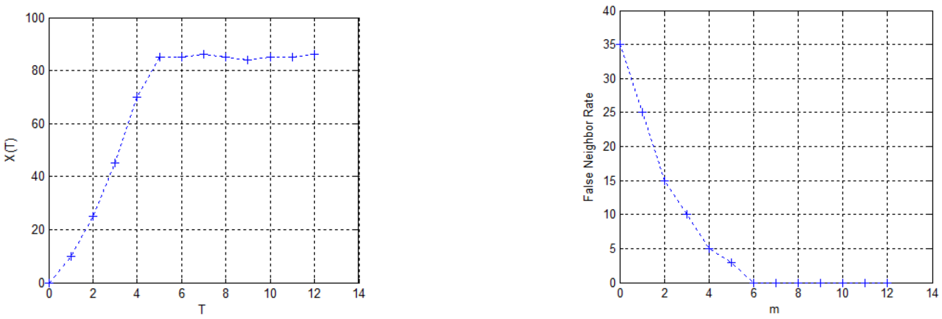


Fig.1 The weak signal detection flow of ELM photoelectric sensor

4. Application examples of weak signal detection of photoelectric sensors

In order to analyze the performance of weak signal detection method of photoelectric sensor based on ELM, a signal of photoelectric sensor system is selected for simulation test. The first 600 data are selected as training samples to build photoelectric sensors, and the last 100 data are used as predictive test samples to analyze and verify the detection performance of weak signals of photoelectric sensors. RBF neural network (RBFNN) and Support Vector Machine (SVM) are selected as the comparison of weak signal detection methods for photoelectric sensors. The root mean square error (RMSE), absolute average relative error (MAPE) and correlation coefficient (R) are selected as the verification indexes of signal detection accuracy. When the results of RMSE or MAPE are relatively small, the prediction accuracy of weak signal for photoelectric sensors is high, otherwise it means photoelectric sensors. Sensor weak signal detection error is large and the effect is poor.



(a) Delay time estimation (b) Embedded dimension estimation

Fig. 3 Phase space reconstruction of weak signal of photoelectric sensor

The delay time (τ) and embedding dimension (m) of weak signal time series of photoelectric sensor are determined by mutual information method and false proximity point method respectively. The results are shown in Fig. 3. According to phase space reconstruction in chaos theory, the delay time (τ) and embedding dimension (m) of the network flow time series are: $\tau=6$, $m=8$ respectively.

Using the above delay time (τ) and embedding dimension (m) to reconstruct the weak signal sequence of the photoelectric sensor, the reconstructed samples are obtained. Then, ELM is used to model and detect the weak signal sequence of the photoelectric sensor, and the weak signal detection value of the photoelectric sensor is obtained. Compared with SVM and RBFNN, the final prediction results of the weak signal of the photoelectric sensor are shown in Tab.1.

Table.1 Comparison of weak signal detection performance of photoelectric sensors

Algorithm	R	MAPE/%	RMSE
RBFNN	9.15	7.47	10.03
SVM	9.28	6.10	8.22
ELM	9.76	3.26	5.64

5. Conclusion

In order to overcome some shortcomings in the process of modeling and detecting weak signals of photoelectric sensors, a method of detecting weak signals of photoelectric sensors based on ELM neural network is proposed in this paper according to the advantages of limit learning machine neural network. The simulation experiments are carried out and the results are analyzed. The following conclusions can be drawn:

(1) De-noising the weak signal data of the original photoelectric sensor, extracting some useful signals, which is conducive to the phase space reconstruction of the weak signal sequence of the follow-up photoelectric sensor, speeding up the detection speed, and providing a new tool for the weak signal detection of complex non-linear photoelectric sensor.

(2) Influenced by external factors, the weak signal of photoelectric sensor is a chaotic time series. Using phase space reconstruction to mine the relationship between data, the modeling process of weak signal of photoelectric sensor is simplified, and the change characteristics of weak signal of sensor are described more accurately, and excellent detection results are obtained.

(3) In the training process, ELM only needs to set the number of hidden layer neurons to get the optimal solution of the problem, which effectively avoids the defects of traditional methods such as complex structure of neural network and difficult determination of support vector parameters, and reduces the interference of human factors. The experimental results show that the detection value of weak signal of photoelectric sensor has good consistency with the real value, and the deviation between them is good. Small difference, good generalization ability, and very ideal detection results of weak signal of photoelectric sensor have certain application and popularization value.

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