Prediction of Ship Motion Attitude Based on BP Network

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Abstract: When the disturbance of ship is compensated, it can't get the specific motion parameters in time. In order to solve this problem, the motion attitude needs to be predicted in advance, and the reliable data also needs to be provided for the wave compensation system. This paper introduces a method of motion attitude prediction based on BP neural network. The method solves the learning problem of hidden layer by selecting the BP neural network model, and the results show that using such method can effectively improve the prediction speed and precision of motion attitude.

Key Words: disturbance compensation, motion attitude, BP network, learning of hidden layer, prediction

1 Introduction

Since the sixties of last century, prediction of ship motion attitude has been extensively studied and formed a reliable theoretical system. In the early stages of development, because of the complication of the calculation method and the process and the limitation of the conditions at that time, it developed relatively slow, and it couldn't be used in real work. After more than 20 years of development, various artificial intelligence algorithms have been proposed, and the process of ship motion attitude prediction is accelerated. No matter in theoretical research or practical application, it has undergone a rapid development [1]. Until now, these theoretical systems are still the main application methods to solve the current problems.

In the motion process of roll, pitch and heave compensation system, conventional prediction of ship motion attitude can optimize ship navigation status. The next position of the platform can be obtained through the measure of prediction. For active compensation system, because of the lag of feedback control, the compensation occurs after the movement. When the system lag is very large, compensation system will be too late to compensate, so compensation of results is not desired [2]. But through motion prediction, the next step of the movement attitude can be obtained and the compensation system can be accordingly adjusted in advance. The implementation of forecasting compensatory control strategy not only improves the accuracy of compensation but also solves the lag problem. In recent years, neural network has rapidly developed in many fields, and it was gradually applied to prediction and has achieved some results.

2 Selection of prediction scheme

During the Second World War, due to the need for war, especially on the military needs of naval battle, it has raised climax of the research on waves. It is in this context that Munk and Sverdrup put forward the theory of ocean wave. In this theory, wave prediction is the focus and core of the study. And the prediction of sea waves provides a reliable theoretical basis for the study of ship motion attitude prediction [3]. Up to now, the short-term results of ship motion prediction have achieved great market applications. The research methods of ship motion short-term prediction can be divided into two categories. The one is based on the application of hydrodynamics, such as Kalman filter and convolution method. The other is based on non-hydrodynamic applications, such as neural networks and spectral estimation [4].

When using Kalman filter for ship motion prediction, the basic theorem of mechanics are used to carry on the force analysis to the ships sailing on the sea. According to the physical model and control theory, the state equation of the system can be established [5]. The purpose of convolution method is to get the prediction of ship motion, in other words, the method can obtain convolution between the hull function and the wave. Neural network is a modern optimization theory, it is the process of reasoning according to certain logical relations. The learning under the premise of network input makes the expected output to be trained by adjusting the weights and thresholds. Spectral estimation is a common signal processing method, and autocorrelation and periodogram are the most commonly used spectral estimation processing. Autocorrelation method is firstly derived from the autocorrelation function of modeling data, then the power spectrum can be obtained by carrying on Fourier transform. Finally, it is able to do extrapolation and prediction by the ship motion attitude model. Periodogram method firstly carries on Fourier transform of modeling data, then the main harmonic components are identified by periodogram. Finally, the ship motion attitude model is obtained and predicted by extrapolation. For the prediction of ship motion attitude, considering the real-time and accuracy requirements, this paper puts forward the method of ship motion attitude prediction analysis based on BP network.

3 The analysis method of ship motion

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attitude prediction based on BP neural network

The variation of wave spectrum is complex, so the higher requirements are put forward for the prediction method of ship motion attitude. In recent years, artificial neural network has been rapidly developed, and it can approximate nonlinear system with any precision [6]. Therefore, this paper selects BP network as its prediction method.

The BP network, as an important branch of neural algorithm, has been widely used in the field of information prediction and pattern control. The structure of algorithm is relatively simple and it's easy to implement, but it also has some disadvantage. On the one hand, it takes longer in training and needs to know a certain sample data before training; On the other hand, the universality of algorithm is poor, and each architecture only can be applied to one or several classes problems. The characteristics of neural network trained by different training samples are also different.

The structure of BP network is mainly divided into three layers. The first layer is the input layer, and it is the input terminal of the processed signal. The second layer is the hidden layer, and the hidden layer can be set not only as one layer but also as multilayer. According to its theory, only one layer can meet the system requirements performance, so it only chooses one layer in most cases. The third layer is the output layer, and the output layer is the output terminal of the signal which plays a role in the output of signal [7]. Through the forward and backward propagation. The learning and training process of neural network is an iterative process of updating weights. It is a kind of guiding training mode. In initial training, the weight coefficient is random. After weighting the weight coefficient, input signal, through the input layer, is passed to the hidden layer. The output signal is obtained by weighting the weights between the hidden layer and the output layer. If the difference between the output signal and the desired signal can't meet the error requirements, the error is back propagation to adjust the weights. The direction of adjustment is to reduce the error according to the gradient direction. The signal finally needs to return to the input layer and carries on the next positive signal propagation. It is because of continuous reverse modification weights that the error accuracy will be increased.

3.1 Selection of BP network model

The model of BP network directly affects the real-time and precision of prediction analysis. In the premise of ensuring its performance, it needs to choose a relatively simple model. BP algorithm solves the learning problem of hidden layer, and it can approximate nonlinear system with any precision. The algorithm can be used in ship motion attitude prediction method of wave compensation system.

For the application of BP algorithm in ship motion attitude prediction analysis, it primarily contents three aspects: input, learning problem, construction of network structure. The signal to be measured is the input of the BP network, and the outputs are the parameters of the swing angle and the rising position of the predicted attitude signal. In order to speed up the training, it oughts to narrow the range of training samples, which has great influence on the output results.

3.2 The construction of the BP network model

The structure of neural network is divided into three parts: input layer, hidden layer and output layer. Because the connection weights are 1 between input layer and hidden layer, the input can be directly mapped to the hidden layer. The output of the BP network is a linear combination of all the hidden layer unit. It only needs to adjust the connection weights between hidden layer and output layer, but it is also a big challenge.

By input layer - hidden layer - output layer, the nonlinear relationship between input layer and output layer can be transformed into linear relationship between the hidden layer and output layer [8]. Structure of algorithm is shown in Fig.1.

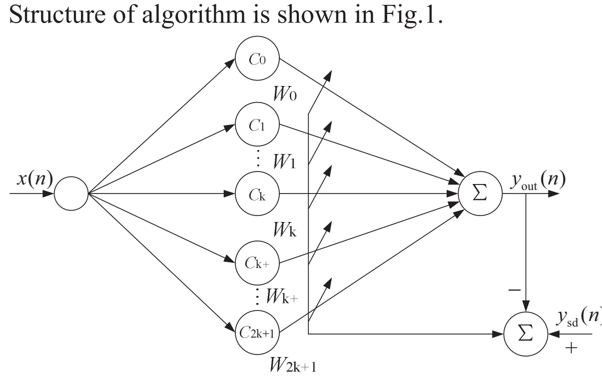

Fig.1 The model of BP network

C is the incentive function of hidden layer, and excitation matrix is $C=[c_1,...,c_{2k+1}]^T$. W is the weights of BP neural network, weight matrix is $W=[w_1,...,w_{2k+1}]^T$ .The mathematical model of performance index can be expressed as

$$e(n)=y_{sd}(n)-y_{out}(n) \tag{1}$$

$$E(n)=\frac{1}{2}e^2(n)=\frac{1}{2}\left[y_{sd}(n)-y_{out}(n)\right]^2 \tag{2}$$

After a lot of trainings, when the output error is less than the minimum error, the training is stopped, and the weight matrix W of BP network is obtained. In this way, the weights will be optimal.

3.3 Weight adjustment

In practical work, BP algorithm utilizes the gradient descent method to adjust weights, which makes the error continuously decreasing. If the actual output matches the desired output, iteration will end. Otherwise if not obtaining the expected output in the output layer, in other words, the definition $E(n)$ can't meet the error requirements, it is converted to the error back propagation, which connects error signal along the path to return. By modifying the weight coefficient between the hidden layer and the output layer to make $E(n)$ meet the error requirements. In the optimization process, every step gains the local optimum, but it is easy to fall into the local minimum point and lead convergence speed to slow, such as E.q (3) and E.q (4) [9]. Once the adjustment is completed, the error function is propagated again according to forward propagation, until it meets the error requirement.

$$\Delta W = -\eta \cdot \frac{\partial E}{\partial W} = -\eta \cdot \frac{\partial E}{\partial e} \cdot \frac{\partial e}{\partial y} \cdot \frac{\partial y}{\partial W} = \eta \cdot e(k) \cdot C(k) \quad (3)$$

$$W(n+1) = W(n) + \Delta W \quad (4)$$

According to the analysis of learning rate, it is difficult to determine a fixed optimal learning rate. Under normal circumstances, the learning rate can't be immutable. For the accuracy of the learning rate, the learning rate should be as small as possible. In contrast, the convergence rate increases with the increase of learning rate. In a word, it needs to consider the selection of a variable learning rate, which adapts to the needs of prevailing conditions. In order to ensure the convergence of the BP network, the learning rate is defined as $0 < \eta < \frac{2}{2K+1}$ based on Lyapunov theorem 1, and the number of hidden layer functions is $2K+1$.

3.4 Training steps of neural network

The training steps are shown in Fig.2.

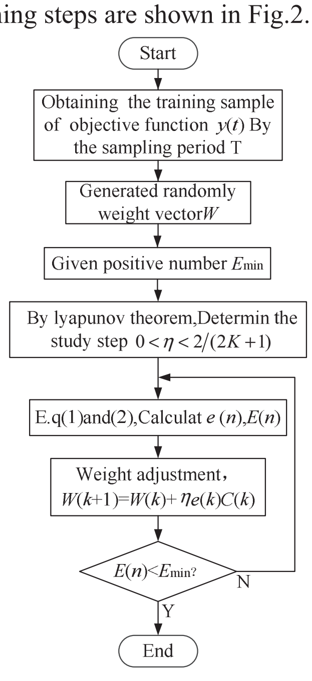

Fig.2: Training steps of neural network

4 The curve simulation of ship motion attitude

In the short-term prediction of ship motion, considering the coupling between waves and hull, the actual motion of hull is very complicated. According to the model established in literature [10], ignoring the effects of pitch and heave motion and using BP neural network algorithm to predict the rolling motion, slope of wave surface $\alpha(t)$ is used as the input layer of the network, and rolling angle $\phi(t)$ is used as the desired output of the system. In the simulation of MATLAB, the variation of ship rolling angle can be obtained with time. Simulation curve of roll angle is shown in Fig.3.

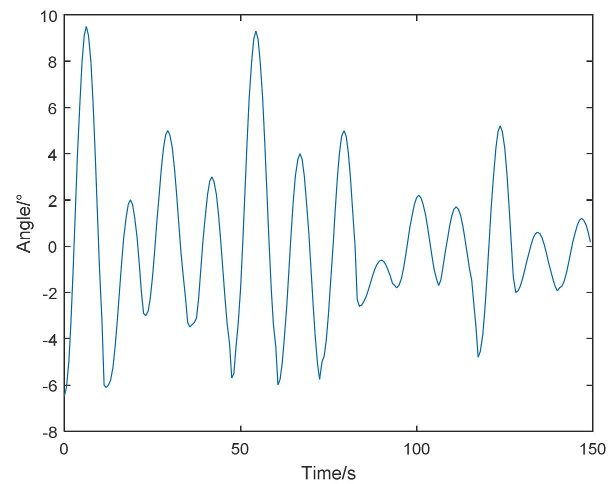

Fig.3 Simulation curve of rolling angle

From the Fig.3, there is some instability in the course of ship motion. Its rolling angle irregularly varies with time, and this change is uncontrollable. The peak is also not expected. In order to compensate the rolling in time by the compensation system. It is necessary to predict the rolling motion ahead of time for accurate wave compensation.

5 Experimental analysis of motion attitude prediction

Aiming at the requirement of operating platform for ship stability in complex sea surface motion and reducing the influence of ocean wave on ship motion, it is necessary to design the operating platform with wave compensation system. The ship motion can be described by three degrees of freedom: rolling, pitching and heave. In order to compensate the influence of wave on hull, the three degrees of freedom need to be predicted for achieving the corresponding design index [11]. Due to the complexity of the three motions, there is no use to analyze three degrees of freedom. This section uses the BP neural network to train the rolling motion and obtain the desired rolling angle output finally. There is only a hidden layer in the network. In order to meet the precise requirements, the performance indicator is set to 0.001. Through the simulation, the prediction curve is shown in Fig.4.

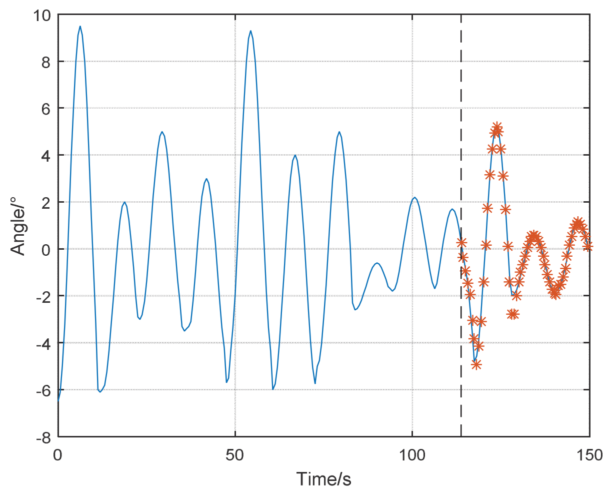

Fig.4 Prediction curve of roll angle

Form the Fig.4, it is the training phase of neural network before 115s, and it is the prediction stage after 115s. Through a series of sampling of ship rolling simulation curve, the BP artificial neural network method is used for the prediction of training by processing the data. The performance indexes are shown in the Fig.5 and Fig.6. From the Fig.5, the prediction value is closer to the target value with the increases of iterations. After 24 iterations, the error satisfies basic requirements which has fast convergence speed and higher simulation precision.

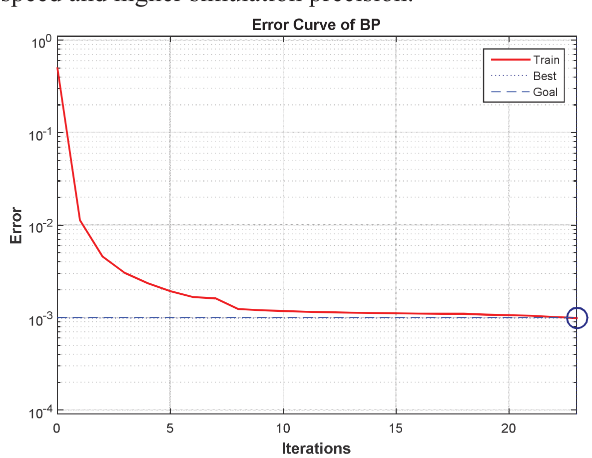

Fig.5 Error iteration of the test signals

From the Fig.6, X axis is the real data, and Y axis is the prediction data. It can be seen from the prediction results that the trend of true value and prediction value is identical. The test results indicate that the use of the prediction model can effectively improve the convergence speed and calculation precision of the BP network. It is obvious that the prediction accuracy is in accordance with the prediction requirements. Further, the algorithm is feasible.

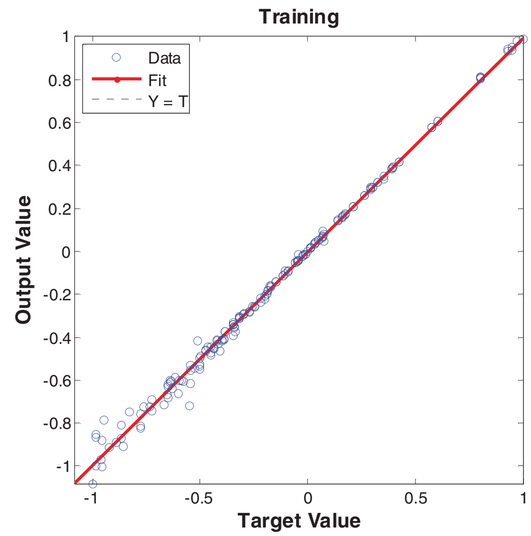

Fig.6 The training comstrast

6 Conclusion

Through the comparison of the prediction scheme, the prediction scheme of ship motion attitude based on BP network is proposed. After further analysis of this scheme, the selection and establishment of BP network model was completed. On the basis of established model, the weight coefficient was updated by gradient descent method, and the optimal learning rate was selected by adjusting the weight coefficient and analyzing the BP model. According to the literature [10], the curve of ship motion attitude has been simulated. The prediction of the curve combined with BP network was conducted to prepare for wave compensation ahead of time. According to the results of the prediction, the method of ship motion attitude based on BP neural network algorithm has the characteristics of high calculation precision and good real-time performance, which can quickly obtain the prediction value of ship motion attitude. However, the method still had some limitations. The training signal source needs to be known, and the number of iterations in the learning process is too much.

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