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Short-term prediction of wave model height based on BP neural network

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Abstract

Since it is difficult to determine the motion of the wave using the traditional method, there is a delay problem in the wave compensation, which is an inevitable defect caused by hardware and calculation. Therefore, in order to solve this problem, BP neural network is used to measure the ocean wave model of energy equalization method offline and online. The results show that BP neural network can solve the delay problem and has higher precision than the traditional wave compensation method. It can provide a new way of thinking and methods for wave compensation technology.

Keywords

Wave compensation; BP; prediction; wave model.

1. Introduction

In today's fast-growing society, marine resources are receiving more and more attention, so the requirements for offshore technology are correspondingly improved, and the demand for wave compensation technology in offshore operations is also increasing. For example, in the development of marine resources, marine replenishment, offshore platforms, etc. [1], there is an urgent need to develop wave compensation technology to improve the ability of offshore operations.

For offshore operations, due to uncontrollable factors such as sea breeze and climate, ships at sea will experience different degrees of sway [2], and the formation of waves is also difficult to control and predict due to uncontrollable factors such as temperature and wind speed. There is a lot of difficulty in wave compensation. Therefore, having a good wave compensation method can greatly improve the efficiency of operations at sea and reduce the probability of accidents.

In wave compensation technology, there are two main forms of compensation, one is active and the other is passive [3, 4]. Since the passive wave compensating device has no controller to control during operation, it is limited in practical applications. Active wave compensation consists of an inductor, a controller and an actuator, where the controller is the core [5]. In the active wave compensation technology, the Kalman filter-based control algorithm is applied to it [6], but due to the uncertainty of the ocean wave model, the Kalman filter requires a lot of complicated calculations, so it has certain limitations. The time series analysis method [7] is also applied as a method in the field of wave compensation, but the time series analysis method is a linear model and is not applicable to a nonlinear and random wave model. PID as a representative of the feedback control algorithm [8] is also applied to the wave compensation technology. But as a traditional control theory, the phase difference caused by the calculation and hardware delay is an unavoidable problem.

The neural network has developed more and more rapidly with the development of machine learning. For the prediction of nonlinear data, the neural network does not need to learn the theory itself, but by constantly adjusting the weight of the parameters and feeding back the correction error to the data. Processing [9]. With the maturity of BP algorithm, BP neural network can acquire knowledge in the

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external environment learning, summarize the sample data, seek the inherent laws of these data, have strong nonlinear mapping ability, and the neural network method is a kind of non- The linear prediction method is effective in the nonlinear prediction system and will be more widely used in the wave compensation wave prediction field.

2. BP neural network

In 1986, Rumelhart and McCellandz proposed the BP network model in the book Parallel Distributed Processing. Its structure is shown in Figure 1. BP neural network algorithm is one of the most effective multi-layer neural network learning methods. Its main features are forward signal transmission and backward error propagation. The final output of the network is adjusted by continuously adjusting the network weight value. As close as possible to the desired output for training purposes.

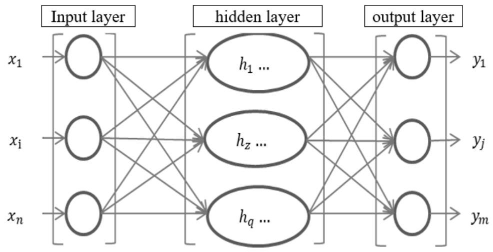

Fig.1 Classic three-layer BP neural network structure diagram

Let the input layer of the BP network have n nodes, the hidden layer has q nodes, the output layer has m nodes. the weight between the input layer and the hidden layer is V_{ki} and the weight between the hidden layer and the output layer is W_{jk} . The transfer function is f.

the output of the BP hidden layer node is:

$$\mathrm{h}_k = f(\sum_{i=0}^{n} V_{ki} \bullet x_i) \quad k = 1, 2, 3, ..., q \tag{1}$$

The output of the output layer node is:

$$y_i = f(\sum_{k=0}^{q} W_{jk} \bullet h_k) \quad j = 1, 2, 3, ..., m \tag{2}$$

The number of nodes in the input layer and the output layer are determined, and the number of hidden layer nodes is uncertain and can be determined according to empirical formulas:

$$h = \sqrt{m+n} + a \tag{3}$$

The main purpose of the BP neural network is to iteratively modify the weights and thresholds to minimize the error:

$$E(\omega, b) = \frac{1}{2} \sum_{j=0}^{n-1} (d_j - y_j)^2 \tag{4}$$

BP neural networks usually use the following two nonlinear activation functions.

$$f(x) = \frac{1}{1+e^{-z}} \tag{5}$$

$$f(x) = \frac{1-e^{-z}}{1+e^{-z}} \tag{6}$$

Due to the good self-learning ability of BP neural network, it can have the ability to predict unknown data. For the complex and variable data of ocean wave, BP neural network can effectively predict it.

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Wave compensation can better solve the problem of phase lag between the collected data and the compensation amount, and can be used as an ideal tool.

3. Establishment and simulation of ocean wave model

In engineering, the wave spectrum is mainly simulated by the power spectrum[10,11]. The formula is:

$$\xi(t) = \sqrt{2}\sum_{i=1}^{\infty}\sqrt{\int_{\omega_{i-1}}^{\omega_i} S_\xi(\omega)d\omega}\cos(\omega_i t + \varepsilon_i) \tag{7}$$

$\xi(t)$ is wave height, Is a function of time t, $S_\xi(\omega)$ is power spectrum density, Its form is as follows:

$$S_\xi(\omega) = \frac{A}{\omega^5}\exp(-\frac{B}{\omega^4}) \tag{8}$$

ω_i and ε_i is Frequency and initial phase. and ε_i~ $(0, \pi)$ evenly distributed.

Since the conventional method is difficult to determine the amplitude and frequency of the waves, an energy equalization method is used to determine the wave spectrum. The idea of the energy equalization method is to divide the $E(\omega)$ by defining a cumulative spectrum $E(\omega)$ and then by a certain number of M parts. So that the area of each part under the $E(\omega)$ curve is equal, so that the size of the sub-area is X, then for $E(\omega)$, there is:

$$E(\omega) = \int_0^{\infty} S(\omega)d\omega \tag{9}$$

$$\int_{\omega_{i-1}}^{\omega_i} S(\omega)d\omega = E(\omega_i) - E(\omega_{i-1}) = X \tag{10}$$

According to formula (9)

$$E(\omega) = \frac{A}{4B} \tag{11}$$

then

$$X = \frac{A}{4BM} \tag{12}$$

$$\omega_i = [B/\ln(M/i)]^{\frac{1}{4}} \tag{13}$$

In 1972, the 11th International Ship Model Pool Conference (ITTC) made a revision based on the P-M spectrum proposed in 1964, due to the effective wave height.

$$\overline{\zeta}_{W/3} = 4[E(\omega)]^{1/2} \tag{14}$$

Therefore, according to formula (12) and formula (15):

$$B = \frac{4A}{\overline{\zeta}^2_{W/3}} \tag{15}$$

Because in P-M spectrum $A = 0.008\lg^2 \approx 0.78$ so bring $B = \frac{4A}{\overline{\zeta}^2_{W/3}} = \frac{3.12}{\overline{\zeta}^2_{W/3}}$ into formula (9) :

$$S_\xi(\omega) = \frac{0.78}{\omega^5}\exp(-\frac{3.12}{\overline{\zeta}^2_{W/3}\omega^4}) \tag{16}$$

In summary

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$$\xi(t)=\sqrt{\frac{A}{2BM}}\sum_{i=1}^{M}\cos(\omega_i t+\varepsilon_i)=\sqrt{\frac{0.125\bar{\zeta}^2_{W/3}}{M}}\sum_{i=1}^{M}\cos(\omega_i t+\varepsilon_i) \tag{17}$$

For equation (17), model simulation was performed using matlab2019a, taking t=100s, simulating the undulation of the ocean wave within 100 seconds. Due to the different sea conditions in the ocean, the sea conditions are divided into 9 grades according to the regulations of the State Oceanic Administration, and 2, 3, and 4 of them are simulated. The effective wave height level is divided as shown in Table 1.

Table1.Wave level division

Wave level	Effective wave height (meter)
Little wave	$0.1\leq \bar{\zeta}_{W/3} < 0.5$
Light wave	$0.5\leq \bar{\zeta}_{W/3} < 1.25$
Medium wave	$1.25\leq \bar{\zeta}_{W/3} < 2.5$

The simulation is carried out in the sea level of the second, third and fourth levels in the table, and the effective wave heights $\bar{\zeta}_{W/3}$ are taken as 0.4m, 1m and 2m respectively. It will be taken as 50, that is, the waves are superimposed by 50 different cosine waves, and the images are respectively shown in Fig. 2, Fig. 3 and Fig. 4.

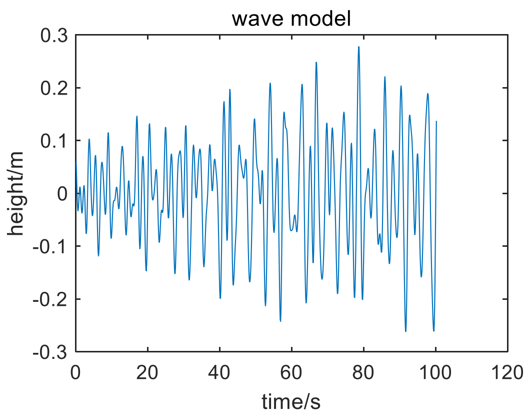

Fig2.Simulated secondary sea state wave model

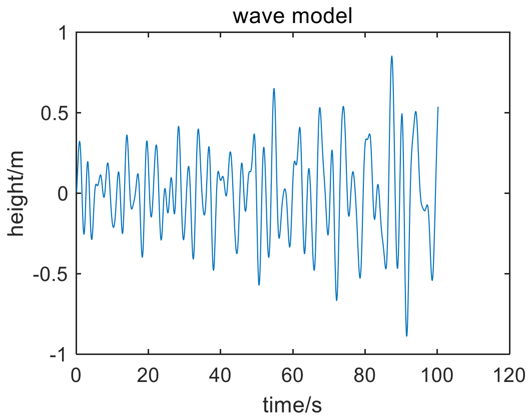

Fig3.Simulated three-level sea state wave model

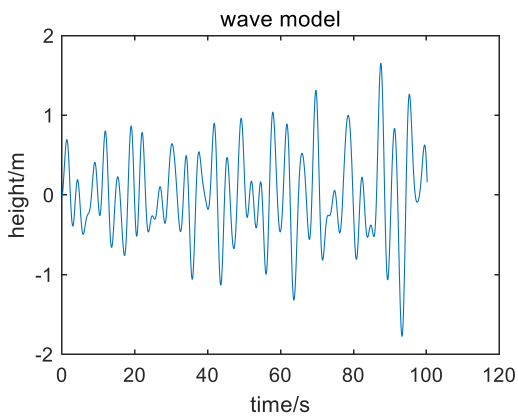

Fig4.Simulation of four-level sea state wave model

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4. Data prediction

In the part of data prediction, BP neural network is used for prediction. The wave model simulates the waveform of the waves within 100 seconds. In this prediction experiment, the input of each time step causes the neural network to output a corresponding predicted value. This article uses the BP model in matlab2019a. When using the model, some variables need to be set and the data should be processed initially. The specific process is as follows:

(1) Model layer setting

Construct a 4-layer BP network, which is the input layer, the hidden layer, the full connection feedback layer and the regression layer. In order to prevent over-fitting or insufficient prediction ability, after multiple adjustments, the BP hidden layer is determined to be 9 hidden. With nodes, the activation function is a hyperbolic tangent function.

(2) Error evaluation setting

For the evaluation criteria of the model output error, the mean square error (MSE), the root mean square error (RMSE) and the mean absolute error (MAE) are used to judge the degree of agreement between the model and the actual data. The calculation formulas are as shown in equations (19), (20), and (21):

$$E_{mse} = \frac{1}{n}(\sum_{i=1}^{n} y_{pi} - y_{ti})^2 \tag{18}$$

$$E_{rmse} = \sqrt{\frac{1}{n}(\sum_{i=1}^{n} y_{pi} - y_{ti})^2} \tag{19}$$

$$E_{mae} = \frac{1}{n}\sum_{i=1}^{n} \left| y_{pi} - y_{ti} \right| \tag{20}$$

Where n is the predicted number of time steps, y_{pi} is the predicted value of the current time step, and y_{ti} is the observed value of the current time step.

(3) data processing

Since the magnitude of the wave data may vary greatly, resulting in inaccurate model prediction, the data should be normalized, the value range is [0, 1], and the usage method is standardization of dispersion, and its formula is as follows (22):

$$X^* = \frac{X\text{-min}}{\text{max} - \text{min}} \tag{21}$$

Where X^* is the normalized data, X is the current training data, and max is the maximum value of the sample data in the training set, and min is the minimum value of the sample data in the training set. Using data normalization, the training set data can be concentrated in the range of [0, 1], eliminating the influence of different dimensions and value ranges in the original data, while preserving the relationship between the original data. The normalized data is trained by the neural network and output, and then the inverse normalization is performed using equation (22), so that the data has its original meaning.

(4) Model training

In the BP neural network, training takes 90% of the total data as a training set and performs 10,000 trainings, and the learning rate is set to 0.001.

(5) Model prediction

In the model prediction process of the neural network, two prediction methods are used to perform prediction respectively. One is to use the training set data to complete the subsequent data, that is, to perform offline prediction of the data, each time the next time step is predicted. , the previous

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predicted value is predicted as the input value, and these steps are repeated until the end of the prediction, but since the network state is updated by the predicted value, the error among them will be cumulatively propagated to the next input, resulting in a long time. The forecast is not accurate. Second, based on the first method, the predicted value in the first method is changed into the actual observation value. When the next data is predicted, the most recent observation value is used as the input instead of the predicted value. Two advantages: 1. Since the observation is performed using the observation value, the cumulative error of the predicted value in the first method is reduced. 2. Since the sensor can perform real-time acquisition of the motion of the compensation platform in wave compensation, the method is feasible.

5. Result comparison

For the offline prediction of data, the data of the last 10 time steps in the wave model of three different sea conditions are taken for BP neural network prediction, that is, the previous data is used as the training set, and the last 10 time step data is used as the test set. Output forecast data after inputting test data $(t, t+1, t+2, \ldots, t+10)$, The data format is as shown in equation (18) and is a wave height function with respect to time t. For the three different sea conditions, the prediction of 10 data is shown in Figure 5, Figure 6, and Figure 7.

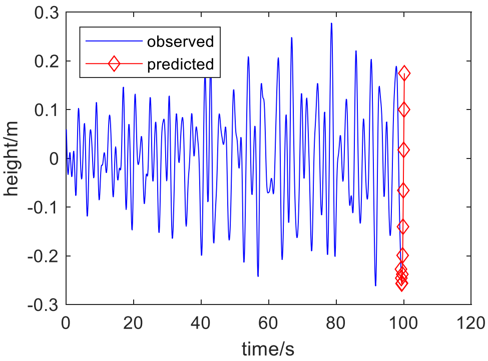

Fig5. Offline prediction of secondary waves

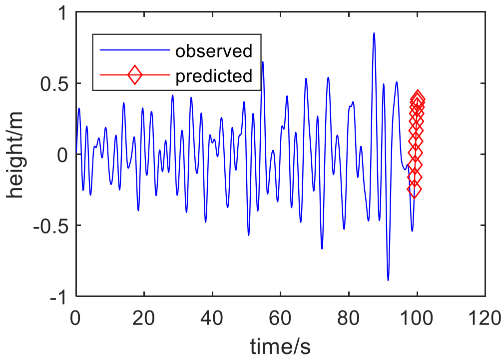

Fig6. Offline prediction of tertiary waves

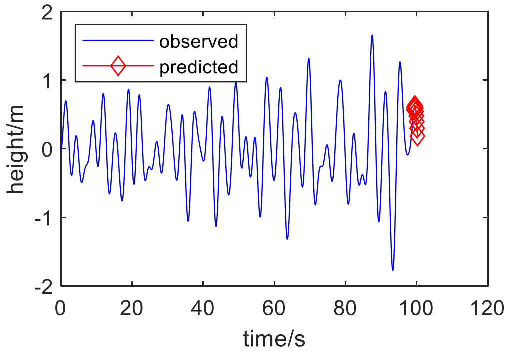

Fig7. Offline prediction of four-level waves

The error data is shown in Table 2.

Table2. Comparison of differences of offline prediction

model	RMSE(m/s)	MAE（m/s）	MSE(m/s)
Secondary sea state	0.2938	0.2593	0.0863
Tertiary sea state	0.5873	0.5856	0.3449
Four-level sea state	0.9501	0.8590	0.9501

For online prediction of data, 10% of the data is predicted by the first 90% of the training set. Since the last 10% of the data is the existing observed data, the real-time incoming data of the sensor during

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wave compensation can be simulated. That is, after each data is output, there will be a data added to update the training set. The online prediction for the three sea conditions is shown in Figure 8, Figure 9, and Figure 10.

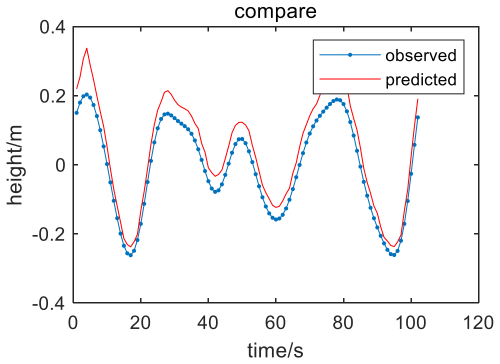

Fig8. online prediction of secondary waves

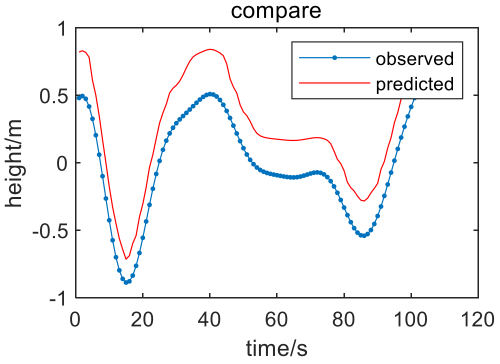

Fig9. online prediction of tertiary waves

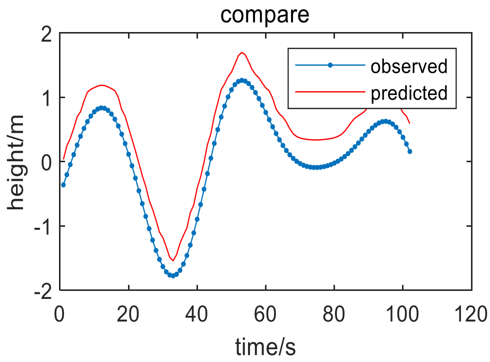

Fig10. online prediction of four-level waves

The error data is shown in Table 3.

Table3. Comparison of differences of online prediction

model	RMSE(m/s)	MAE (m/s)	MSE(m/s)
Secondary sea state	0.0531	0.0513	0.0028
Tertiary sea state	0.2748	0.2736	0.0755
Four-level sea state	0.4355	0.4220	0.1897

From the above chart, the BP neural network can better predict the wave height of the ocean wave, and it can have good effects in short-term offline data prediction and long-term online data prediction, and when the wave height difference is small in the same time step, The prediction accuracy is higher. From the overall trend, BP neural network can describe the trend of wave waves excellently, and has good applicability in the modeling and application of wave compensation.

6. Conclusion

Since the wave height is affected by many uncertain factors, it is difficult to find the law in the wave compensation, which leads to the phase lag caused by the hardware calculation and other factors when the equipment is compensated. This paper constructs the BP neural network to the height of the ocean wave model. The prediction is presented, and a prediction method based on BP neural network is proposed to solve the phase lag problem. The following conclusions can be drawn through modeling and simulation:

(1) The BP neural network model constructed in this paper can effectively predict the wave height signal and verify its effectiveness.

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(2) In this paper, the height of the ocean wave model is predicted by offline prediction and online prediction. It is found that the BP neural network can adapt to two different prediction modes and has high engineering application value.

(3) When the difference in wave height between adjacent time steps is large, the prediction accuracy will be reduced accordingly. Therefore, in the further research, the parameters can be adjusted by adjusting the hyperparameters, adjusting the number of neurons, and using other methods to optimize the BP neural network problem.

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