Long-term wave prediction and analysis based on time-series analysis

Liangliang Liu 1, Shuting Huang 1, Yanjun Liu 1,2, *

1 Institute of Marine Science and Technology, Shandong University, Qingdao, China
2 School of Mechanical Engineering, Shandong University, Jinan, China

*Corresponding author e-mail: Lyj111ky@163.com

Abstract. The efficiency of the oscillating float-type wave energy devices is closely related to the wave conditions in its working area. Seasonal changes in actual sea conditions are obvious, and they vary greatly throughout the year. Therefore, it is necessary to analyse and predict the wave, and adjust the oscillating float-type wave energy device’s parameters according to the wave conditions to improve the efficiency. Based on the analysis of the long-term wave variation and the short-term stationary characteristics of the wave, the moving regression algorithm is used to predict the wave. Adjust the device parameters according to the wave condition prediction data, and match the wave power and load power to achieve a certain efficiency in the wide power range of the device. The research results can be used for variable load control of wave energy devices.

Keywords: Wave energy; wave prediction; time-series analysis; Long-term wave analysis.

1. Introduction

Increasingly frequent extreme weather phenomena caused by global climate change and growing energy demand promote people to actively seek renewable energy. Compared with wind energy and solar energy, wave energy has the advantages of high energy density, good stability and no land resources needed, received wide spread attention of many researchers around the world. As a typical stochastic process waves cannot be accurately predicted and reproduced. Wave front changes are usually described in wave spectra, and long-term changes in wave conditions are described by time series based on spectral characteristic parameters.

Oscillating float-type wave energy devices usually have a certain energy capture bandwidth, and large changes of annual wave conditions cause distortion of resource evaluation and low efficiency of long-term testing of the device [1]. In order to improve the efficiency of the device, many kinds of control methods such as optimal control [2], latch control [3], etc. are proposed. These methods need to predict the random wave accurately and in real time. Many wave prediction methods have been proposed [4, 5, 6, 7]. J. Ross Halliday et al [8], used fast Fourier transform based on measured values to predict waves. D. Q. Truong et al [9], used the modified grey model MGM to predict the irregular waves and achieved good results, but the real-time control of wave energy device is difficult to achieve.
2. Wave analysis and prediction based on time series

Time series is a series of observed data arranged in time order. The method of analyzing time series is called time series analysis. In the time series, data is related to each other. When the change of data has some regularity, the corresponding model can be established through time series analysis for system analysis, correlation prediction and system intervention through prediction.

The time series of waves in this paper refer to the change of wave surface elevation. Because the wave is generated by the wind, the change of the wind condition on the sea surface is continuous, so the change of the wave condition is also continuous and relatively stable in the short term, which is the prerequisite for the analysis and prediction of the wave condition.

2.1. Long-term wave data pretreatment

In this paper, the channel coastal observatory monitoring network wave-hub buoy data from January to December 2017 [10] is taken as an example for analysis. The original recorded data includes recording time, buoy coordinates, significant wave height, maximum wave height, peak period, average wave period, wave direction and other parameters. The time interval of adjacent recorded data is 0.5h. Due to equipment failure or extreme sea conditions and other factors, there is a lack of data in the recorded data, which needs to be processed. Generally, we choose to ignore the missing data or smooth the data. In this paper, we choose to smooth the missing part of the original record data as follows: (a) judge the missing data; (b) assign the missing data to the average of normal data; (c) reassign the assigned data in (b) to the average of adjacent n points according to the change trend of normal data. Wave condition as shown in the figure1.

![Figure 1. Wave condition after pretreatment](image)

Among wave characteristics, significant wave height $H_s$ and average wave power $P_{\text{wave}}$ should be considered. The average wave power can be derived from the following equation.

$$P_{\text{wave}} = \frac{g^2}{64\pi} H_s^2 T_e$$

Where: $\rho$ (Kg/m$^3$) and $g$ (m/s$^2$): water density and gravity acceleration; $H_s$(m) and $T_e$(s): significant wave height and energy period; $P_{\text{wave}}$ (W/m). The annual wave energy distribution is shown in Table 1.
2.2. Wave prediction

The significant wave height is the function of time. If we only analyze the significant wave height, it is one-dimensional data. The oscillating float wave energy device is a typical non-linear system, whose state depends on the wave state and its own state in a period of more than ten seconds. According to the prediction of the characteristic parameters of wave spectrum, the parameters of wave energy device is adjusted to improve the long-term average efficiency.

For one-dimensional time series \( \{X_t\} \), the simple moving average prediction algorithm is

\[
X_{t+1} = \left( X_t + X_{t-1} + \cdots + X_{t-n+1} \right) / n
\]

Where:
- \( X_{t+1} \): Predicted value for the next moment;
- \( X_t \cdots X_{t-n+1} \): Measured value before;
- \( n \): Time window.

The physical meaning of \( n=2 \) in this work is to predict the wave condition within half an hour after the current time according to the wave condition within one hour before the current time.

3. Analysis of simulation results

When \( n=2 \), \( X_{t+1} \) is the forecast target, the simulation results are shown in Figure 2. Select different time windows to predict the significance wave height. The results are shown in Table 2.

![Figure 2](image-url)  
Figure 2. (a) Significant wave height. (b) Average wave power.

The results of the prediction of significant wave height series are almost the same, which shows that the wave condition is statistically stable in a period of time, and the method is more reliable in a certain error range. The degree of short-term stability of waves in different seasons needs further analysis.

**Table 1.** Annual wave power distribution.

| \( P_{\text{wave}} \) (kw/m) | <2  | <10 | <50 | <100 | <150 |
|----------------------------|-----|-----|-----|------|------|
| Probability                | 13.73% | 50%  | 92.6% | 97.97% | 99.46% |
| Occupied energy ratio      | 0.9%  | 11.46% | 64.38% | 84.13% | 93.44% |
| Load level                 | L1   | L2   | L3   | L4   | L4   |
Table 2. Prediction error table of the significant wave height.

| Error (m) | n = 1   | n = 2   | n = 3   |
|-----------|---------|---------|---------|
| <0.1      | 61.78%  | 61.53%  | 60.97%  |
| <0.2      | 83.49%  | 83.95%  | 84.07%  |
| <0.3      | 91.61%  | 92.10%  | 91.60%  |
| <0.4      | 94.94%  | 95.60%  | 94.79%  |
| <0.5      | 96.92%  | 98.00%  | 96.91%  |

It is assumed that the oscillating float type device works normally when the wave power is between 2kW and 150kW. Then the annual average wave energy power of the sea area is 18820W/m, and the annual average power of available wave energy is 17575W/m. As shown in Table 1, half of the time, the average wave energy is low and more than 10% of the time the device even does not work. Seasonal variation has the greatest influence on wave condition, and the storm weather also has a significant impact on wave condition. More than 93% of wave condition is concentrated in 10-150kw/m.

Select different time windows for prediction, The absolute value of the prediction error is taken, and the probability of different standards of the absolute error is calculated, and the error results are shown in Table 2. It shows that the wave condition is statistically stable in a period of time, and the method is more reliable within a certain error range.

When the oscillating float wave energy device works in a wide power range, the power-take off (PTO, P1, P2, P3) system and load need to be adjusted reasonably so that the load part can obtain higher efficiency in different power ranges. Considering economy, feasibility, reliability and other factors, the wave state and device load are divided into four levels, as shown in Table 3.

Table 3. Prediction error table of the significant wave height.

| Wave power(kw/m) | 2-10 | 10-50 | 50-100 | 100-150 |
|------------------|------|-------|--------|---------|
| Power level      | L1   | L2    | L3     | L4      |
| PTO              | P1   | P2(+P1) | P3(+P1) | P2+P3(+P1) |

The classification of wave condition level is shown in Table 3, and the change of annual wave condition level is shown in Figure 3. According to the prediction results of wave condition, choose appropriate load control strategy, balance the relationship between efficiency, reliability and economy.

Figure 3. (a)Wave power level changes throughout the year. (b)load changes throughout the year.

As shown in Figure 4, when wave power fluctuates up and down at the adjusted threshold will generate high frequency noise signal, which will damage the life and efficiency of the device, especially for electric generator. Then, appropriate load adjust control strategies based on are needed.
4. Conclusion
This article analyzes and predicts long-term waves based on buoy observation data. Time series analysis of the long-term wave characteristic parameters can be used for the evaluation of wave energy resources and the average efficiency of wave energy devices in the sea area. According to the working characteristics of the wave energy device, the wave condition is classified, and the natural frequency and the load of the device are adjusted according to the wave condition to improve the energy capture efficiency and reduce the number of load adjustments.

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