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Wind Speed Prediction System based on Kalman Filter for Offshore Blade Hoisting

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Abstract

As countries pay more and more attention to clean energy, the world has begun to vigorously develop the offshore wind power market. However, the establishment of offshore wind speed models, especially the forecast of wind speed when offshore wind turbines are hoisted, is still a difficult problem. In order to make the wind speed model more realistic and more convenient. This paper proposes a wind speed prediction system, including simulation system, observation system, and Kalman filter system. The simulation system is based on the improved combined wind speed model, adding a mathematical model that increases the wind speed with the increase in altitude to make it closer to the wind speed in the actual marine environment. Considering that all observers in the observer system have errors, this article will introduce a Kalman filter system to filter the observation errors, so that the estimated value is closer to the real value. The simulation results obtained under the above system are real and rapid, which is convenient for researchers to apply when simulating offshore wind speed.

Keywords

Wind speed prediction; Combined wind speed model; UKF.

1. INTRODUCTION

In recent years, the global offshore wind power industry has developed rapidly, many offshore equipments have been built and put into use. By the end of 2019, the installed capacity of wind power had increased 25 times from the end of 2008 [1]. Therefore, relevant research on the marine environment has received widespread attention from all sectors of society in recent years. The marine environment mainly contains factors such as wind, waves, and currents. At present, there are many studies on waves and currents [2]. However, when the factor of wind is involved, the method of adding Gaussian white noise on the basis of steady wind to simulate wind speed fluctuations is mostly adopted. Although this method is relatively simple and convenient to calculate, it is different from the actual situation [3]. In the actual marine environment, the wind speed is based on the basic wind speed, and it changes randomly in real-time within a certain range, and as the altitude increases, the wind speed will gradually increase. This is different from the onshore wind speed model. Especially in the blade hoisting, which has received wide attention in recent years, as the lifting height of the blade increases, the average wind speed acting on the blade will be different at each moment. The traditional combined wind speed model cannot express this feature. At the same time, in actual operation, the wind speed is obtained by the observer. This result usually contains errors, so it is not accurate. In order to improve the above shortcomings and better simulate the characteristics of wind speed in blade lifting, this paper will establish a wind speed simulation system based on the combined wind speed model. The system innovatively introduces the improved method mentioned in the literature [4] into the wind speed prediction of the blade during hoisting, and

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uses this method as the basic theory to simulate in MATLAB, and adds a Kalman filter system to filter the error caused by inaccurate observers.

This paper draws on the research ideas of literature [4], applies this method to wind speed prediction in blade hoisting, and proposes a new blade hoisting wind speed prediction system. The whole system includes three parts: simulation system, observer system and Kalman filter system. In the simulation system, the traditional combined wind speed model is improved as in the literature [4], which makes the wind load changes caused by the height changes of the blades. The wind speed prediction result obtained in the simulation system is closer to the actual working conditions. At the same time, the author also designs an observer in this wind speed prediction system model, and adds an error to the result of the simulation system to simulate the result obtained by the actual measurement. The last system is a filtering system. At this time, the author introduces Unscented Kalman filtering to reduce errors caused by insufficient measurement technology, ensure the accuracy of the wind speed prediction model system, and improve the efficiency of wind speed prediction. The simulation results show that the wind load on the blades during the lifting process will change greatly with the changes of height and time. This result is consistent with the actual situation and is more realistic than the original steady wind method, which makes the theoretical research of blade hoisting more accurate. At the same time, the combination of the Unscented Kalman filter and the wind speed prediction model can provide the wind speed prediction value more accurately, and has the advantage of higher accuracy than the existing wind speed prediction system. In actual operation, if the observation value is the only available data, the observation error can be filtered through the system to obtain a result closer to the actual value. The wind speed observer system proposed in this paper is convenient for the development of blade hoisting related research, especially for the advancement of blade control related research.

2. THE TRADITIONAL COMBINED WIND SPEED MODEL

The main object of existing research on wind speed models is onshore wind fields. Currently, the most widely used wind speed models include probability distribution wind speed models, ARMA models, combined wind speed models, etc. This paper mainly uses the combined wind speed model as the basis for subsequent numerical simulations. The combined wind speed model is the most widely used wind speed model today. Its basic theory is to divide the actual wind speed into four parts, namely: basic wind, gradual wind, gust and random wind [5]. These four parts will be separately modeled and generated in the numerical simulation, and finally superimposed to obtain the final real-time wind speed value.

2.1. Basic Wind

Basic wind speed is generally the average wind speed of a wind field, which is the most important parameter in a wind field. When the marine environment has been determined, this part will generally not change over time and is a fixed constant.

$$V_b = N \tag{1}$$

2.2. Gust

The gust wind is used to express the change of wind speed in the actual wind field in a short period of time, and it can also be used to simulate the strong wind. The gust calculation formula is as follows:

$$V_g = \begin{cases} \frac{\mathrm{V_{gmax}}}{2}\left[1-\cos 2\pi\left(\frac{\mathrm{t-T_1}}{\mathrm{T_g}}\right)\right], & \mathrm{T_1 < t < T_1 + T_g} \\ 0 & \text{else} \end{cases} \tag{2}$$

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In the above formula, V_{gmax} is the peak wind speed of the gust; T_1 is the time when the gust starts; T_g is the duration of the gust [6].

2.3. Gradual Wind

Gradual wind is mainly used to express the part that gradually changes in the composition of wind speed in actual situations. The calculation formula of gradual wind is as follows:

$$V_c = \begin{cases} 0, \ (t < T_{c1} \ or \ t > T_{c1} + T_c \\ V_{cmax}\frac{t-T_{c1}}{T_{c2}-T_{c1}}, T_{c1} \le t \le T_{c2} \\ V_{cmax}, T_{c2} \le t \le T_{c2} + T_c \end{cases} \tag{3}$$

In the above formula, V_{cmax} is the peak wind speed of the gradual wind; T_{c1} is the time when the gradual wind starts; T_{c2} is the time when the gradual wind ends, and T_c is the duration of the wind speed gradient.

2.4. Random Wind

Random wind is mainly used to describe the stochastic nature of wind in a natural wind field. It is an important component in wind field simulation. It is usually necessary to introduce related parameters such as wind field surface resistance coefficient and wind speed fluctuation scale coefficient. The calculation formula is as follows:

$$V_n = 2\sum_{i=1}^{n}[S_v(\omega_i)\Delta\omega]^{0.5}\cos(\omega_i t + \varphi_i) \tag{4}$$

$$S_v(\omega_i) = \frac{2K_N F^2|\omega_i|}{\pi^2\left[1+\left(\frac{F\omega_i}{\mu\pi}\right)^2\right]^{\frac{4}{3}}} \tag{5}$$

$$\omega_i = (i - 0.5)\Delta\omega \tag{6}$$

In the above three formulas, ω_i is the angular frequency under the i-th random component; $\Delta\omega$ is the discrete distance between random components, generally 0.5-2.0rad/s, and in this paper, the value is 1.3; φ_i is a random variable uniformly distributed between [0,2π]; $S_v(\omega_i)$ is the amplitude corresponding to the i-th random component; K_N is the expansion coefficient of the wind field plane or the surface resistance coefficient; F is the disorder scale factor (or called the wind speed fluctuation scale factor); μ is the average wind speed on the reference height plane; N is the number of random components, and N=50 in this paper.

After completing the mathematical modeling of the above four parts, sum them up to obtain a mathematical model that simulates the actual wind speed. The summation is as follows:

$$V = V_b + V_g + V_c + V_n \tag{7}$$

From the above description, it can be seen that the traditional wind speed model has the advantage of simple calculation, and each component can be easily and quickly calculated through the numerical model; The model also has the advantage of being consistent with the actual wind speed characteristics, and can simulate the randomness and interval of the wind speed in the actual environment, ensuring the authenticity and reliability of the numerical simulation results. The traditional combined wind speed model is often used to simulate the change of wind speed in the same plane over time. When it comes to the impact of height changes on platforms, blades, etc., as well as changes in wind speed due to changes in the state of sea waves, the original model cannot show them. In addition, in the traditional wind speed model, the simulation of random wind needs to determine more parameters, and the selection of these parameters needs to be completed through actual measurement data analysis. However, most offshore wind farms have less measured data, which brings greater difficulty to random wind simulation. These shortcomings make the traditional combined wind speed model difficult to apply in the wind speed simulation in the marine environment.

3. THE IMPROVED COMBINED WIND SPEED MODEL

This paper selects the combined wind speed model as the basic mathematical model for the numerical simulation of wind speed. It is improved on the basis of the traditional combined wind speed basic model: in the calculation of basic wind speed components, a model representing the characteristics of offshore wind speed is added; in the calculation of random wind, a parameter-free method is added. The improved combined wind speed model still has the advantages of rapid calculation speed like the original wind speed model, and also reflects the characteristics of offshore wind speed changes, making the simulation results of the system more realistic and reliable, and more suitable for actual conditions such as platforms and blade hoisting based on the marine environment [4].

3.1. Wind Speed Changes Caused by Altitude Changes

In the marine environment, the sea level is not flat due to the existence of waves and currents. For this reason, a frictional boundary layer is formed between sea level and wind. The closer the wind speed is to this boundary layer, the smaller the value, and the farther away the wind speed is, the larger the value. In order to simulate this characteristic of the marine environment, the following model is introduced. First determine the wind speed value at the standard height, and then use the method of dividing by the conversion factor to calculate the wind speed value at the target height. For the convenience of calculation, this paper takes the standard reference height as 10m. The law of wind speed changing with height is:

$$V_Z = \frac{V_{10}}{k_z} \tag{8}$$

$$k_z = \frac{\ln(\frac{10}{Z_0})}{\ln(\frac{z}{Z_0})} \tag{9}$$

In the above formula, k_z is the height conversion coefficient of the sea area, V_{10} is the basic wind speed at standard height (10m), z is the actual height, V_Z is the wind speed at the height z, and Z_0 is the state coefficient of the sea surface wave in the sea area. In the marine environment, the greater the wind speed, the greater the waves, which causes the sea level to be more uneven, and the wave state coefficient of the sea surface increases. Usually, the wind power level 4 (wind speed is 7m/s) is the boundary of the wave state coefficient. When the wind speed is greater than or equal to 7m/s, $Z_0 = 0.02222$ is often used, and when it is less than 7m/s, $Z_0 = 0.023$ is often used.

3.2. Non-parametric Method to Calculate Random Wind

In the traditional combined wind speed model, the random wind component calculation needs to determine two parameters: the wind field surface resistance coefficient and the wind speed fluctuation scale coefficient, and most of these two parameters are obtained through actual measurement. However, for the marine environment, the measured data is scarce, which makes it difficult to determine the specific values of the parameters. In order to make the

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combined wind speed model more convenient for application in the marine environment, this paper uses the non-parametric modeling method in the conventional random wind component mathematical modeling method according to the literature [4], which makes the case that the wind field surface drag coefficient and wind speed fluctuation scale coefficient is unknown, the simulation of random wind components can also be realized. Through the analysis of the traditional combined wind speed model modeling formula, the randomness of the random wind is mainly expressed by the cosine calculation of the modeling formula. The calculation part involving the two parameters has no decisive effect on the manifestation of randomness. Therefore, the processing method of the non-parametric method is as follows:

(1) Replace the random component amplitude S_v(The maximum wind speed at this part) with the overall wind speed extreme value $\mathrm{V_{nmax}}$ of the random wind; this paper uses a uniformly distributed random variable between $[0, \mathrm{V_{nmax}}]$ for calculation;

(2) Replace the random component ω_i with a constant.

After improvement, the random wind calculation model of non-parameter method is:

$$\mathrm{V_n} = \mathrm{V_{nmax}} R_{am}(0,1)\cos(\omega_n t + \varphi_n) \tag{10}$$

In the above formula, V_{nmax} is the peak value of random wind speed; $R_{am}(0,1)$ is a random variable uniformly distributed on [0,1]; ω_n is a constant that replaces the random component ω_i, and 1.6π is used in this article; φ_n is a uniformly distributed random variable in [0,2π].

4. SIMULATION SYSTEM

The simulation system mainly simulates the actual hoisting of the blade, that is, from the sea level to the target height. In order to make the blade as stable as possible during the hoisting, this article also makes the blade move upward in a straight line at a uniform speed. The schematic diagram of blade hoisting is shown in Figure 1. As can be seen from the Figure., the blade is hoisted horizontally from the transport ship by a lift wire, and is connected to the winch at the top of the crane by the lift wire. Winch shortens the lift wire by twisting to provide an upward force for the blades that rises at a constant speed and gradually approaches the hub. When the blades and the hub are almost in a horizontal plane, the lifting process is completed. When the blade is hoisted, the blade moves upward at a constant speed under the lifting force provided by the hoisting line, which makes the height of the blade increase at each moment, and the corresponding main wind speed acting on the blade changes. The wind speed prediction in this process is more complicated. In order to express the movement of the blade in the air under the action of wind more conveniently and accurately, the wind speed prediction model described above is used as the basis to estimate the main wind speed acting on the blade.

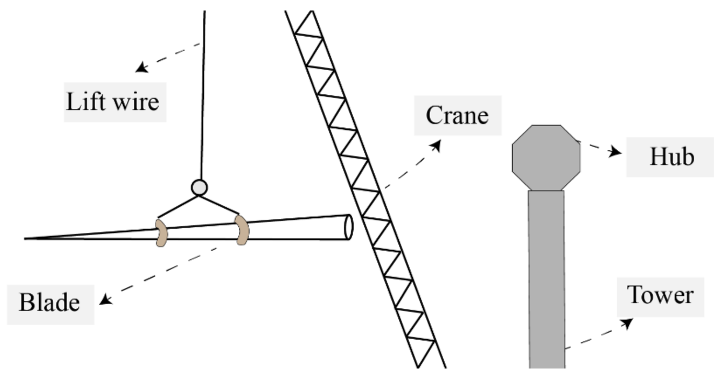

Figure 1. Sketch of blade hoisting

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The coordinate frame is specified as follows. In the global frame, the origin O is any point on the sea level, and the z-axis is vertically upward. Because the main wind speed and direction will not change randomly in a certain sea area, the x-axis is the same as the main wind direction. The y axis is determined by the right-hand rule. The positional relationship between the blade and the coordinate frame is shown in Figure. 2 [7].

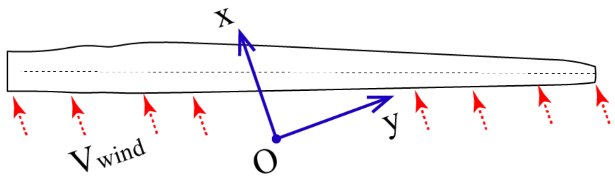

Figure 2. Schematic diagram of coordinate system

In this coordinate frame, it is assumed that the blade is a rigid body with 3 degrees of freedom, and it is lifted upwards at a uniform speed at a speed of V_z per second, ignoring the vertical movement caused by the displacement of the blade in the horizontal direction. Then the wind speed prediction when the blade is hoisted is as follows:

$$H = V_z t \tag{11}$$

$$V_{wind} = V_b(H) + V_g(t) + V_c(t) + V_n(t) + w_w \tag{12}$$

The above formula constitutes the non-linear relationship of wind speed prediction. H is the height of the blade above the hoisting plane at each moment; the four parts of the wind will output different results according to different moments. Considering the instability of wind speed, Gaussian white noise w_w is added. Sum the above parts to get the corresponding wind speed of the blade at different heights.

5. KALMAN FILTER SYSTEM AND OBSERVER SYSTEM

The Kalman filter system and the observer system are built by establishing the mathematical model of the two. In the research of the wind speed simulation, it is often necessary to design an observer system. The system often simulates the error of the observer by adding Gaussian white noise. In order to obtain the wind speed value at each moment more accurately, this paper will introduce a Kalman filter to filter the measurement error. By estimating the state value at this moment, a filtered value closer to the actual value than the measured value is obtained. Kalman filter can only be applied to linear systems. In order to better use Kalman filter theory to deal with the nonlinear blade hoisting wind speed prediction system, this paper introduces the unscented Kalman filter theory, and uses an unscented transform method to deal with the problem of non-linear transfer of mean and covariance in the filter. Therefore, the unscented Kalman filter algorithm has higher calculation accuracy for nonlinear systems [8].

UKF needs to determine the state equation and measurement equation, set the state vector $X=[H, V_z]^T$ during the blade hoisting, and the noise matrix $V=[v_z, v_v]^T$ of the observer vector of $\boldsymbol{Y}=[H, V_z]^T$. At time k the following state equation and measurement equation can be formed:

$$\begin{cases} X(k+1)=f(X(k)) \\ Y(k)=HX(k)+V(k) \end{cases} \tag{13}$$

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f is the nonlinear state equation function, the covariance matrix of W(k) and V(k) are Q and R respectively, and H is the nonlinear observation equation function. Here is the observation matrix. Expressed as:

$$H=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix} \tag{14}$$

Assuming that the dimension of the state vector X is n, the mean value is $\overline{X}$, and the variance is P, in order to deal with the problem of non-linear transmission of mean and covariance in the filter, this paper uses the following unscented transform to obtain 2n+1 sigma sample Points X^i and its mean and variance corresponding weights ω_m^i, ω_c^i.

$$X^i=\begin{cases}\overline{X} & i=0\\ \overline{X}+\sqrt{(n+\lambda)P} & i=1\sim n\\ \overline{X}-\sqrt{(n+\lambda)P} & i=n+1\sim 2n\end{cases} \tag{15}$$

$$\omega_m^i=\begin{cases}\frac{\lambda}{n+\lambda} & i=0\\ \frac{\lambda}{2(n+\lambda)} & i=1\sim 2n\end{cases} \tag{16}$$

$$\omega_c^i=\begin{cases}\frac{\lambda}{n+\lambda}+(1-\epsilon^2+\zeta) & i=0\\ \frac{\lambda}{2(n+\lambda)} & i=1\sim 2n\end{cases} \tag{17}$$

Among them, λ is an adjustable scaling parameter to reduce the total prediction error, $\lambda=\epsilon^2(n+\delta)-n$, ϵ is a control parameter that controls the distribution of sampling points; ζ is a weight coefficient greater than or equal to zero; δ is the parameter to be selected. its value must be guaranteed that $(n+\lambda)P$ is a positive semi-definite matrix. After many experiments, take $\epsilon=1$, $\zeta=0$, $\delta=2$.

Then, 2n+1 sampling points of the i-th state vector at time k are:

$$X^i{}_{k|k}=\left[\overline{X}_{k|k}, \overline{X}_{k|k}+\sqrt{(n+\lambda)P_{k|k}}, \overline{X}_{k|k}-\sqrt{(n+\lambda)P_{k|k}}\right] \tag{18}$$

Then the state prediction value and its mean value and covariance at time k+1 are:

$$X^i{}_{k+1|k}=f\left(X_{k|k}\right) \tag{19}$$

$$\overline{X}_{k+1|k}=\sum_{i=0}^{2n}\omega^i X^i{}_{k+1|k} \tag{20}$$

$$P_{k+1|k}=\sum_{i=0}^{2n}\omega^i\,[\overline{X}_{k+1|k}-X^i{}_{k+1|k}][\overline{X}_{k+1|k}-X^i{}_{k+1|k}]^T+Q \tag{21}$$

Using the unscented transformation again, the sampling point at k+1 time is $X^i{}_{k+1|k}$, then the predicted value of the observer, its corresponding mean and covariance can be calculated with the following formula:

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$$Y^{i}_{k+1|k}=HX^{i}_{k+1|k} \tag{22}$$

$$\overline{Y}_{k+1|k}=\sum_{i=0}^{2n}\omega^{i}\,Y^{i}_{k+1|k} \tag{23}$$

$$P_{y_k y_k}=\sum_{i=0}^{2n}\omega^{i}\,[Y^{i}_{k+1|k}-\overline{Y}_{k+1|k}][Y^{i}_{k+1|k}-\overline{Y}_{k+1|k}]^{T}+R \tag{24}$$

$$P_{x_k y_k}=\sum_{i=0}^{2n}\omega^{i}\,[X^{i}_{k+1|k}-\overline{Y}_{k+1|k}][Y^{i}_{k+1|k}-\overline{Y}_{k+1|k}]^{T} \tag{25}$$

Calculate the Kalman gain matrix of the system:

$$K_{k+1}=P_{x_k y_k}P^{-1}_{y_k y_k} \tag{26}$$

Then the following update calculation formulas for the state vector and covariance matrix can be obtained:

$$\overline{X}_{k+1|k+1}=\overline{X}_{k+1|k}+K_{k+1}[Y(k+1)-\overline{Y}_{k+1|k}] \tag{27}$$

$$P_{k+1|k+1}=P_{k+1|k}-K_{k+1}P_{y_k y_k}K^{T}_{k+1} \tag{28}$$

The above equations (13)-(28) are the unscented Kalman filter system for blade hoisting. The wind speed observer system can also be constructed by formula (13).

6. SIMULATION

Based on the above filter and wind speed prediction theory, this paper uses MATLAB/Simulink to establish a simulation program for the wind speed prediction system when the blade is hoisted. First select the model parameters of the system, and then establish the simulation system, observer system and Kalman filter system according to the equation (11)-(28). The running process of the entire simulation system in Simulink is shown in Figure. 3. At different moments, the simulation system obtains the height according to the speed of the blade, and calculates the basic wind speed value through the relationship between height and wind speed, and at the same time obtains the corresponding values of the other three parts of the wind at each moment according to the law of combined wind speed, and output to the observation system after being superimposed. The observation system simulates the actual observation result by adding white noise, and outputs the result to the Kalman filter system. The Kalman filter system filters errors through the filter model described above and outputs the final estimated value. Based on the above, this paper simulates the lifting process of a rigid-body blade from the deck which takes 110 seconds to complete the whole process according to the actual hosting of the blade, and predicts the main wind speed act on the blade during lifting. It is assumed that the displacement of the blade on the horizontal plane will not affect the vertical movement. That is to say, in the z direction, the blade will move upward at a constant speed of 1m/s, and the lifting process will be completed at 110s.

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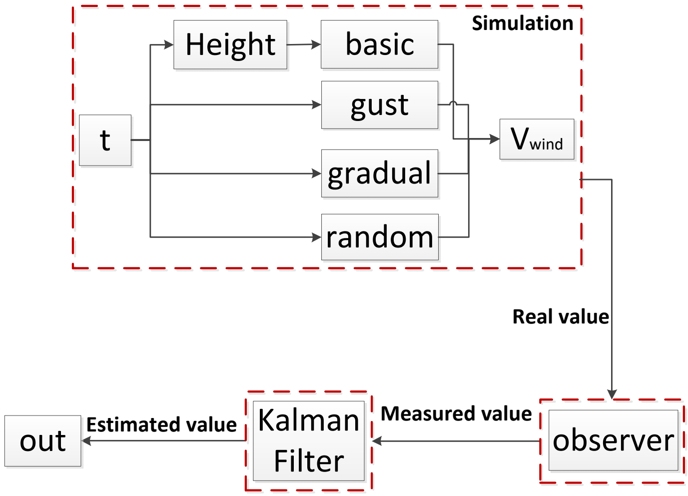

Figure 3. Flow chart of wind speed prediction system

The blade is hoisted from the deck H=0m, assuming that the basic wind speed is 10m/s at H=10m, that is, at 10m sea level. In order to simulate a more realistic wind field environment, the above-mentioned improved combined wind method is used to simulate the wind load model, that is, the actual wind speed is a superposition of basic wind speed, random wind, gust and gradual wind. The main wind speed act at the blade changes with the change of the blade lifting height H and time t. When the blade is lifted to H=110m, the blade starts to align. At the same time, it is stipulated that the start time of gust is 10s-110s, the start time of gradual wind is 0-110s, and the random wind exists throughout the simulation. In the above simulated wind field, this paper adds Gaussian white noise with a variance of 0.01 to the simulation results to approximate the observation results during the blade hoisting process. The simulated wind speed vertical to the blades during hoisting is shown in Figure. 4.

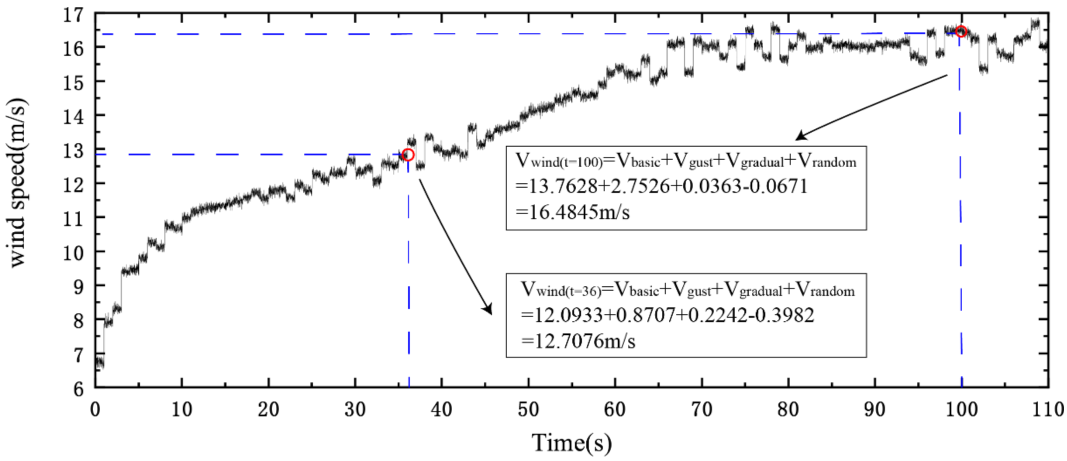

Figure 4. Wind speed variation diagram during hoisting

It can be seen from Figure. 4 that as time goes by, the height of the blades increases at a uniform speed, and the wind speed acting on the blades shows an overall increasing trend. This is because the basic wind increases with the increase in height. The results also show the correctness of the prediction system. The wind speed fluctuates slightly in the overall growth trend, which is mainly due to the changes in the basic wind values of gusts, gradual winds, and random winds. In order to more accurately reflect the value of wind speed, two nodes are selected for analysis. When t=36s, the blade height is 36m, and the corresponding basic wind speed is 12.7076m/s. The other three parts are 0.8707m/s, 0.2242m/s, and -0.3982m/s. Here, the negative value of random wind means the amount of wind in the upwind direction, which means that the wind will fluctuate along a certain value and the randomness of the wind. When t=100s, the corresponding four parts are: 13.7628m/s, 2.7526m/s, 0.0363m/s, -0.0671m/s. Through the analysis of numerical simulation results, it is found that the improved wind speed simulation system can not only express the characteristics of wind speed in the marine environment, but also meet the requirements of accuracy and convenience in simulation calculation.

According to the above-mentioned state equation, observation equation and the basic theory of Kalman filter system, the simulation is completed in Simulink. In order to more accurately show the relationship between the predicted value, the real value and the measure value, two time periods are selected for analysis: 36s in the time period when the wind speed increases rapidly, and the wind speed is relatively stable at 100s.

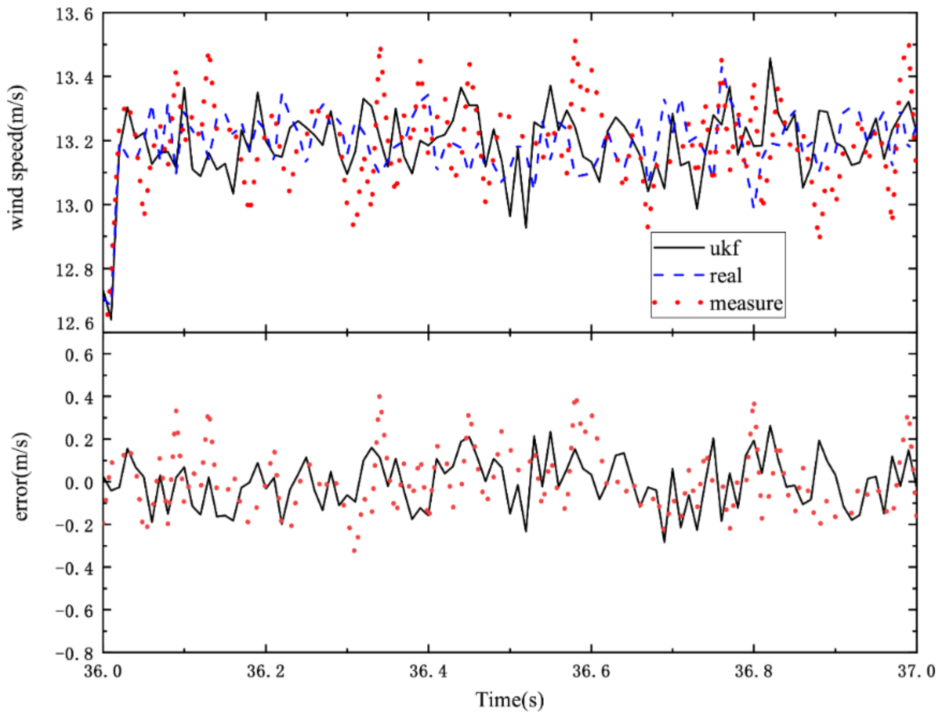

Figure 5. Estimated results and errors within 36s

The measured value is the final result obtained by the observer system, the UKF value is the estimated value obtained by the Kalman system, and the real value is the main wind speed of the blade received by the wind speed simulation system during hoisting. In order to analyze the role of UKF in the system in detail, this paper lists the comparison of real values, measure values and filtering(UKF) values of wind speed in a relatively unstable period of time, namely 36-37s, in Figure. 5. It can be seen from Figure. 5 that when the blade is lifted at 36s-37s, the wind speed acting on the blade is basically stable near the value of 13.2m/s, and the maximum value can reach 13.341m/s. In this second, the wind speed increased by 0.7519m/s, mainly due to the increase in gust wind and the basic wind. And in this period, there is a certain error between the measured value and the true value. When the UKF is used, the error is significantly improved, and a result closer to the real value is obtained. In this period of time, the amplitude is reduced from 0.4308 to 0.2629, which is a decrease of 38.97%, and the discreteness of error data has been significantly improved. This shows that UKF can indeed effectively improve the error caused by the observer and give a more accurate result.

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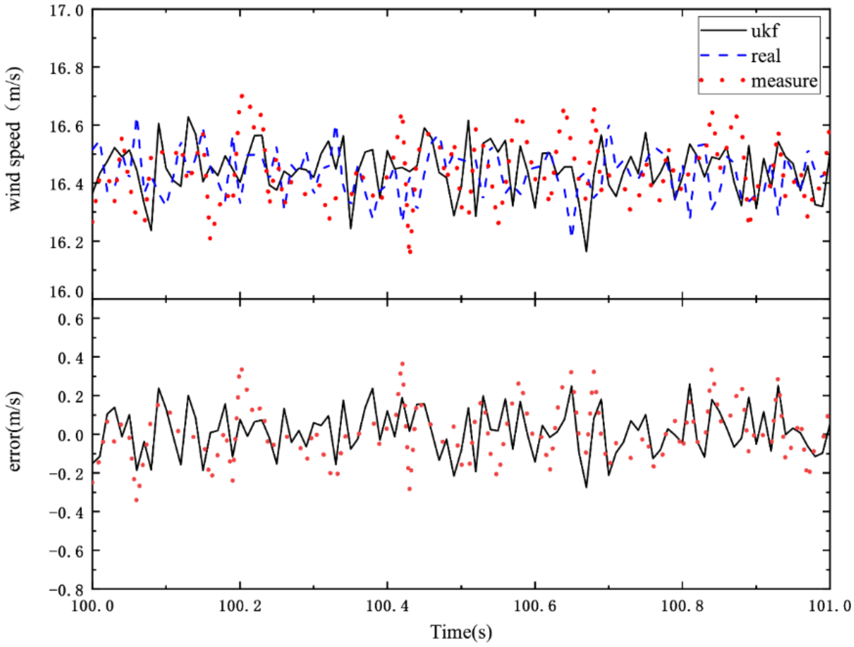

Figure 6. Estimated results and errors within 100s

Figure. 6 shows the wind speed prediction results and the numerical results of the filtering system within 100-101s. During this time period, the wind speed was basically stable around 16.5m/s, an increase of 3.3m/s compared with 36s-37s. This increase was mainly due to the increase in the basic wind brought about by the height change and the increase in gusts. The amplitude at this moment is about 0.1m/s, and the wind speed increase during this time period is only 0.0661m/s, mainly from the increase in the basic wind caused by the height change during the blade lifting, but the height is therefore higher. The increase in wind speed caused by altitude changes is small. Therefore, the wind speed during this period is relatively stable. At the same time, because the gust has reached its maximum at this time, it is relatively stable and has no obvious growth, and the values of other parts except the basic wind fluctuate within a range. The comparison of estimated value, the real value, and the observed value in this time period also illustrates the significance of the unscented Kalman filter that the estimated value is obviously more consistent with the real value. In comparison with the error between real value, when the UKF is added, the amplitude is reduced from 0.3931m/s to 0.2594m/s, a decrease of 34.01%, which greatly reduces the error caused by the observer and makes the final result more accurate.

7. CONCLUTION

This paper proposes a wind speed prediction system combined with blade hoisting. The system includes three parts: blade hoisting wind speed simulation system, observation system and filter system. The simulation system will calculate the wind speed at different times according to the blade height, and the observer system will add noise to the real value calculated by the simulation system to obtain the observation noise. The Kalman filter system filters errors when only the observation value is the only input, and obtains an estimated value closer to the real value. This paper combines the unscented Kalman filter and the improved wind speed prediction system to design a wind field simulation system, which simulates the main wind speed act on the blade when hoisted in the marine environment. The main conclusions are as follows:

(1) The simulation system is based on an improved combined wind speed model, which still retains the original advantages of simple calculation and accurate results, and is more in line

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with the characteristics of offshore wind speed. Especially when the blade height changes rapidly when the blade is hoisted, the main wind speed at different heights at each moment can be quickly calculated and output. The result obtained in this way is closer to the actual marine environment. Such a simple and accurate prediction system facilitates the research and advancement of force analysis and automatic control of blade hoisting.

(2) Through the analysis of the results, the final results show that when the blades are at a low height, the basic wind is greatly affected by changes in height, and will increase rapidly with the increase in height. When the height is higher, the change in the basic wind caused by the height increase decreases. In addition to the basic wind being affected by the height change, the change of the gust is also an important reason for the change of the wind speed value. When the gust shows an increasing trend, the main wind speed changes greatly. When the gust stabilizes, the main wind speed is only affected by the basic wind speed.

(3) The system also simulates the observation system by adding Gaussian white noise, and introduces a Kalman filter system to filter errors to obtain a filter value closer to the real value. In actual operation, when the measured value is the only information, this step can effectively increase the reliability of the final value and facilitate subsequent research. The simulation results show that the addition of UKF greatly reduces the error caused by the observer, and also effectively improves the discreteness of error. The filtered value is closer to the real value, which meets the requirements. This feature facilitates the combination of the system with other actual working conditions.

For the simplicity of the results, this paper ignores the influence of wind turbulence and observer position on wind speed measurement, which is deviated from the actual marine environment. In addition, this article ignores the vertical height change caused by the swing of the blade on the plane, and follow-up research can be carried out around this aspect.

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