Research on Correction Method of Wind Measurement based on Platform Attitude

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Abstract. On the moving platform, the accuracy of wind measurement is also affected by the attitude of the platform. The influence of platform attitude on wind measurement is analyzed. Based on the coordinate system transformation in mathematics, the compensation and correction model of wind measurement based on platform attitude is deduced, and the verification method is designed. The sea test results show that the method can effectively restrain the influence of low frequency attitude movement of ship platform on wind measurement, and effectively improve the accuracy of wind measurement on the moving platform.

1. Introduction

Wind is the horizontal flow of air, which has an important impact on human activities at sea. It is of great significance to strengthen the wind monitoring of offshore platforms for ship navigation safety, high-precision offshore operations, marine meteorological forecast, etc. On the fixed platform on land, the wind measurement error is only related to the accuracy of the sensor; on the moving platform such as the ship, the accuracy of the wind measurement is also affected by the attitude of the platform.

Johnson et al. [1] studied a system of wind sensor motion compensation on a mobile platform, which was used to correct the relative wind speed, but this paper did not give a method of wind direction compensation. Jiang Lijun et al. [2] studied the dynamic measurement modeling method of wind speed and direction under the condition of ship motion. Li Zhiqian [3] analyzed the error of wind measurement data in navigation state, and pointed out the error sources of wind speed and direction in all directions. Ren Xiaowen [4] studied the influence of ship motion on the measurement of wind direction and wind speed, and used BP neural network to fit the curve of motion speed, attitude and measurement results. Wang Guofeng et al [5] proposed an error compensation algorithm of wind speed and direction measurement based on the spatial model, and established the spatial model of wind speed and direction vector under the state of ship motion. Zhou Yiwu et al [6] proposed a compensation algorithm based on multivariable non-linear fitting, which realized the dynamic measurement of the ship's rolling down wind speed. Yu Yongqing et al. [7] designed a digital simulation system for the dynamic measurement of wind speed and direction and error compensation of ships, and carried out the digital simulation for the dynamic measurement of wind speed and direction and error compensation of ships in rolling and pitching states. Zhang Yonggang et al. [8] corrected the measurement error of the wind direction anemometer by using the angular velocity of the three degrees of freedom motion of the ship's sway,
pitch and bow rotation. Zhao Yongsheng et al [9] invented a dynamic measurement method and device of wind speed and direction with motion attitude compensation. Li Zhiqian et al. [10] classified various error sources of wind measurement on ships and their influence on true wind.

The above researches analyze the wind measurement error on the ship by different methods, and propose a series of solutions, but do not point out the root cause of the wind measurement error on the moving platform. Starting from the platform attitude, this paper analyzes the influence of the platform attitude on the wind measurement, establishes the error compensation and correction model of the wind measurement on the moving platform by using the idea of coordinate system transformation in mathematics, so as to compensate and offset the influence of the platform motion on the wind measurement, and achieves good results.

2. Influence of platform attitude on wind measurement

Generally speaking, the ship on the sea is a moving platform, and its navigation attitude is easily affected by waves, surges and other current factors, resulting in the hull pitching and rolling, resulting in the installation plane of the wind sensor can not be kept parallel with the horizontal plane, and the measurement result of the wind sensor in the inclined state has a large deviation from the true value. Since the parameters describing the pitch and roll angle are the pitch angle and roll angle of the ship. When the ship is sailing on the sea, for the propeller type wind sensor, the existence of roll angle will cause additional wind pressure difference on the tail, and the pitch angle will produce friction resistance on the blade rotation, which is reflected in the wind measurement. The roll angle mainly affects the wind direction, and the pitch angle mainly affects the wind speed.

3. Compensation and correction model of wind measurement based on platform attitude

3.1 Compensation and correction ideas

Based on the idea of space coordinate transformation in mathematics, coordinate transformation can be divided into stretching, rotation and translation. Among them, the stretch transformation corresponds to the wind error correction caused by the angular velocity around the axis, the rotation transformation corresponds to the distortion correction caused by the angular velocity around the axis, and the translation corresponds to the wind error correction caused by the displacement of the origin of the coordinate system.

Take geodetic coordinate system $O'\hat{X}'\hat{Y}'\hat{Z}'$, the origin $O'$ is at the center of gravity of the balance ship, $O'\hat{X}'$ is in horizontal position, the $O'\hat{X}'$ -axis is to bow, $O'\hat{Y}'$ -axis is perpendicular to $O'\hat{X}'$ axis pointing to the right, and the $O'\hat{Z}'$ -axis is vertical up. The coordinate system is the ship's balance position and does not sway with the ship. Take ship coordinate system $OXYZ$, the origin $O$ is at the center of gravity of the rocking ship, $OX$ is in tilt position, the $OX$ -axis is to bow, $OY$ -axis is perpendicular to $OX$ axis pointing to the right, and the $OZ$ -axis is vertical up. The coordinate system is consolidated with the hull and shakes with the ship.

Then take another middle coordinate system $\hat{O}\hat{X}\hat{Y}\hat{Z}$, it is parallel to the geodetic coordinate system, the origin coincides with the hull coordinate system, and only oscillates with the hull. The relative positions of these three coordinate systems are shown in Figure 1 and Figure 2.

![Fig 1 the geodetic coordinate system](image1)

![Fig.2 the hull coordinate system](image2)
The measured value given by the wind sensor is the wind vector in the hull coordinate system. It is assumed that the current position of the hull coordinate system is changed from the middle coordinate system to the current position by three times.

First, turn the middle coordinate system \(O^\wedge X^\wedge Y^\wedge Z\) around the \(^\wedge OX\)-axis by \(\alpha\) angle, Let it go to the plane determined by \(OZ\) and \(^\wedge OX\). And then rotate \(\beta\) angle around the \(^\wedge OY\)-axis, Make \(^\wedge OZ\) coincide with \(OZ\), Now plane \(^\wedge OX^\wedge Y\) coincide the \(OXY\), Finally, rotation \(\gamma\) angle of plane \(^\wedge OX^\wedge Y^\wedge Z\) about \(OZ\)-axis, In this way, the intermediate coordinate system \(O^\wedge X^\wedge Y^\wedge Z\) and the hull coordinate system \(OXYZ\) are completely coincident.

In the above relationship, \(\alpha\) corresponds to roll angle, \(\beta\) corresponds to pitch angle, \(\gamma\) corresponds to yaw angle, \(x_0, y_0, z_0\) are the displacement of the platform in three directions, which can be obtained by integrating the acceleration in three axis directions with time. The relative wind measured by the sensor can be corrected to the original undisturbed state by using the above space coordinate system transformation idea.

### 3.2 Compensation and correction of measurement error caused by angular velocity around the axis

The attitude’s conduction vector \(\bar{L}\) is defined as the position vector \((L_x, L_y, L_z)\) of the attitude measurement point in the ship coordinate system, which can be obtained from the ship designer. The disturbance vector \(\bar{e} = \begin{vmatrix} \omega_x \cdot L_x \\ \omega_y \cdot L_y \\ \omega_z \cdot L_z \end{vmatrix}\) caused by the angular velocity is obtained after obtaining three angular velocities \((\omega_x, \omega_y, \omega_z)\) around the axis.

### 3.3 Compensation and correction of measurement error caused by the angle around the axis

Two points \(P_1(x_1, y_1, z_1)\) and \(P_2(x_2, y_2, z_2)\) in 3D space, \(P_2\) can be obtained by \(P_1\) passing through the rotation matrix \(R\), \(P_2 = R \cdot P_1\) (Right hand coordinate system, left multiply), Where rotation matrix \(R\) is orthogonal matrix \(R \cdot R^T = I\).

Rotation matrix of rotation angle about \(OX\)-axis (roll):

\[
R_x(\alpha) = \begin{bmatrix}
1 & 0 & 0 \\
0 & \cos \alpha & -\sin \alpha \\
0 & \sin \alpha & \cos \alpha
\end{bmatrix}
\]

Rotation matrix of rotation angle about \(OY\)-axis (Pitch):

\[
R_y(\beta) = \begin{bmatrix}
\cos \beta & 0 & \sin \beta \\
-\sin \beta & 0 & \cos \beta \\
0 & 1 & 0
\end{bmatrix}
\]

Rotation matrix of rotation angle about \(OZ\)-axis (yaw):

\[
R_z(\gamma) = \begin{bmatrix}
\cos \gamma & -\sin \gamma & 0 \\
\sin \gamma & \cos \gamma & 0 \\
0 & 0 & 1
\end{bmatrix}
\]
Because matrix multiplication does not satisfy commutative law, rotate in $OX, OY, OZ$ order, then the rotation matrix $R$ from $P_1$ to $P_2$:

$$R = R_z(\theta_3)R_y(\theta_2)R_x(\theta_1)$$

$$= \begin{pmatrix}
 c_3 & -s_3 & 0 \\
 s_3 & c_3 & 0 \\
 0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
 0 & 0 & s_2 \\
 0 & 1 & 0 \\
 -s_2 & 0 & c_2
\end{pmatrix}
\begin{pmatrix}
 1 & 0 & 0 \\
 0 & c_1 & -s_1 \\
 0 & s_1 & c_1
\end{pmatrix}$$

$$= \begin{pmatrix}
 c_2c_3 & -s_3 & s_2c_3 \\
 c_2s_3 & c_3 & s_2s_3 \\
 -s_2 & 0 & c_2
\end{pmatrix}
\begin{pmatrix}
 0 & 0 & 1 \\
 0 & c_1 & -s_1 \\
 0 & s_1 & c_1
\end{pmatrix}$$

$$= \begin{pmatrix}
 c_2s_3 & s_1s_2c_3 - c_1s_3 & s_1s_3 + c_1s_2c_3 \\
 c_2c_3 & c_1c_2 + s_1s_2s_3 & c_1s_2s_3 - s_1c_3 \\
 -s_2 & s_1c_2 & c_1c_2
\end{pmatrix}$$

$R$ is an orthogonal matrix, $R_o$ is also an orthogonal matrix, we can obtain $R_o^* = R_o^T$ from:

$$\begin{bmatrix}
 x' \\
 y' \\
 z'
\end{bmatrix}
= R_o^T
\begin{bmatrix}
 x^* \\
 y^* \\
 z^*
\end{bmatrix}$$

That is, the inverse rotation matrix from ship coordinate system $OXYZ$ to intermediate coordinate system $OXYZ$ is $R^T_o$. From the inverse rotation matrix $R^T_o$, the wind measurement value $(x, y, z)$ in the ship coordinate system $OXYZ$ can be transformed into the wind vector $(x^*, y^*, z^*)$ in the middle coordinate system $OXY^*Z$.

### 3.4 Compensation and correction of wind measurement error caused by axial displacement

From the parallel relationship between the middle coordinate system $OXYZ$ and the geodetic coordinate system $O'X'Y'Z'$:

$$\begin{bmatrix}
 x' \\
 y' \\
 z'
\end{bmatrix}
= \begin{bmatrix}
 x^* \\
 y^* \\
 z^*
\end{bmatrix} + \begin{bmatrix}
 x_0 \\
 y_0 \\
 z_0
\end{bmatrix}$$

We can get the vector $(x^*, y^*, z^*)$ under the geodetic coordinate system $O'X'Y'Z'$.

### 4. Model validation

Similarity comparison between two vectors: the smaller the distance is, the more similar the two vectors are. In Euclidean space, the distance between two points $a(x_1, y_1)$ and $b(x_2, y_2)$ is:
\[ d_{a,b} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \]

Use the following formula to normalize the similarity:

\[ \text{sim}(a,b) = \frac{1}{1 + d_{a,b}} \]

Then the value range of similarity is \((0,1]\). The smaller the distance is, the closer the value is to 1, indicating the greater the similarity between the two vectors.

In Figure 3, although \( \|c\| = \|b\| \), \( \overrightarrow{a} \) is closer to \( \overrightarrow{b} \), so \( \text{sim}(a,b) > \text{sim}(b,c) \), it is noted that compared with C, a and B are more similar.

Through the data comparison test to verify the effectiveness of the platform attitude based wind measurement compensation and correction model, refer to the selection principle of the comparison sensor: mature application in the industry, with the attitude compensation and correction function of the wind sensor. Through investigation, the 200wx type ultrasonic integrated weather station produced by Airmar Company of the United States meets the requirements, and its wind measurement value can be used as the reference comparison data of this test. In the process of model verification and comparison, taking the wind measurement value of integrated meteorological station as the reference true value, the validity of the model is verified by comparing the close degree of \( \text{sim} \) value and 1 before and after correction.

5. Offshore test

Make the data before attitude correction set A, data after attitude correction set B, and ultrasonic data set C, calculate the mean \( \mu \) and variance \( \sigma \) of \( \text{sim}(A,C) \) and \( \text{sim}(B,C) \) respectively:

\[
\begin{align*}
\mu_{AC} &= 0.5012 \\
\sigma_{AC} &= 0.0642 \\
\mu_{BC} &= 0.7639 \\
\sigma_{BC} &= 0.0832
\end{align*}
\]

Compared with \( \mu_{AC} \), \( \mu_{BC} \) is closer to 1, which shows that the compensation correction model based on platform attitude is effective and the correction results are significant.
The data on May 22, 2020, and its processing results are as follows:

![Graph showing processing results on May 22, 2020]

6. Conclusion

Wind measurement on a moving platform is an important way of data acquisition, but due to the influence of platform attitude on wind measurement, the measurement results are distorted. Starting from the demand of wind measurement on the moving platform and based on the idea of coordinate system transformation in mathematics, the compensation and correction model of wind measurement on the moving platform is derived, and the sea trial is carried out. The results show that after the model compensation and correction, the wind measurement distortion caused by the change of platform attitude is well eliminated, which shows that the compensation and correction model of wind measurement based on platform attitude is effective and can be applied to ships. It is used to correct the error of wind measurement caused by the attitude of the platform.

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