Floating offshore wind measurement system by using lidar and its verification

Atsushi Yamaguchi and Takeshi Ishihara

1. Introduction

The use of floating lidar will be an important technology to reduce the cost of offshore wind measurement. Floater motion due to wave force may result in the error of measured wind speed and floater motion compensation is necessary.

Several studies have been carried out focusing on floater motion compensation[1). However, the detailed algorithm for motion compensation is not described. The most simple motion compensation algorithm is simply to perform coordinate transformation. Fujitani[2)] applied coordinate transformation for sonic anemometer on ship. But due to the difference in the mechanism of wind speed measurement between sonic anemometer and lidar, the coordinate transformation may not be used. Another problem is that there is no validated method for the measurement of the motion of the floater. Typically gyro and accelerometer are used to measure the floater motion. But numerical integral may introduce additional error. On the other hand, GPS can give the position of the floater directly, but the accuracy easily changes depending on satellite conditions.

In this study, first, a method to measure the motion of the floater is established, and then, different motion compensation algorithms are applied and their applicability is investigated.

2. Approach

A floater motion measurement algorithm is developed by using inertial censors such as accelerometers and gyros, and RTK-GPS (Real Time Kinematic GPS). The developed algorithm is validated by using the floater motion measurement at the substation of the Fukushima floating offshore wind farm, where accurate floater motion is measured by using three RTK-GPS sensors.

Figure 1 The substation of the Fukushima Floating Offshore Wind Farm

Then, an algorithm fot the motion compensation for the lidar is developped based on the mechanism of how it measures wind speed. The developped algorithm and conventional algorithm based on coordinate transform are applied and the applicability of each method was investigated.

3. Main body of the abstract.

3.1 Floater motion measurement

From the measurement data at Fukushima substation, a 10 minutes time series, when all the three RTK-GPS sensror continuously measured position of the sensors in RTK mode, was chosen and used for the validation of the proposed method. From three RTK-GPS, all the six degree of freedom of the floater can be identified, and identified motion was used as reference data.

Due to the limitation of the size, floating lidars can be equipped with only one GPS sensor, in which case, gyro have to be used to identify the rotational degree of freedom of the floater motion while GPS is used to identify the transverse degreee of freedom. It was shown that this approach shows good agreement with the measured motion identified from three GPS senseors.

Another problem is the lack of the GPS data due to sattelite condition. Especially, in case of offshore wind farm, the distance between the GPS sensor and the base station is large, and the measurement in RTK mode fails quite often. In this study, accelerometer was used to interpolate the missing mesurement of RTK-GPS. Figure 2 shows the position of the GPS sensror (a) measured by GPS and integration of accelerometer and their Fourier spectrum. When the integration in frequency domein is used, the high frequency component shows good agreement with GPS data. But lower frequency component has problem.

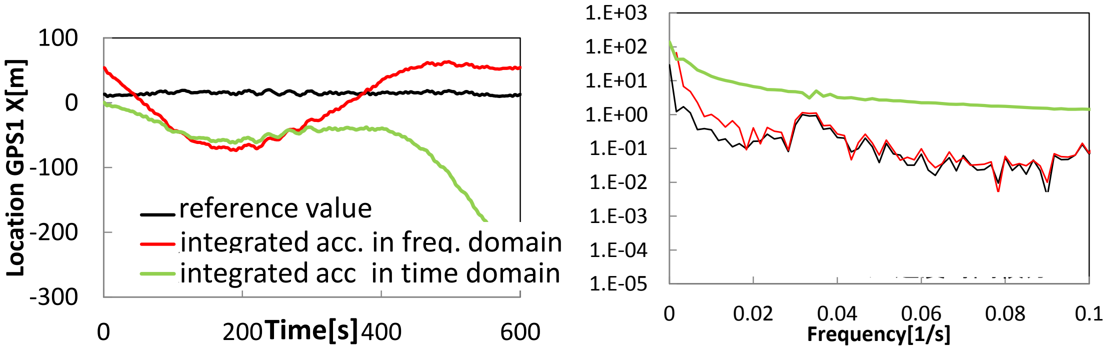

Figure 2 Displacements obtained from accelerometer and their Fourie spectrum

On the other hand, figure 3 shows the position of the GPS sensor when some data are missing, and their Fourier spectrum. In this case, low frequency component shows good agreement with reference value but high frequency component does not.

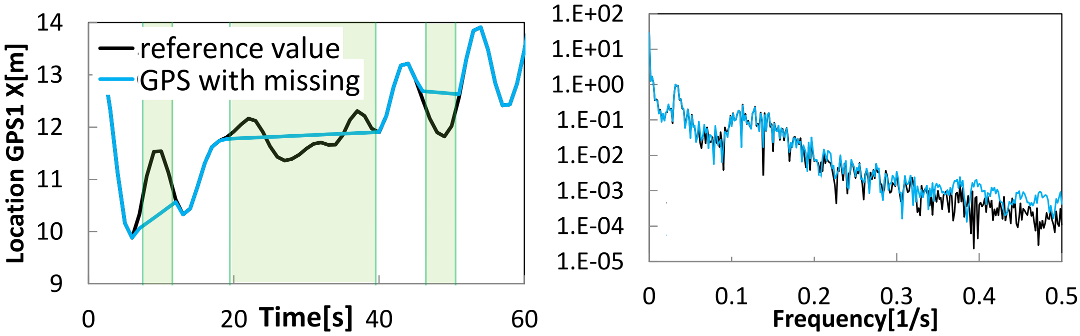

FIgure 3 Time history of GPS displacement with/without missing dateand their Fourier spectrum

This implies that the displaceent data measured by GPS and obtained by integrating accelerometer can be combined in frequency domain. i.e., for low frequency component, the GPS data can be used and for high frequency component, integrated accerelometer can be used.

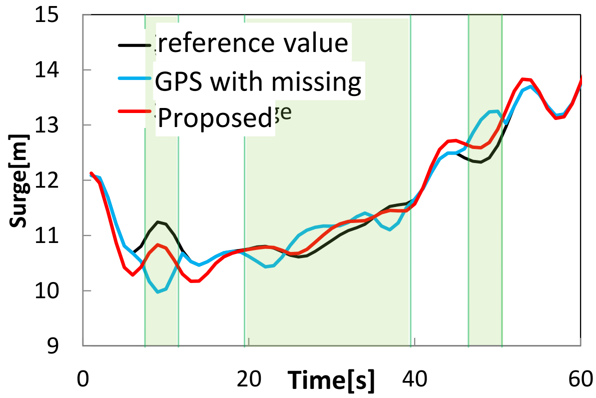

Figure 4 The surge response of the floater

Figure 4 shows the surge responce of the floater by using this method. Even with the lack of some GPS measurement data, the identified surge motion shows good agreement with reference data.

3.2 The motion compensation algorithm of doppler lidar

Figure 5(a) shows the inclined lidar in both pitch and roll direction. The measurement point along the line of sight is shifted from the intended measurement height. In this study, the wind speed in the line of sight direction at the intended height is interpolated from the point below and above (figure 5(b)).

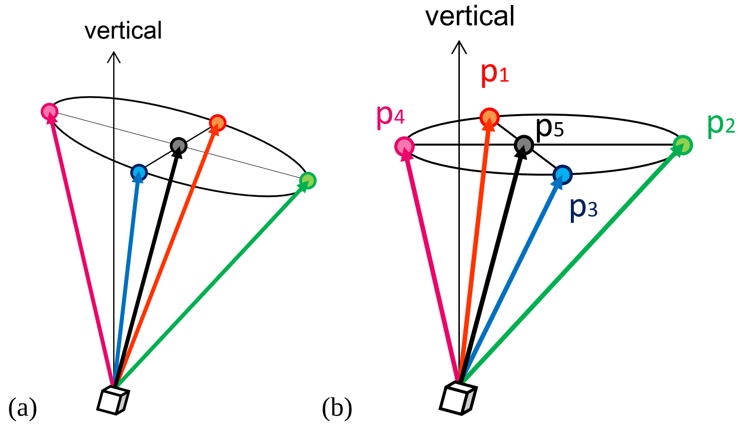

図 5 Inclined lidar and its line of sight

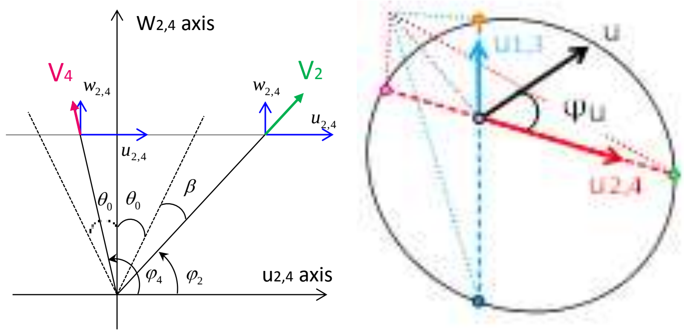

図 6 Cross section of lidar

Then, as shown in figure 6(a), the horizontal wind speed in the plane that contains the vector of line of sight, $\mathbf{u}_{1,3}$ and $\mathbf{u}_{2,4}$ are obtained. Lastly, the true horizontal wind speed $\mathbf{u}$ can be calculated as shown in figure 6(b).

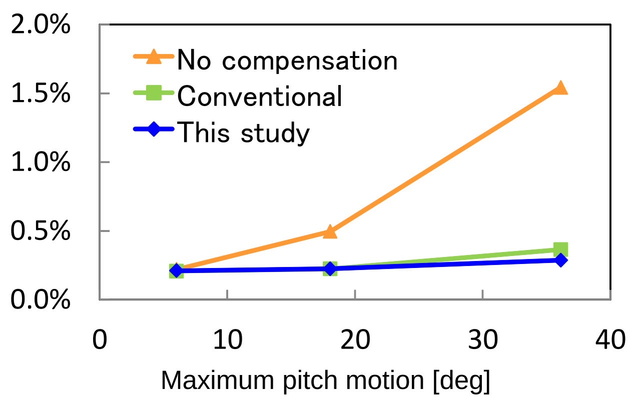

Figure 7 Wind speed prediction error for different maximum pitchmotion

Numerical simulation was carried out to verify the accuracy of the proposed method. In this simulation, the maximum pitch motion angle of the floater is set to 6 degree, 18degree and 36 degree. Figure 7 shows the prediction error for different maximum pitch motion. When conventional simple coordinate transform was used, the error becomes significant when maximum pitch motion is 36 degree. On the other hand, proposed method in this study is applicable for all the pitch angle case.

5. conclusion

In this study, a method to measure the floater motion and a motion compensation method for lidar are proposed and verified. Following results were obtained.

1) Proposed method can measure the displacement even when some of the RTK-GPS data are missing.
2) Proposed motion compensation method for lidar can predict the wind speed

regardless of the maximum pitch angle. When maximum pitch is 36degree, the error in horizontal wind speed becomes 1.5% without motion compensation., but can be reduced to 0.3% by using motion compensation.

6. Learned objectives

Both GPS and accelerometer are needed to appropriately measure the motion of the floater. The motion compensation of the lidar is not simple. If simple coordinate transformation is applied, the wind speed error increases as the floater motion increases.

Acknowledgement

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Reference

1) Julia Gottschall, Hristo Lilov, Gerrit Wolken-Möhlmann, Bernhard Lange : Lidars on floating offshore platforms /About the correction of motion-induced lidar measurement errors (simulations and first experiments) , EWEA, 2012.4
2) Fujitani,T.: Direct measurement of turbulent fluxes over thesea during AMTEX. Pap. Meteor. Geophys., 32, 119–134, 1981.