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Validation and Measurements of Floating LiDAR for Nearshore Wind Resource Assessment Application

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Abstract

Validation and measurements of a Floating LiDAR (Light Detection And Ranging) Device (FLD) were performed at Hsing-Da Harbor in the south of Taiwan from October 16th to 26th, 2013. Six range gate heights were set at 50m, 70m, 90m, 110m, 150m and 200m from the FLD sensor lens. Wind speeds, wind directions and turbulence intensities measured by the FLD were compared with those measured by a portable LiDAR, installed on the top of Taiwan Ocean Research Institute (TORI) building. The distance between two LiDARs was about 320m. 1388 available timestamp datapoints were recorded during the deployment campaign. During the test period, the majority of the wind directions were from the north. The averaged wind speeds for the range gate of #1~6 were 4.7, 4.9, 5.3, 5.5, 5.6 and 5.8m/s respectively with the corresponding maximum 10-minute average wind speeds 13.6, 14.2, 14.8, 15.9, 15.9 and 16.9m/s and the averaged turbulent intensities 0.187, 0.190, 0.191, 0.193, 0.197 and 0.192 for the six range gates.
The results showed good agreements with 10 minute averaged data of the wind speed and wind direction measured by the two LiDARs. This implied that the motion compensation function of the FLD performed as specified. The present preliminary test and validation results showed good performance from the FLD, which will be a key tool for assessment of offshore wind resources in future offshore wind farm developments.

Keywords: Floating LiDAR, range gate, wind speed, wind direction, turbulent intensity.

Introduction

The world's first offshore wind farm was established at Vindeby (5MW), Denmark in 1991. After 22 years, 5,415MW of offshore wind power has been commissioned globally by the end of 2012. More than 90% of offshore wind farms were installed in northern Europe. According to optimistic projections, a total of 80GW could be invested by 2020 worldwide, with three quarters of this in Europe [1]. Recently, Taiwan has published plans to develop offshore wind farms in the Taiwan Strait and a survey by ITRI/GEL (April, 2011) reported a total of 12GW power potential in the Strait. The Ministry of Economic Affairs in Taiwan publicly announced the implementation of "The Incentive Program of Offshore Wind Power Demonstration System" on July 3, 2012. Three offshore wind firm developers were founded to complete demonstration projects, each having 1 metrological mast and 2 wind turbines, by 2016.

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For the development of offshore wind farms, it is necessary to analyze wind characteristics and sea states for both wind energy assessment purposes and for the design of wind turbines. Conventionally, this is achieved by installing a meteorological mast with the altitude reaching the hub height of the wind turbine, however, the construction and maintenance of an offshore metrological mast is expensive (more than $10 million, e.g. FINO 1, Germany [2]). Direct measurements by a Floating LiDAR Device (FLD) are a more cost effective option to accelerate wind resource assessment for offshore wind power development.

Light Detection and Ranging (LiDAR) is a remote wind sensing technology capable of measuring three-dimensional relative wind velocity at multiple fixed distances from the optical transceiver. The sensor transmits laser beams that interact with atmospheric constituents such as dust, aerosols, and pollen, along with other particulates as the laser pulses travel through the atmosphere towards the target plane. These atmospheric particles reflect the laser light back towards the receiver of the system along the beam path, known as backscatter. In doing so, the velocity of the backscatter (which represents the speed and direction of the air mass) is imprinted onto the reflected laser signal in the form of a Doppler frequency shift. Using the concept of time-of-flight, the reflect laser signal is gated in time so that the data represents a measurement at a particular range from the optical transceiver. The accuracy of LiDAR systems has been tested against meteorological masts with wind sensors in both onshore and offshore settings [3, 4].

Experimental Arrangements

In this study, the validation of AXYS WindSentinel FLD [5] was performed at Hsing-Da harbor in south of Taiwan from October 16th to 26th, 2013. The system was deployed inside the harbor with 6 measured range gate heights setting at 50m, 70m, 90m, 110m, 150m and 200m from the lens. The measured wind speeds, wind directions and turbulent intensities were compared with measurements using a portable WINDCUBE V2 LiDAR [6], installed on the roof of the Taiwan Ocean Research Institute (TORI) building, with 6 measurement heights equivalent to the FLD. The distance between the two LiDARs was approximately 320 meters. Except for the Hsing-Da thermal power plants located at southwest of the deployed location, there are no high buildings or terrain obstacles in the area of the Hsing-Da harbor. The laser wind sensor data sets were recorded at one-second intervals. The industrial standard of 10-minutes average was employed to make a comparison. A total of 1388 data timestamp measurements were available, including wind speed, wind direction and turbulence intensity.

Results and Discussion

The present study focused on the comparison of the FLD and the land-based WINDCUBE V2 to identify the effectiveness of the motion compensation technology of the WindSentinel FLD. A statistical regression model was employed to the correlation between the two measurements. We treated data sets in statistics to mean differences (Md), standard deviation (Sd) and standard error (Se). The statistical summary of the wind speed measurements for two LiDARs in test period is shown in Table 1. The average wind speed shown in Table 1 was obtained by the FLD. It increased with the measurement height as expected. The mean differences between two LiDARs were less than 0.15m/s. In regression analysis, the values of standard deviation of the mean differences were also better than the smallest operationally significant value [3]. The R^2 (correlation coefficient) values of RG#1 to 5 were above 0.99, implying the good agreement level of confidence. The R^2 of RG#6 was 0.986, showing the best practice level (>0.98) of acceptance criteria as set by the Carbon Trust Roadmap for the Commercial Acceptance of Floating LIDAR Technology [7], the world's leading set of key performance indicators for the sector. The slightly lower correlation coefficient may be the result of the fact that the range gate measurement was near the signal strength limitation. This was demonstrated by the lower data availability for 10-minute data at this height when compared with other range gates. During the test period, the average wave height in the harbor was about 0.02 meters. In determining the effectiveness of in the WindSentinel's motion compensation, the top 50th highest wave (form 0.08 to 0.2 meters) data were selected for comparison, as depicted by red circles in Figure 1. The R^2 value (red text) of these data was lower than that of total data for each range gate. This may be caused by the compensation sensor, equation or operation, etc. However, the R^2 values were still higher than 0.95, indicating that the floating LiDAR system can effectively measure and immediately correct the influence of wave oscillation in the sea.

Table 1 Statistical summary of Wind speed difference

Range Gate	Ave. Wind Speed (m/s)	Md (m/s)	Sd	Se (%)
50m	4.74	-0.10	0.40	1.1
70m	4.92	-0.12	0.38	1.0
90m	5.27	0.06	0.34	0.9
110m	5.47	0.15	0.36	1.0
150m	5.64	0.11	0.34	0.9
200m	5.81	0.07	0.33	0.8

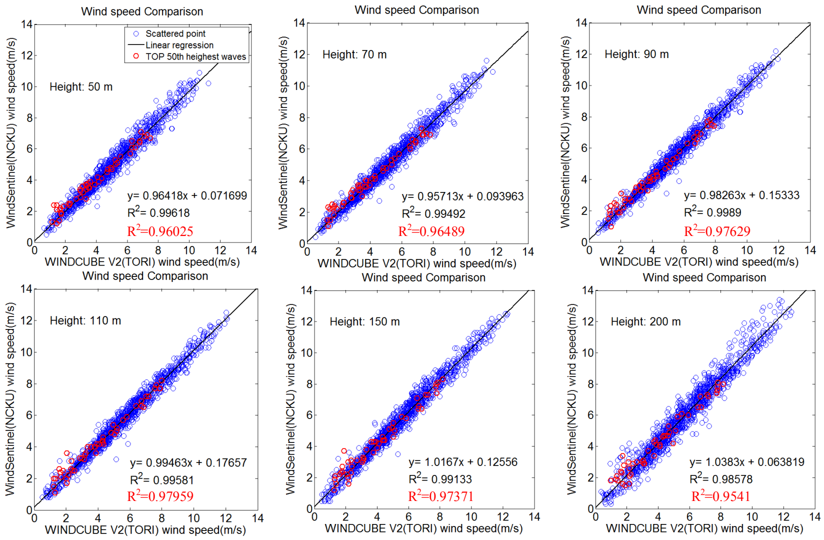

Figure 1 Wind speed comparisons at 6 range gates

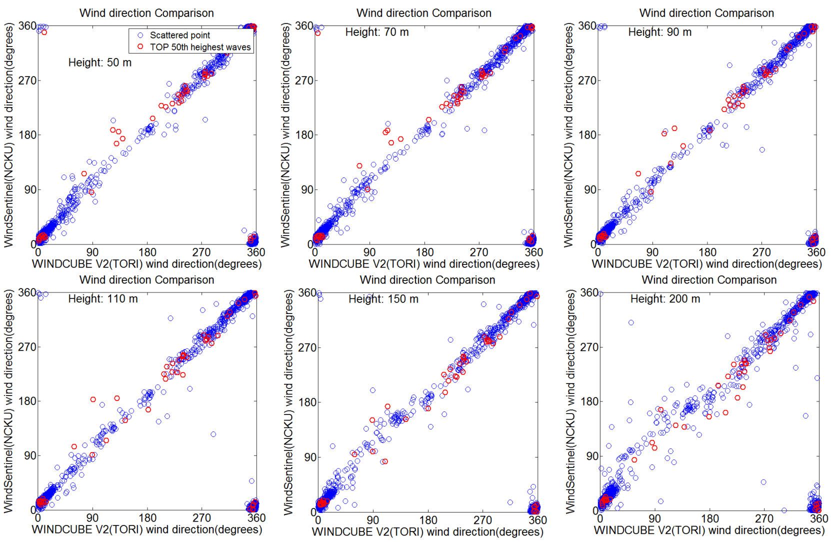

Figure 2 Wind direction comparisons at 6 range gates

Comparisons of the wind direction detected by the two LiDARs are shown in Figure 2. It is found that the two comparable data sets have high correlation; and that especially in the range of 330 to 30 degree, the wind direction measurement results agree with each other. According to the report of Bureau of Meteorology, the prevailing wind has seasonal variation in Taiwan. In autumn and winter, the wind was the northeast monsoon. Taiwan's Central Mountain Range has sufficient height to block most of onshore northeast monsoon, therefore, the northeast wind enters the Taiwan Strait from the north and its wind speed is increased, because the mountain restriction from both sides causes the Venturi effect. This is the main reason that Taiwan Strait has the potential to be one of the best offshore wind farms in the world. The deployment site is located at Hsing-Da harbor in the south of Taiwan, as shown in Figure 3. During the test period, the wind characteristic was the monsoon blowing from the sea. In the test region, the terrain was in a form of a diffuser. The wind direction therefore, was demonstrated to have changed to follow the mountain, from north to south.

Figure 3 Taiwan Strait monsoon patterns and test location in Hsing-Da harbor

Conclusion

Although the application of FLD on offshore wind measurement is more convenient, cheaper and flexible, so far the data from FLDs has not been certified by IEC [8]. The present study of an FLD provides an initial validation to ensure the function and accuracy of the floating system. Measurement results showed good agreements between the FLD and the land-based LiDAR in both ten-minute averaged wind speed and wind direction. The accuracy of the measurement by the FLD and the success of motion compensation function under the condition of small waves were then justified. An overall validation of the FLD is being planned to compare with an offshore metrological mast in the near future. This preliminary validation and measurements shows the usefulness of the floating LiDAR for the offshore wind resource assessment applications.

Acknowledgment

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