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Special Report

FLOATING-LIDAR SYSTEM

Julia Gottschall, Gerrit Wolken-Möhlmann, Thomas Viergutz, Claudia Rudolph, Bernhard Lange

Introduction

A general challenge for offshore wind resource assessments is the lack of suitable data for prospecting purposes. Offshore meteorological (met.) masts at future wind farm sites are scarce, and if new masts are erected, they pose a significant capital and logistical commitment for the developers. Moreover, the installed masts rarely reach the hub heights of future offshore WTs, which results in additional uncertainties when vertically extrapolating the mast measurements.

In this connection, floating lidars represent a cost-effective alternative to an offshore met. mast, lowering first of all the CAPEX of the project. Additional benefits are a shorter process of approving in terms of lower requirements for a corresponding marine licence application, a significantly smaller disturbance of the environment, and a greater flexibility of the system enabling a deployment at different locations.

A (buoy-based) floating lidar system is here defined as a lidar device integrated in or installed on top of a buoy. The offshore environment corresponds to a major challenge to the lidar instrument but also to the complete system: the harshness of the environment sets requirements on all system components, its non-stability (with changing water depths, wave conditions and ocean currents) requires a certain adaptability, and the limited access affects the availability, and finally also the reliability, of the system. Power supply may be a critical issue, and needs to be ensured by a technically mature approach – similarly as data storage and communication.

Furthermore, the quality of the lidar measurements – in terms of accuracy and precision – is affected by the motion of the buoy. Platform-typical motions, including up to six degrees of freedom, may cause systematic measurement errors, appearing e.g. as a wrong projection of the wind velocity vector, a confused wind direction measurement, added velocity components, increased lidar turbulence intensity or a wrong measurement height.

The development of suitable and for an application in the offshore wind industry optimized floating-lidar systems has made considerable progress during the last few years, and has resulted in realisations that vary not only in the adapted lidar and buoy technologies but also in the used concepts for installation or data handling, and in particular the consideration of motion effects on the recorded data.

R&D project "Offshore Messboje"

Fraunhofer IWES has been engaged in the development of floating-lidar concepts since 2009. An own correction algorithm for motion compensation was developed and tested both in simulations and first onshore motion tests. In 2011 the R&D project 'Offshore Messboje' was granted by the BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) within that an own and novel floating-lidar system, were to be designed, built and tested.

The prototype of the Fraunhofer IWES Wind Lidar Buoy was completed in May 2013, and as a start tested in the inner harbour near the Fraunhofer IWES buildings in Bremerhaven for a couple of weeks. The final performance of the system was verified in an offshore test next to the met. mast FINO1 in the German North Sea from August to October 2013. After concluding the test campaign, the Fraunhofer IWES Wind Lidar Buoy was introduced and presented to the offshore wind industry at the EWEA Offshore event in Frankfurt in November, and the project was successfully completed by the end of the year 2013.

Wind Lidar Buoy next to FINO1 met. mast

Figure 1: Fraunhofer IWES Wind Lidar Buoy before and during its first offshore trial. (Photographs: Caspar Sessler, Fraunhofer IWES))

Technical specifications of the system

The Fraunhofer IWES Wind Lidar Buoy – see figure 1 for pictures from the first offshore trial – is a floating-lidar system integrating a Windcube® v2 lidar device in an adapted marine buoy.

The basic components of the system are:

- the body of the buoy with an overall height of 7.2 m, a diameter of 2.55 m, and a weight of 4.7 t, that is designed according to the dimensions of a standard 'Leuchtfeuertonne' (LT81);
- the lidar device, measuring the wind vector for up to 12 range gates between 40 m and approximately 250 m with a data sampling rate of 0.7 s, in a custom-made housing;
- an autonomous power system based on three micro-WTs, PV panels and AGM batteries for energy storage;
- a data transfer protocol comprising a wireless connection (with a range of up to 300 m) for data transfer and a satellite connection for the transfer of selected status data and alarms;
- the integration of additional sensors as e.g. motion sensors, a weather station for measuring different meteorological parameters and a bottom-based AWAC current meter for measuring waves and currents.

The correction of the recorded lidar data, using the simultaneously measured data from a satellite compass and an AHRS (Attitude Heading Reference System), was implemented as part of the post-processing of the data.

Offshore test next to FINO1

The performance of the Fraunhofer IWES Wind Lidar Buoy was tested in a nine-weeks offshore measurement campaign in an environment that is representative for the later application – next to the research platform FINO1 located in the German North Sea about 45 km to the north of the East Frisian island Borkum. The water depth at the location is approximately 30 m. The prevailing wind direction is South-West. The direction of the sea currents is governed by the prevailing tide.

The Fraunhofer IWES Wind Lidar Buoy was installed on 2 August 2013 at the location N 54° 01.00’ E 6° 34.89’, i.e. north-west of the met. mast in a distance of about 450 m. The bottom-based AWAC system, recording in parallel the prevailing sea conditions, was installed during the first visit for inspection on 28 August 2013 at the location N 54° 00.99’ E 6° 34.63’. Both systems were recovered according to plan on 6 October 2013.

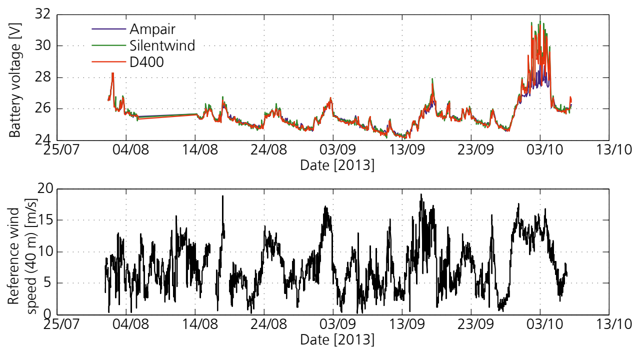

Figure 2: Transmitted status data (voltages of battery banks assigned to micro-WTs) during offshore test next to FINO1, in relation to reference wind conditions.

The status of the floating-lidar system during the offshore trial was monitored on the basis of the satellite messages that were transmitted every two hours, and included data on the amount of available stored energy (voltages from the three battery banks, one attached to each micro-WTs as essential energy generators) and a few additional signals indicating the operability of the system. Figure 2 shows the transmitted voltage data in relation to the prevailing wind conditions, reference wind speed at 40 m height measured at the FINO1 met mast. The battery voltages clearly go up and down with the changing wind speed but never reach their pre-defined minimum level, ensuring the operation of the floating-lidar system for the complete test period.

For an assessment of the accuracy and precision of the floating-lidar wind measurements, recorded 10-min-mean horizontal wind speeds were compared with the corresponding reference values from the mast, measured by cup anemometers at the same height – see figure 3 for the data measured at 100 m height. The relevant valid measurement sector had to be reduced due to significant mast effects to the wind direction range 280° to 350°, all other data were filtered out. A linear regression of the remaining data shows a very good correlation, similar to the results of an onshore lidar-mast comparison, where no additional motions affect the measurements and the distance between mast and lidar device is typically only a few meters.

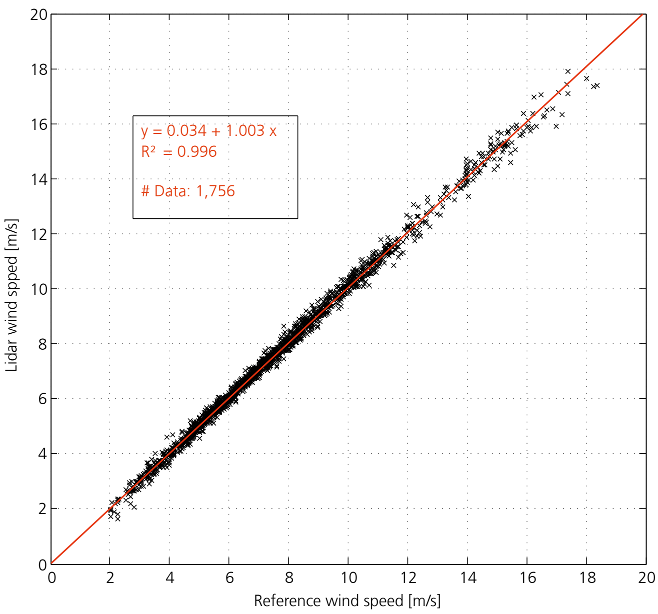

Figure 3: Correlation between measured 10-min mean wind speeds from floating-lidar device and reference cup anemometers at 100 m measurement height.

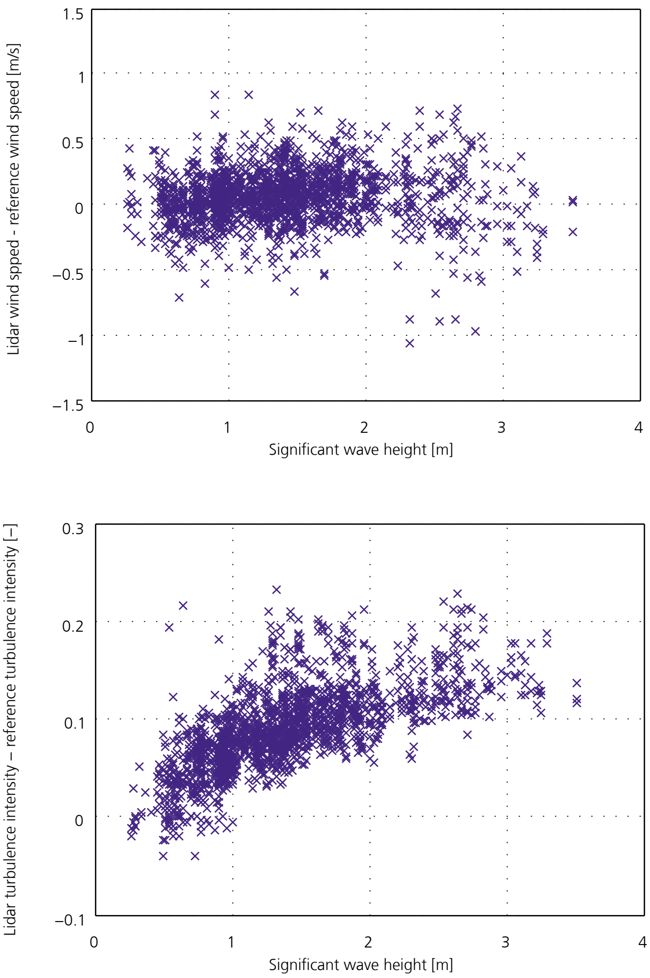

Figure 4: Deviation in measured (a) 10-min-mean wind speeds and (b) TI values from floating lidar and cup anemometer versus simultaneously recorded (30-min-mean) significant wave height – for 100 m measurement height.

In figure 4a the same data are shown, this time as a difference lidar wind speed minus reference mast wind speed, in relation to the simultaneously recorded significant wave height. Wave data were recorded as 30-min-mean data and assigned to the respective 10-min-mean wind data. The plot shows no trend or significant dependence of the measured mean wind speeds from the floating-lidar system on the prevailing wave conditions. Though significant wave heights, averaged over 30 min, of up to 3.5 m do not correspond to severe winter storms, the results definitely give a positive and promising indication.

Figure 4b shows the recorded difference in Turbulence Intensity (TI) between lidar and reference mast measurements again in relation to the prevailing significant wave heights. This time a clear trend, depicting a larger positive deviation of the lidar values from the reference for higher wave heights, is visible for the uncorrected floating-lidar data. This significant influence of the sea conditions can be compensated by applying the motion correction algorithm developed by Fraunhofer IWES. Figure 5 shows the correlation between lidar and reference TI for different stages of motion compensation, including different sets of degrees of freedom. The correction that considered the most detailed information on the motions of the system gives the best results and a correlation that is more than acceptable for a lidar-mast comparison in terms of turbulence.

Best practices for the application of floating-lidar systems

As floating-lidar systems become more and more interesting for the offshore wind industry – holding out the prospect of less expensive offshore wind measurements, more accurate and precise wind resource assessments and better yield estimations resulting in benefits with respect to the financing of offshore wind projects – there is a need for best practices and more detailed protocols for the application of the technology. In 2012, as part of the IEA Wind Task 32 on Wind Lidar Systems for Wind Energy Deployment, a working group was formed to collect experiences that are made with the technology and their application, and prepare a first version of a Recommended Practices document by the end of 2014. The working group consists of or is supported by basically all relevant players on the market for floating-lidar applications and is coordinated by Fraunhofer IWES. In parallel, the Carbon Trust together with the partners of the Offshore Wind Accelerator have developed a roadmap for the commercial acceptance of floating LIDAR technology that was for the first time published in November 2013. The two working groups are collaborating to a certain level and exchange information regularly.

Conclusions

The Fraunhofer IWES Wind Lidar Buoy is a floating-lidar system integrating a Windcube v2 pulsed lidar device in an adapted marine buoy. The concept of the system was developed within the BMU-funded R&D project 'Offshore Messboje'. A first prototype was completed in 2013 and tested in an offshore test next to the FINO1 met. mast from August to October.

The results of the nine-weeks test show a very good correlation for the recorded mean wind speeds for the floating-lidar device with the met mast data. Measured turbulence intensities are significantly influenced by the system motions, the effects can be corrected for with the motion-correction algorithm developed by Fraunhofer IWES however.

Floating- lidar is a promising technology for the offshore wind industry, with the potential of saving significant costs in the project development and planning phase, and the Fraunhofer IWES Wind Lidar Buoy was proven to be a suitable concept for this task meeting the requirements of a high data accuracy and a good system availability offshore.

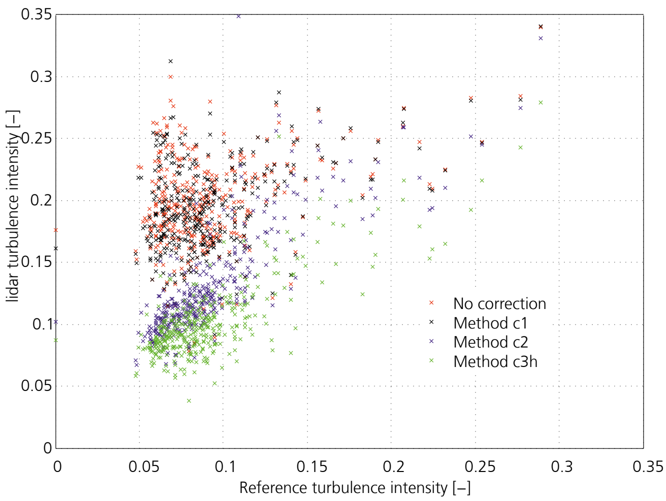

Figure 5: Correlation between measured Turbulence Intensity (TI) from floating lidar and reference cup anemometers at 100 m measurement height for different correction approaches. Method c1 only considers the recorded yaw angles for the correction of the lidar data, c2 additionally the horizontal tilt angles, i.e. roll and pitch, and c3h in additon the heave of the buoy.

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