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Dynamic Motion Effects and Compensation Methods of a Floating Lidar Buoy

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Abstract

With the growing number of floating lidar systems that are currently being developed in order to provide a possibility for reliable, flexible and affordable offshore wind measurements, methods are needed to identify and compensate uncertainties in the wind speed measurement of the lidar due to the wave induced motions. This poster presents a simulation tool for such a motion influenced lidar device. Furthermore the effects of different simulated motion conditions on the lidar wind measurement and related data compensation methods will be presented and compared.

Motion and Lidar Simulation Tool

The simulation model consists of a combination of constant or turbulent wind fields and of a wave motion influenced lidar system. The input parameters for the motion of the lidar system can be freely chosen within the Matlab based simulation tool. The rotations and translations which result in 6 degrees of freedom (DOF) of the system can be simulated independently or combined. In a simple example the lidar is assumed to follow the wave surface, which is simulated using the Airy wave theory. Where η is the wave height, h_η is the wave peak-to-peak amplitude, k_η the angular wavenumber and T_p the wave period.

$$\eta(x,t) = \frac{h_\eta}{2}\cos\left(k_\eta x - \frac{2\pi}{T_p}t\right) \qquad (1)$$

Based on the simulated lidar raw data and a simplified wind and lidar model with flexible measurement trajectories, the wind vector can be estimated using a model based wind field reconstruction method [1]. The plots below show possible measurement trajectories for the moving lidar (red) compared with a fixed lidar system (grey) for $T_p = 5\,\mathrm{s}, h_\eta = 4\,\mathrm{m}$).

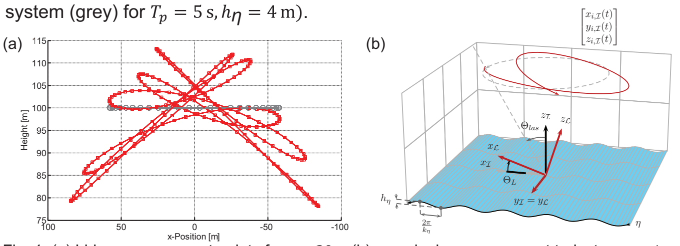

Fig. 1: (a) Lidar measurement points for $t = 20\,\mathrm{s}$, (b) one single measurement trajectory $t = 1\,\mathrm{s}$, for a fixed (grey) and moving (red) lidar with focus length $f = 100\,\mathrm{m}$.

Model Based Reconstruction Method

Earlier works [2] and [3] have shown the need for a motion compensation. However the benefit of such techniques is highly depending on the lidar system, the type and magnitude of the motions as well as the meteorological conditions and the temporal resolution of the measurements. This work presents a wind field reconstruction method which serves as motion compensation algorithm.

Model **B**ased **A**pproach using **R**otational and **T**ranslational DOF (MBART)

In contrast to the standard VAD technique this method uses not only the local coordinates in the lidar coordinate system L to calculate the line-of-sight wind speed v_{los} for a focus length f, but instead the transformed coordinates of the inertial system I, taking into account lidar displacement and rotation (transformation matrix T_{LI}, see also Fig. 1b).

$$v_{los} = \frac{1}{f}\begin{bmatrix}x_I\\y_I\\z_I\end{bmatrix}\begin{bmatrix}u_I\\v_I\\w_I\end{bmatrix} \quad \text{with} \quad \begin{bmatrix}x_I\\y_I\\z_I\end{bmatrix} = T_{LI}\begin{bmatrix}x_L\\y_L\\z_L\end{bmatrix} + \begin{bmatrix}x_{LI}\\y_{LI}\\z_{LI}\end{bmatrix}. \qquad (2)$$

Hence the error of the VAD technique can be reduced if the lidar displacement, velocity and inclination are known. In this way the estimated wind speed v_0, the horizontal inflow angle α_H and vertical linear shear δ_V can be found by minimizing the error between the measured wind speed v_{los} and the estimated wind speed $\hat{v}_{los}$. Here, an 3D inhomogeneous flow model within the wind coordinate system W is used, which is rotated within the inertial frame by α_H:

$$\hat{v}_{los} = \frac{x_W}{f}(v_0 + \delta_V z_W) \quad \text{with} \quad \begin{bmatrix}x_W\\y_W\\z_W\end{bmatrix} = T_{IW}(\alpha_H)\begin{bmatrix}x_I\\y_I\\z_I\end{bmatrix}. \qquad (3)$$

The following minimization problem is solved for every circular scan.

$$\min_{v_0,\alpha_H,\delta_V} \|v_{los} - \hat{v}_{los}\|_2 \qquad (4)$$

Parameter studies

In this analysis a cw-lidar focusing in $z_{I,L} = 100\,\mathrm{m}$ is simulated (50 points/s, circular scan, half opening angle 30°). The following plots show the results for four measurement cases of a turbulent wind field with a mean wind speed of 10 m/s and turbulence intensity of 21 % as well as IEC-conform shear of $\alpha = 0.14$ with varying T_p and h_η simulated for $t = 20\,\mathrm{s}$. In this method the lidar system inclination and heave displacement are calculated by assuming that the floating lidar system is aligned with the sea surface and only able to change its vertical position ($x_L = y_L = 0$) and inclination in pitch direction.

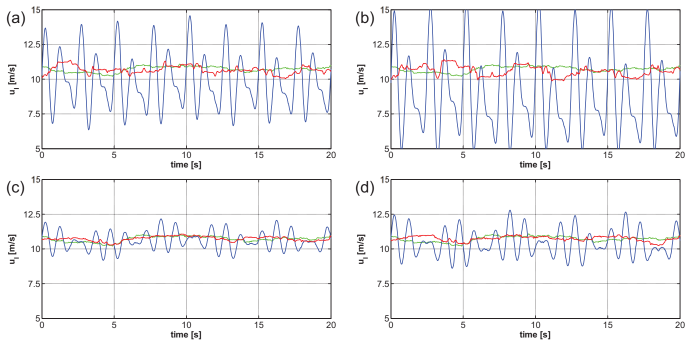

Fig. 2: (a) $T_p = 5\,\mathrm{s}, h_\eta = 4\,\mathrm{m}$, (b) $T_p = 5\,\mathrm{s}, h_\eta = 6\,\mathrm{m}$, (c) $T_p = 8\,\mathrm{s}, h_\eta = 4\,\mathrm{m}$, (d) $T_p = 8\,\mathrm{s}, h_\eta = 6\,\mathrm{m}$ VAD (blue), MBART (red), VAD fixed (green).

It can be noted that depending on the wave motions the VAD technique shows varying errors. However the model based approach reduces these errors significantly and shows good wind velocity estimation for different wave motions.

A parameter study ($t = 60\,s$ for each case) with T_p ranging from $4\,\mathrm{s}$ to $20\,\mathrm{s}$ in steps of $1\,\mathrm{s}$ and h_η ranging from $0\,\mathrm{m}$ to $10\,\mathrm{m}$ in steps of $0.5\,\mathrm{m}$ has been carried out to identify the behaviour of the model for a wider wave spectrum. The criteria for wind speed error estimation has been selected as the ratio of the mean wind speed $\bar{u}_I$ of the VAD and MBART model to the mean wind speed $\bar{u}_{I,fixed}$ of a fixed lidar.

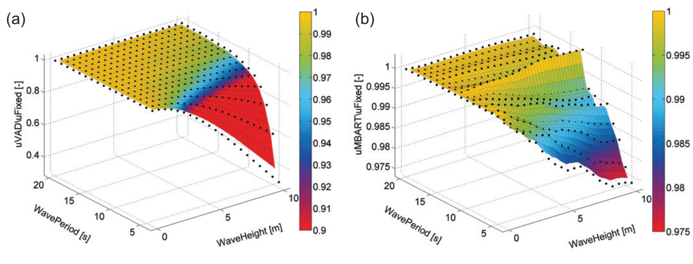

Fig. 3: Parameter studies for the (a) VAD and (b) MBART method.

For the VAD model the error is higher than 10 % for large ranges of the wave spectrum whereas the MBART model results in a very good wind speed estimation with deviations of less than 2,5 % even for extreme wave conditions.

Conclusions & Outlook

This work illustrates that the presented model based reconstruction method is capable of reducing the errors resulting from motion affected lidar measurements of inhomogeneous wind fields. Next steps include the integration of all 6 DOF and the verification of the model with real measurement data.

References

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