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Perspectives on lidar assisted floating wind turbine control, relying on an enhanced embedded wind field reconstruction solution

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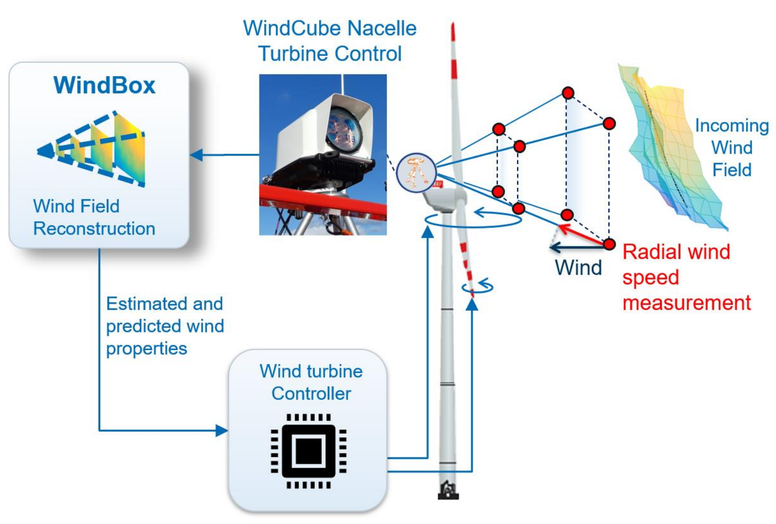
CONTEXT

Lidar Assisted wind turbine Control (LAC) benefits:

- Reduced fatigue and extreme loads
- Increased energy production
- Design enhancement perspectives

To do so, relevant information of incoming wind is needed by the controller including wind speed, wind direction, turbulence intensity, shears and gust detection.



DEVELOPED SOLUTION

In partnership with Vaisala, IFPEN has developed a high-performance embedded processing software application, currently deployed and available in the WindCube Nacelle Turbine Control (WCN-TC), named "**WindBox**" Reconstruction algorithm and composed of 3 main steps and features:

- **Nacelle angle correction** (for floating designs): to handle the moving LiDAR position and attitude induced by a floater motion as observed in Figure 1, locations of the LiDAR measurements are derived in terrestrial reference from a nacelle Inertial Measurement Unit (IMU) and appropriate geometric corrections ;

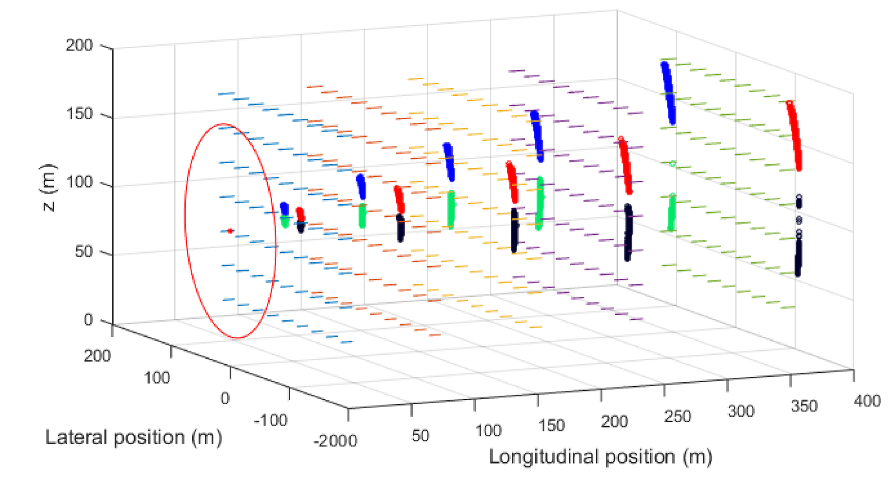


Figure 1: Representation of the mesh upstream of the rotor and LiDAR measurement locations swept, for a spar design

- **3D Wind Reconstruction:** a 3D reconstruction of the incoming wind field is based on an online optimization described in [1]. A substantial advantage of this approach is the **robustness to outliers and data loss** that may be caused by obstacles such as the turbine blades. Several useful metrics are obtained from the wind field reconstruction, in particular: Rotor Averaged Wind Speed (**RAWS**), Direction (**RAWD**), Turbulence Intensity (**TI**), **shear** and **veer**, along with their **quality flags** ;
- **Free wind preview at rotor plane:** considering the estimated wind properties at each measurement distance, especially RAWS, a **turbine induction effect** is estimated. The corresponding velocity deficit is then used to build a realistic wind propagation sequence to the rotor plane and derive a Rotor Average Wind Speed preview (**RAWS preview**). The RAWS preview is representative of the turbine mechanical loads and power production. The RAWS preview is available as a time series with 0-, 1-, 2- and 5-seconds advance. The processing is illustrated below in **Figure 2**.

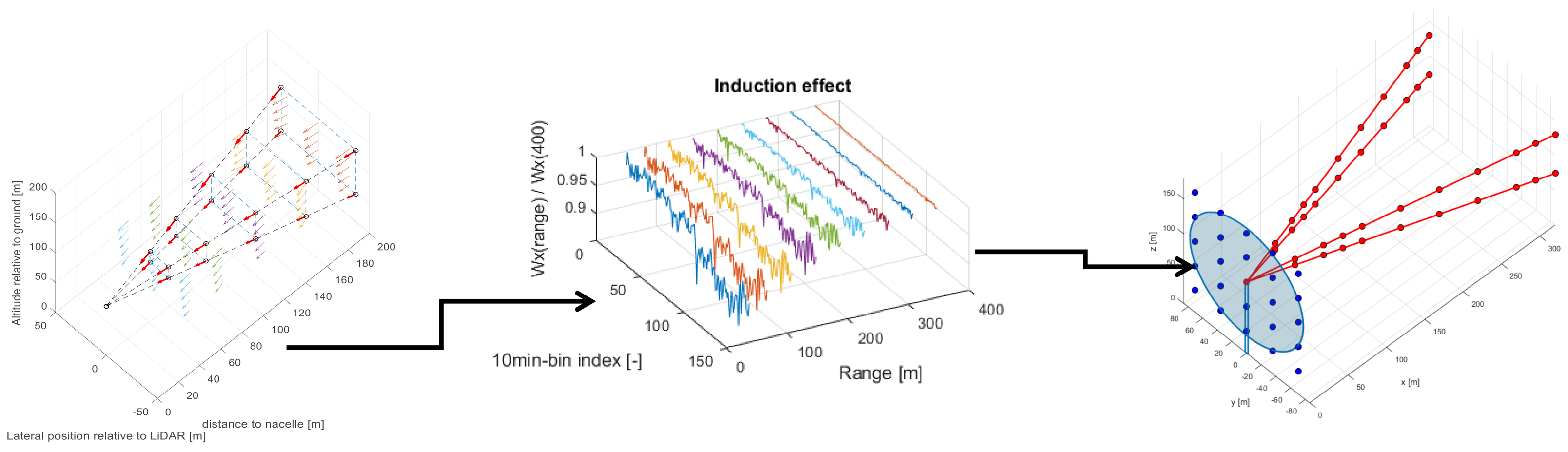


Figure 2: Illustration of the induction zone effect identification, allowing for the derivation of a free wind preview at rotor plane

PERFORMANCE RESULTS

Several experimental evaluations have been achieved during the ANR SmartEole collaborative project campaigns [2] and by turbine OEM. Below shared results are obtained from SmartEole campaigns.

- Figure 3 shows the superimposition of the "RAWS from SCADA" (taken as reference) and the "0s" and "5s" RAWS preview time series. Figure 4 shows the spectral coherence of the "0s" RAWS preview with the "RAWS from SCADA" compared to a "Turbulence Frozen Hypothesis (TFH) preview" obtained at 100m upwind of the rotor plane. These plots emphasize **the accuracy of the wind preview** together with the advantage of relaxing the TFH.

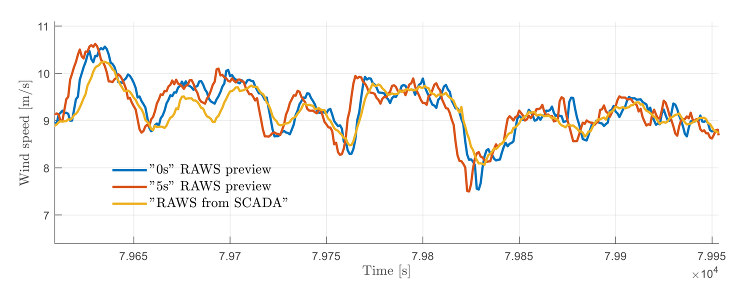


Figure 3: Time series of the 0s and 5s RAWS preview compared to the reference RAWS from a 2MW wind turbine electrical power

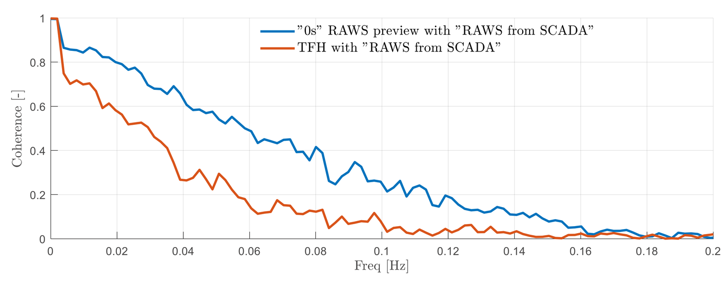


Figure 4: Temporal coherence between the RAWS preview at 0s advance and the RAWS from the turbine SCADA as a function of frequency

- An IFPEN LAC strategy [3] is compared in simulation with a baseline feedback controller. Values are computed over the set of DLC 1.1-1.5 IEC 61400-1, with average wind speed from 7m/s to 25 m/s. Performance results are summarized in Table 1 below, emphasizing the added value of LAC, especially for structural Damage Equivalent Loads (DEL).

RESULTS			
Type of controller	Baseline Feedback	LAC using RAWS measurement	LAC using RAWS preview
Wind speed measurement availability	✗	✓	✓
LiDAR wind speed prediction availability	✗	✗	✓
Rotor speed standard deviation	0,686 rpm	0,582 rpm	0,572 rpm
Blade pitch standard deviation	3,98 deg	4,18 deg	4,02 deg
Short-term DEL for root blade moment	100%	92%	87%
Short-term DEL for fore aft tower base moment	100%	79%	68%
Short-term DEL for side-to-side tower base moment	100%	81%	70%
Energy production (in operating conditions - 140 min)	3525 kWh	3564 kWh	3580 kWh

Table 1: Table summarizing the benchmark of LAC strategies vs a baseline feedback controller

PROSPECT FOR FLOATING WIND TURBINES

The added value of the angle correction algorithm is assessed in simulation with the application of a static tilt to the WindCube Nacelle Turbine Control.

In **Figure 5**, The comparison of the WindBox outputs with and without the use of the correction feature, against horizontal reference, illustrates the positive impact on RAWS **mean error mitigation**.

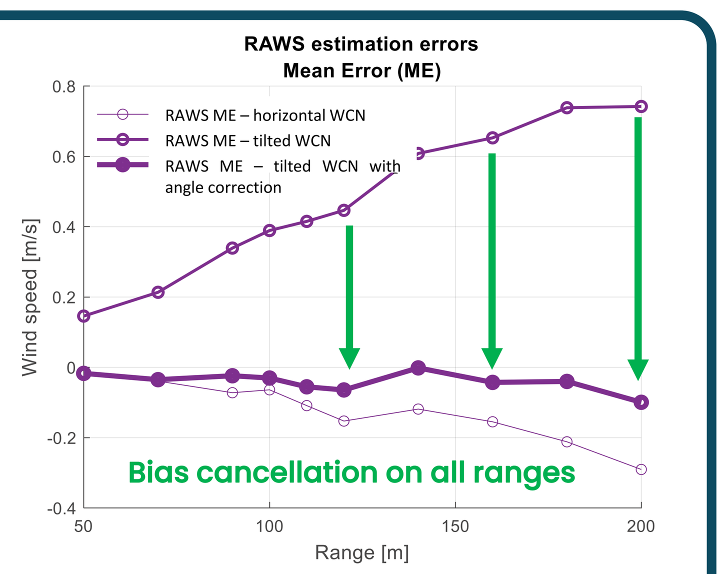


Figure 5: Comparison, in simulation, of the RAWS mean error in presence of static tilt compared with a horizontal reference, with and without correction

TAKEAWAY

- WindBox solution has been tested in experimental campaigns.
- Noticeable enhancements, like data availability increase, have been observed. In addition, a RAWS preview at rotor plane is provided as a new data. In combination with IFPEN Lidar Assisted Control,, the approach shows positive results regarding loads reduction.
- Application to **floating wind turbines** and associated added value is currently evaluated, with promising intermediate results.
- WindBox is now commercially available and provided by Vaisala with the WindCube Nacelle Turbine Control.

[1] Guillemin, F., Nguyen, H.N., Sabiron, G., Di Domenico, D., Boquet, M. (2018) 'Real-time three-dimensional wind field reconstruction from nacelle LiDAR measurements', J. Phys.: Conf. Ser.1037, 032037
[2] SMARTEOLE collaborative project (2015-2019), ANR-14-CE05-0034
[3] Di Domenico, D., Guillemin, F., Nguyen, H.-N., Sabiron, G. (2018) 'Turbine loads and production optimization through Lidars assisted wind turbine control', SmartEole colloquium