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Enhancement of Lidar feed-forward control technology through embedded wind reconstruction and preview solution

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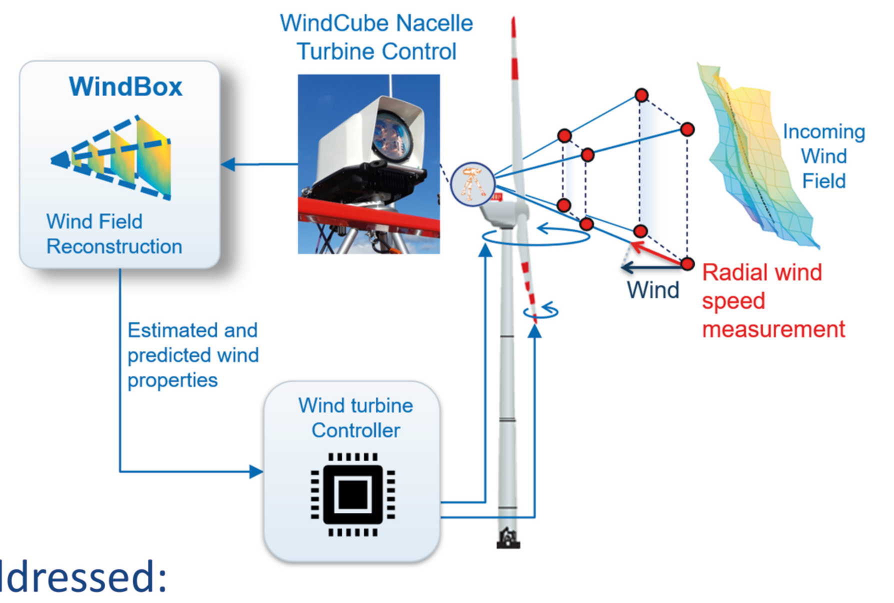
Abstract

Lidar Assisted wind turbine control (LAC) leads to several benefits, including:
- Reduced fatigue and extreme loads
- Increased energy production
- Design enhancement perspectives such as longer blades, reduced CAPEX, wind class upgrade

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



Several challenges and issues need to be addressed:
- Reliable estimation and **prediction of incoming wind**
- **Availability and accuracy** of processed data
- Robustness to various wind configurations
- **Robustness to data loss** (Atmosphere back scattering, blade blocking)
- Limited computational resource

➔ IFPEN has developed, in partnership with Vaisala, a high-performance embedded processing software, currently deployed and available in the WindCube Nacelle Turbine control (WCN-TC), as "**WindBox**" Reconstruction algorithm.

Developed solution

A two-stage algorithm is implemented, the first one dedicated to wind information reconstruction at distances of measurement, the second one using it to derive wind previews at rotor plane.

3D Wind Reconstruction: **f**irst, a 3D reconstruction of the incoming wind field is based on an online optimization, that was exposed in [1]. A great advantage of this approach is the **robustness to outliers and data loss** that may be caused by obstacles such as the turbine blades. This leads to **improved accuracy and availability** of the output data, such as illustrated in **figure 1**. Moreover, the implementation of this stage provides a standard deviation of the estimation, from which an **automatic quality index** is derived. Several useful metrics are derived 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**.

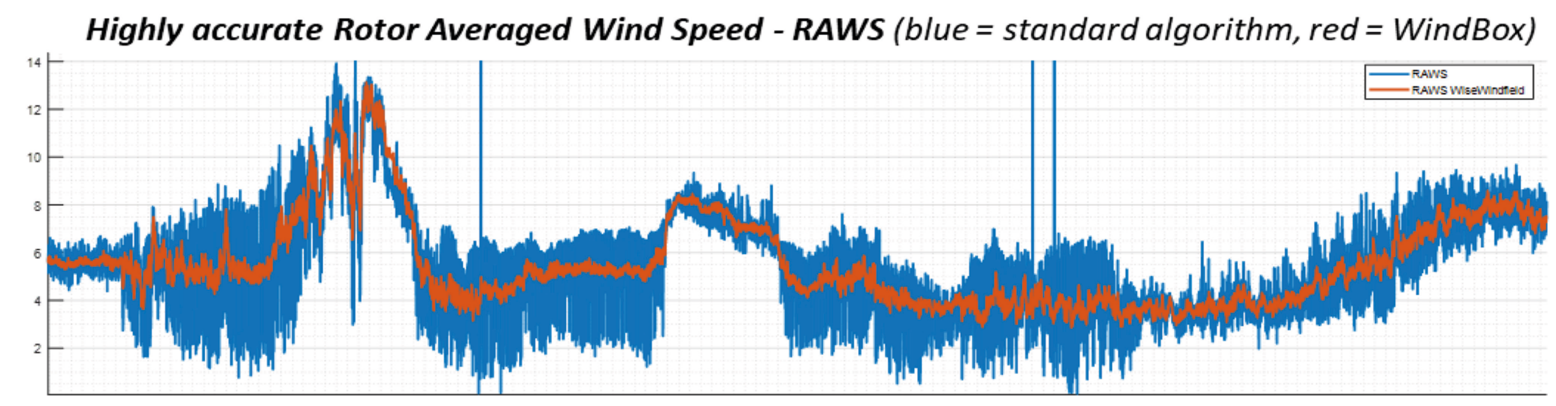


Figure 1: Comparison of the Rotor Average Wind Speed provided by a state of art reconstruction (blue) with the one provided by the WindBox algorithm (red)

Free wind preview at rotor plane: Considering the estimated wind properties at each measurement distance, especially RAWS and RAWD, the second stage implements a calculation of the **turbine induction effect**. The corresponding velocity deficit estimate 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. This quantity can be understood as a short-term forecast of the rotor average free wind speed that pass the rotor plane. The RAWS preview is available as a time series with 0, 1, 2 and 5 seconds advance, further noted respectively "0s", "1s", "2s", "5s" RAWS preview.
The processing is emphasized below in **figure 2**.

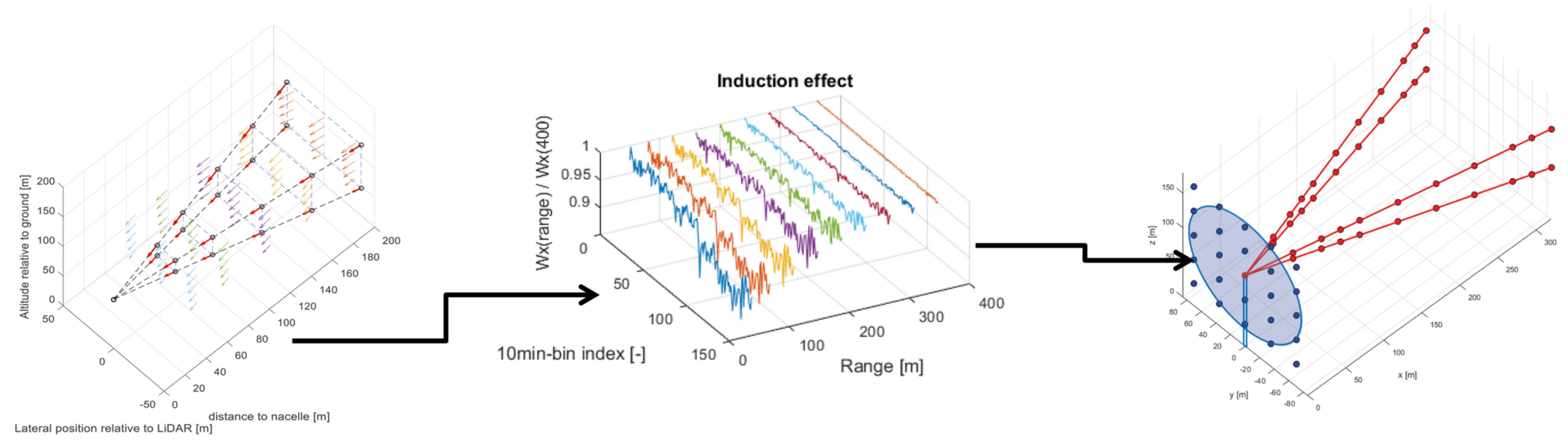


Figure 2: Illustration of the induction zone effect identification, allowing for the derivation of a free wind preview at rotor plane

Performance evaluation method

To validate the representativeness of the RAWS preview time series, a reference must be considered. To do so, a realistic wind speed model is developed using SCADA data, turbine parameters, torque map and dynamic equations. An adapted inversion of this model, through a minimization, leads to the "Rotor Average Wind Speed from SCADA (**RAWS from SCADA**)" time series, expected to be representative to the turbine production and loads.

The added value of the RAWS preview is quantified by comparing, against the reference, with a standard Turbulence Frozen Hypothesis propagation-based preview (**TFH Preview**), using the RAWS obtained at 100m upwind the rotor plane.

Experimental findings

Several experimental evaluations have been achieved, during the ANR SmartEole collaborative project campaigns [2], and by OEMs as Vaisala customers. Below shared experimental results are obtained from SmartEole campaigns.

Figure 3 shows the superimposition of the "RAWS from SCADA" and the "0s" and "5s" RAWS preview as time series. **Figure 4** shows the spectral coherence of the "0s" RAWS preview with the "RAWS from SCADA", compared to "TFH preview". These plots emphasize **the accuracy of the wind preview** together with the advantage of relaxing the TFH.

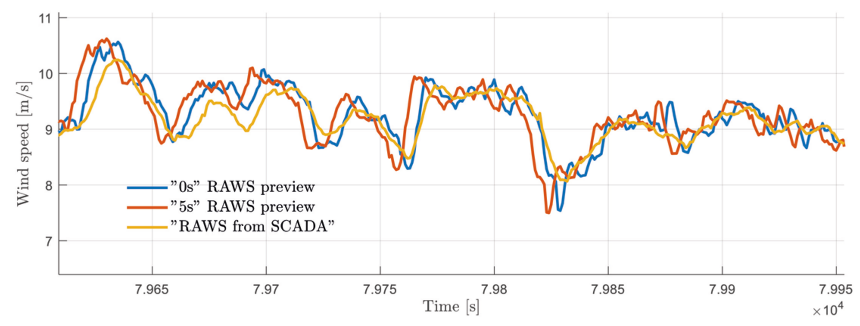


Figure 3: Time series of the 0s and 5s RAWS preview compared to the reference RAWS from a 2MW wind turbine electrical power

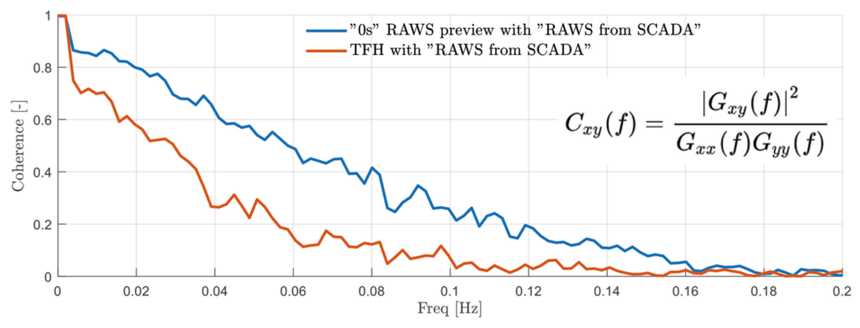


Figure 4: Temporal coherence between the RAWS preview at 0s advance and the RAWS from the turbine SCADA as a function of frequency

Figure 5 emphasizes the repeatability of the observed performance, with regards to the **higher coherence** of the "Free RAWS preview" with the "RAWS from SCADA", than the "TFH preview", for several production and wind conditions.

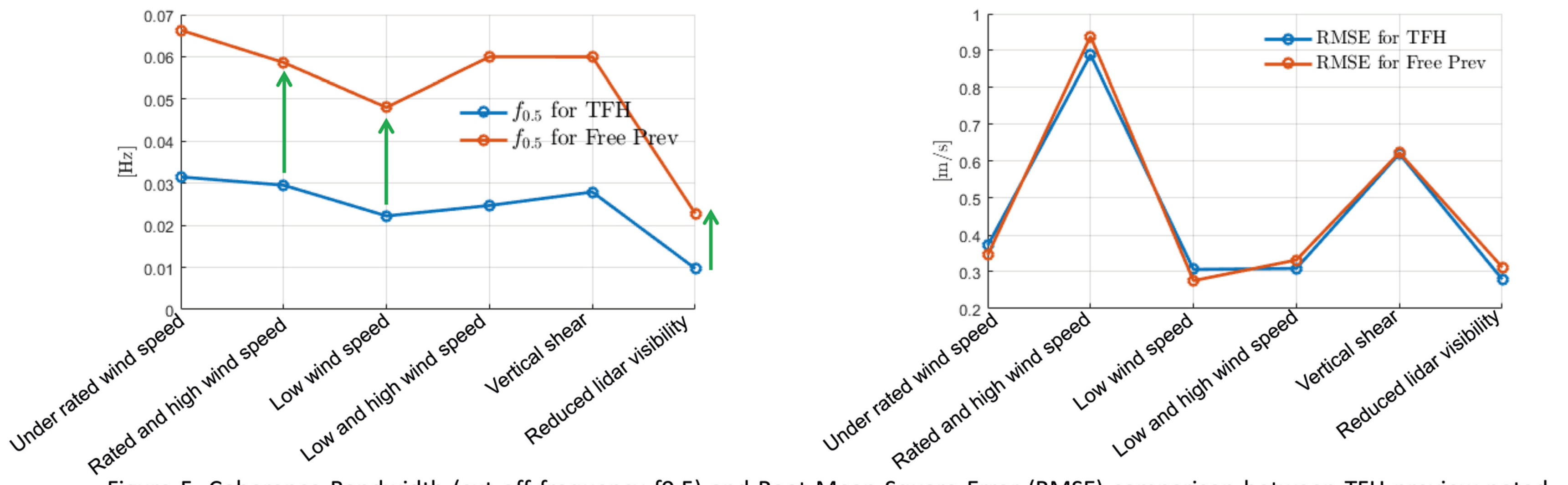


Figure 5: Coherence Bandwidth (cut-off frequency f0.5) and Root Mean Square Error (RMSE) comparison between TFH preview noted "TFH", and Free RAWS Preview at 0s advance noted "Free Prev", for several wind conditions mentioned on the "x" axis

Conclusion and application perspectives

The WindBox innovative and robust algorithms have been embedded into the "WindCube Nacelle Turbine Control" processing unit and widely tested during several experimental campaigns.

Noticeable enhancements under harsh conditions, like data availability increase, have been observed. In addition, new quantities such as wind speed preview at rotor plane are provided as input to adapted feed-forward lidar assisted controllers.

Several LAC strategies of the state of art have shown, in simulation, promising results regarding loads alleviations [3][4]. Campaigns for load reduction demonstration are being planned by OEMs to fully quantify the added value of the wind preview for advanced LAC solutions on their own assets.

"WindBox" is now commercially available and provided by the Lidar manufacturer Vaisala.

References

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[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

[4] Wai Hou Lio, A., Meng, F., Larsen, G.C. (2022) 'On LiDAR-assisted wind turbine retrofit control', J. Phys.: Conf. Ser. 2265, 022060

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