Control-Oriented Wind Direction Modelling

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Introduction and Research

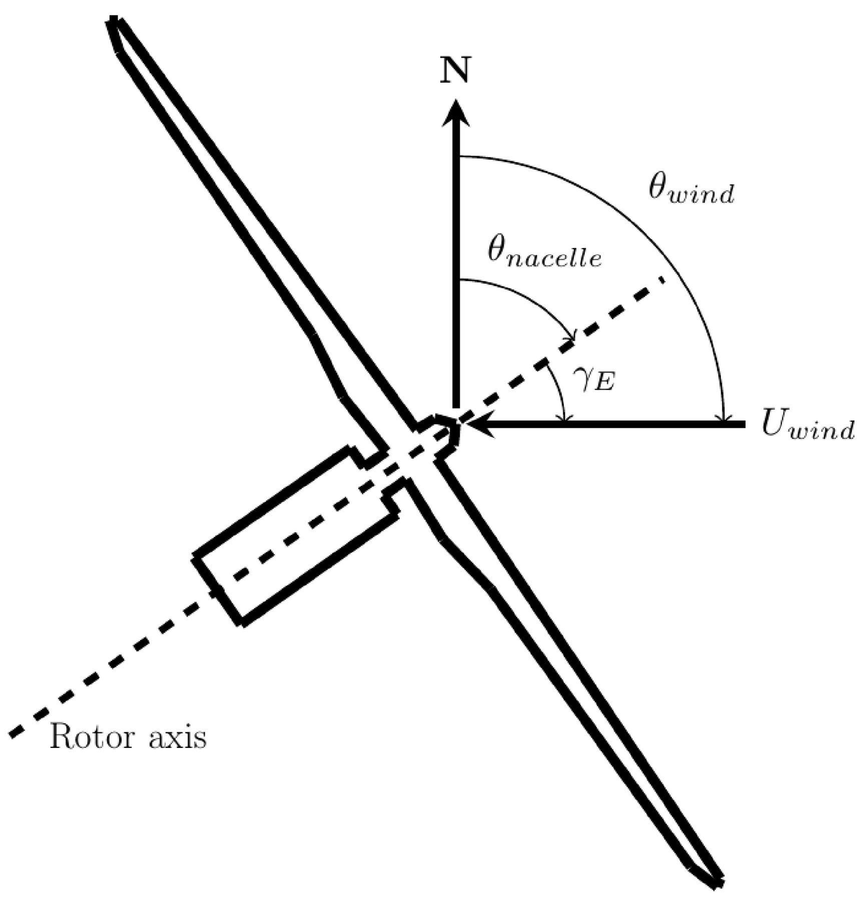
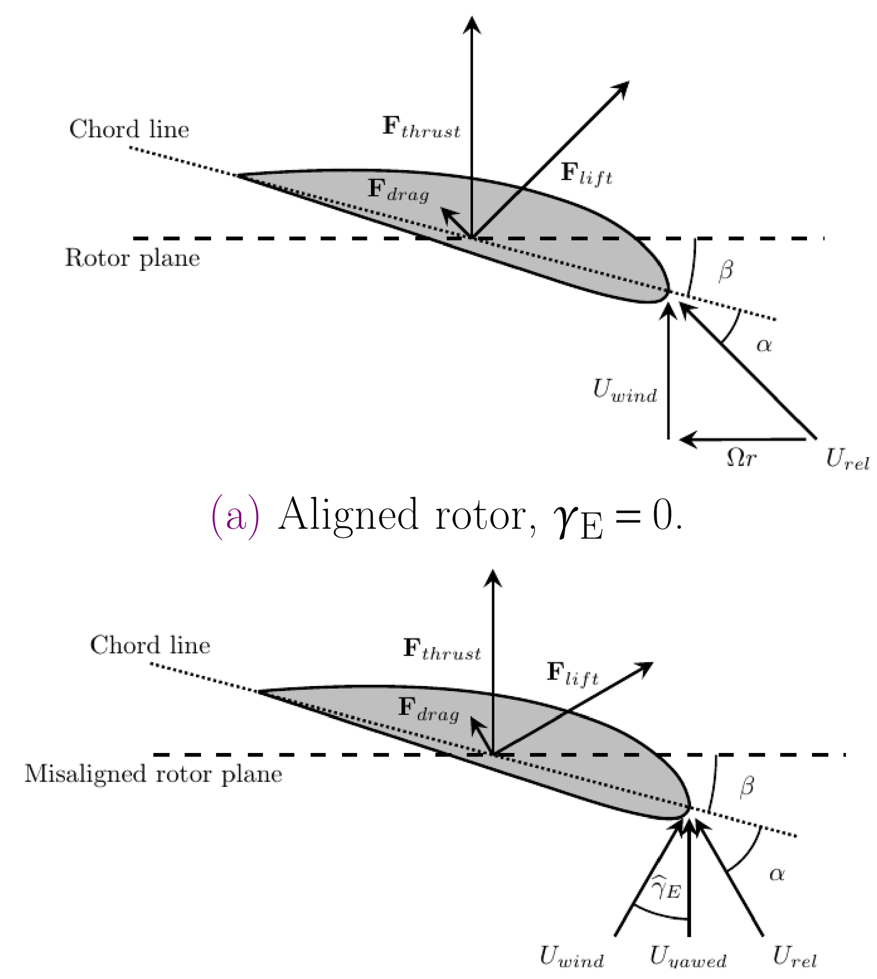


Figure 1. Positive yaw misalignment $\gamma_E = \Delta_{\min}(\theta_{\text{nacelle}}, \theta_{\text{wind}}) > 0$ on a horizontal axis wind turbine which is defined as a counter clockwise rotation of the nacelle axis θ_{nacelle} away from the hub height wind direction θ_{wind} viewed from above [3].

Wind direction variation and its impact on wind farms are both poorly understood. Measurement bias and direction variation mean that the yaw system often operates sub-optimally, resulting in yaw misalignment (Fig. 1) and significant deterioration in turbine performance (Fig. 2) [2].

Control-oriented modelling of wind direction variability is an approach that aims to capture the relevant dynamics of wind direction variability for improving controller performance over a complete set of farm flow scenarios, performing iterative controller development, and/or achieving real-time closed-loop model-based feedback control. My research is concerned with how to achieve these objectives through a data-driven approach.

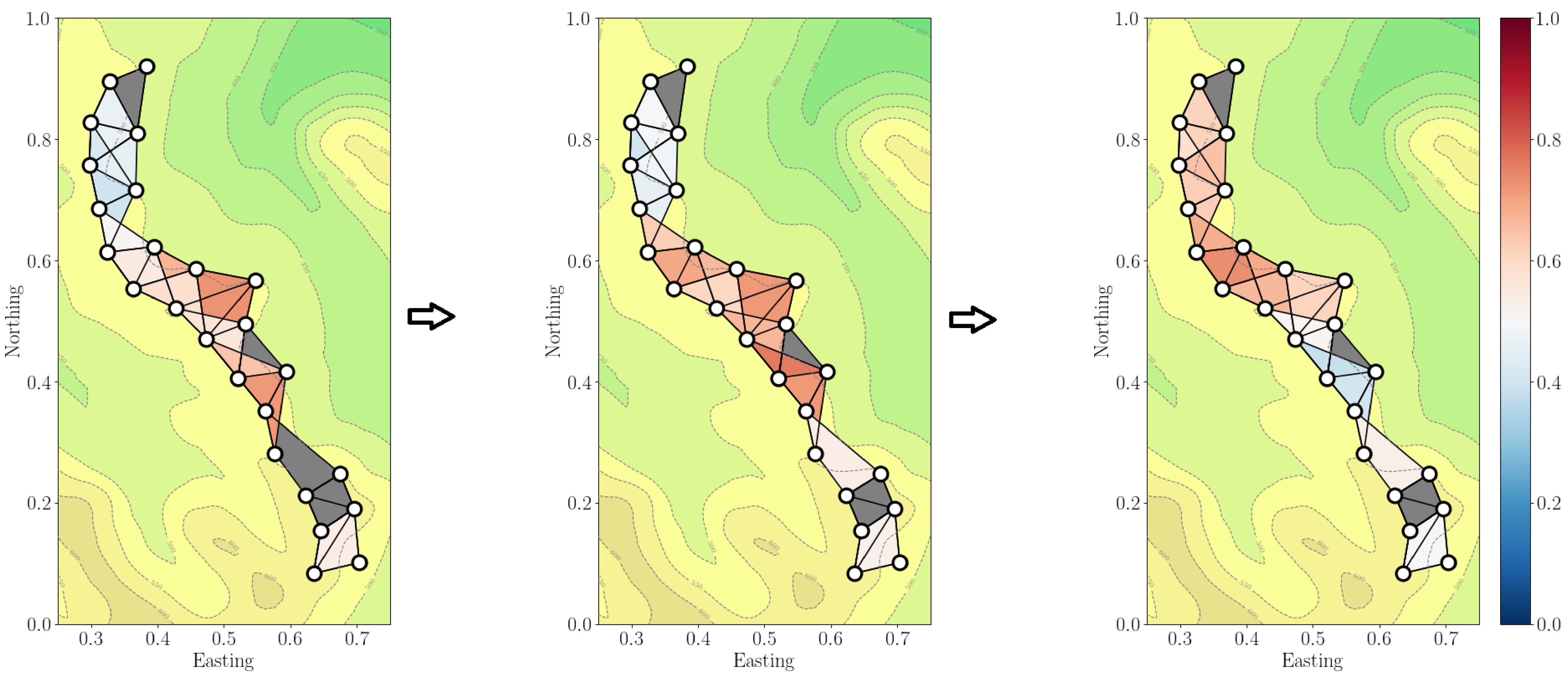
Variability is present both as high and low frequency changes in the wind direction measurements. For control-oriented modelling, farm-wide low frequency meandering and abrupt changes in direction are relevant. Figure 3 shows a sudden correlated direction change 'pulse' passing through a wind farm, whereas Figure 4 shows long term correlation.



(a) Aligned rotor, $\gamma_E = 0$.

(b) Misaligned rotor, $\gamma_E \neq 0$.

Figure 2. Blade element dynamics under a) aligned and b) misaligned conditions, where $\hat{\gamma}_E = \gamma_E \sin(\theta)$ and $U_{\text{yawed}} = U_{\text{wind}} \cos(\hat{\gamma}_E)$ [4].



(a) t = 0 min (b) t = 3 min (c) t = 6 min

Figure 3. Correlated wind direction change 'pulse' travelling through a wind farm. Circles represent turbine locations, coloured triangles indicate 'local' averaged 10 min wind direction cross correlations and grey triangles indicate missing data.

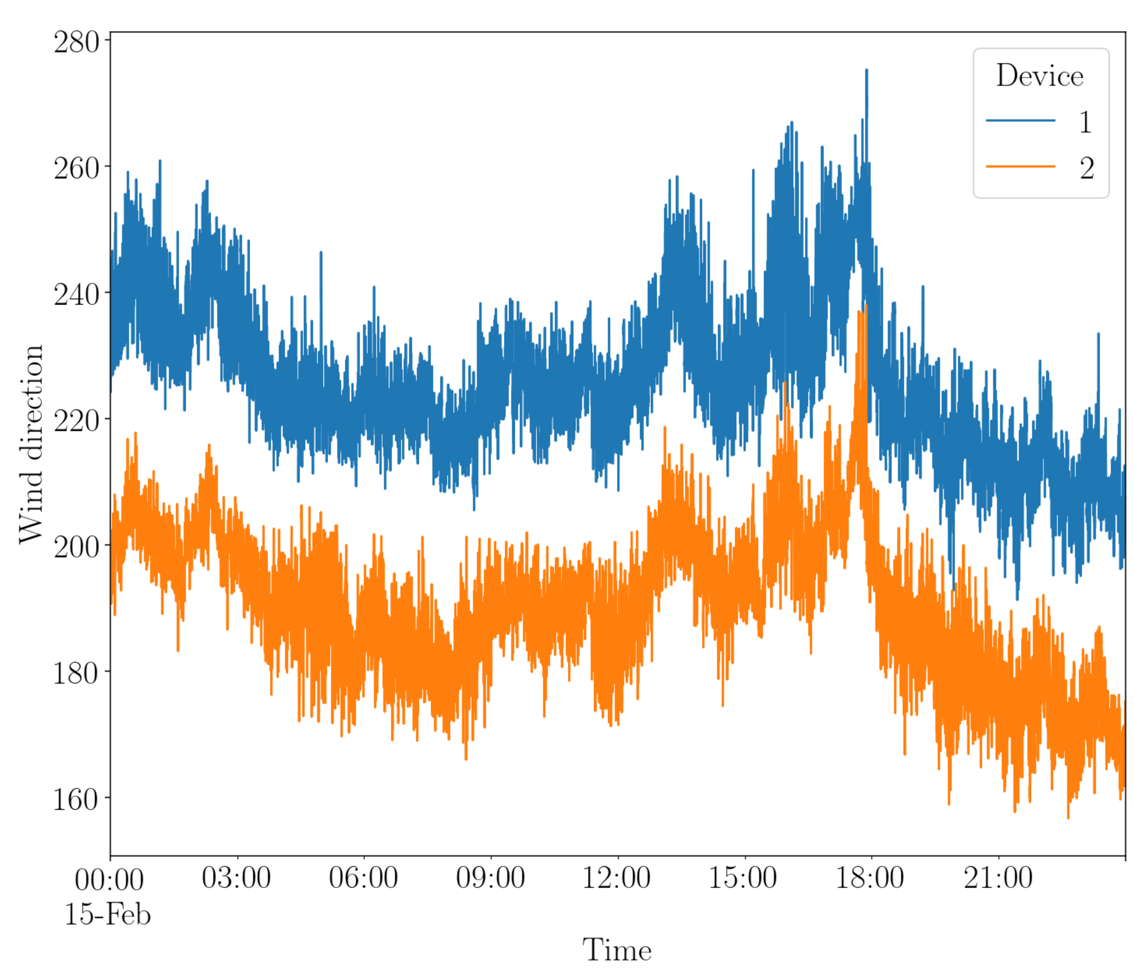


Figure 4. Wind direction time series of two neighbouring turbines over a 24-hour period.

Collective Control

The reduction in noise and error terms through consensus wind direction measurement, estimation and prediction methods means they can be used to improve yaw and wake steering controller performance through collective yaw and wake steering control. Table 1 outlines past research and selected findings.

Software Used	Control Method	Consensus Method	Power Gain	Yaw Duty Reduction	Identifies Yaw Bias	Paper
LongSim	CYC	Weighted average	$\approx 0.2\%$	$\approx 24\%$	No	[2]
FLORIS Version 2.1.1	CYC, CYC + WSC	Weighted average	0.5%, 4.7%	46.1%, 17.0%	No	[5]
Custom in-house	CYC	Gaussian processes	NA	$\approx 20\%$	Yes	[6]
Custom in-house	CYC	Distributed optimisation	NA	NA	Yes	[1]

Table 1. Selected details of past research. CYC = Collective Yaw Control, WSC = Wake Steering Control.

Future Work

Future research in this area includes,

- A Gaussian processes based data-driven wind direction model to produce realistic wind farm flow scenarios for simulations
- Real-time wind direction estimation and wake identification within a control framework.
- Predictive control to reduce extreme loads and increase power capture.

Tackling these challenges will contribute to improving performance and reliability, and ultimately help to reduce the LCOE of wind energy.

References

[1] Jennifer Annoni, Christopher Bay, Kathryn Johnson, Emiliano Dall'Anese, Eliot Quon, Travis Kemper, and Paul Fleming. Wind direction estimation using scada data with consensus-based optimization. Wind Energy Science, 4(2):355–368, 2019. https://doi.org/10.5194/wes-4-355-2019.

[2] Ervin Bossanyi. Optimising yaw control at wind farm level. Journal of Physics: Conference Series, 1222, 2019. https://doi.org/10.1088/1742-6596/1222/1/012023.

[3] Paul Fleming, Matt Churchfield, Andrew Scholbrock, Andrew Clifton, Scott Schreck, Kathryn Johnson, Alan Wright, Pieter Gebraad, Jennifer Annoni, Brian Naughton, et al. Detailed field test of yaw-based wake steering. In Journal of Physics: Conference Series, volume 753, page 052003. IOP Publishing, 2016. https://dx.doi.org/10.1088/1742-6596/753/5/052003.

[4] Michael F Howland, Carlos Moral González, Juan José Pena Martínez, Jesús Bas Quesada, Felipe Palou Larranaga, Neeraj K Yadav, Jasvipul S Chawla, and John O Dabiri. Influence of atmospheric conditions on the power production of utility-scale wind turbines in yaw misalignment. Journal of Renewable and Sustainable Energy, 12(6):063307, 2020. https://doi.org/10.1063/5.0023746.

[5] Michael Sinner, Eric Simley, Jennifer King, Paul Fleming, and Lucy Y Pao. Power increases using wind direction spatial filtering for wind farm control: Evaluation using floris, modified for dynamic settings. Journal of Renewable and Sustainable Energy, 13(2):023310, 2021. https://doi.org/10.1063/5.0039899.

[6] Daan Van Der Hoek, Michael Sinner, Eric Simley, Lucy Pao, and Jan-Willem van Wingerden. Estimation of the ambient wind field from wind turbine measurements using gaussian process regression. In 2021 American Control Conference (ACC), pages 558–563. IEEE, 2021. https://doi.org/10.23919/ACC50511.2021.9483088.