WindForS Wind Energy Research Alliance

University of Stuttgart Germany

AREVA

SWE

RAVE RESEARCH AT ALPHA VENTUS
Eine Forschungsinitiative des Bundesumweltministeriums

Lidar Assisted Wind Turbine Control

D. Schlipf [1], J. Anger [1], O. Bischoff [1], M. Hofsäß [1], A. Rettenmeier [1], I. Würth [1], B. Siegmeier [2], P. W. Cheng [1]

[1] Stuttgart Wind Energy (SWE) - Universität Stuttgart

[2] AREVA Wind GmbH

RAVE 2012 Bremerhaven, 8.-9.5.2012

Gefördert auf Grund eines Beschlusses des Deutschen Bundestages

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

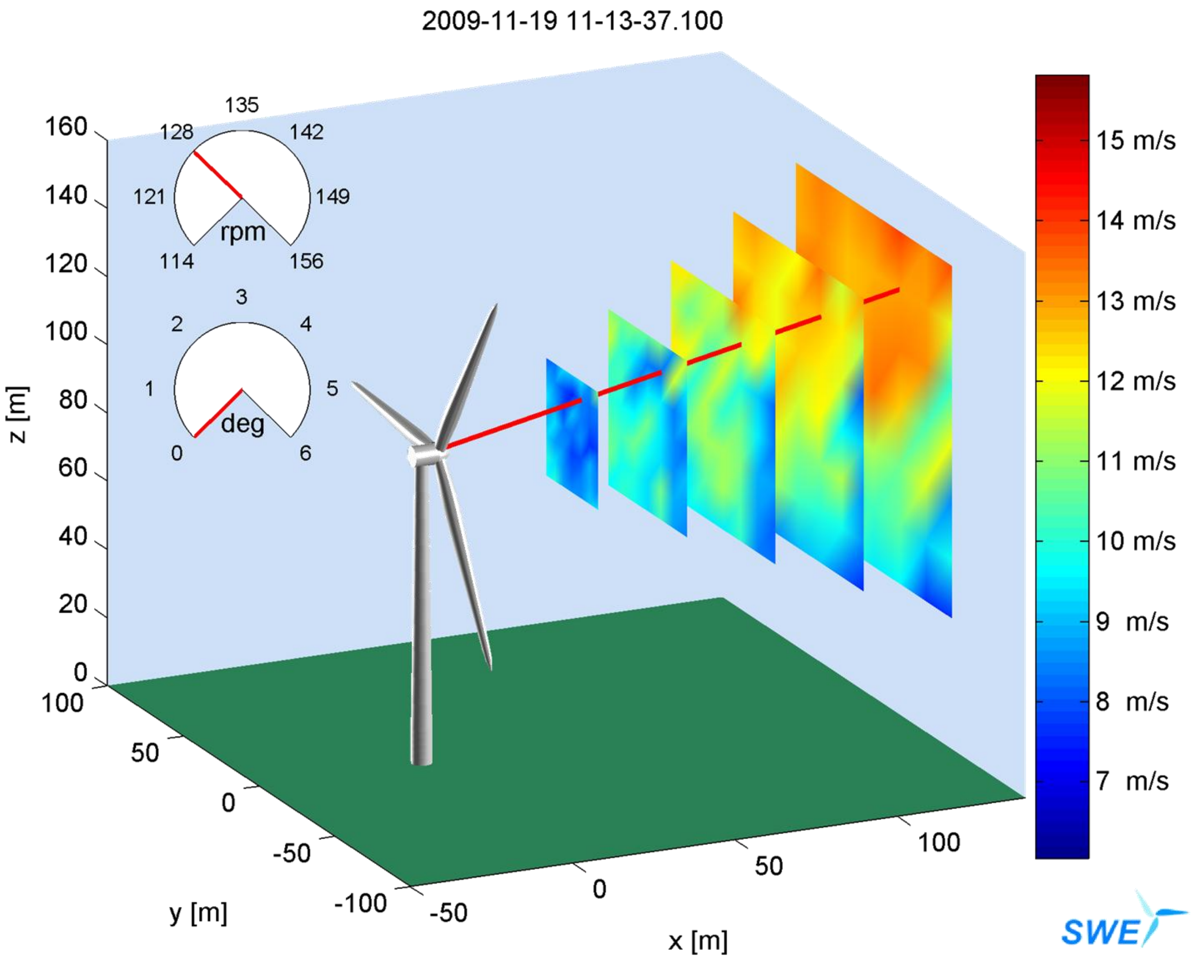
Projektträger

PtJ Projektträger Jülich Forschungszentrum Jülich

Koordination

Fraunhofer IWES

Motivation



Measurements from AREVA Wind prototyp in Bremerhaven 2009 within LIDAR I

Can Lidar help to get …

… more energy with
Yaw control?
Speed control?

… less loads with
Collective pitch control?
Individual pitch control?

Lidar Assisted Yaw Control

Yaw control normally by nacelle sonic/wind vane

- disturbed by blades
- only point measurement

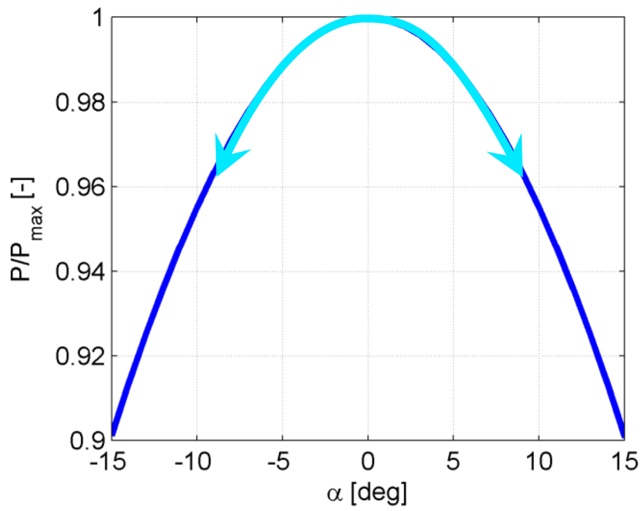
Lidar based yaw control

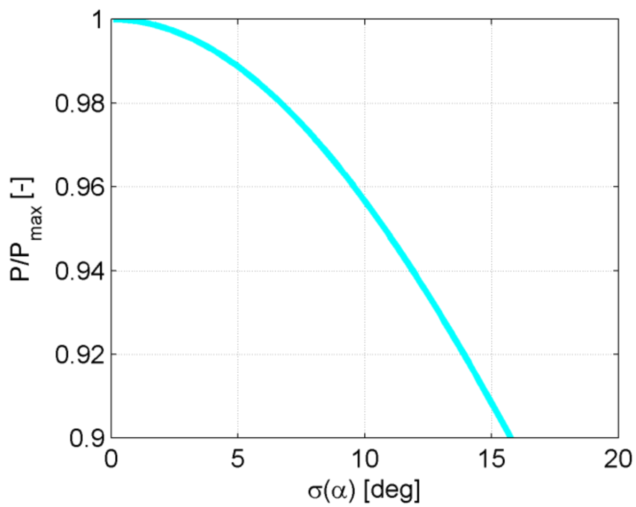
- undisturbed inflow
- measurement over rotor area

AREVA Wind prototyp in Bremerhaven

Lidar Assisted Yaw Control

Theoretical Considerations





Static misalignment expressed by mean $\bar{\alpha}$:

$$P(\bar{\alpha}) = P_{max} \cos^3 \bar{\alpha}$$

Could be solved by better calibration of nacelle anemometer!

Dynamic misalignment expressed by standard deviation $\sigma(\alpha)$:

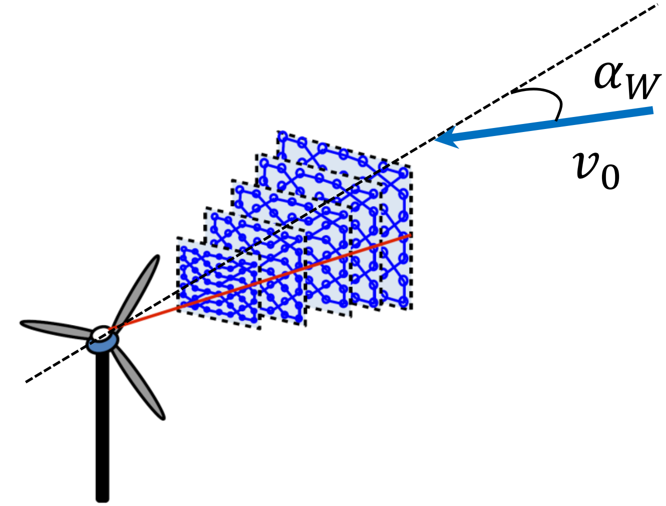
$$P(\sigma) = P_{max} \int_{-\infty}^{\infty} \varphi_{0;\sigma} \cos^3 \alpha \ d\alpha$$

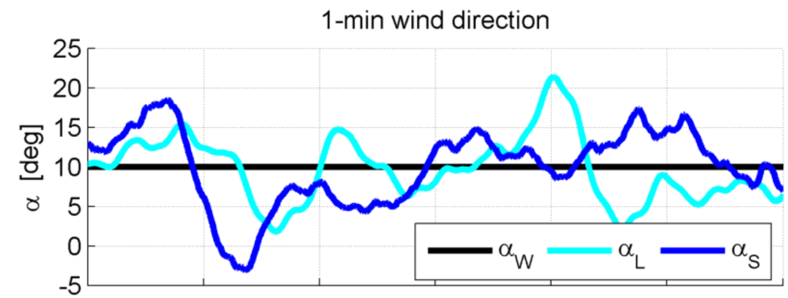
Could be solved by Lidar,
but depends on control strategy!

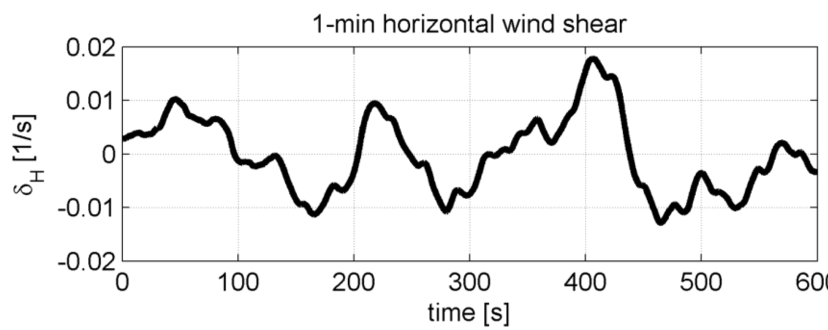
Lidar Assisted Yaw Control

Simulated Measurements

- NREL 5MW + Lidar simulator
- Turbulent wind fields α_W=10°
- Assumption: homogeneous inflow
- α_L similar to undisturbed simulated hub anemometer α_S
- Robust against vertical shear, disturbed by horizontal shear
- Absolute error <1° for 10 min







But we have no model for

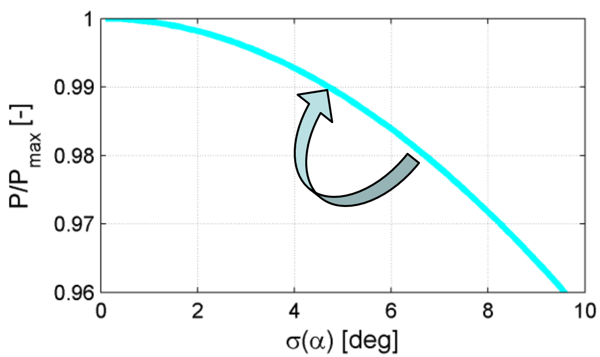
- Anemometer disturbance
- Inhomogeneous inflow
  - ➢ Consider real data!

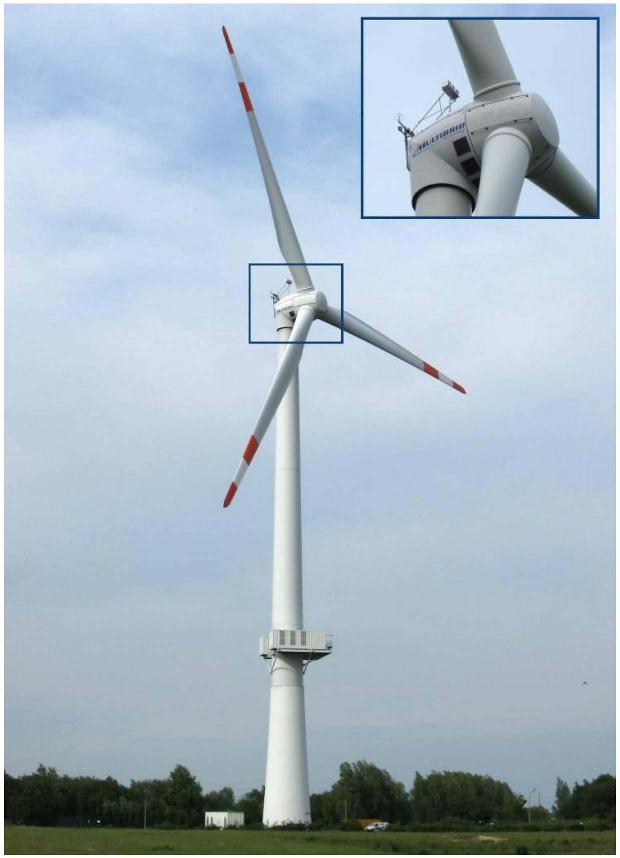
Lidar Assisted Yaw Control

Simulation with Real Measurements

- 5 month of inflow measurement
- 10 min Lidar wind direction assumed as perfect
- compared to sonic
- same control strategy is assumed for Lidar and sonic: turbine yaws if 10 min average > 10°

Static:
overall mean error 1°
Dynamic:
standard deviation 6° → 4°





AREVA Wind prototyp in Bremerhaven

- With standard control maximal 1%!
- Maximal 2% more energy output!

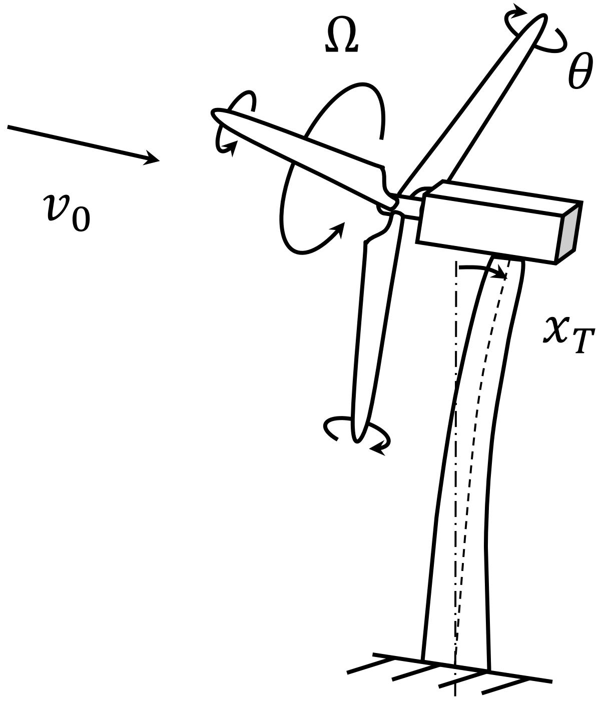
Lidar Assisted Collective Pitch Control

Collective pitch control normally by rotor/generator speed feedback only

- delayed reaction due to inertia

Lidar based collective pitch control

- reaction in time

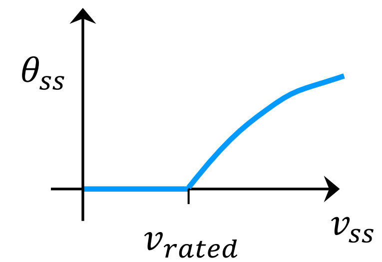


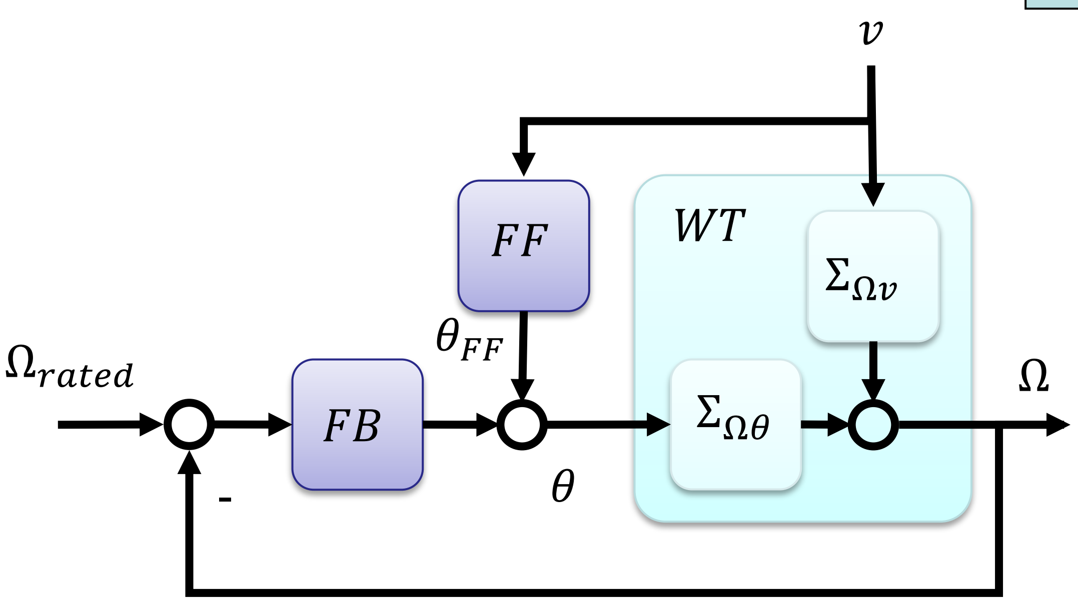
Lidar Assisted Collective Pitch Control

Theoretical Considerations

Theoretically full compensation: $\Sigma_{FF} = \Sigma_{\Omega\theta}^{-1}\Sigma_{\Omega v}$

- Not feasible for aeroelastic model
- Possible for reduced nonlinear model





Using static pitch curve $\theta_{ss}(v_{ss})$ with prediction time τ:

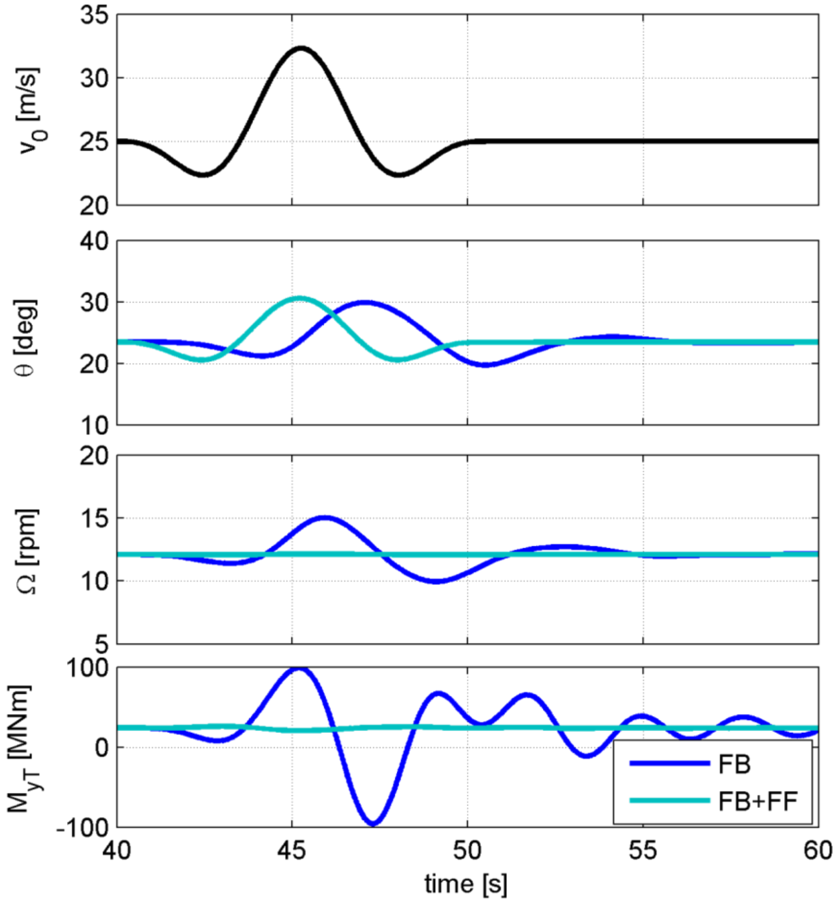
$$\theta_{FF}(t) = \theta_{ss}(v_{FF}(t-\tau))$$

Advantages:

- simple update
- guaranteed stability
- 1 design parameter τ
- few model information

Lidar Assisted Collective Pitch Control

Simulated Extreme Loads



- FAST NREL 5MW
- perfect Lidar measurement
  - ➢High load reduction.

But not realistic, because of

- Wind evolution
- Lidar error
- Turbulence
  - ➢Consider real data!

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Lidar Assisted Collective Pitch Control

Estimation Rotor Effective Wind Speed from Turbine Data

law of conservation of angular momentum

$$J\dot{\Omega} = M_a - M_{LSS} - M_{loss}$$

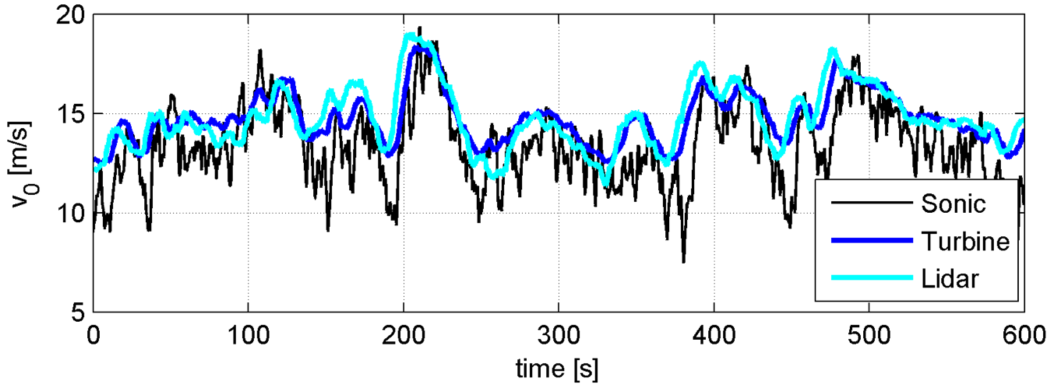
$$\frac{1}{2}\rho\pi R^2 c_P(\lambda, \theta) v_0^3/\Omega$$

$$P_{el}/(\eta\Omega)$$

$$\Omega R/v_0$$

turbine data

AREVA Wind prototyp in Bremerhaven

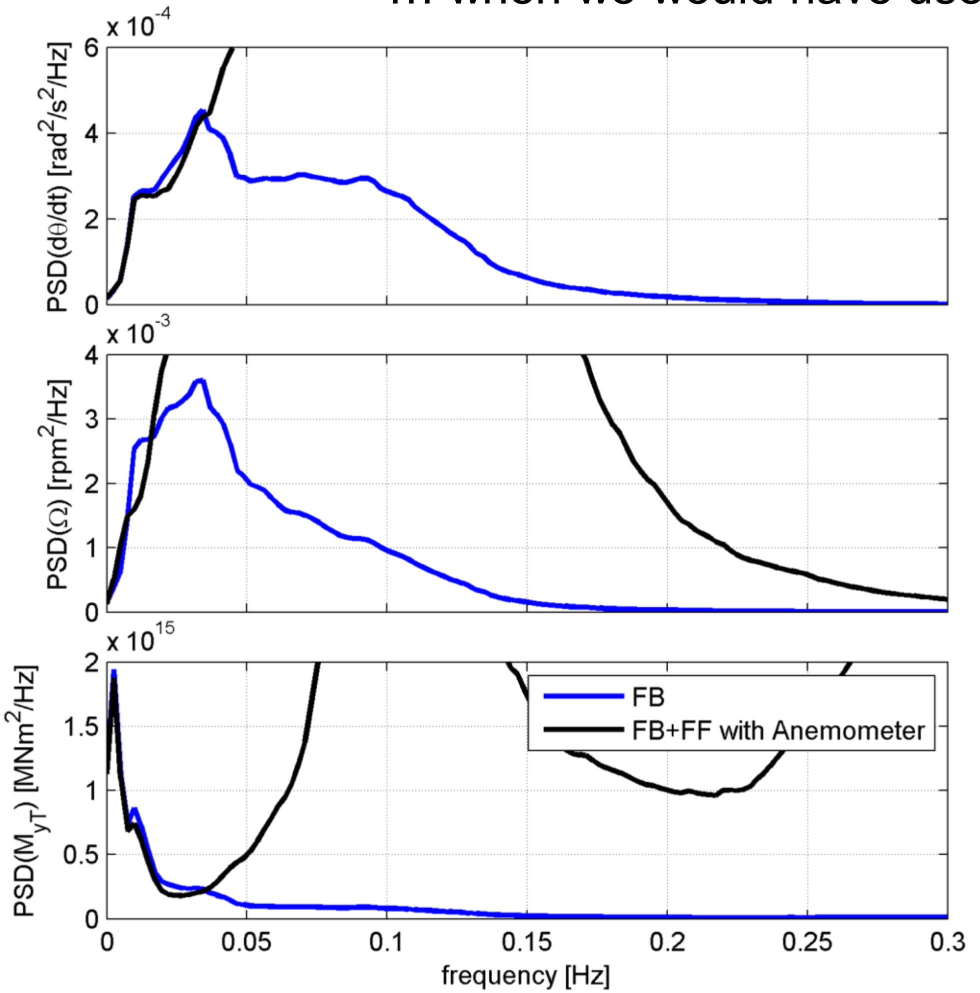


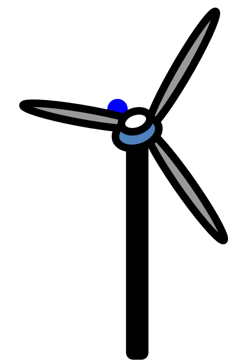
Used for simulations:

“What would have happened….”

~~Lidar~~ Anemometer Assisted Collective Pitch Control

… when we would have used the nacelle anemometer?





	$\sigma(\dot{\theta})$	$\sigma(\Omega)$	$DEL(M_{yT})$
FB+FFA	+ 712 %	+ 272 %	+ 559 %

Really bad idea!

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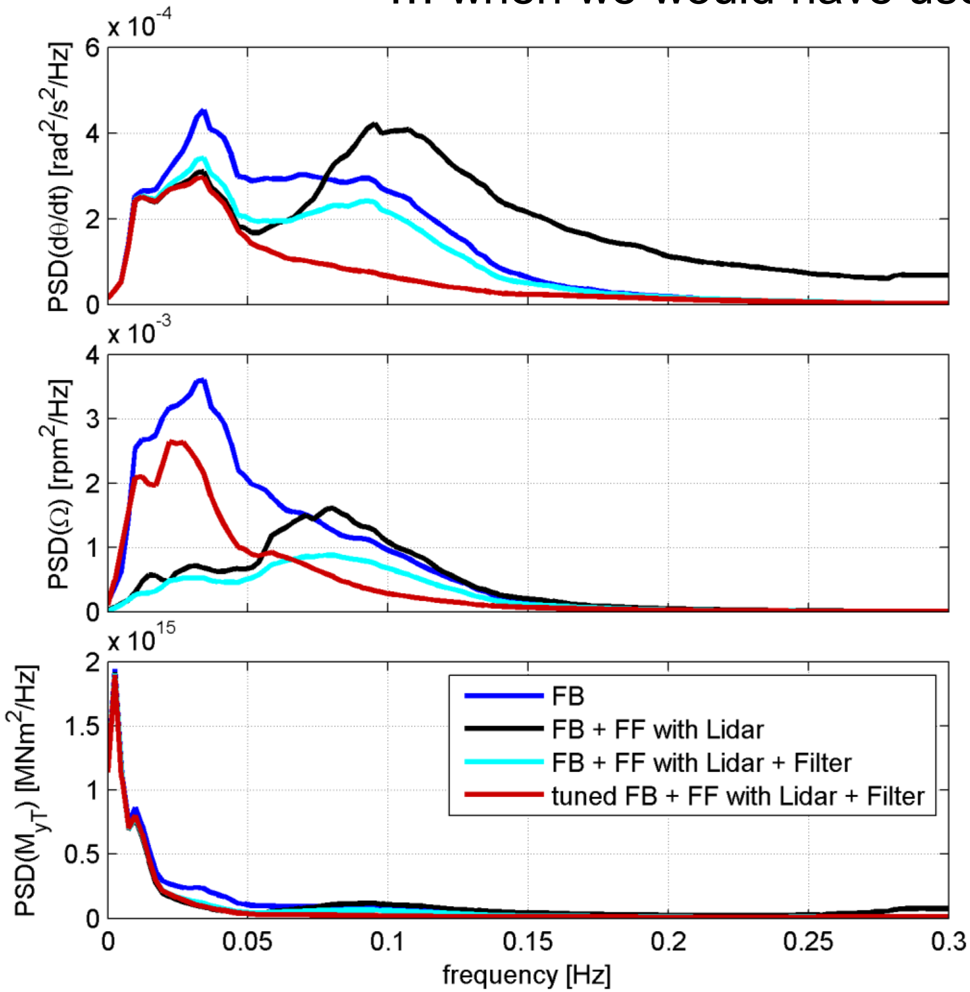
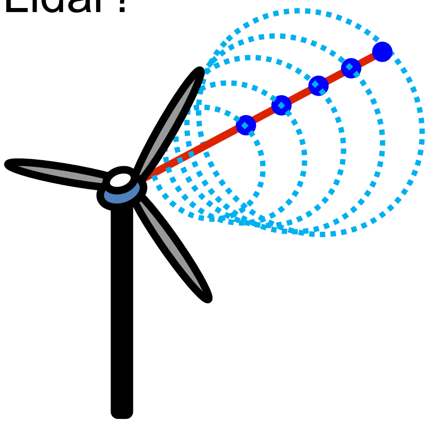
Lidar Assisted Collective Pitch Control

… when we would have used the scanning Lidar?





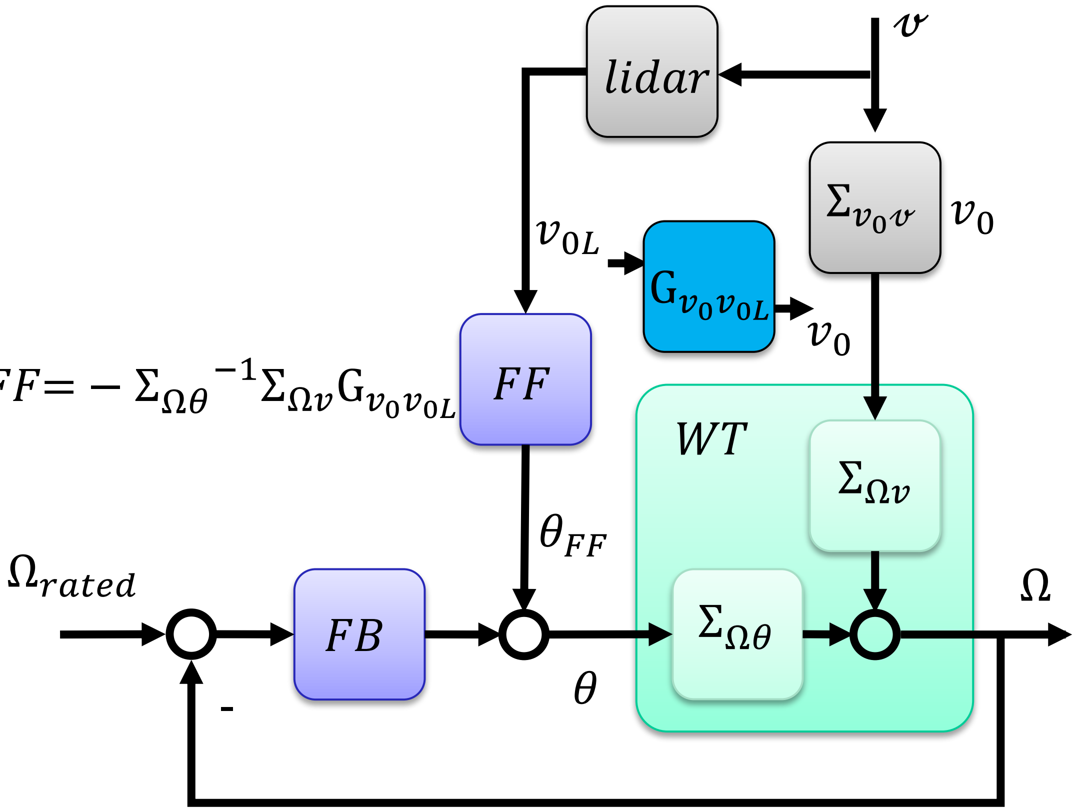
	$\sigma(\dot{\theta})$	$\sigma(\Omega)$	$DEL(M_{yT})$
FB+FFL	+ 54 %	- 25 %	+ 29 %
FB+FFL+F	- 11 %	- 41 %	- 12 %
FBT+FFL+F	- 30 %	- 24 %	- 20 %

- filter necessary to reduce rotor speed variation + loads
- further reduction by retuning

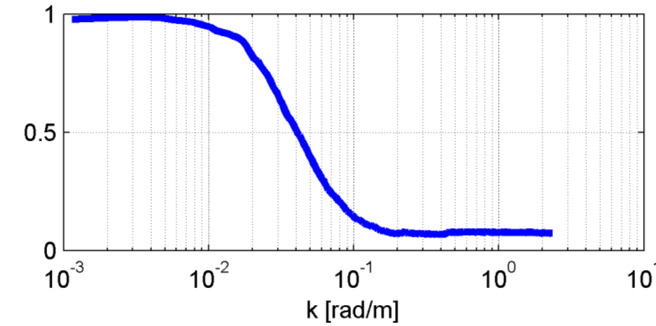
Lidar Assisted Collective Pitch Control

Adaptive Filter Design

$$FF = -\Sigma_{\Omega\theta}^{-1}\Sigma_{\Omega v}G_{v_0 v_{0L}}$$



$$|G_{v_0 v_{0L}}| = \left|\frac{S_{LL}}{S_{TL}}\right|$$

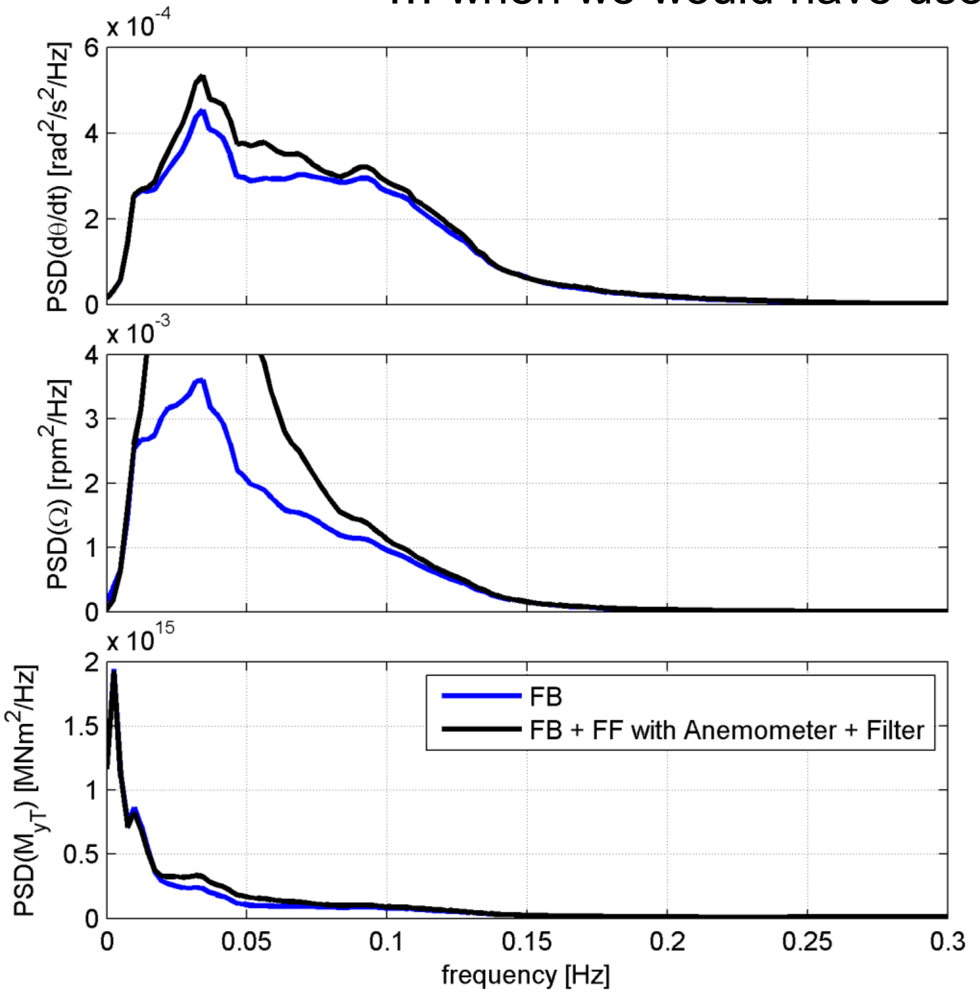


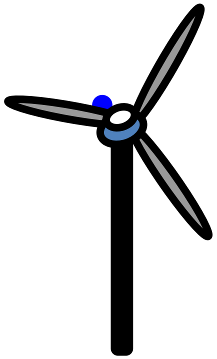
$$\hat{k} \sim 0.04\,\frac{rad}{m} \longrightarrow f_{cutoff} = \frac{\hat{k}\bar{u}}{2\pi}$$

- correlation depending on mean wind speed $\bar{u}$, stable over k
- for this turbine + trajectory only turbulence eddies up to ~160 m can be compensated

~~Lidar~~ Anemometer Assisted Collective Pitch Control

… when we would have used the nacelle anemometer + a filter?

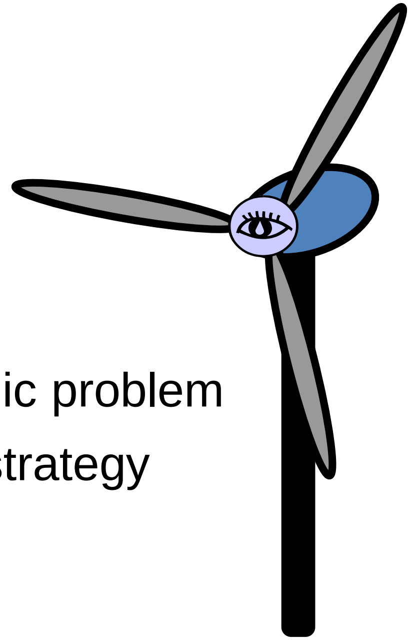




	$\sigma(\dot{\theta})$	$\sigma(\Omega)$	$DEL(M_{yT})$
FB+FFA+F	+ 6 %	+ 38 %	+ 6 %

- phase delay through filter
- feedforward action too late

Conclusions



Lidar Assisted Yaw Control

- yaw misalignment can be distinguished as static and dynamic problem
- some energy gain, depends on inhomogeneity and control strategy

Lidar Assisted Collective Pitch Control

- filter necessary to avoid wrong pitch action
- preview necessary to apply filter
- low frequency reduction of rotor speed variation of rotor speed variation, pitch activity and loads, e.g. tower
- frequency depends on turbine size and lidar scan

Current Research and Outlook

- Scanner used in other campaigns
  - At DTU (Denmark) for fundamental research
  - At NREL (US) for wield tests on a small turbine

- Improving lidar measurements at “alpha ventus”
- Development of robust lidar and test in LIDAR II
- Proposal to control of AV7 (AREVA M5000) in LIDAR II+

AREVA M5000 im Testfeld alpha ventus

Thank you for your attention!

Feel invited for further presentations on LiDAR technology

<u>**Session 5: Wind turbine control and wind farm flow**</u>

5.5 **Analysis of wake-induced wind turbine loads**
Project: RAVE - OWEA
J.J. Trujillo, B. Kuhnle, H. Beck, ForWind - University of Oldenburg

<u>**Session 6: Site conditions**</u>

6.4 **Statistics of extreme wind events and power curve monitoring**
Project: RAVE - LIDAR, RAVE - OWEA
Dr. M. Wächter, ForWind - University of Oldenburg