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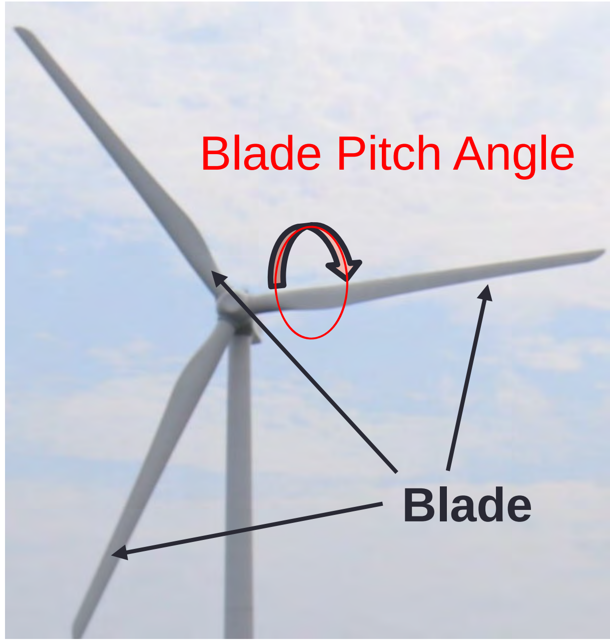
Blade Pitch Control for Floating Wind Turbines:
Design and Experiments Using a Scale Model

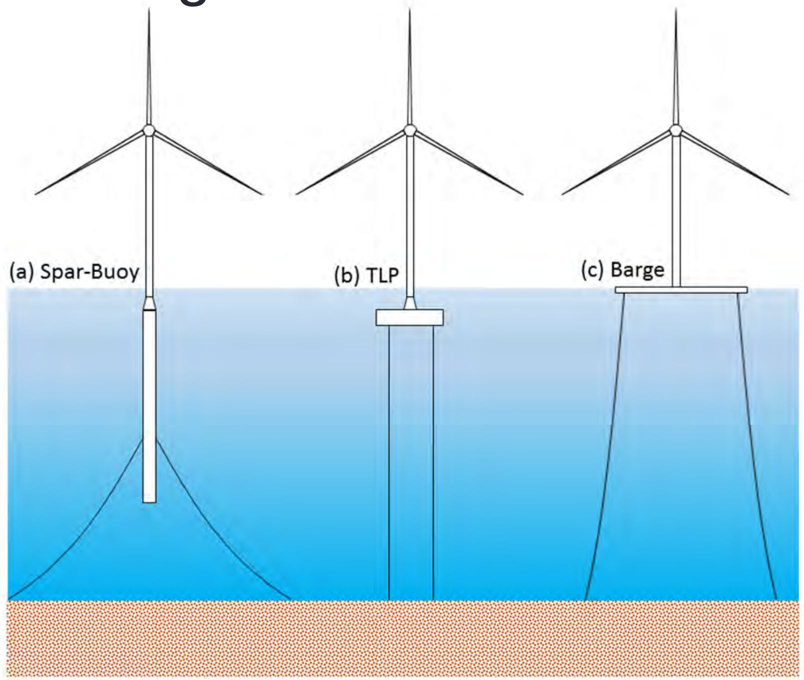
Naoyuki Hara (Department of Electrical and Information Systems, Osaka Prefecture Univ.)
Yasunori Nihei (Department of Marine System Engineering, Osaka Prefecture Univ.)
Kazuhiro Iijima (Department of Naval Architecture and Ocean Engineering, Osaka Univ.)
Keiji Konishi (Department of Electrical and Information Systems, Osaka Prefecture Univ.)

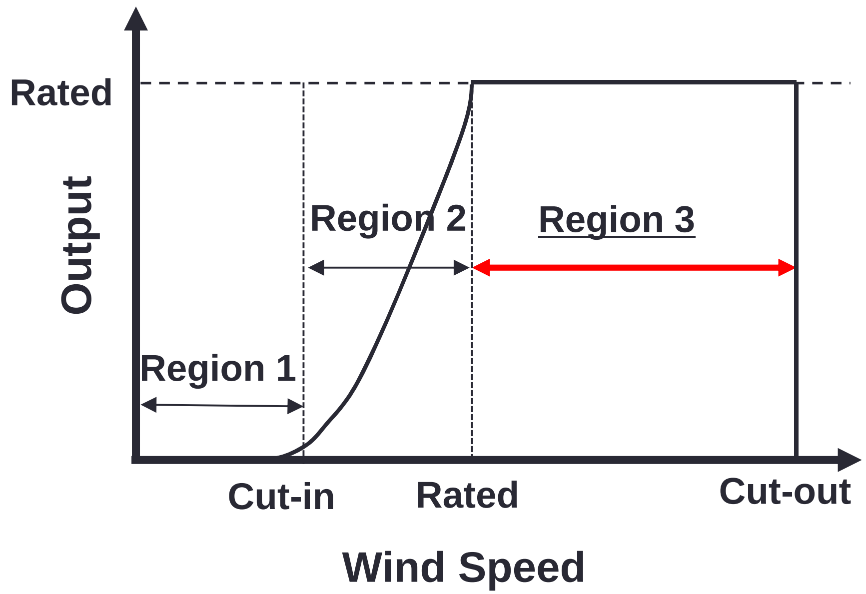
Introduction

- Blade Pitch Control in Wind Turbines
  - Used in Region 3
  - (main) Objective: keep the power output to the rated value.



- Floating Offshore Wind Turbines





Introduction

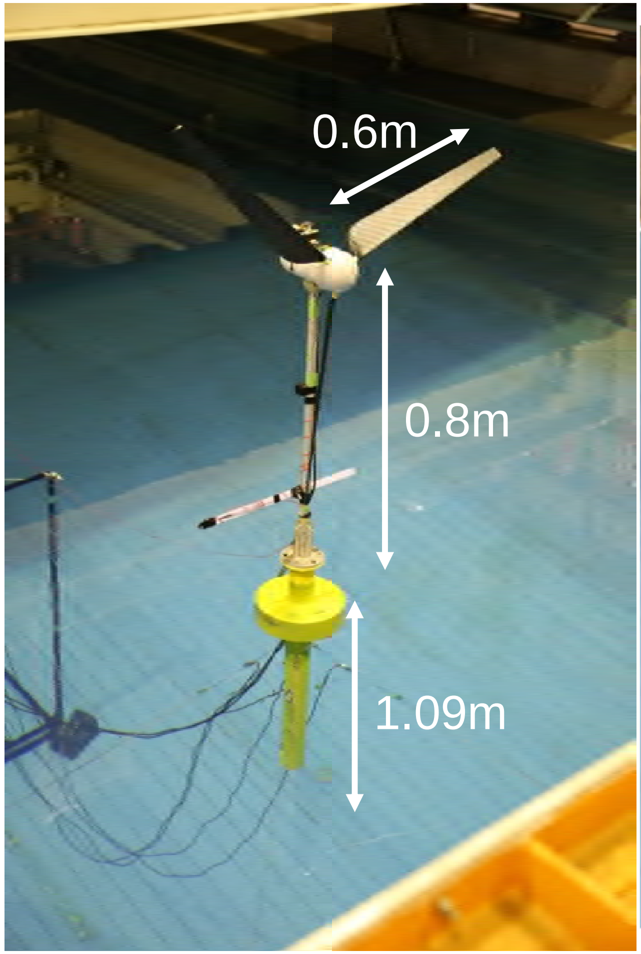
- Example of FOWT (Floating Offshore Wind Turbine)

2MW FOWT (spar-buoy type)
Offshore Nagasaki, Japan (August 25, 2014)

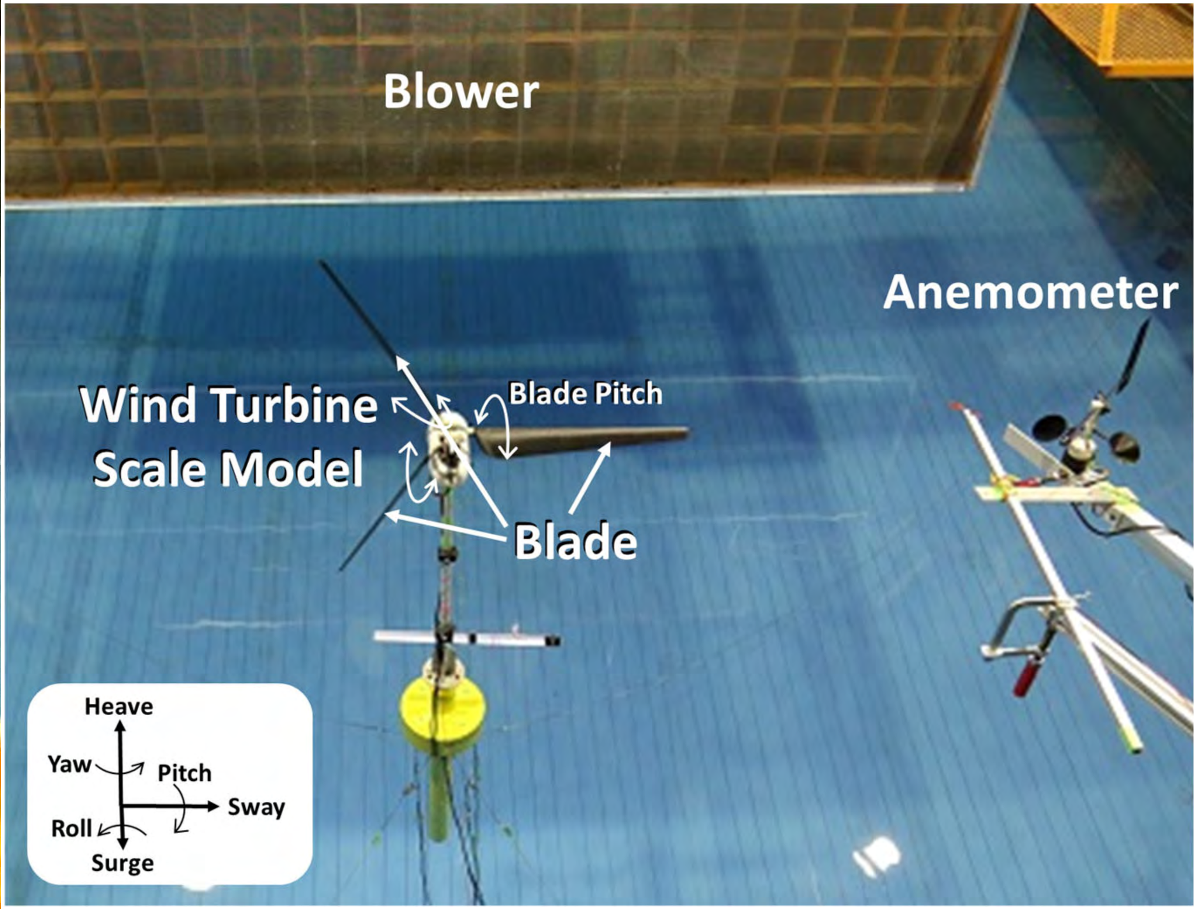
Introduction

- Blade pitch control for FOWTs
  - The platform (floater) is not fixed at the seafloor.
  - BP control affects not only the rotor's dynamics, but also platform motions. (both aerodynamic torque and thrust force change)
- Previous studies of advanced BP control for FOWTs
  - Simulation: H. Namik & K. Stol; *IEEE TCST* 2014, S.Raach et al.; *2014 ACC*, O. Bagherieh et al.; *2014 ACC*, B. Shahsavari et al.; *2016 ACC*, etc.
  - Experiment: N. Hara et al; *Wind Energy*, 2017
    - 1/100 scale model of a 5MW FOWT was used. H_∞ controller designed.
    - Problems: Uncertainty and integral action were not considered.
- This study
  - Design a BP controller using H_∞ loop-shaping design procedure.
  - Based on the loop-shaping concept. Integral action is easily incorporated.

FOWT Scale Model



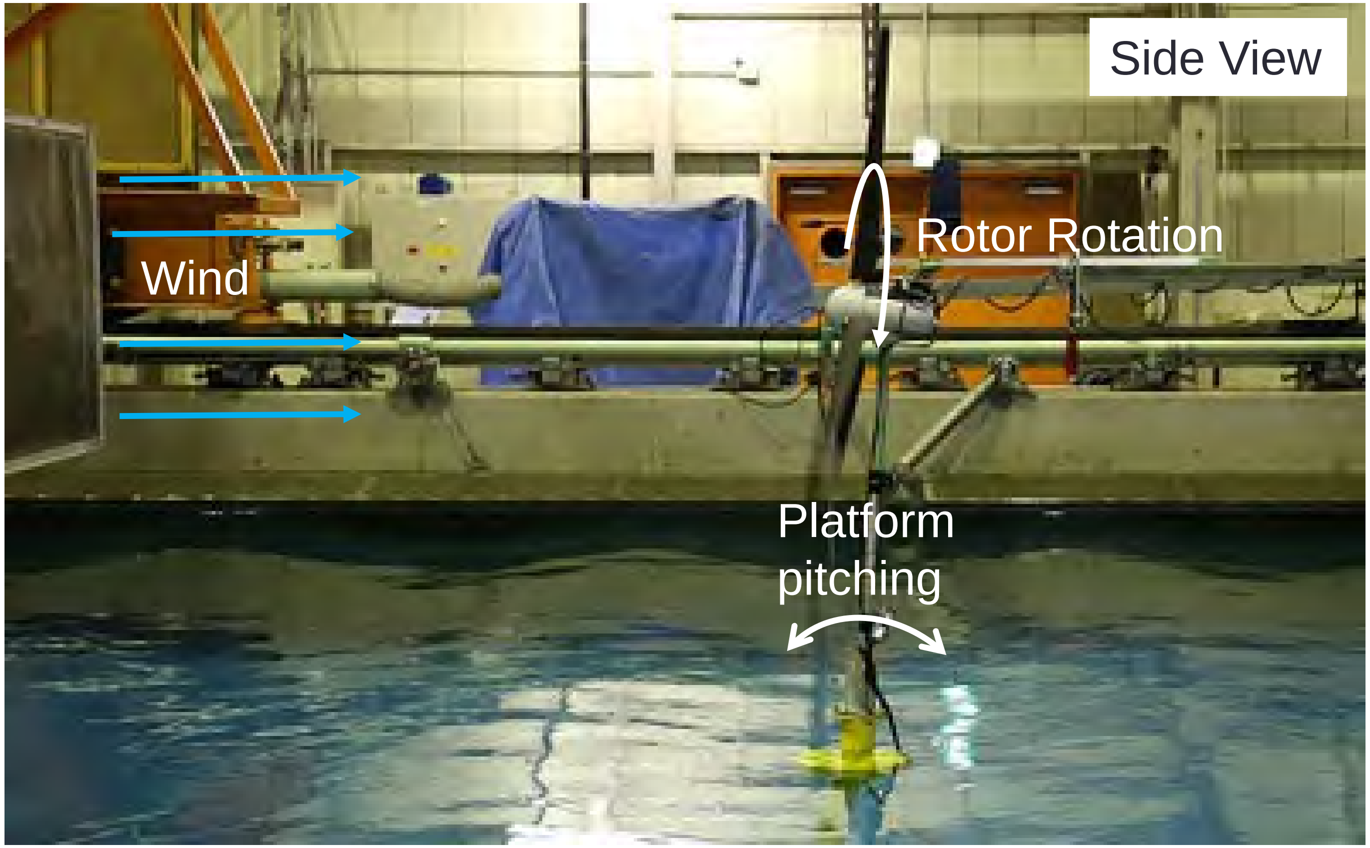
1/100 Scale Model of a 5MW wind turbine.



Experimental setup.
(Water tank facility, the Univ. of Tokyo)

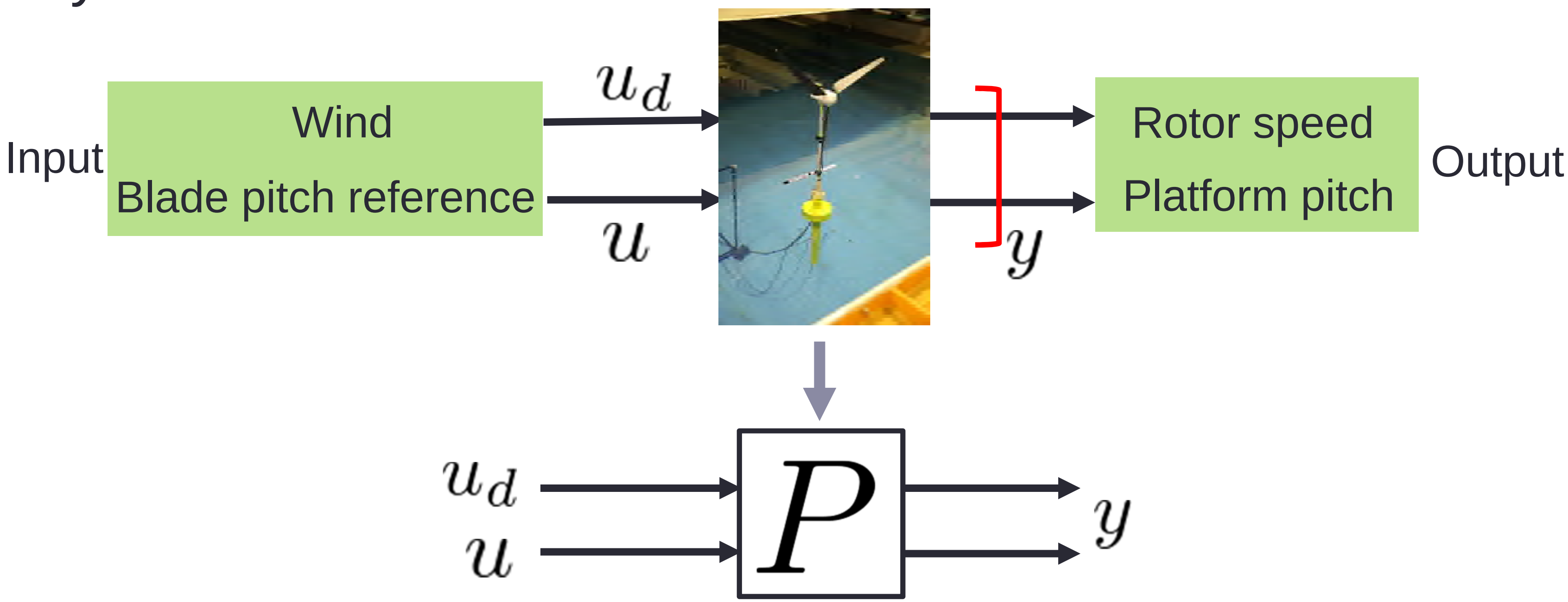
FOWT Scale Model

- Control Objective
  - Keep the rotor speed at 1.8Hz and suppress platform pitch fluctuations by the collective blade pitch control.

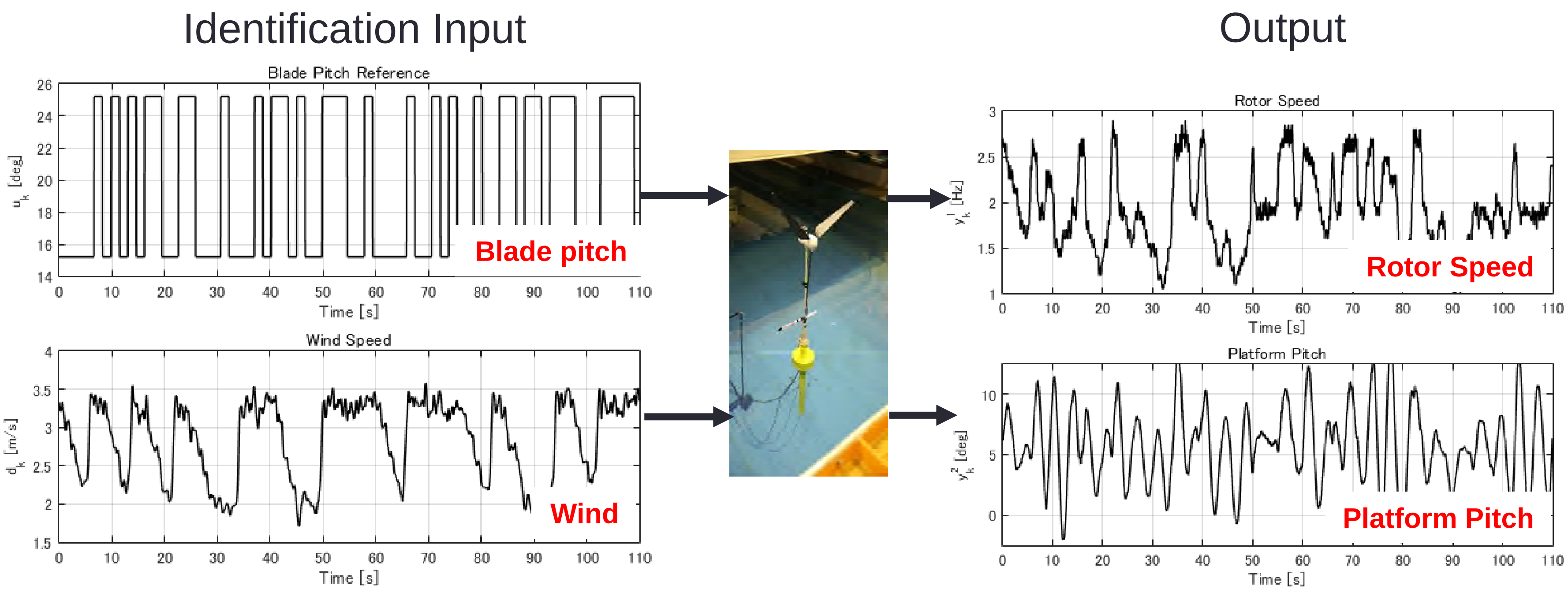


Nominal Model and Controller Design

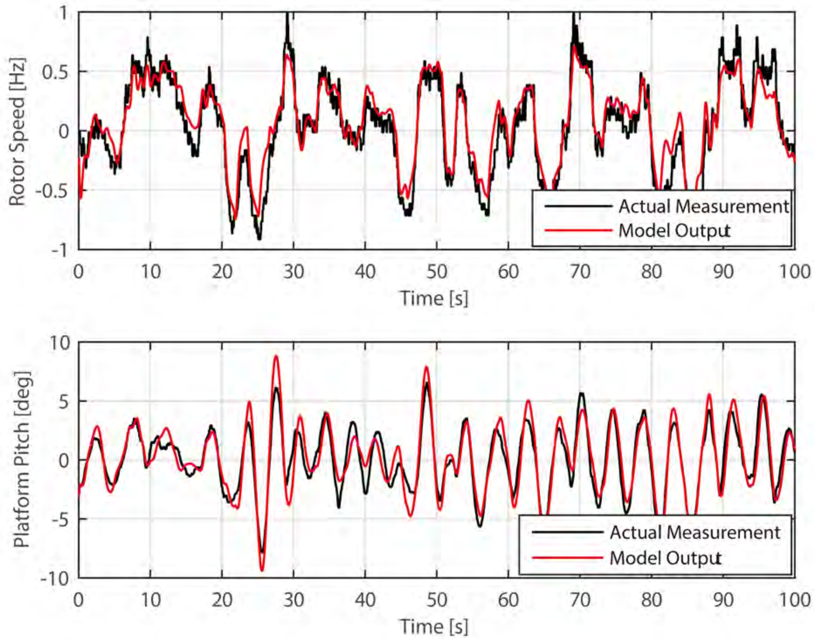
- Create a linear model around an operating point:
  - Wind speed: 2.7 m/s
  - Blade pitch angle: 20.20 deg
  - Rotor speed: 1.8 Hz
  - Platform pitch angle: 5.25 deg
- System identification



Identification Input / Output



- System Identification
  - Obtain a set of input and output signals.
  - Subspace ID method
- Results
  - Fourth-order LTI system (dT =0.04)
  - Validation test

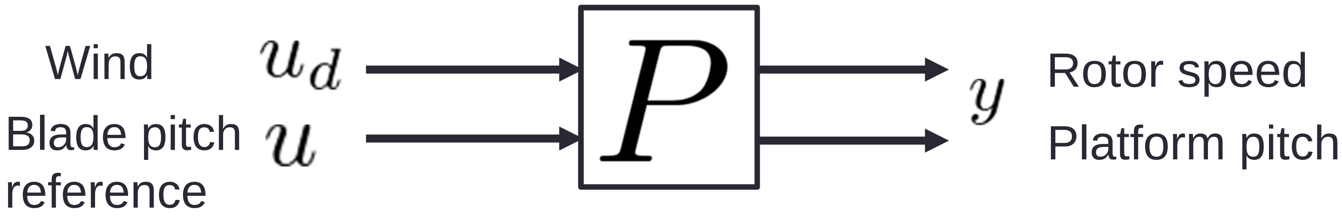


Controller Design by *H*∞ LSDP

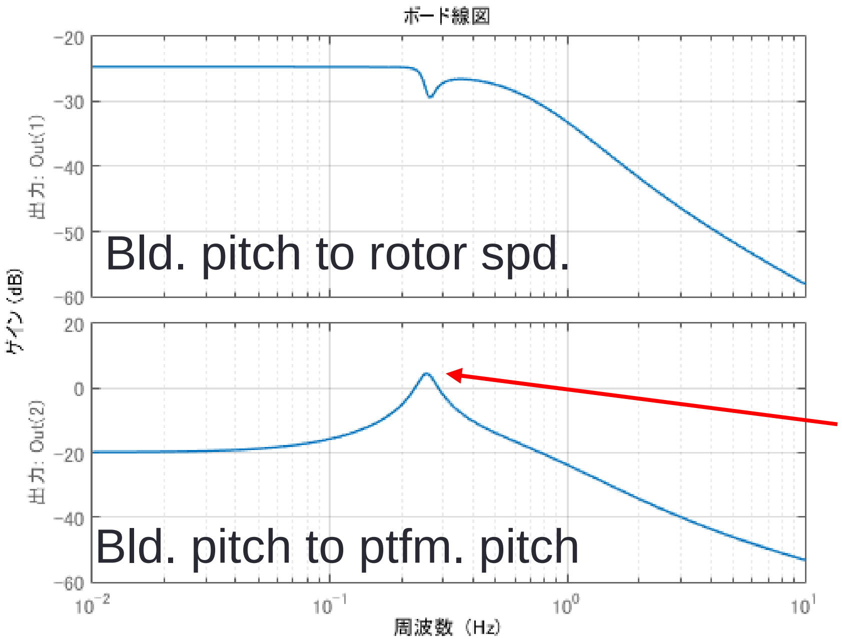
- Continuous-time nominal model for controller design

$$\dot{x}(t) = Ax(t) + Bu(t) + Dv(t)$$

$$y(t) = Cx(t)$$



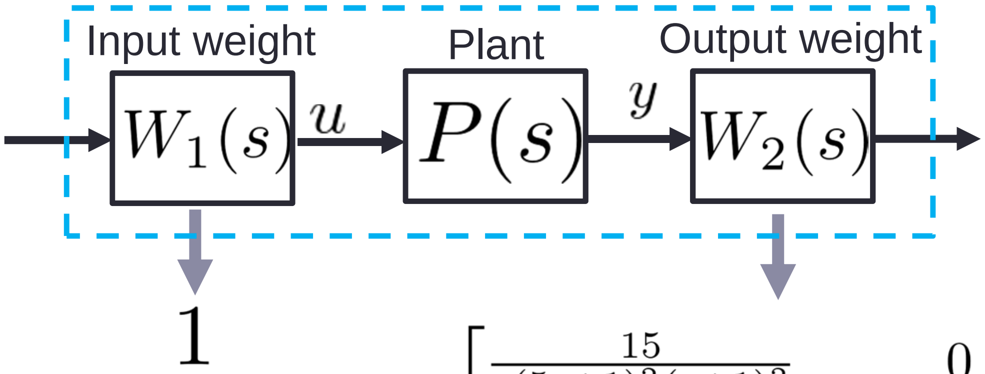
Frequency Response
(Gain characteristics)

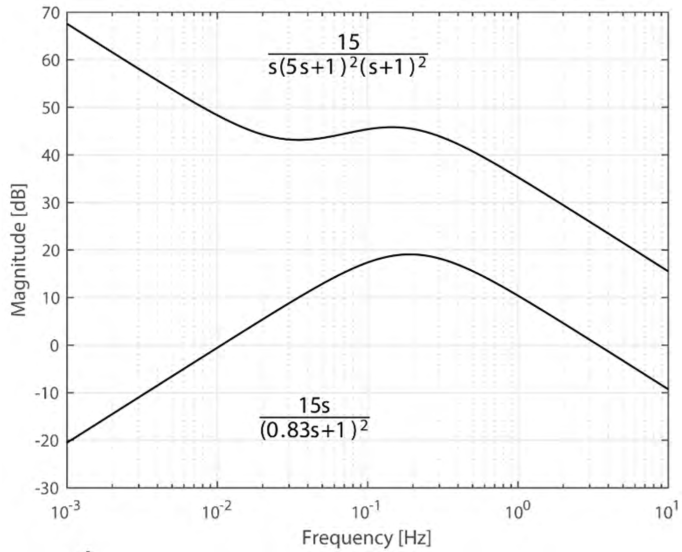


Resonance
peak

Controller Design by *H*∞ LSDP

- *H*∞ Loop-Shaping Design Procedure (LSDP)
  - Robust control design method
  - Based on the (classical) loop-shaping concept, guarantee robustness for a class of perturbations
- Design: choice of weighting matrices

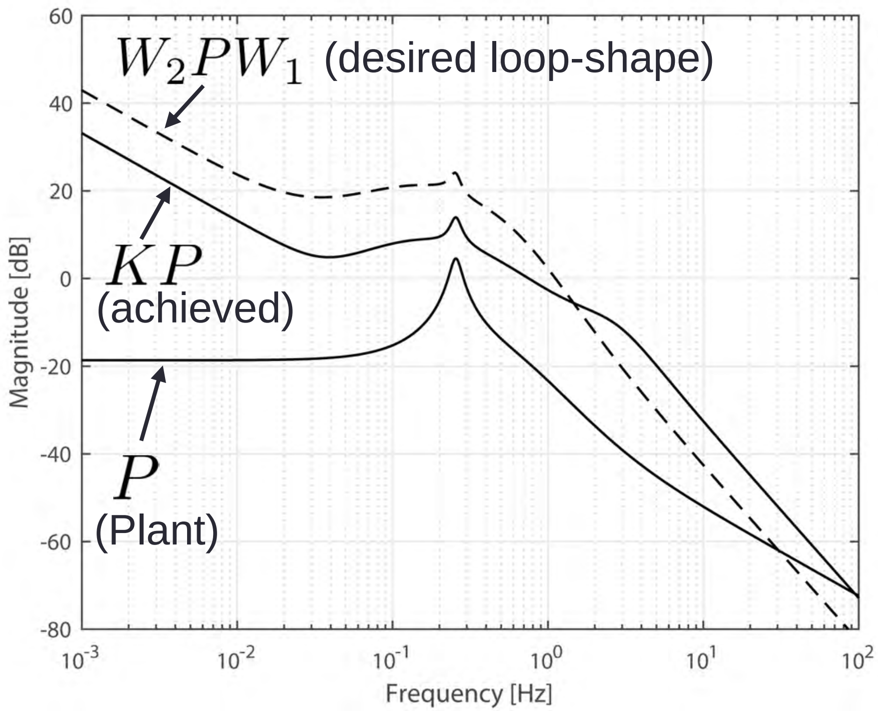




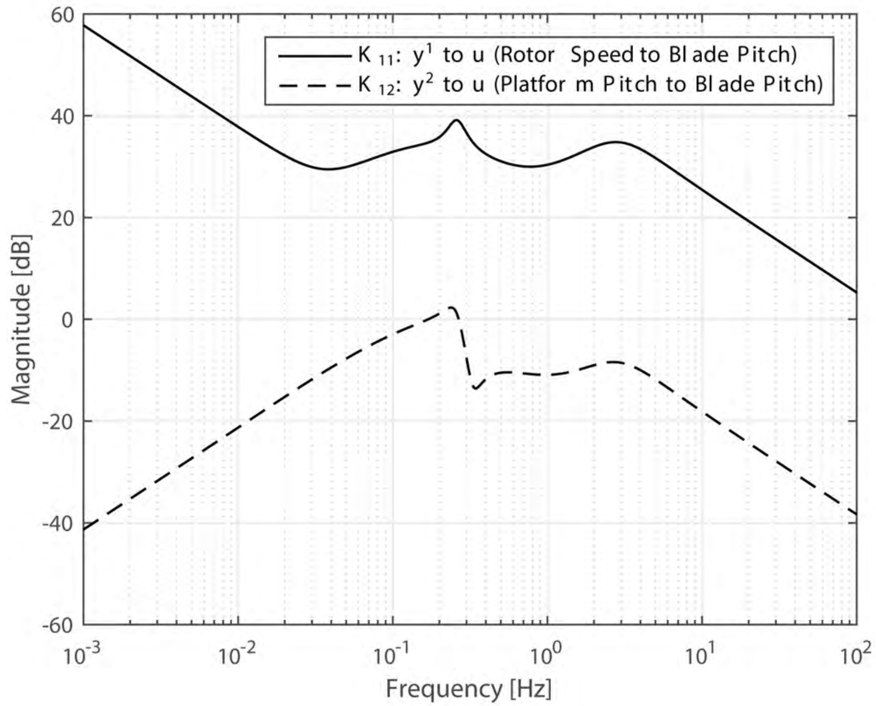
$$\begin{bmatrix} \frac{15}{s(5s+1)^2(s+1)^2} & 0 \\ 0 & \frac{15s}{(0.83s+1)^2} \end{bmatrix}$$

- Remark
  - Include an integrator (rotor spd. Output); resonance peak is suppressed (ptfm. Pitch)
  - The controller *K* was obtained ($\gamma = 3.2511$)

Controller Design by *H*∞ LSDP



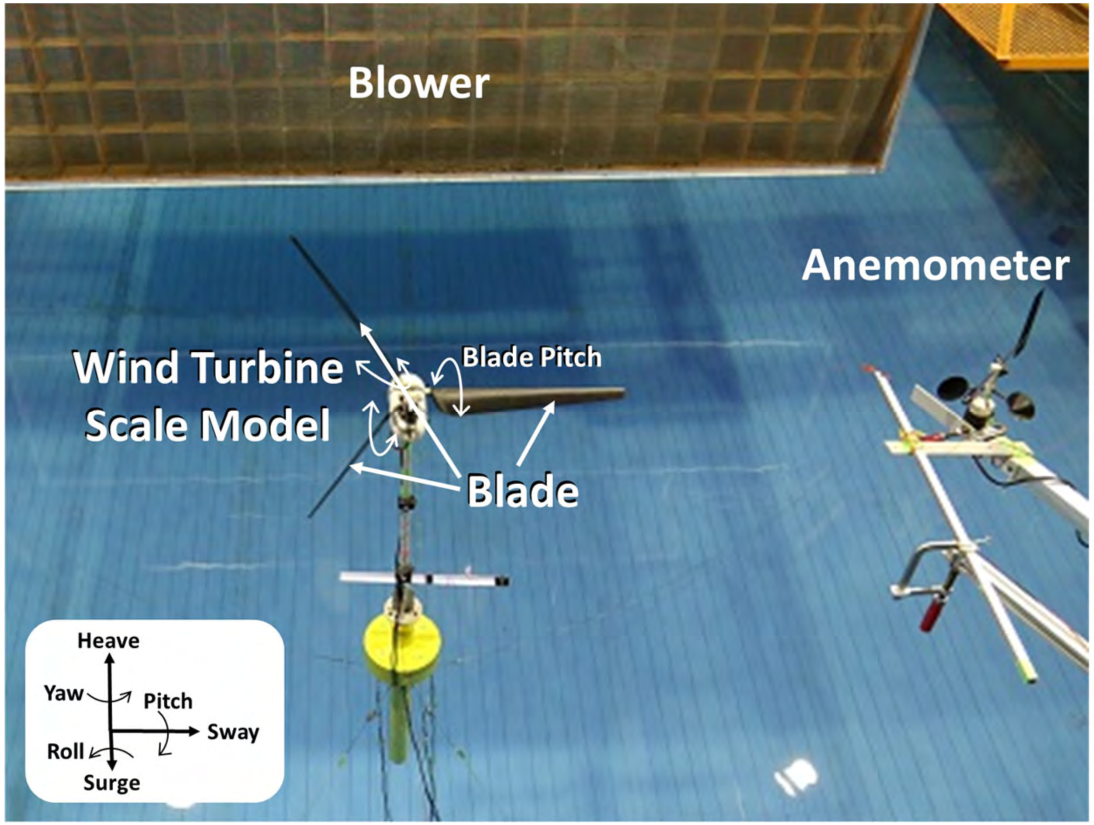
Loop-shape.
(Singular value plot)



Gain plot of the designed controller.

Experimental Results

- Experimentally evaluated the effectiveness of the controller in terms of
  - Rotor speed regulation
  - Platform pitching suppression
- Designed controller
  - Implemented in PC with a sample time of 0.04 [s].



Experimental setup.
(Water tank facility, the Univ. of Tokyo)

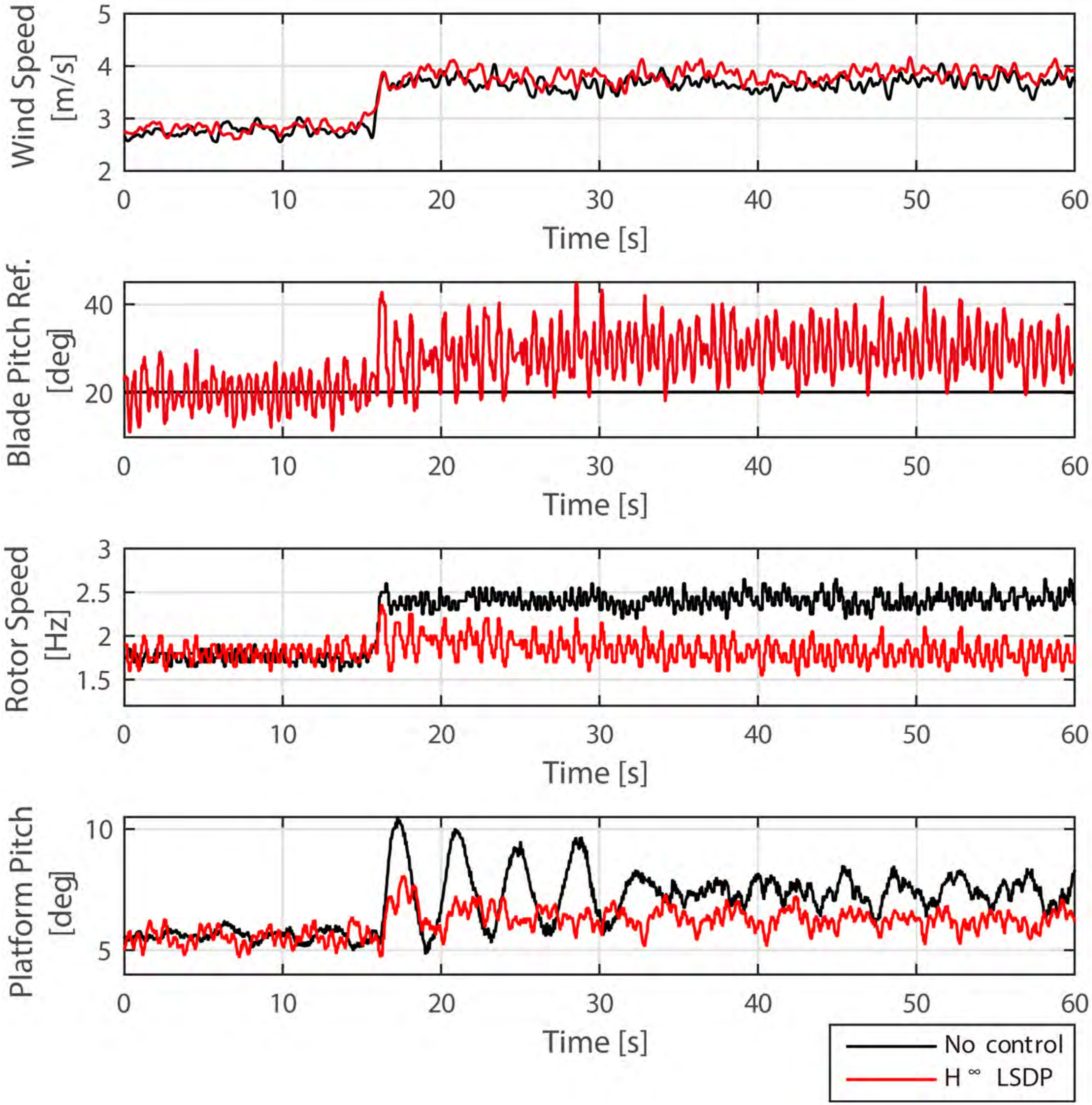
Step wind change

Wind

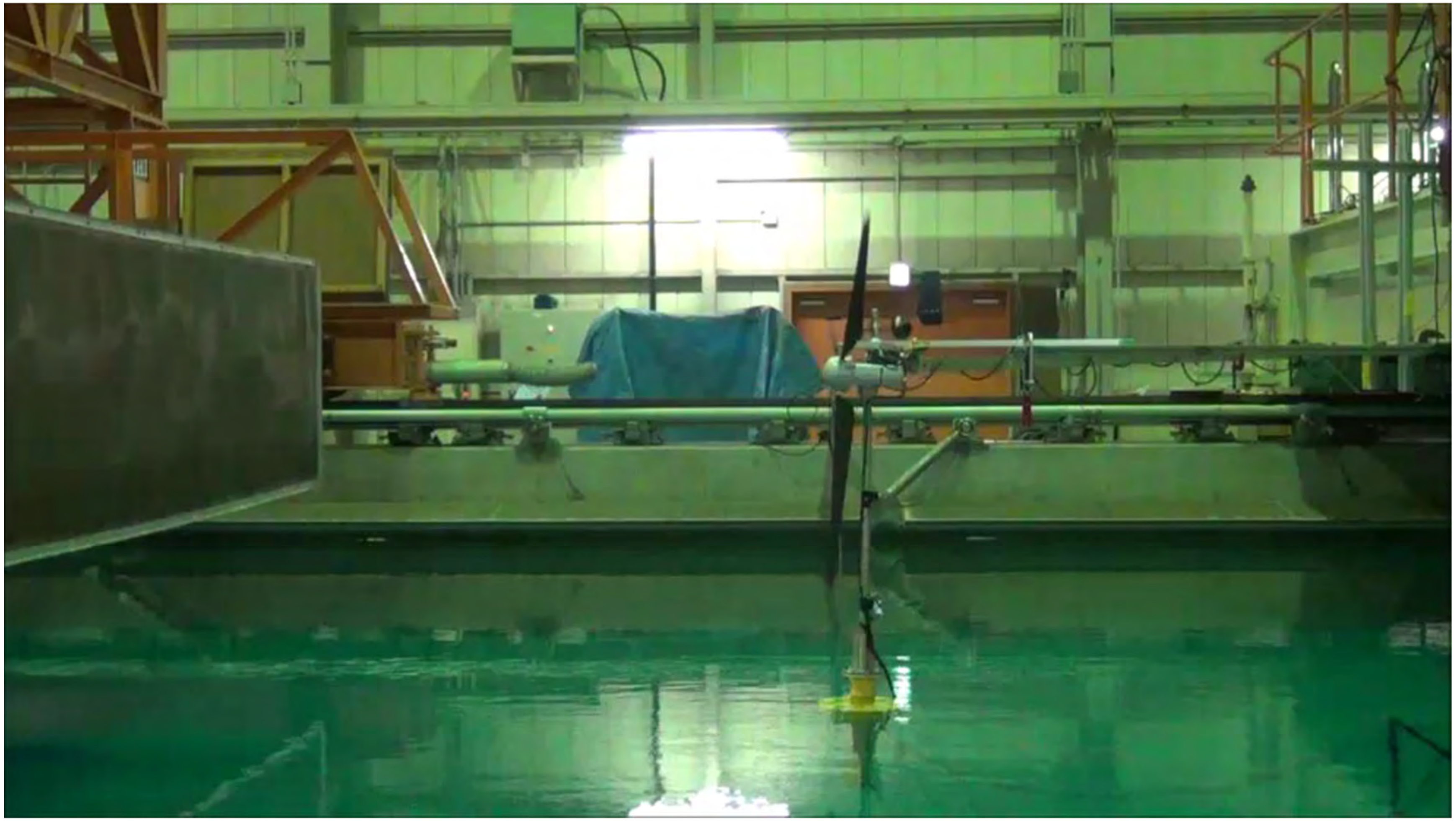
Blade pitch ref.

Rotor speed

Platform pitch

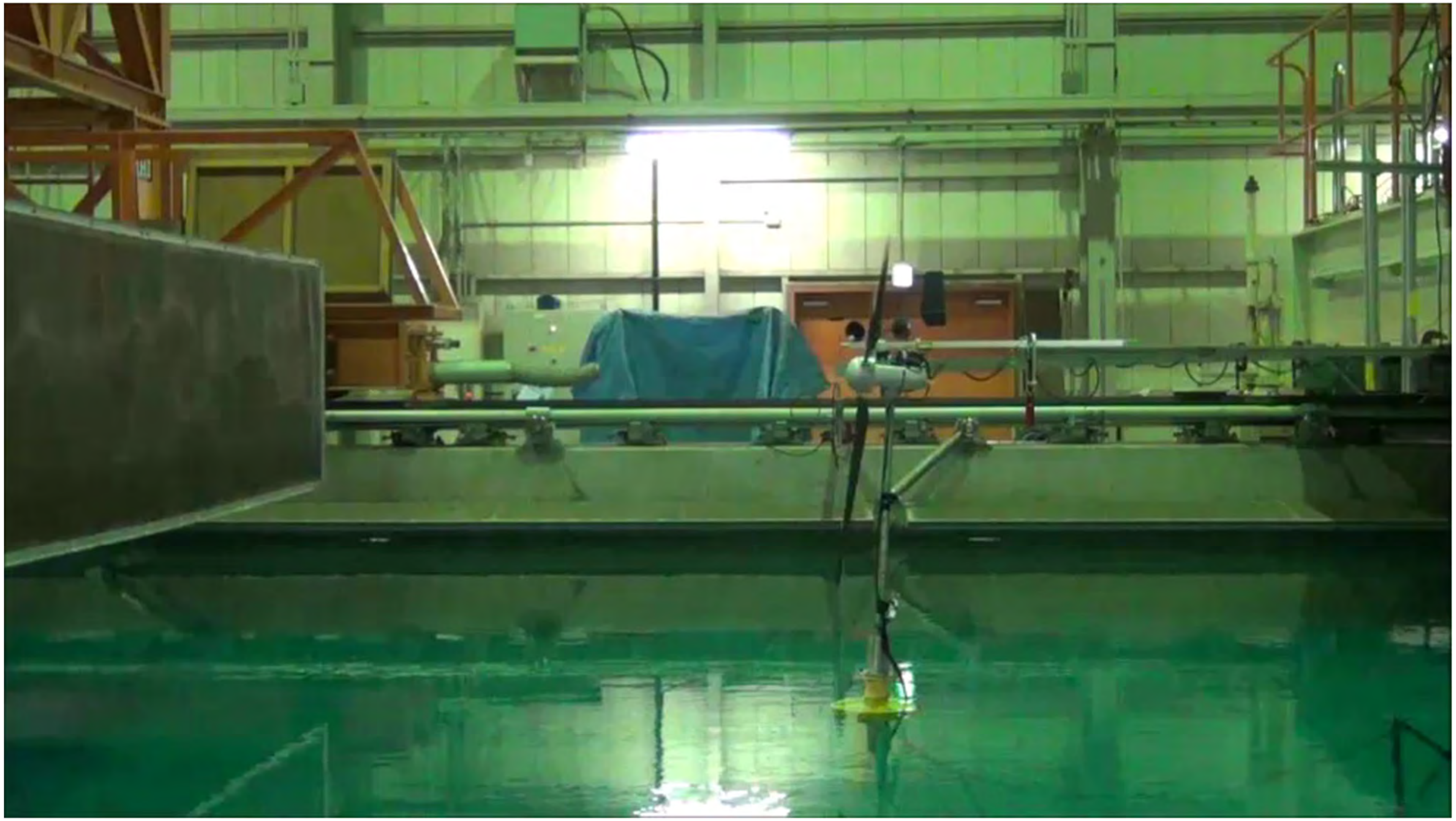


Result（const. blade pitch）



Movies are available at: http://www.eis.osakafu-u.ac.jp/~n-hara/CCTA2017.htm

Result（designed H_∞ LSDP controller）



Movies are available at: http://www.eis.osakafu-u.ac.jp/~n-hara/CCTA2017.htm

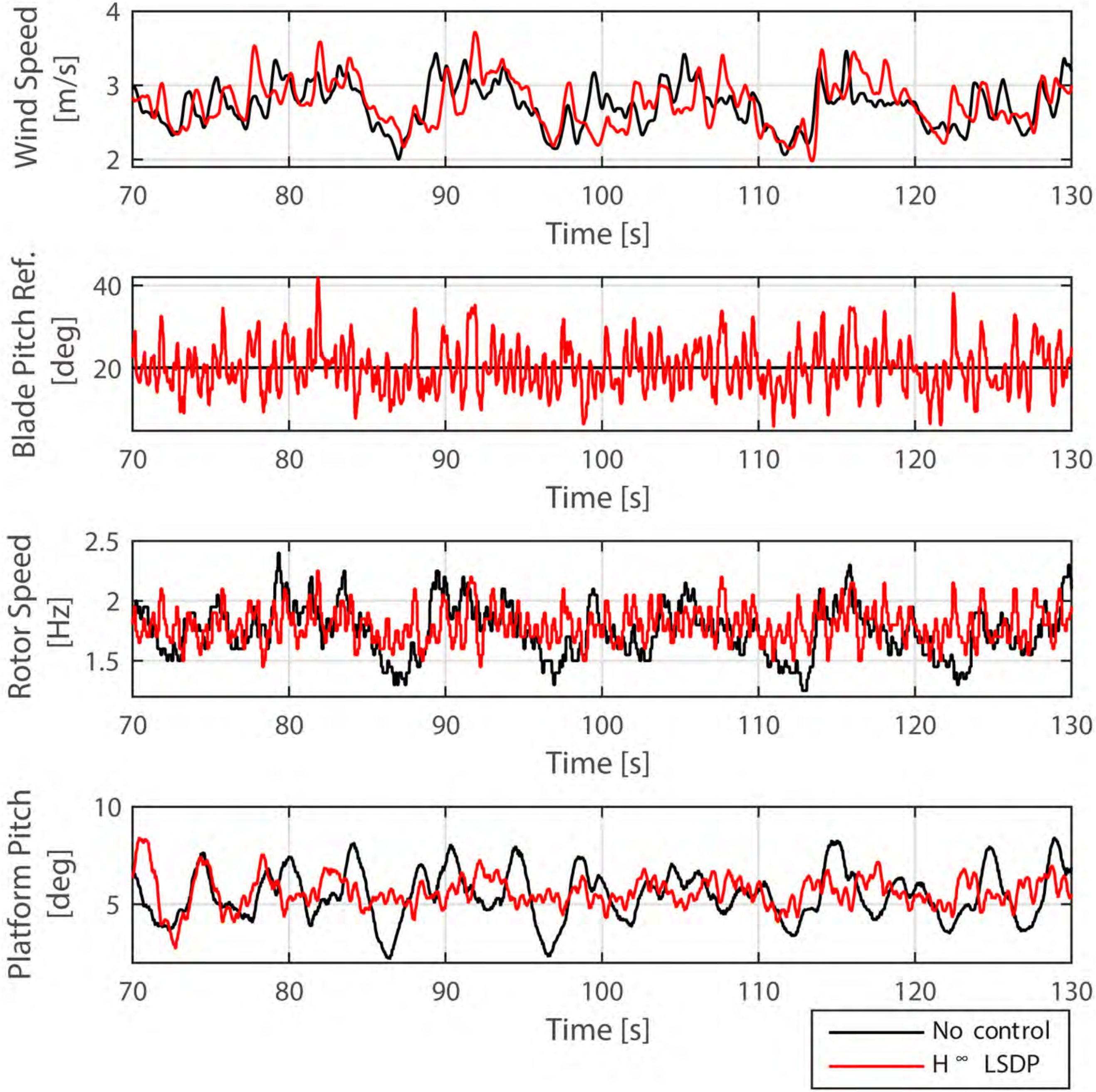
Fluctuating Wind

Wind

Blade pitch ref.

Rotor speed

Platform pitch



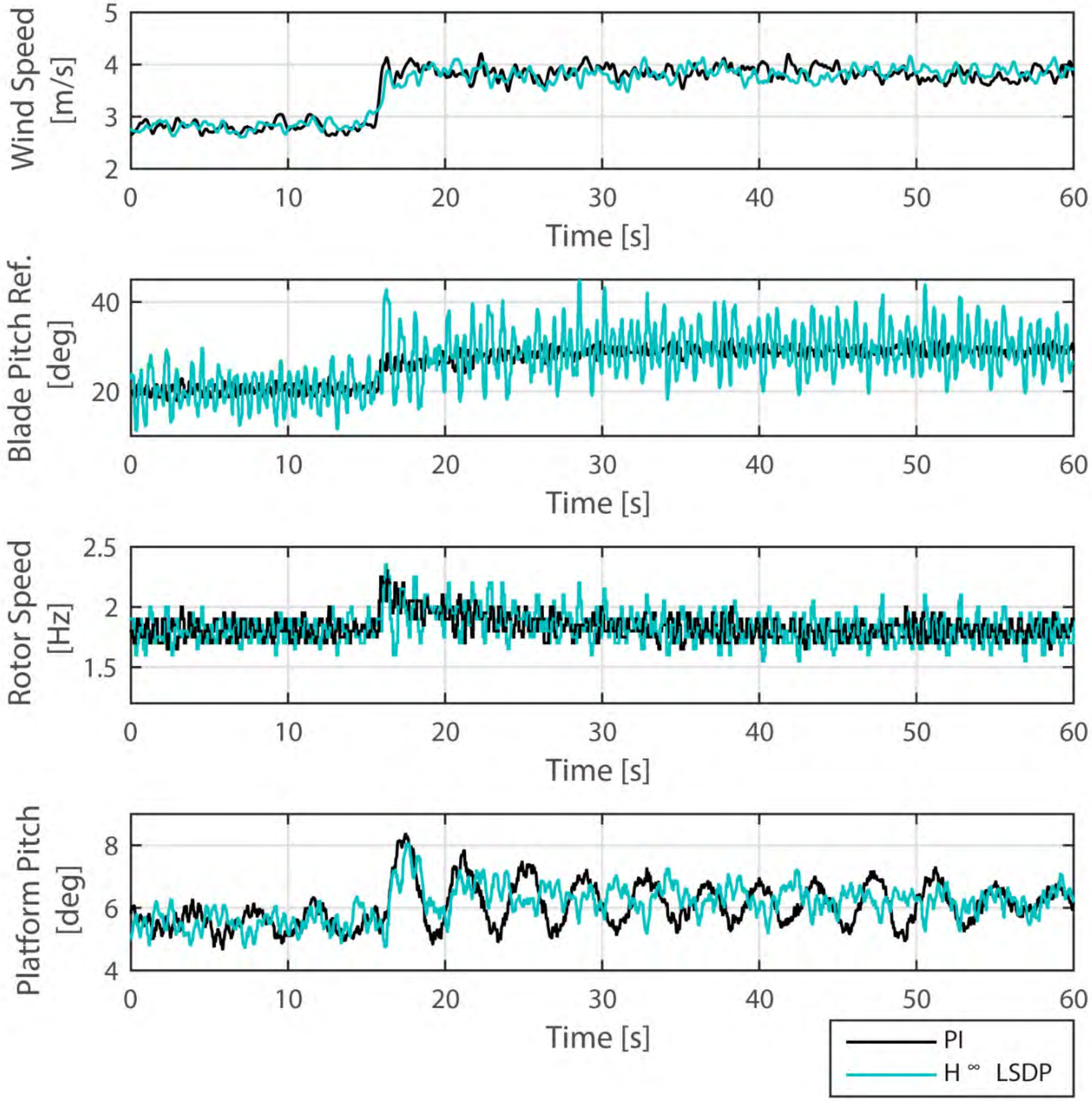
Comparison with PI

Wind

Blade pitch ref.

Rotor speed

Platform pitch



Concluding Remarks

- Designed a (collective) blade pitch controller
  - Plant: obtained by system identification
  - Controller: design by H_∞ LSDP
- We carried out the experiments
  - Platform pitching was suppressed.
  - Blade pitch reference tends to be large. Need some more tuning of the weights.

- Future research topics
  - Evaluation of fatigue loads (tower base, blade root, etc)
  - LTV identification
  - Comparison with the behavior of the corresponding full-scale model.
  - Individual blade pitch control (in progress, currently fabricating a scale model.)

Thank you for your attention!

Acknowledgement

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Contact

Please feel free to contact me if you have any questions:

n-hara@eis.osakafu-u.ac.jp