NONLINEAR MODEL PREDICTIVE CONTROL FOR BIRD STRIKE PREVENTION IN WIND TURBINES

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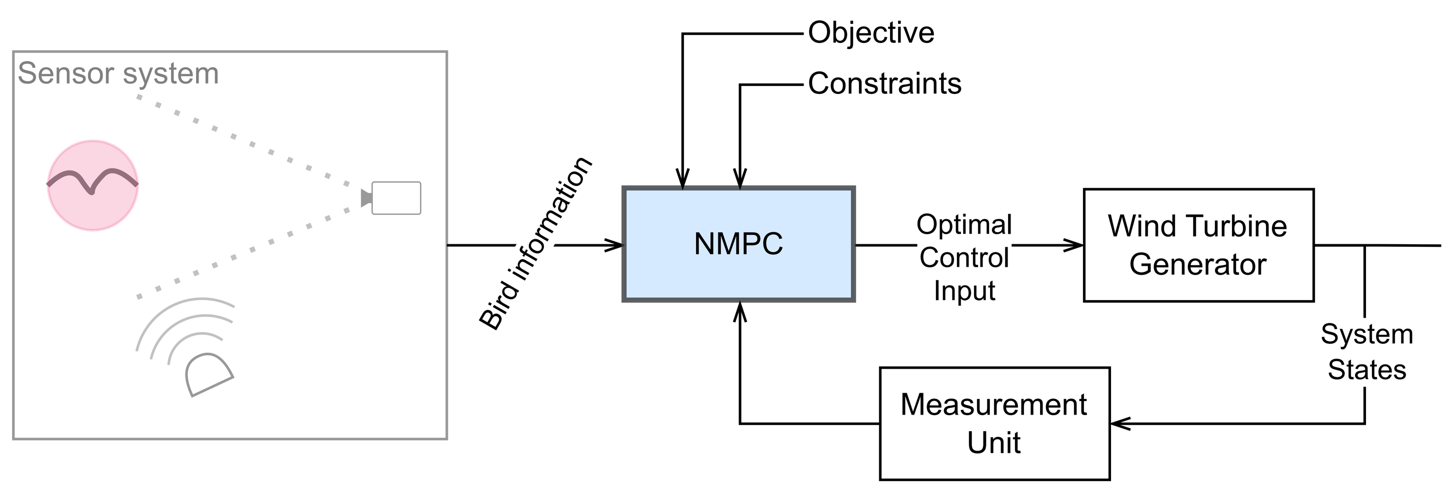
ABSTRACT

This work develops a nonlinear model predictive controller (NMPC) for wind turbines to actively avoid bird strikes. At the same time, we wish to minimize the energy loss resulting from the actions made to avoid bird strikes. This is an extension of the SKARV concept presented in [1]. The proposed control scheme takes inspiration from obstacle avoidance in mobile robots, where a mathematical model of a wind turbine is utilized to predict and optimize the system's behavior with respect to the output power and bird collision constraints. Simulations demonstrate the controller's effectiveness in avoiding bird strikes in a simplified setup. The control scheme results in negligible power loss, indicating that it can be a good alternative to other mitigation strategies.

CONCEPT OVERVIEW



Assumptions

- Sensors are used to locate birds
- Bird trajectories are known, e.g. estimated by mathematical models and machine learning techniques

Objective

- The bird trajectory information is passed to the control scheme
- An NMPC computes optimal control inputs to avoid bird strikes

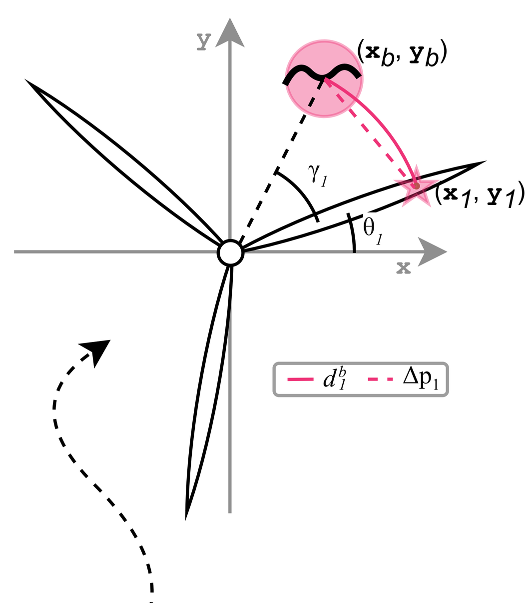
MODEL PREDICTIVE CONTROL DESIGN

The NMPC scheme utilizes a mathematical model of the NREL 5MW wind turbine generator through the dynamics presented in [2]. The dynamics is discretized using the direct multiple shooting method, which is implemented using CasADi [3]. The controller is designed to optimize the behavior of the wind turbine through an optimal control problem, with goals and subsequent implementation strategies presented in Table 1.

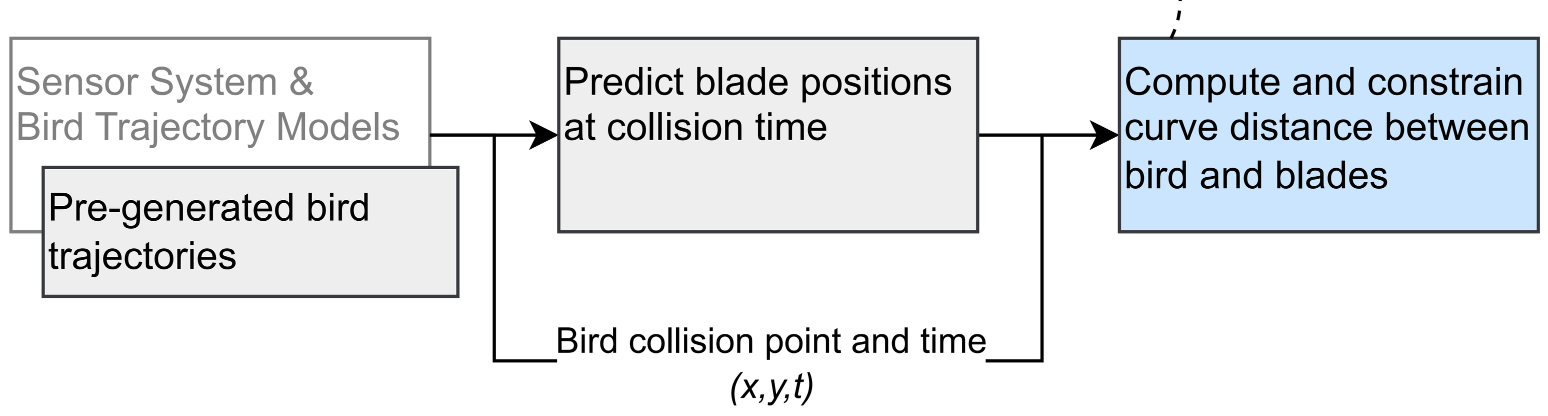
Goal	Implementation
Avoid bird strikes	Require a minimum bird-blade distance at the potential collision time step.
Allow unavoidable bird strikes	Add a slack variable to the bird-blade distance constraint with substantial cost in the objective.
Minimize effects on power production	Implement power reference tracking in the objective function.
Smooth control inputs	Penalize abrupt changes in blade pitch in the objective function.

***Table 1**: Description of the controller goals and the strategies applied to achieve the goals.*

The bird strike avoidance constraint is computed utilizing the curve distance between the bird and the blade.



A set of pre-generated bird collision points *(x,y,t)* are used in place of the sensor system and bird trajectory prediction model.

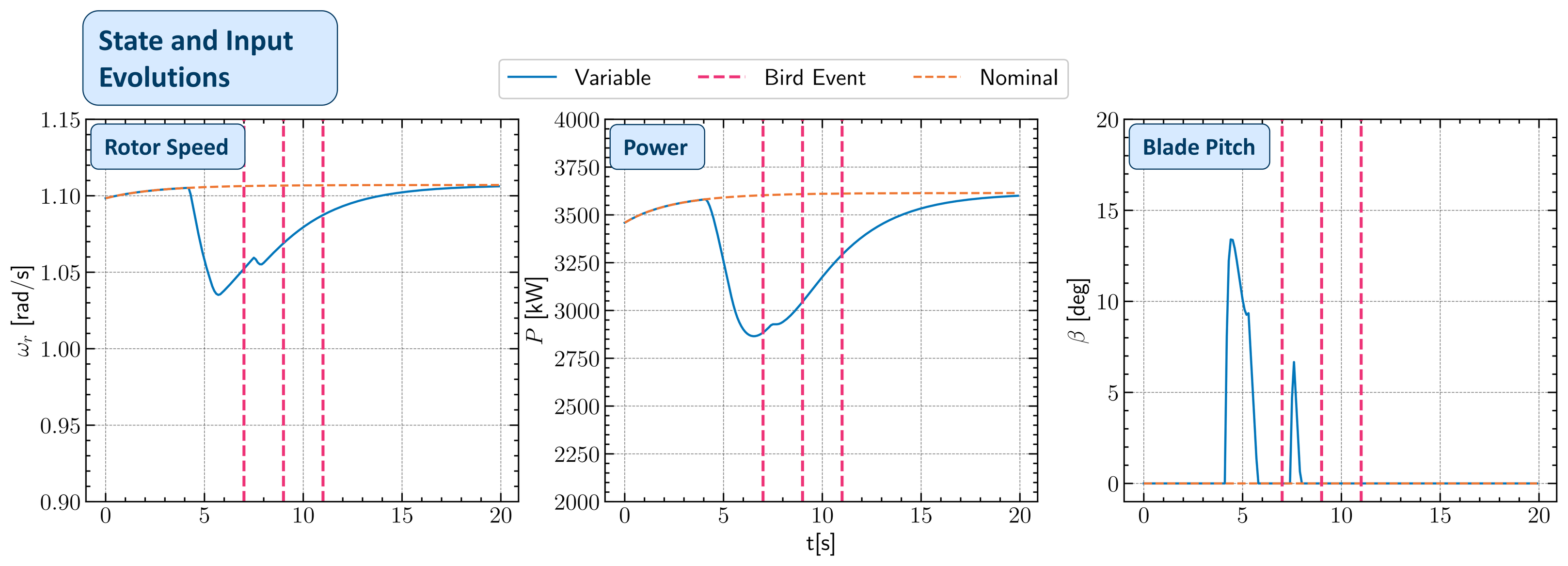


BIRD INTERSECTION SIMULATION

Test case

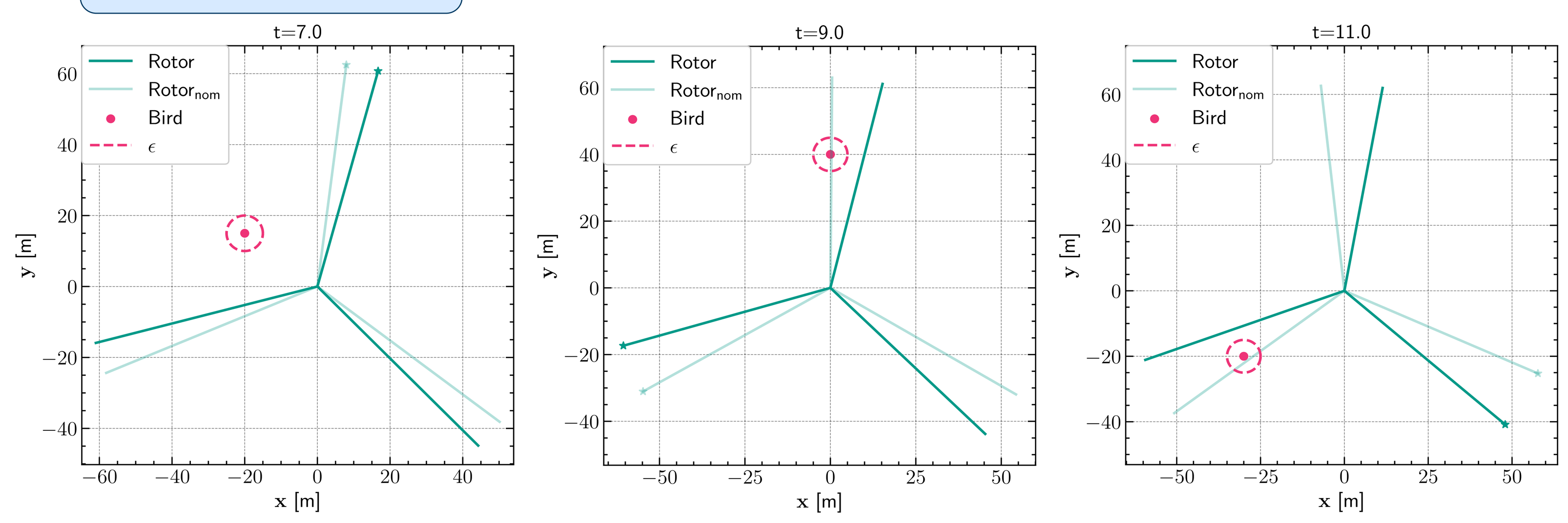
- Wind speed of 10 m/s
- Prediction horizon of 5 seconds
- Bird intersections at 7, 9 and 11 seconds

State and Input Evolutions



- ➢ The rotor speed is temporarily reduced to avoid the birds
- ➢ The power output is briefly impacted by the control scheme
- ➢ Control action is initiated at 4 s due to collision danger with the second bird
- ➢ Additional control action at 7.5 s due to the third bird

Rotor Snapshots at Collision Time



- ➢ Low chance of collision with the bird
- ➢ The controlled case deviates from the nominal case due to collision risk with the next birds
- ➢ In both cases, the birds would collide in the nominal case
- ➢ The birds are avoided by the turbine

CONCLUSIONS

- The suggested control scheme shows promise, where it is successful in avoiding bird strikes.
- The controller only leads to a small power loss implying that it might be a good alternative to other techniques such as turbine shutdown on-demand.
- To employ such a control scheme, well-developed sensor systems and bird trajectory models must be in place.

FUTURE WORK

- Expand the scheme to the stochastic case, allowing for uncertainties in wind speed and bird trajectories.
- Include noise in measurements and estimates.

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