Summary

▶ Comparison of classical and machine-learning modeling methods
▶ Design of a nonlinear model predictive controller
▶ Hard real-time implementation in C++
▶ Evaluation on a real-world AWE prototype

Modeling

▶ Classic Approach: Quadratic Model & LLS Fitting

\[
\dot{x}_i = x_i^\top A_{i\text{quad}} x_i + A_{i\text{lin}} x_i + B_i u + C_i
\]

- linear: \( A_{i\text{quad}} = 0, C_i = 0 \)
- lasso, elastic and huber use respective regularizer with learned weighing parameters

▶ Novel approach:
  - approximate system dynamics via neural network (NN)
  - nonlinear state augmentation (quadratic and trigonometric)

Control

▶ Nonlinear Model Predictive Control (NMPC)
▶ Direct Multiple Shooting using explicit RK4
▶ Gauss-Newton Hessian approximation + condensing
▶ Constrained control surface position and speed
▶ C++ Code Generation from MATLAB via ACADO / QPOASES
▶ 4 states, 1 control, 100 steps, @20Hz, 5 sec Horizon

Real-world setup

▶ Reduced-DOF plane for rotational start experiments
▶ Custom hardware designed in-house for sensor/actuator IO
▶ Fully equipped for lift-mode energy production

Conclusion

▶ Robust results with linear regression fit
▶ Quadratic elements can reduce error, but are easy to overfit
▶ ML refinements achieve further improvement reduce overfitting
▶ Neural networks achieve good short time prediction and are suitable for integration in NMPC
▶ Evaluation on real-world setup shows adequate performance of machine learning approaches in a real-time control setup
▶ Future research aims to apply the presented approaches to tethered flight operation

Experimental Results

![Graph showing Mean Square Prediction Error vs. Horizon Length](image)

![Graph showing Elevation Angle vs. Time](image)

<table>
<thead>
<tr>
<th>Model</th>
<th>MSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>lasso</td>
<td>6.281e-04</td>
</tr>
<tr>
<td>linear</td>
<td>6.826e-04</td>
</tr>
<tr>
<td>elastic</td>
<td>6.949e-04</td>
</tr>
<tr>
<td>quad</td>
<td>9.100e-04</td>
</tr>
<tr>
<td>huber</td>
<td>9.161e-04</td>
</tr>
<tr>
<td>ridge</td>
<td>1.826e-03</td>
</tr>
<tr>
<td>∆-lin</td>
<td>3.164e-03</td>
</tr>
<tr>
<td>Lin+NN</td>
<td>1.269e-02</td>
</tr>
</tbody>
</table>