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Kernel-based Identification of Periodically Parameter-Varying Models of Power Kites

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In airborne wind energy (AWE) systems, model mismatch may in practice lead to severe performance deterioration. It is thus desired to assess closed-loop performance from experimental trajectory data with a closed-loop model, to analyze the performance of existing flight systems and design additional control loops.

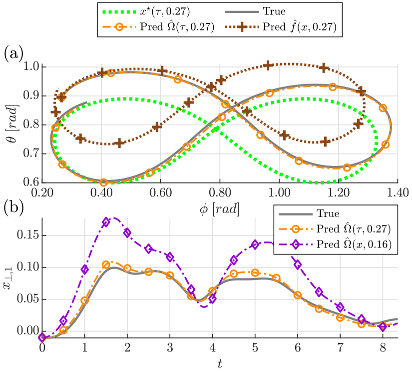
Therefore, we are interested in identifying power kite dynamics moving along a periodic orbit, which can be modeled as a periodic system parametrized with the location on the orbit. Concerning performance close to the orbit, the periodic system can linearized locally. This work proposes an approach to identifying the local dynamics with a linear periodically parameter-varying model from experiment trajectory data.

The approach decomposes the dynamics into two parts: one along the orbit, and one on a transversal hyperplane of the orbit [1]. Let the state of the kite be x, and the nominal periodic trajectory be $\{x^\star(\tau) \mid \tau \in [0, T)\}$. Define $S(\tau)$ as a hyperplane transversal to the orbit. The state can be decomposed as $(\tau, x_\perp)$, with dynamics modeled as

$$\begin{cases} \dot{x}_\perp &= A(\tau)x_\perp + O(|x_\perp|^2), \\ \dot{\tau} &= 1 + g(\tau)x_\perp + O(|x_\perp|^2). \end{cases}$$

The proposed identification method identifies $A(\tau)$ and $g(\tau)$ as smooth functions of τ. Measured data are first decomposed into transverse coordinates. The problem is then recast as a function learning problem, where the kernel method is applied to learn the model. This approach also handles additional operating parameters (e.g., radius, nominal speed), noisy measurements, and exogenous inputs (e.g., wind gusts, additional actuation).

The identification algorithm is tested on simulation data generated by a simulation model of tethered kites with a multi-loop control design. Results show that the proposed approach is able to obtain reliable predictions of closed-loop trajectories under various scenarios.



Predicted trajectories with additional parameter $v_{\theta\phi}/r$. Orange: proposed method, brown: black-box nonlinear identification, purple: without $v_{\theta\phi}/r$ modeling.

References:

*[1] Manchester I. R.: Transverse Dynamics and Regions of Stability for Nonlinear Hybrid Limit Cycles. IFAC Proceedings Volumes. **44**(1), 6285-6290 (2011)*