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Iterative Learning-Based Kite Path Optimization for Maximum Energy Harvesting

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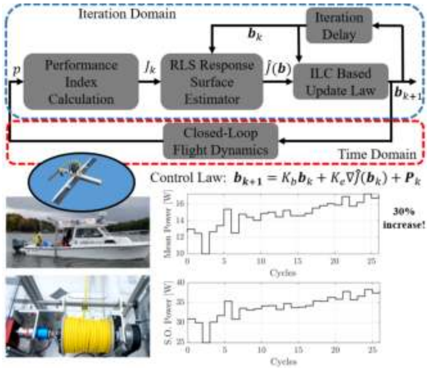
In this work, we have adapted and validated an iterative learning-based basis parameter optimization that optimizes the parameters of a flight path or orientation trajectory for an *airborne wind energy* or *marine hydrokinetic kite system*. This algorithm, first seen in [1] and further developed in [2], was adapted to accommodate parameters that describe target roll and yaw trajectories.

The algorithm consists of two steps that take place after each spool-out/spool-in ("pumping") cycle of the kite. In the first step, a meta-model is updated using a recursive least squares estimate to characterize an economic performance index as a function of a set of basis parameters ($\mathbf{b}_k$) that describe either a spatial path or orientation (roll and yaw) trajectory. The second part is an iterative learning update, which uses information from past cycles to update basis parameters at future cycles using a gradient ascent formulation with an added perturbation ($\mathbf{P}_k$) to push the controller out of local maxima.

While this algorithm can be applied to either airborne or underwater kites, it was experimentally validated on a $1/12^{th}$ scale experimental prototype underwater kite system towed behind a test vessel in Lake Norman, North Carolina. On top of the iterative learning update, a state machine was used for transitioning from figure-8 cross-current flight when spooling tether out to wings-level flight on spool-in. Furthermore, lower-level controllers were used to track setpoints generated based on the parameters updated by the iterative learning algorithm. Using our experimental system and algorithm, we were able to increase cycle-averaged power by 30 percent, relative to an initial baseline controller.



System diagram, control law, experimental apparatus, and results for an iterative learning-based optimization applied to a kite system. ***Diagram:*** *$\mathbf{b}_k$, are the basis parameters, p are the plant variables, J_k is the performance metric, and $\hat{\mathbf{J}}(\mathbf{b})$ is the estimated response surface.* ***Control law:*** *K_b and K_e are controller gains and $\nabla \hat{\mathbf{J}}(\mathbf{b}_k)$ is the estimated gradient of the response surface.* ***Results:*** *Cycle- and spool-out-averaged power are greatly increased.*

References:

[1] M. Cobb, K. Barton, H. Fathy, and C. Vermillion, "Iterative learning-based waypoint optimization for repetitive path planning, with application to airborne wind energy systems," in 2017 IEEE 56th Annual Conference on Decision and Control (CDC), Dec 2017, pp. 2698–2704.

[2] M. Cobb, J. Reed, J. Daniels, A. Siddiqui, M. Wu, H. Fathy, K. Barton, and C. Vermillion, "Iterative learning-based path optimization with application to marine hydrokinetic energy systems," IEEE Transactions on Control Systems Technology, 2021.