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Analysis and Experimental Validation of a Low-Complexity Enhanced Orientation-Based Controller for Tethered Energy Harvesting Systems

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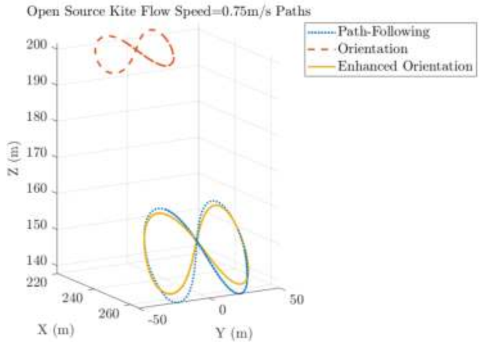
This work introduces a new flight control technique for kites that combines the simplicity and robustness of orientation-based control with the performance of more sophisticated hierarchical path-following controllers. Conventional orientation-based control strategies guide a kite to track periodic, open-loop roll and yaw setpoint trajectories. In the proposed control strategy, termed “enhanced orientation-based control," the roll setpoint trajectory is modified continuously to track a desired elevation angle. Orbital stability is validated in a low-order simulation framework (presented in [1]) for a proprietary and open-source kite model under multiple flow conditions via a Floquet analysis. Using both kite models, the performance of the proposed controller is benchmarked in a medium-fidelity simulation framework (using a dynamic model derived from [2]) to both an orientation-based and path-following controller (wherein a desired 3D flight path is tracked). In simulation, the proposed strategy was shown to generate 88.4%–97.3% and 81.1%–86.5% of the power generated by the path-following controller for the open source and proprietary kite models respectively, without requiring high-precision, real-time localization. Meanwhile, the orientation-based strategy generated 48.9%–53.6% and 68.7%–69.9% of the power generated by a path-following strategy for the open source and proprietary kite models respectively. The proposed strategy was tested experimentally on an underwater kite towed behind a boat to simulate an ocean current where this strategy outperformed an orientation-based strategy by 9.6%–18.8%.



Flight paths flown by the open-source kite for a flow speed of 0.75m/s and a tether length of 500m. As shown, the enhanced orientation-based controller drives the kite to a comparable elevation angle to the path-following controller, which results in much more efficient flight than orientation-based control alone.

References:

[1] Fernandes, Manuel and Vinha, Sergio and Paiva, Luis and Fontes, Fernando: L0 and L1 Guidance and Path-Following Control for Airborne Wind Energy Systems. Energies, 1390 (2022)

[2] Rapp, Sebastian and Schmehl, Roland and Oland, Espen and Haas, Thomas: Cascaded Pumping Cycle Control for Rigid Wing Airborne Wind Energy Systems. Journal of Guidance, Control, and Dynamics, 2456-2473 (2019)