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Stability Certificates for a Model-Based Controller for Autonomous Power Kites

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One of the main challenges we are facing in AWE systems research is the reliability of the controller for automatic flight operation of the kite within a given range of environmental conditions. Various control designs ranging from structurally simple model-free proportional-integral-derivative (PID) controllers to more complex model-based optimal control algorithms have been employed for the automatic control of kites. Independent of the choice of controller, the challenge of assessing the reliability remains. With reliability we refer to the guarantee of stably controlling the kite such that it does not diverge from a desired range of trajectories.

We propose an algorithm for controlling the crosswind flight in the energy-generating phase of a two-phase pumping cycle with guarantees of stability. The controller is based on a parameter varying linear quadratic regulator (LQR). For this model-based controller, we employ the kinematic model suggested by Wood et al. [1] to represent the kite's dynamics. In order to make our controller feasible in real time, LQR gains depending on the state of the kite, i.e., its position, heading and velocity, are computed offline. Similar to an approach proposed by Tedrake et al. [2], the control gains are stored in a so called LQR-tree library. Given an estimate of the kite state at any measurement instance, the corresponding stabilizing LQR gain can be recovered from the library. A crucial step for this library-based control scheme to guarantee stability is the assessment of the stabilizing region of the state space for each LQR gain. This information is obtained by performing a region of attraction (ROA) analysis for each gain. Our ROA analysis mainly follows the procedures proposed by Manchester [3]. The method is based on a Lyapunov analysis where sums-of-squares programs are employed in order to obtain certificates of semi-algebraic set containment which guarantee stability for the considered region. Using semi-definite relaxations, the set containment problem is solved efficiently by a series of semi-definite programs. The obtained certificates allow us to choose a stabilizing controller gain at any instance such that the kite follows a predefined desired trajectory.

The controller performance is sensitive to the accuracy of the state estimates. Measurements of the position and orientation of the kite from line angles or onboard sensors are often noisy and biased due to, e.g., line sag and time delays. In order to obtain more accurate measurements and improve the control performance, we are working on an active camera tracking system for state estimation. The pan-tilt-zoom camera system is able to detect both the position of the kite in the wind window and its heading in real time. In this talk we will briefly highlight the benefits of this vision based estimation approach.

References:

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