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Nonlinear Model Predictive Path Following Control of a Fixed-Wing Single-Line Kite

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A reliable flight control of Airborne Wind Energy (AWE) kites is known to be a challenging problem both from academic and industrial perspectives. In recent years, several modeling and trajectory tracking strategies were suggested for the fixed-wing single-line class of energy kites [2]. However, validation and experimental results for these methods are not available. This work aims at further studying AWE systems dynamics and application of optimization-based algorithms for path following control of energy kites. To assess the quality of the developed model an experimental study was carried out with a micro-scale indoor AWE system prototype.

A mathematical model of a fixed-wing single-line kite with 6 DoF is derived. Aerodynamic model of a flying vehicle includes lift and drag coefficients as well as stability and control derivatives. A tether dynamics is described utilizing the Kelvin-Voigt viscoelastic model.

The software framework consists of the kite simulation module, generic Extended Kalman Filter (EKF) implementation, and Nonlinear Model Predictive Path Following (NMPF) control algorithm. For the latter, we consider the constrained output path following problem of a closed path defined as a parametric curve in the output space of the system [1]. The path parameter is treated as a virtual state, governed by an additional ODE. The Chebyshev pseudospectral collocation technique is chosen for the trajectory discretization to account for the inherently unstable and highly nonlinear nature of the system.

The test platform comprises a radio controlled commercial propelled airplane, tailored with a nylon thread to the ground station unit. The station is capable of measuring line angles, tether force and control reeling in of the tether. The flying facility is equipped with OptiTrack^{TM} motion capture system that provides ground-truth position and attitude measurements.

Throughout piloted flight experiments we identified viscoelastic parameters of the tether and adjusted values of some stability and control derivatives. Then the developed estimation and control framework is successfully tested to track a circular path in the flight simulator. Further research will be focused on extending the presented approach to operate with environmental and parametric uncertainties.

References:

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