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An Efficient Optimal Control Method for Airborne Wind Energy Systems with a Large Number of Slowly Changing Subcycles

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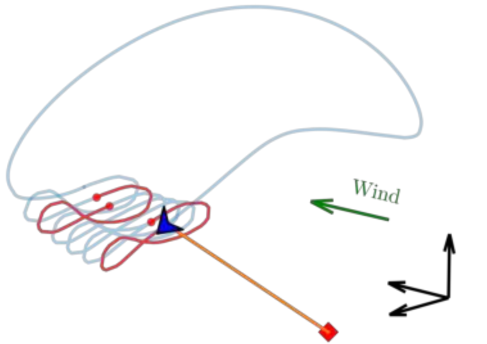
We present a simulation method to efficiently solve highly oscillatory optimal control problems and discuss in detail its application to the optimization of pumping airborne wind energy systems with a long reel-out phase duration.

In the context of AWE systems, the reel-out trajectory of a kite can be considered highly oscillatory since it is composed of a sequence of fast cycles (circular loops or lemniscate patterns) superimposed on a smooth reel-out trajectory (slowly changing average flying height or tether length). For a large number of cycles in the reel-out phase, the optimal control problem (OCP) of finding power-optimal trajectories becomes increasingly more computationally expensive to solve.

Instead of exactly simulating all cycles of an oscillating trajectory, we only simulate a few of them to gather information about the slow change that occurs over the time horizon. We numerically approximate the slow change using a semi-explicit differential-algebraic equation (DAE), that can then be integrated with large integration steps. For the use in optimal control problems, we provide a way to parametrize the controls.

We utilize this method to find the optimal trajectory of a simple AWE kite system model by [1]. We solve the DAE OCP with 20 cycles in the reel-out phase. Since we assume that the cycles are very similar to each other, we also have to restrict the control scheme for a single cycle to only vary slowly over the horizon. Compared to a 'full' OCP, where we simulate the whole trajectory, the DAE OCP slightly overestimates the power that the AWE system can generate by less than one percent. Due to the smaller problem size, we solve the DAE OCP about six times more efficiently.



Example trajectory of an AWE kite system. The two subcycles used to approximate the slow reel-out dynamics are marked in red.

References:

[1] M. Erhard, G. Horn, and M. Diehl, "A quaternion-based model for optimal control of the skysails airborne wind energy system," ZAMM Journal of applied mathematics and mechanics: Zeitschrift für angewandte Mathematik und Mechanik, vol. 97, 08 2015