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Drone Trajectory Planning Considering Battery Capacity

Zdeněk Bouček[1]

1 Introduction

One of the big challenges in the drone field today is long-term missions with several drones at the same time. This is mainly due to the emphasis on strong system autonomy and low battery life (a few tens of minutes). Therefore, this paper addresses the problem of trajectory planning with respect to battery "state of charge" (SoC) (see Zhang (2020)).

It is approached as an optimal control problem (OCP) which considers a standard Unmanned Aerial Vehicle (UAV) with simple flat dynamics (see Baca (2019)). The battery SoC behavior is described with nonlinear discharge model, and minimum and maximum capacity. The SoC is also reflected in the objective function, where it is maximized. UAV acceleration is used as a control input. In addition, collision-avoidance is addressed in the paper, where the UAV has to avoid randomly generated static obstacles.

OCP is solved by an indirect transcription method called Pseudospectral method (PSM) that transforms the time-continuous nonlinear boundary value problem into nonlinear program. Finding a solution is achieved by using an NLP solver.

2 Chebyshev Pseudospectral Optimal Control

The PSM (see Trefethen (2000)) gives an exact solution to the problem at "grid" or so-called "collocation" points and approximates the function outside these points by a polynomial. Each polynomial has a set of collocation points that are optimal. The points are the roots of the polynomial, which can be augmented by boundary points.

In this paper, the standard Chebyshev polynomial of first kind with a grid containing the boundary points is chosen. Integral objective is approximated with Clenshaw–Curtis quadrature and derivative which is needed for approximating dynamics is calculated using differential matrix. The Chebyshev approximation can be used on the interval $[-1, 1]$. Therefore, it is necessary to transform the coordinates of the problem when solving the OCP.

The PSM is characterized in particular by its high accuracy with lower computational complexity than alternative approaches. Therefore, it is advantageous to use it for drone trajectories as it allows fast computation when replanning is required and low complexity, so it can be used even on an up-board computer.

3 Trajectory Planning

This section will provide a description of the problem and implementation details. The state of the system consists of the position and speed of the drone and the SoC. Each state is bounded by box constraints. The problem contains fixed boundary points except for SoC and

[1] student of the doctoral study program Applied Sciences and Informatics, field of study Cybernetics, specialization Intelligent Adaptive Systems, e-mail: zboucek@ntis.zcu.cz

tf, which have a free end-points. Objective function includes SoC maximization. The problem is further supplemented with constraints for obstacles in form $-\|r - c_i\|_2 + R^2 \leq 0$, where r is position, c_i is center of i-th obstacle and R is a radius of obstacle. Obstacles are sampled randomly through the whole space with uniform distribution.

State of battery is described in standard manner using SOC which is given as 0.0 and 1.0 for empty full battery, respectively. The dynamics is described as $\dot{x}_b(t) = B_b\left(v_x^2 + v_y^2 + v_z^2\right) + D_b$, which includes linear discharging with time (parameter D_b) and also dependency on the square root of UAV velocity.

4 Results

The problem was solved in Python using the Pyomo optimization toolbox. The apparatus for the Chebyshev polynomial approximation was rewritten based on the MATLAB implementation in Trefethen (2000). The solution was sought using well-known open-source NLP solver IPOPT. The UAV successfully avoided all obstacles and flew from the initial to the target point. Path of UAV is showed in Figure 1, where the blue spheres are obstacles, green point is start and red is the end-point. The SoC value is shown in Figure 2.

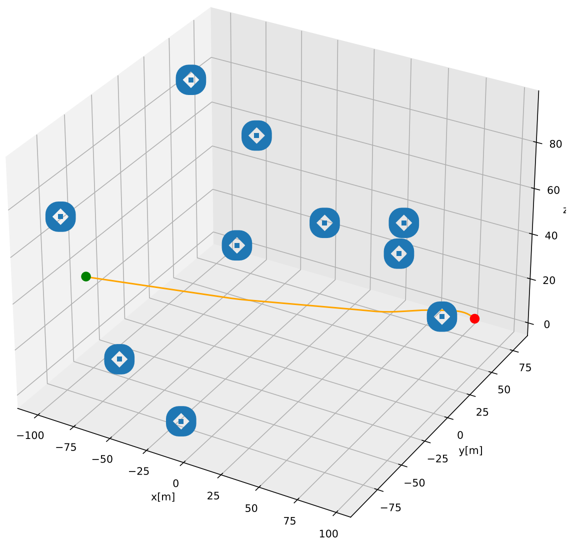

Figure 1: Drone passage through an environment with obstacles.

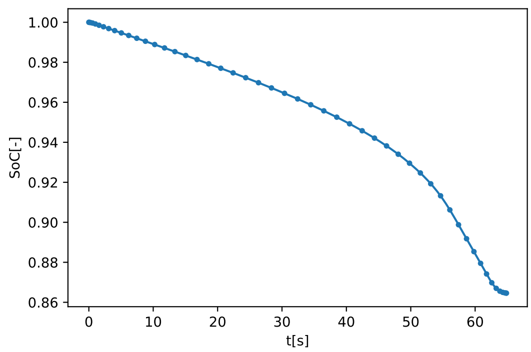

Figure 2: State of Charge trajectory is dependent on velocity (1.0 is maximum and 0.0 minimum charge).

The results show that an optimal trajectory that considers battery discharge has been successfully found. The problem could be extended in the future, for example, to reflect the temperature during battery discharge, scheduling battery replacement at service stations, or the interaction of several drones simultaneously.

References

Baca, T. et al. (2019) “Autonomous landing on a moving vehicle with an unmanned aerial vehicle,” *J. F. Robot*, , doi: 10.1002/rob.21858.

Trefethen, L. N. (2000) *Spectral Methods in MATLAB*. Society for Industrial and Applied Mathematics.

Zhang, D. et al. (2020) ”Real-Time Capacity Estimation of Lithium-Ion Batteries Utilizing Thermal Dynamics,” in *IEEE Transactions on Control Systems Technology*, vol. 28, no. 3, pp. 992-1000, doi: 10.1109/TCST.2018.2885681.