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PERFORMANCE ANALYSIS OF REAL-TIME OPTIMAL GUIDANCE METHODS FOR VERTICAL TAKE-OFF, VERTICAL LANDING VEHICLES

Abstract

In the frame of technology development for reusable launch vehicles and future planetary landing missions the German Aerospace Center (DLR) is developing a demonstrator vehicle (EAGLE) for vertical take-off and landing. The mission profile of EAGLE requires the capability to compute feasible ascent and descent trajectories in real-time. This is achieved using guidance methods based on convex optimal control theory. By applying loss-less convexification, the powered-descent and landing fuel-optimal control problem is converted into a second order cone programming problem. We combine different transcription methods (pseudospectral and multiple shooting) and automatic scaling routines to improve the numerical conditioning of the problem. The resulting second order cone programming problems are solved using the embedded conic solver ECOS. In this paper, the developed algorithms are compared with well-known literature results for a pinpoint landing scenario, with hard and relaxed boundary conditions. In addition, a heuristic kinematics-based estimation for the fuel-optimal flight time is suggested to generate an optimization start value based on the initial and final conditions of the optimal control problem. The approach is tested using Monte Carlo simulations for both ascent and descent scenarios to determine the influence of integral and differential operators on accuracy and computational load. Therefore, we assess the performance of the transcription methods in rapid-prototype simulations and processor-in-the-loop testing on EAGLE's real-time onboard computer system. The results show that the proposed strategies based on convex programming are a significant step towards achieving real-time optimal control in Europe.