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ADAPTIVE SEMI-ANALYTICAL GUIDANCE FOR AUTONOMOUS PLANETARY LANDING

Abstract

Autonomous, precise and safe landing is a key feature for the next space missions. The chance to adapt and correct the final landing pinpoint almost up to the touch down increases both the robustness and the flexibility of the vehicle operations, allowing hazard avoidance, retargeting to in loco detected scientifically relevant sites, or adaptation to actuators failures.

The short duration of the terminal descent phase together with the telecommunications delay imply full autonomy; onboard computation imposes low computational cost, without penalizing accuracy.

This paper focuses on an adaptive guidance algorithm that updates the trajectory to the surface by means of a minimum fuel optimal control problem solving.

A semi-analytical approach is proposed. The trajectory is expressed in polynomial form, of minimum order to satisfy a set of 17 boundary constraints: 12 state constraints, from the initial and final state; 5 control constraints, derived from initial and final lander attitude. The resulting acceleration profile is quadratic in altitude, cubic for the two horizontal directions.

By imposing boundary conditions, separately for each axis, a fully determined descent profile is obtained, function of only two parameters: time-of-flight and initial thrust magnitude. The thrust-to-mass ratio and the thrust vector profile can be extracted from the acceleration. Integral terms are solved by high accuracy numeric methods, such as the Clenshaw-Curtis formula.

Eventually, the complete descent guidance profile, in terms of thrust magnitude, pitch and roll angles, can be extracted from the thrust vector.

The optimal guidance computation is reduced to the determination of the time-of-flight and initial thrust magnitude, according to additional path constraints due to the actual lander architecture: available thrust and control torques, visibility onto the landing site, any potential constraint not implicitly satisfied by the polynomial formulation.

Solution is achieved with a simple two-stage pattern search algorithm: the algorithm firstly finds a feasible solution; whenever detected, it keeps solving for the optimum; nonlinear constraints are evaluated numerically, by pseudospectral methods.

The algorithm is computationally very fast, well suited for real time applications and can run either triggered on special events occurrences such as failures or landing site changes, or periodically to cope with dispersions.

Results on different scenarios for a Moon landing mission are shown and discussed to highlight the effectiveness of the proposed algorithm and its sensitivity to the navigation errors.