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# ATTAINABLE LANDING AREA COMPUTATION OF LUNAR LANDERS WITH PSEUDO-SPECTRAL AND POLYNOMIAL BASED GUIDANCE METHODS

**Abstract**

Future interplanetary space missions target a fully autonomous landing with recently developed technologies, such as using camera images and known landmarks on the surface of the body. Hazard detection and avoidance algorithms target a safe landing site by generating risk maps considering the surface properties of the candidate landing region. However, these risk maps do not take into account the physical limitations and capabilities of the spacecraft. A map of attainable landing area, that also considers the physical capabilities of the lander, actuators limitations and available propellant, is required for safe landing.

In this study, an optimal control based reachability analysis algorithm is developed for evaluating the performance of the guidance and control methods for space missions considering the desired performance index. The developed method considers a soft-landing problem for a Moon mission as the case study, and attainable area of the lander as the performance index. The method computes feasible trajectories for the lunar lander between the point where the terminal landing maneuver starts and points that constitutes the candidate landing region. The candidate landing region is discretized by equidistant points on a two dimensional plane and for each grid point a distance function is defined. This distance function acts as an objective function for a related optimal control problem (OCP).

Each infinite dimensional OCP is transcribed into a finite dimensional Nonlinear Programming Problem (NLP) by using Pseudo-Spectral Methods. The NLPs are solved to obtain feasible trajectories and approximated reachable sets with information about the states of the dynamical system at the grid points. The proposed method approximates reachable sets of the lander with propellant-to-reach cost by solution of NLPs.

A polynomial-based Apollo guidance scheme is used to compare the results for the developed method. The coefficients that define the position of the lander are obtained by solving a series of explicit equations for the given initial and final states. A model inversion based PD controller is designed to track the generated trajectory. Feasible solutions that satisfy safe landing conditions are filtered to obtain attainable landing area.

The paper will describe a Pseudo-Spectral based trajectory optimization algorithm and Apollo era polynomial guidance method in computing the safe attainable landing area incorporating the physical limitations of the lander during the terminal landing. The simulation results will be presented and compared for both methods in terms of computation times, geometry of the attainable landing areas and propellant-to-reach maps.