IAF ASTRODYNAMICS SYMPOSIUM (C1)
Guidance, Navigation and Control (2) (2)

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NEAR REAL-TIME FUEL-OPTIMAL TRAJECOTRY OPTIMIZATION FOR POWERED PLANETARY LANDINGS BASED ON ANALYTICAL SHOOTING EUQATIONS

Abstract

With the increasing demand for reuable launchers and planetary landings from deep space exploration, real-time and optimal trajectory optimization has become a basic requirement to achieve pinpont soft landings. However, the existing analytical guidance methods such as Apollo and ZEM/ZEM can only deal with enery-optimal scenarios, and nonlinear dynamics/ constraints cannot be addressed. Meanwhile, traditional numerical optimal methods including indirect and direct methods suffer the real-time and convergence shortages. In this study, we adopt the indirect method to address the fuel-optimal scenarios for powereed planetray landings, and near real-time trajectory optimizaton is achieved with the help of analytical shooting equation derivations and a practical homotopy technique. Specifically, three contributions are emphasized. First, on the premise that analytical solutions of fuel-optimal planetary landings can not be obtained, the analytical shooting equations is derived to replace traditional time-consuming trajectory integral. Consequently, the computational speed of trajectory optimization is greatly improved. Then, the original three-dimensional landing problem is conected with a simplified one-dimensional problem which only consider the vertical dynamics, and its analytical solution is obtained based on the Pontryatin's minimum principle. Finally, starting with the analytical solution, the accurate solution of the original landing problem can be obtained through an adaptive homotopy process. Simulations and results of Earth and Mars landing scenarios are given to substantiate the effectiveness of the proposed techniques and illustrate that the developed method can obtain a fuel-optimal landing trajectory in 10 ms with 100% convergence rate.