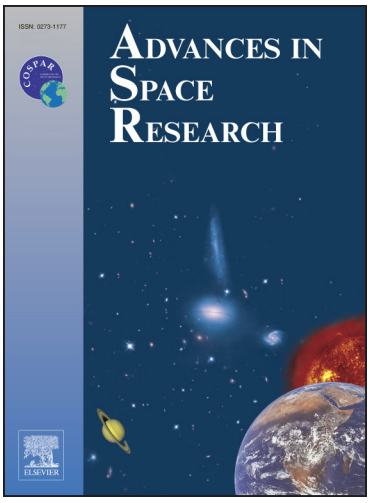

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Trajectory Optimization for Lunar Soft Landing with Complex Constraints

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Abstract

A unified trajectory optimization framework with initialization strategies is proposed in this paper for lunar soft landing for various missions with specific requirements. Two main missions of interest are Apollo-like Landing from low lunar orbit and Vertical Takeoff Vertical Landing (a promising mobility method) on the lunar surface. The trajectory optimization is characterized by difficulties arising from discontinuous thrust, multi-phase connections, jump of attitude angle, and obstacles avoidance. Here R-function is applied to deal with the discontinuities of thrust, checkpoint constraints are introduced to connect multiple landing phases, attitude angular rate is designed to get rid of radical changes, and safeguards are imposed to avoid collision with obstacles. The resulting dynamic problems are generally with complex constraints. The unified framework based on Gauss Pseudospectral Method (GPM) and Nonlinear Programming (NLP) solver are designed to solve the problems efficiently. Advanced initialization strategies are developed to enhance both the convergence and computation efficiency. Numerical results demonstrate the adaptability of the framework for various landing missions, and the performance of successful solution of difficult dynamic problems.

Keywords: complex constraints; initialization strategies; trajectory optimization for lunar soft landing.

1. Introduction

Early in 1959, the lunar exploration began when the Soviet Union proposed the Luna program. The Luna 2 was launched. This was the first spacecraft to reach the lunar surface and successfully made the first crash landing on the Moon. The United States began the Apollo program in 1961, which accomplished the transporting of humans to the Moon [1]. Recently, studies for lunar exploration have been pursued in many countries [2]. Chinese lunar exploration program, which began in 2004, is divided into three main operational phases, including orbital missions, soft landing mission, and sample return mission. The Chandrayaan-2 developed by the Indian Space Research Organization has a planned launch to the Moon by the end of 2017 or by the beginning of 2018. This will be India's second lunar exploration mission after Chandrayaan-1. Luna-Glob, a lunar exploration program by the Russian Federal Space Agency, will be the first of the missions planned before the creation of a fully robotic lunar base, and has a planned launch on 2024. The Japanese Lunar Exploration Program is a project of robotic and human missions to the Moon, and its main goal is to elucidate the origin and evolution of the Moon and utilize the Moon in the future. After the Apollo

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