Paper ID: 101742
student

IAF SPACE EXPLORATION SYMPOSIUM (A3)
Interactive Presentations - IAF SPACE EXPLORATION SYMPOSIUM (IP)

Author: Ms. Wenjie Su
Beihang University, China

Prof. Haichao Gui
Beihang University, China

STOCHASTIC TRAJECTORY OPTIMIZATION FOR LUNAR HOP WITH CHANCE CONSTRAINTS

Abstract

The extreme and contrasting conditions in the lunar south pole area make it challenging but meaningful for scientific discoveries in future lunar exploration missions, such as Chang'e-7 mission proposed by China. This region is characterized by numerous impact craters and rugged, complex terrain, where traditional rovers struggle to meet exploration requirements in such harsh environments. Hoppers, however, demonstrate significant potential due to their capability to hop terrain obstacles and rapidly access targeted areas while maintaining operational efficiency.

Trajectory optimization is critical for hoppers to reach targets in complex lunar scenarios while ensuring safety and reliability. Classical convex programming-based methods can generate feasible trajectories with constraint satisfactions. In realistic environments, however, stochastic disturbances such as sensor measurement errors and external forces inevitably occur. To enhance closed-loop control performance, it is essential to incorporate stochastic uncertainties into the trajectory optimization framework.

This paper proposes a novel covariance control-based trajectory optimization approach to address external disturbances and initial state uncertainties. The hopping process is divided into two primary phases, including the powered take-off and descent landing. For each phase, the stochastic fuel-optimal trajectory is modeled as a chance-constrained covariance control problem, where the disturbances are characterized by Gaussian process, and constraints such as obstacle avoidance, glide slope limitations and thrust magnitude bounds are considered. The sub-optimal solution to the original problem can be obtained by iteratively solving a series of semidefinite cone programs, which are systematically constructed through three key steps. First, the nonlinear dynamics are discretized and linearized, while the uncertainty propagation is quantifies by their first two moments. Second, sufficient conditions for the chance constraints are proposed to conservatively reformulate them into deterministic forms. Subsequently, the nonconvex items in the uncertainty propagation and constraints are convexified by slack variables and successive linearization techniques.

The effectiveness of the proposed method is validated using numerical simulations. Results demonstrate that the proposed method can not only ensure the optimality and the robustness but also enable probabilistic trajectory evaluation within a stochastic framework, quantifying final state distributions and constraint satisfaction probabilities. In future missions, it can be a promising tool for future lunar hopping missions to integrate trajectory design and performance evaluations.