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Autonomous Entry Guidance Using Linear Pseudospectral Model Predictive Control

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Abstract: This paper aims at developing an autonomous entry guidance method that requires no mission-dependent adjustments and will be applicable to a wide range of entry scenarios with worldwide destinations. Firstly, a nonlinear reduced-order entry dynamical system with coupled lateral and longitudinal motions as well as a spherical and rotating Earth is proposed. This system relates the vertical and lateral lift-to-drag ratio profiles to the position and azimuth angle variables with the energy as the independent variable. It has a high computational accuracy even only three differential equations are involved. Secondly, a trajectory planning problem with only two bank reversals is formulated based on this reduced-order system with parameterized control. Trajectory integration prediction and linearization method are applied to transfer the original planning problem into iteratively solving a group of linear dynamical equations. Gauss Pseudospectral Method and Calculus of variations are employed to discrete them so as to derive a series of analytical correction formulas to eliminate the final errors, mathematically, which achieves high accuracy with a small number of points. Moreover, these control parameters include not only the magnitude of bank angle, but also bank reversal points, which will significantly increase its ability to shape the entry trajectory. After the last bank reversal, lateral and longitudinal guidance laws are designed to ensure multiple final constraints. Nominal testing and Monte Carlo simulations on the proposed method and the comparison with the typical predictor-corrector method are carried out. Results demonstrate that, even in highly dispersed environments, this method has wide applicability, strong robustness, and excellent performance. Moreover, its computational efficiency is so high that it sufficiently satisfies the requirement on onboard application.

Keywords: Entry Guidance Algorithm; Linear Pseudospectral Method; Model Predictive Control; High Lift to Drag Ratio Vehicle.

1. Introduction

Entry flight is the most critical phase for Space Transportation Mission, in which the entry vehicle has to withstand high surface temperature exceeding 3500 degrees Fahrenheit or more and severe uncertainties involving modeling and atmosphere. The entry guidance system is responsible for providing the steering commands to guide the vehicle from its initial condition to reach the specific final condition safely and precisely. Obviously, its performance and robustness to response to such harsh condition is of vital significance for the success of entry flight.

Since the pioneering efforts of Project Apollo and Space Shuttle Program, entry guidance has received much attention in the last five decades and there were a great number of entry guidance algorithms. Although special algorithms are different depending on the types of missions and vehicles, those entry guidance algorithms, in essence, fall into two general categories: traditional reference-tracking algorithm and recently developed predictor-corrector algorithm. Undoubtedly, Space

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