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ROBUST TRAJECTORY OPTIMIZATION FOR MARS ASCENT VEHICLES USING POLYNOMIAL CHAOS EXPANSION AND PICARD ITERATION

Abstract

In Mars exploration missions, the takeoff of the Mars Ascent Vehicle (MAV) from the Martian surface and its entry into the predetermined orbit is a crucial stage. However, the Martian environment is complex and changeable, and the MAV faces numerous uncertain factors during its flight, such as deviations in the initial state, uncertainties in the Martian atmosphere model, and fluctuations in engine performance. These uncertainties may cause the vehicle's trajectory to deviate from the expected path, and in severe cases, they may even jeopardize the success of the mission. Therefore, studying the rapid trajectory optimization of the MAV in the presence of uncertainties to ensure the safe and efficient completion of the mission is an important issue that urgently needs to be addressed in the field of aerospace. This study proposes a rapid and robust trajectory optimization method for MAV under uncertainties. First, an uncertainty quantification technique based on polynomial chaos expansion is employed to transform the original low-dimensional dynamic model, which considers initial state and model uncertainties, into a high-dimensional dynamic model. By utilizing this high-dimensional form, low-order moments during the dynamical evolution process are obtained, thereby expressing constraints that account for mission safety. Unlike offline shooting methods such as Monte Carlo simulations, this uncertainty quantification method integrates uncertainty factors into the optimal problem-solving process, ensuring a safe solution. Although this approach sacrifices a bit of optimality, it significantly enhances reliability. To improve computational efficiency, the Picard iteration is utilized to approximate the system's dynamic equations, allowing the state variables in the constructed optimal control problem to be directly approximated from the previous results rather than obtained through integration. This offers a significant advantage: the convex optimization problems do not require consideration of high-dimensional dynamic equality constraints, greatly simplifying the problem-solving process. This method addresses the complexity of solving high-dimensional dynamics introduced by polynomial chaos expansion and ensures convergence even without an ideal initial guess. Numerical simulations of the Mars ascent problem demonstrate that the proposed method exhibits strong adaptability to flight scenarios under uncertainties, ensuring mission safety and maintaining high computational efficiency. This is important for Mars ascent missions, which are characterized by complex environments and high risks.