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SURROGATE-BASED OPTIMAL ATMOSPHERIC ENTRY GUIDANCE USING HIGH-FIDELITY SIMULATION DATA

Abstract

For Mars exploration, spacecraft must pass through atmospheric entry and power descent stages to safely decelerate and accurately land. Atmospheric Entry Guidance (AEG) controls the atmospheric drag of a spacecraft to achieve these objectives. Researchers have been working on optimal AEG to maximize fuel savings during the subsequent powered descent by terminating the entry phase with a minimum velocity trajectory. These optimal AEG methods have relied on ideal dynamic models with uncertain differences from the actual entry environment. Therefore, more advanced and complex computational modeling and simulation technologies have been developed and utilized to minimize these discrepancies. Despite the advantages of Monte Carlo simulation, the increased complexity makes it an impractical method to quantify modeling uncertainty. In addition, the entry vehicle's onboard computer is not powerful enough to run optimal AEG with a complex model. To address these limitations, this research aims to create a surrogate-based optimal guidance system, trained on high-fidelity data from complex simulations. The proposed guidance method enhances safety and efficiency in space exploration by reducing computational burden, saving spacecraft fuel, and enabling modeling uncertainty quantification. A surrogate-based AEG system, trained using high-fidelity simulation data from advanced entry system modeling (ESM) will be introduced in this paper. For this novel AEG, preparing precise and computationally efficient training data that effectively encapsulates the core of atmospheric entry is crucial. This paper identify the dominant variables influencing AEG performance and generate the required training data using advanced entry simulation tool. Various surrogate models for training, such as Gaussian Process Regression and Generalized Additive Model, is also be explored. The contribution is establishing an onboard optimal AEG framework using a trained surrogate. This framework can incorporate various feedback control algorithms to aid in planetary entry missions on Earth, Mars, Venus, and Titan. While prior research has focused on applying surrogates for subcomponent modeling such as air density and fluid and aerothermal dynamics, this approach targets application to optimal guidance and will accelerate calculation speed for implementation on embedded platforms. To reduce computations and training time, this research proposes a simplification method for the entry guidance profile that can also reduce the dimension of the training data.