IAF ASTRODYNAMICS SYMPOSIUM (C1)
Guidance, Navigation and Control (2) (2)

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REAL-TIME OPTIMAL ENTRY GUIDANCE BASED ON DEEP REINFORCEMENT LEARNING

Abstract

Entry guidance system plays an important role in ensuring a successful atmospheric entry of hypersonic vehicles. The entry guidance problem is essentially an optimal control problem which is traditionally solved by direct methods or indirect methods. However, these methods suffer from the shortcomings of unpredictable iterative process and computational time, no guaranteed convergence. In this study, an intelligent entry guidance approach is proposed to achieve real-time optimal control for entry flight based on Deep Reinforcement Learning (DRL). This study focuses on the following four contributions. First, the entry problem in longitudinal channel is formulated as a Markov decision process based on an improved compound bank corridor, and two constraint management algorithms are developed to help achieve guaranteed satisfaction of both path and terminal constraints. Second, a DRL algorithm using an actor-critic framework is developed to learn the optimal control policy for bank decision-making and optimize a long-term reward by interacting with flight dynamics. In order to facilitate the learning effect, relevant learning architecture and reward function design are optimized. Third, a predictive heading control logic is proposed to determine the bank reversal based on a neural network-based lateral range predictor, which is trained along with the DRL algorithm. This lateral control scheme not only achieves the controllability of the reversal number but also performs excellent robustness and autonomy. On these bases, an intelligent, multi-constrained entry guidance algorithm is developed to achieve real-time and optimal entry flight control. Since the entry problem on longer needs to be solved on-board, the proposed DRL-based algorithm successful overcomes the long-standing challenge of the existing numerical optimal control methods in real-time performance. Simulations are conducted through comparing with the state-of-the-art numerical optimal control methods, and the results demonstrate that the proposed DRL-based entry guidance is capable of providing real-time optimal, high-precision, reliable, and robust entry control for hypersonic vehicles.