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ANALYTICAL CONTROL FOR REAL-TIME OPTIMAL LANDINGS BASED ON DNN-BASED REFERENCE TRAJECTORIES

Abstract

In this study, an analytical control approach is proposed to achieve real-time optimal landings for asteroid explorations, where an off-line trained DNN provides optimal reference trajectories, and analytical solutions are used to eliminate the landing errors. The combination of traditional control and new deep learning techniques enjoys the merits of excellent adaptability and real-time optimal decision-making. Real-time control is essential to achieve accurate pinpoint landings for asteroid exploration missions. The asteroid landing problems are essential optimal control problem which are traditionally solved by direct and indirect methods. However, both of them suffer the contradiction between control accuracy and optimization time. Specifically, the computation time of direct methods increases with the increment in the number of discretization variables when a high-accuracy solution is required. While the initial solutions of indirect method are traditionally randomly guessed, and repeated iterations will increase the solution time and endanger the flight safety in real applications.

To address the contradiction between control accuracy and optimization time, an analytical real-time optimal control approach is proposed based on the DNN for providing reference trajectories. This study focuses on the following three contributions. First, the landing problems are formulated as two point boundary value problems and a DNN is developed to approximate the costates corresponding to flight states. Then, in real-time landing flight, the trained DNN is used to provide approximate costates. Based on the linear error motion equations relative to the reference trajectories, an analytical control law is developed to eliminate the flight errors based on the approximate costates for landing control. Consequently, the contradiction between control accuracy and optimization time of existing numerical trajectory optimization algorithms is overcome. Third, an adaptive dynamical identification algorithm is developed to identify and compensate dynamic errors, and consequently the flight adaptability and robustness are further enhanced. Simulations are conducted to demonstrate the effectiveness of the proposed techniques, results show that the proposed landing algorithm is capable of providing real-time optimal, highly-precise and robust landing control.