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REAL-TIME TRAJECTORY OPTIMIZATION FOR ASTEROID LANDING USING PICARD ITERATION-BASED CONVEXIFICATION AND DEEP NEURAL NETWORKS

Abstract

Asteroid landings have received increasing attention, especially since the Hayabusa and Hayabusa-2 sample return missions. Considering the remote communication delays, irregular shapes, and complex gravitational fields, real-time trajectory optimization is crucial to enhance the autonomy and reliability of asteroid landings. However, solving such a highly nonlinear and constrained optimization problem in real time is not trivial. Both indirect and direct methods have been used to address the asteroid landing problems. Indirect methods are intrinsically accurate and efficient, but frequently suffer from high sensitivity to the initial unknowns. Auxiliary homotopic techniques can help to improve the convergence behavior but correspondingly increase the computational burden. In contrast, convex optimization, as a direct method, has been widely applied in aerospace trajectory optimization due to its good convergence property and high computational efficiency. In general, the high-fidelity gravity of the irregular asteroid is computationally expensive, considerably increasing the time consumption of convex optimization procedures. Recently, deep neural network (DNN) techniques have been adopted to construct the asteroid gravity model with guaranteed computational efficiency and accuracy. Nevertheless, DNN-based gravity models are difficult to be convexified explicitly and then embedded into a convex optimization framework directly. How to combine the convex optimization and DNN-based gravity models to leverage the advantages of both approaches warrants investigation. This paper aims to develop a real-time trajectory optimization method for asteroid landings, by utilizing the Picard iteration-based convexification and DNN techniques. First, a DNN-based gravity model is designed to generate high-accuracy asteroid gravity with low computational cost. Then, the Picard iteration is employed to handle the nonlinear dynamics, instead of the successive linearization technique. By doing so, the states on the right-hand side are approximated by the previous solution, and therefore the DNN-based gravity term no longer needs to be linearized. Furthermore, the Picard iteration decouples the states at each time step and therefore relaxes the dynamic constraints, which can reduce the problem size and improve the computational efficiency, as well as enlarge the feasible region size and improve the convergence performance. In this way, the asteroid landing problem can be solved efficiently and accurately, even starting from a poor initial guess. Numerical simulations of fuel-optimal landings are performed to demonstrate the effectiveness and efficiency of the proposed method. (Typical landing examples on 433 Eros can be solved within 0.5 s by the proposed method using the MOSEK solver in a MATLAB environment with an Intel Core i5 2.6GHz processor.)