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AUTONOMOUS RECONNAISSANCE TRAJECTORY GUIDANCE AT SMALL NEAR-EARTH ASTEROIDS USING REINFORCEMENT LEARNING

Abstract

Recent missions to near-Earth asteroids (NEAs) have identified feasible operational strategies. While they have demonstrated precise characterization of target bodies is possible, the conventional operation relies heavily on support from ground stations, which could be costly. Capability for spacecraft to autonomously explore target bodies could be a key to realize future asteroid missions, where cost-effective small spacecraft are distributed to various NEAs for increased scientific and engineering returns.

A challenge in NEA exploration is that there is a large a priori uncertainty in a target's physical parameters, such as its size and mass. Since the dynamical environment is not known precisely, it may be impractical to design a nominal trajectory ahead of time. An alternative approach is to design a trajectory on the spot adaptively as the spacecraft's onboard navigation algorithm provides a solution. As one such implementation, in prior work, we have proposed an autonomous exploration scheme based on onboard navigation with optical measurements and event-driven orbit control (Takahashi and Scheeres, JGCD 2021, https://doi.org/10.2514/1.G005733). In the event-driven orbit control, transfer trajectories are designed every time a certain distance is crossed as measured from the asteroid to relocate the spacecraft to a predetermined position. The control scheme is adaptive in that it uses a current state to design a transfer. However, it is still inflexible because a sequence of orbit transfers must be specified in advance, which may not be suitable for complex tasks that require a change of actions depending on the current state.

This paper considers the application of reinforcement learning and function approximation by neural networks to design autonomous guidance algorithms for improved adaptability. Specifically, we focus on hovering trajectories in the reconnaissance phase for surface imaging. In this problem, a spacecraft nominally moves along the circumference of a circle at a given distance from an asteroid as seen in the Sun-asteroid fixed frame, occasionally applying impulsive maneuvers. The goal is to observe all of the target locations on the surface as efficiently as possible from multiple phase angles. By formulating the problem as a Markov decision process (MDP), the proximal policy optimization (PPO) algorithm is used to obtain a feedback controller that determines the next orbit transfer given a current state. The preliminary result shows that by incorporating the asteroid's parameters as part of the state and randomizing them during training, the obtained controller can complete the task for a range of parameter values.