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Autonomous Exploration of Small Near-Earth Asteroids

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The capability to autonomously explore a small near-Earth asteroid (NEA) could be a pivotal element in realizing future asteroid missions where cost-effective small spacecraft are distributed to various targets for increased scientific and engineering returns. Recent missions to NEAs such as Hayabusa-2 and OSIRIS-REx have identified feasible operational modes for asteroid exploration, such as initial characterization, near-inertial hovering, orbiting, and slow flybys. These operations currently rely heavily on support from the ground stations for navigation and orbit control, which could be costly. To overcome the limitation, we propose and study the feasibility of an onboard navigation scheme that incorporates optical information and delta-v measurements based on onboard accelerometers. Aside from navigation, onboard orbit control strategies are studied. For an orbital phase, approaches to efficiently define more stable frozen orbits under various perturbations are studied, leveraging the analytical insight of the underlying averaged dynamics. For a close hovering phase, we study the application of reinforcement learning, combined with function approximation by neural networks, to obtain an offline policy for global mapping under maneuver control noise. By performing the training in a simulation environment using various asteroid models, an adaptive policy that changes the behavior depending on the target asteroid is obtained. The robustness of the onboard global mapping policy is tested by performing end-to-end numerical simulations that combine both onboard navigation and control, which shows that the approach is robust. The research suggests that these techniques could be used in future asteroid exploration missions, potentially lowering the cost of such missions and bringing richer scientific and engineering returns.