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MODULAR PIPELINE FOR SMALL BODIES GRAVITY FIELD MODELING: ENHANCING ACCURACY AND EFFICIENCY FOR PROXIMITY OPERATIONS

Abstract

Proximity operations to Small Bodies, such as asteroids and comets, demand high levels of autonomy to achieve cost-effective, safe, and reliable solutions. Enabling autonomous guidance, navigation, and, control (GNC) capabilities in the vicinity of these targets is vital for future space applications. However, the highly non-linear and uncertain environment characterizing their vicinity poses unique challenges that need to be assessed to grant robustness against unknown shapes and gravity fields. In this paper, a comprehensive pipeline designed to generate gravity field models for small bodies is proposed, allowing the generation of a coherent set of scenarios that can be used for design, validation, and testing of GNC components. The proposed approach consists in processing a given shape model of the body, incorporating specified physical properties, such as mass and density distribution, and defining a set of desired operational requirements. The main objective is to generate a high-fidelity gravity model suitable for both on-ground mission design and as a truth model for validation and testing algorithms, alongside a lower fidelity model optimized for on-board implementation. The proposed method integrates state-of-the-art techniques, including polyhedral, mascon, and spherical harmonics expansion modeling, with innovative approaches based on local representation of the gravity field aimed at enhancing on-board execution efficiency. By leveraging these methodologies, the aim is to achieve a balance between modeling accuracy and computational complexity, ensuring practical feasibility for real-world space missions. To validate the approach, extensive simulations are conducted across a diverse set of targets with varying morphological and physical properties, encompassing different mission scenarios and operational regimes. Our analyses span a range of operative distances and dynamical conditions typical of missions approaching small bodies. Simulation results demonstrate the effectiveness of the methodology, showing good performances in terms of modeling accuracy and computational efficiency. By comparing the on-ground and on-board models with a high-fidelity polyhedral representation of the asteroid's gravity field, reliability and applicability across different mission scenarios is discussed. This research presents a faster and more robust framework for generating environmental models to be used in simulation and hardware-in-the-loop testing of on-board GNC algorithms, paving the way for advancing our knowledge and understanding of these objects .