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AUTONOMOUS OPTICAL NAVIGATION FOR SMALL SPACECRAFT IN CISLUNAR SPACE

Abstract

The Earth-Moon system is expected to be increasingly populated thanks to large space like the Lunar Gateway, and small spacecraft are also part of these future projects. However, these missions are heavily challenged by limited access to ground stations and constraints on on-board components. Hence, small spacecraft could greatly benefit from the development of autonomous optical navigation, allowing for higher levels of independence, flexibility, and lower operation costs.

The scope of this study is to assess the feasibility of performing autonomous optical navigation in cislunar space, employing images of the Earth and the Moon against background stars. This includes the definition of strategies for autonomous navigation and the evaluation of expected navigation accuracies for different scenarios of interest, including: (a) the deployment of multiple CubeSat as secondary payloads like in NASA's Artemis I mission, (b) a CubeSat in a periodic orbit around the Lagrange points, and (c) a CubeSat performing a series of lunar swing-bys to eventually depart the Earth-Moon system.

The simulation framework is implemented in Python+Vapory+OpenCV. It simulates the image acquisition process (generation of synthetic images of the Earth and Moon based on camera specifications), the processing of images (e.g., object and landmark detection, disk-fitting/centroiding techniques), and the filtering of the observations (Kalman filter or non-linear, non-Gaussian filters) in the dynamically complex cislunar environment.

A Monte Carlo analysis is then performed in order to: (a) gain a better understanding of the evolution of navigation accuracies along these orbits, and (b) assess the effects of different sources of errors and uncertainties (e.g., camera performance, attitude knowledge, image processing, and observation filtering). Numerical simulations thus provide a comprehensive viability analysis of the proposed autonomous navigation algorithms for cislunar space. Ultimately, this work contributes towards the development of autonomous capabilities for small spacecraft in a scenario of immediate interest to the community.