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AN EFFICIENT OPTICAL NAVIGATION MODEL FOR MONTE-CARLO FEASIBILITY ANALYSIS: LIMITS OF HORIZON-BASED CISLUNAR AUTONOMY

Abstract

With the expanding plans for lunar missions in the space industry, there is a demand for low-cost and performant navigation solutions in cislunar space. Using ground antennae communications to support missions drives costs up and will come with limited accessibility. Future missions will benefit from implementing autonomous capabilities, including optical navigation. Previous efforts in literature have proposed horizon-based position estimation algorithms and compared them in terms of accuracy and computational demand. However, incorporating an optical navigation process (i.e., image acquisition/generation, edge detection, centroiding, position estimation, etc.) into a simulation tool is computationally expensive, limiting the ability to perform comprehensive navigation analyses and evaluate these accuracies that can be achieved in cislunar space (e.g., through Monte Carlo analysis). This study proposes an approach to efficiently model the accuracy and covariance matrix of horizon-based positioning measurements at a range of distances and observation geometries from the Moon. The performance of the optical navigation process can be approximated through lower-demand Monte Carlo simulations. Furthermore, such an approach evaluates navigation accuracies along various cislunar trajectories of interest and ascertains the limits of autonomous optical navigation in the Earth-Moon system. This work will: (1) provide insights into the performance of optical navigation as a function of distance to the Moon, direction, and Moon phase, (2) propose and validate a four-dimensional look-up table interpolation approach to model the accuracy and covariance matrix of optical navigation measurements (as a function of two observation angles, distance, and time), and (3) provide insights into the navigation accuracies and limits of autonomous optical navigation along various cislunar trajectories of interest. This discussion, proposed approach, and analysis will prove valuable to the analysis and design of future cislunar space missions featuring optical navigation, and provide a comprehensive study of autonomous optical navigation capabilities for a new era of space exploration.