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RECONSTRUCTION OF LUNAR GRAVITY ANOMALIES AND HETEROGENEOUS DENSITY DISTRIBUTION BASED ON OPTICAL GUIDANCE INFORMATION

Abstract

Since the launch of China's Lunar Exploration Program in 2004, the project has conducted a three-step approach of "orbiting, landing, and returning". On June 2, 2024, the Chang'e-6 successfully landed in the South Pole-Aitken Basin on the far side of the Moon. To support future Earth-Moon space exploration, the prediction and selection of resource-rich regions are particularly crucial. In particular, the South Pole-Aitken Basin is not only the largest and deepest impact basin among terrestrial planets in the solar system but also the region with the highest density of impact craters on the lunar surface. Therefore, reconstructing lunar gravity anomalies and predicting heterogeneous density are of great significance for exploring deep planetary materials and internal structures, as well as guiding in-situ resource utilization on the Moon and other terrestrial planets.

So far, global lunar gravity field models are primarily developed by tracking the orbits of satellites orbiting the Moon and calculating orbital perturbations. These gravity fields are typically represented using spherical harmonic series. However, as the degree of spherical harmonic analysis and synthesis increases, computational efficiency decreases, and series divergence issues may arise in regions with complex terrain.

Compared to the traditional gravity-inverse method, one of the authors, Liang et al. developed a flight-information-perceived approach that has a superb capacity for constructing the interiors of a differentiated celestial body, e.g., giant asteroids, utilizing the flight paths of a spacecraft. Through a serial works, this novel approach was proved to show superb numerical performances in bi-directional mapping (Liang et al. 2023 MNRAS) and remarkably good match to the scientific results of Dawn team for Vesta and Ceres (Liang et al. 2025 JGR). Following this idea, instead of a simple reproduction to Moon, this paper is an important progress to future incorporation with autonomous guidance with two technical challenges explored, i.e., optical images by camera self-calibration in complex environments and uncertainty of gravity anomaly w.r.t orbital position data and heterogeneous density distribution.

To achieve these goals, this study introduces emerging deep learning algorithms, leveraging data-driven approaches to learn the underlying functional relationships within the data, which can be applied to planetary gravity field research and internal structure analysis. Moreover, with the modeling based on a single data source-optical images-achieved, it would satisfy the requirements for capturing both the long-wavelength signals of the global lunar gravity field and the short-wavelength signals related to surface topography.