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INTEGRATED OPTICAL TERRAIN RELATIVE NAVIGATION FOR AUTONOMOUS LUNAR LANDING

Abstract

Spacecraft landing on celestial bodies is a very challenging phase for the Guidance, Navigation, and Control system. Due to the very fast dynamics, autonomous navigation to properly manage the whole landing phase in real-time is mandatory. Vision-based navigation accomplished with a monocular camera is a possible strategy, beneficial in terms of cost and complexity containment.

Two main navigation strategies can be considered: Relative Navigation (RN) and Absolute Navigation (AN). The former exploits features with unknown coordinates, and only the relative pose with respect to the previous frame can be computed. The latter allows determining the spacecraft pose with respect to a planetocentric reference frame: features with known location are exploited, which asks for at least partial knowledge of the landing environment.

Nonetheless, both methods have inherent limitations. AN experiences a decreasing number of known observable landmarks throughout descent, preventing state estimation during crucial final phases (altitudes below 15-20 km). RN accumulates error over time, leading to a drift in the state estimation process.

This paper presents a novel navigation configuration to solve those limitations for pinpoint landing applied to the lunar specific scenario. An Integrated Navigation, based on the fusion of both information from Relative and Absolute Navigation, is adopted. In particular, AN provides drift correction, while RN increases algorithm robustness and flexibility, removing the need to rely on known landmarks.

Relative Navigation is here performed through Visual Odometry techniques. The features are extracted adopting an ORB detector with adaptive threshold and then tracked over multiple frames. Absolute Navigation adopts as landmarks craters, together with lunar rilles and wrinkled ridges to achieve complete coverage of the lunar surface. More specifically, Convolutional Neural Network-based detectors combined with standard image processing techniques lead to landmarks identification. The extracted features are then matched against a database for inertial location of known craters, ridges and rilles. Measurements coming from both navigation threads are then fused in an Extended Kalman Filter. The proposed strategy is specifically applied to the lunar Powered Descent phase.

The algorithm performance and robustness under various illumination, camera pointing, and terrain conditions are evaluated through a numerical simulation with synthetic lunar calibrated images, showing how Integrated Navigation can lead to an accurate and robust solution for pinpoint landing on the Moon.