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OPTICAL AND RADIO DATA FUSION FOR SPACECRAFT NAVIGATION AND GEOPHYSICAL INVESTIGATIONS

Abstract

Interplanetary spacecraft navigation has been mainly accomplished through radio-tracking-based systems that enable the acquisition of precise velocity and position measurements of interplanetary spacecraft with respect to Earth's ground stations. This approach is well-suited to determine the spacecraft trajectory in an inertial reference frame, but it requires data analysis and processing on the ground. Deep space operations that are conducted in proximity to celestial bodies in the solar system require real-time updates of the robotic probe localization. Therefore, instruments onboard the spacecraft, including optical cameras, provide key information for an accurate navigation relative to the surface of the central body. The combination of deep-space radio tracking measurements with auxiliary datasets is thus key to enhance the spacecraft navigation capabilities and support thorough scientific investigations, thus addressing the challenging tasks of future planetary missions. Optical measurements are used to determine the state of the spacecraft relative to surface features on the orbited body, such as craters, which are detected in the images. The synergistic combination of optical and radiometric data processing is crucial for enhancing the scientific outcomes of future exploration missions. Radiometric measurements provide constraints along the line-of-sight between the spacecraft and the ground stations. Optical data constrain the spacecraft orbit with respect to the central body. The software developed in this study led to the accurate processing of optical images by using a machine-learning crater detection algorithm, which identifies the centroid of the observed features. The optical data analysis pipeline includes a crater-matching algorithm that establishes correspondences between the detected craters and those reported in an onboard catalogue, which are projected on the image plane according to a preliminary estimate of the spacecraft position and attitude. The crater matching task is conducted by using a method based on geometrical invariants of crater triads. The joint processing of radio tracking and optical data in a least-squares batch filter and the onboard sequential estimation using only optical data are both well-suited to support the reconstruction of the spacecraft trajectory and the estimation of key geophysical parameters, including the spin rate and pole orientation of the central body. We present here the results obtained by using our novel method to combine radio and optical measurements of the Mars Reconnaissance Orbiter mission.