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ONBOARD PERCEPTION-BASED AUTONOMOUS VISUAL NAVIGATION AROUND SMALL CELESTIAL BODIES

Abstract

The research presented in this article aims to establish a robust autonomous navigation architecture tailored for precise proximity operation around small celestial bodies. Asteroid exploration is gaining significance within the global space community as it contributes to advancing our comprehensive understanding of the fundamental scientific inquiries regarding the origin of the universe and the history of the solar system, while also playing a crucial role in planetary protection by providing insights into potential threats and strategies to safeguard Earth from celestial impacts. This article contributes to establishing an onboard perception-based autonomous navigation framework for proximity operations, enabling spacecraft to accurately localize and safely navigate surrounding asteroid bodies while amidst the dynamic illumination conditions and orbital perturbations. The spacecraft is considered to be equipped with multiple onboard sensors including Inertial Measurement Unit (IMU), monocular camera, Light detecting and ranging sensor (LiDAR) and star tracker to provide comprehensive perception in dynamic environment. In order to achieve a representative visual navigation scenario, a realistic high-fidelity visual simulation environment has been established, featuring an orbiting spacecraft around the rotating 3D model of the Ryugu asteroid within the open-source, realistic physics-based GAZEBO simulation engine. This comprehensive augmented reality setup embeds a realistic onboard visual perception with integrated sensor measurements that faithfully represents the simulated motion of the spacecraft around the asteroid. The key feature points extracted from successive image frames captured by the onboard camera are associated with Lidar point clouds projected onto the image plane and assimilated through a novel Lidar-integrated Visual Simultaneous Localization and Mapping (SLAM) framework, facilitating the establishment of the spacecraft's pose around the asteroid. The proposed Lidar-integrated visual odometry pipeline comprises several stages, encompassing (a) Map Initialization, (b) Scale Factor Augmentation, (c) Feature Tracking, (d) Local Mapping, and (e) Loop Closure. Owing to the difficulties associated with the inherent drifting nature of SLAM-based odometry, arising due to perception incapability resulting from the scale factor associated with the mismatch between visual perception and the real displacement, real scale factor augmentation obtained from the onboard LiDAR sensor is integrated. As the spacecraft enters the dark side, visual assistance substantially degrades, and navigation persists using the remaining sensor suite with rel-

atively degraded performance. A similar phenomenon is observed when the spacecraft passes through an overexposed region illuminated with sunlight. The overall novel concept is extensively validated in simulations with promising results to advance onboard-assisted localization perception in dynamic illumination scenarios.