AUTONOMOUS NAVIGATION NEAR ASTEROIDS BASED ON VISUAL SLAM

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ABSTRACT

Small celestial bodies (SCB) such as asteroids and comets have started to become the center of attention of near-term space exploration missions amongst the various space agencies across the world. While JPL-NASA has already completed several missions targeting SCB with NEAR-Shoemaker, Stardust, or Deep Impact, JAXA's Hayabusa mission was a first in landing on an asteroid, recovering samples, and returning to Earth to deliver them. Since the end of this successful mission to the asteroid Itokawa, ISAS-JAXA has been preparing the follow-up Hayabusa II mission, and is also actively studying new visual navigation schemes that will enhance the autonomy and accuracy for a potential Hayabusa Mark II mission.

The constraints associated with the navigation near SCB is very different than for large planetary bodies. The very rugged surface of SCB makes safe landing sites sparse and narrow, requiring precision down to the order of 10's of meters, while the very week gravitational pull imposes strict constraints on the landing speed required to avoid either damaging the spacecraft or make it bounce back from the surface.

This research focuses on the localization aspect of navigation near SCB. It proposes a single-camera-based Simultaneous Localization and Mapping (SLAM) scheme in the context of a Hayabusa-type mission. This research is the continuation of the authors' work presented at the 22nd ISSFD conference on using linear visual pose estimation algorithms based on the triangulation of SURF visual descriptors as interest points, for the generation of hypotheses for a Particle Filter based SLAM.

The SLAM proposed in this work extends the scheme presented previously by integrating these linear pose estimation algorithms within a Rao-Blackwellized Particle Filter (RBPF), and using them as a replacement of the typical algebraic motion model. Additionally, the proposed SLAM makes use of a novel visual landmark mapping module that maps landmarks spatially using an octree database designed for very large environments, and sorts landmarks by their visual descriptor -or signature- using a modified binary search tree dynamically linked to their position within the octree. This scheme facilitates and accelerates associating new landmark observations with previously visited ones. It also offers a solution to the inherent problem of falsely associating visual landmark when only considering their 3D position.

Although it is well know that RBPF SLAM are very sensitive to the number of particles generated and kept between each iteration, this research has found that the stability and precision

of the SLAM was also highly dependent on the operational parameters of the mapping module which sets: the level of discretization of the space where visual landmarks are mapped; how long a visual landmark is kept in memory; and how often its visual signature is updated.
Thus, this work includes a sensitivity analysis defining the range of the mapping module parameters for which convergence can be achieved, as well as the average localization precision that was observed during the loop-closure of the SLAM for those range of parameters.

While the proposed scheme is computationally intensive, it has the merit of offering a new approach to spacecraft visual navigation, and to identify some key parameters of the SLAM's components that are usually neglected in the literature and that have a direct impact on its performance.