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NOVEL HYBRID SLAM ALGORITHM FOR SPACE DEBRIS GRASPING

Abstract

Robotic Active Debris Removal, grasping debris with a robotic arm mounted on the chaser spacecraft, relies on the precise characterization of the debris for further motion-planning and safe grasping. Real-time constraints requires on-board estimation of the attitude and attitude rate of the target. When dealing with known target, a simplified 3D model of the target can be used to retrieve its pose from sensing using specific 3D to 3D or 2D to 3D alignment algorithms. When dealing with unknown target however, the attitude and the shape of the target have to be simultaneously estimated in order to select a grasping point and safely approaching it.

The state-of-the-art theoretical solution to this problem uses Simultaneous Localization And Mapping (SLAM) framework where a chaser images the target and simultaneously reconstructs the shape, pose and pose rate of the target. After extracting features from raw sensor data and correlating them from sampling to sampling (known as front-end), two main paradigms offer a solution to the estimation problem (known as back-end): filtering and Bundle Adjustment (BA). Owing to the problem's non-linear nature, the filtering approach relies on Extended Kalman Filters (EKF), Unscented Kalman Filters (UKF) or their variants, while BA relies on a non-linear least-square (NLS) estimator, typically Levenberg-Marquardt. BA was proven to be more accurate, but its computational load makes it an unrealistic solution for a space computing unit. Filtering, on the other hand, is relatively computationally light but provides a less accurate estimate. This is the main reason that applying SLAM approach in relative state estimation for space debris remains an open research question.

In this paper, we propose a novel blended algorithm building on the strength of both approaches and specialized for Active Debris Removal mission requirements. A non-linear filtering approach is used to make a first coarse estimate of target's shape, motion and associated covariance. This estimate is then refined through a weighted NLS estimator which also provides the associated covariance. In addition, an adaptive feature management is introduced, with an incremental reconstruction of target's shape alleviating computational load. This novel approach allows to obtain a more accurate estimate whilst guaranteeing a reasonable computation time thanks to the NLS initialization close to the global minimum. Preliminary simulation results on an ENVISAT-like mission shows a mean error of 0.22 degrees on target pose estimation and 10cm on target's shape reconstruction. These results are also compared with filtering or BA techniques to demonstrate more superior performance of the proposed hybrid method.