Improved Shape Determination for Autonomous Navigation

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The success of advanced robotic missions such as satellite servicing or proximity operations about small bodies like asteroids or comets is heavily dependent on the capacity of spacecraft to operate autonomously throughout their mission. Performing science or engineering tasks without reducing the mission envelope thus requires spacecraft to perform data processing and decision making without external input. To this end, sensors providing unambiguous measurements of the target's state (such as Lidar) complemented with efficient on-board processing are highly desirable. For instance, Flash Lidar enable gathering of range data collected over a focal plane typically comprised of 128 x 128 elements. The resulting point clouds correspond to the intersections of the individual laser rays and the instrument's target. Lidar's high frequency of operation combined with its data's information-rich content make them really suitable for sequential estimation applications [1].

Our research work at CU Boulder aims at developing efficient Lidar processing algorithms bolstering autonomous spacecraft operation. Previous results have demonstrated the interest of using only Lidar observations for satellite navigation in the vicinity of asteroid Itokawa [2]. Current work focuses on utilizing Lidar data in complex cases where navigation, shape estimation and attitude determination may happen simultaneously. This hybrid mission profile would require an efficient algorithm framework sequentially 1) collecting Lidar data, 2) mapping the resulting point cloud onto an estimated shape model, 3) extracting relative attitude and position information and 4) augment the shape model with the collected point cloud. The difficulty of the task is two-fold. First, raw point cloud measurements are too dense to be readily incorporated into the target's estimated shape model and thus require on-board processing before being used. Second, the procedure of finding the rigid transform best aligning a collected point cloud with the existing shape model relies on registration algorithms such as the Iterative Closest-Point-to-Plane algorithm (ICP2P) [3] which are computationally demanding.

Our research approach tackles all the challenges listed above. First, we derived an improved formulation of the ICP2P algorithm making use of Modified Rodrigues Parameters and compared it to the legacy implementations employing Euler angles. Simulations demonstrated a major improvement of the alignment routine of the MRP ICP algorithm in terms of speed and accuracy over Euler angles. Moreover, we are currently developing methods extracting relevant shape information from the raw point clouds, effectively downsampling the point cloud information to enable sequential filtering processes. This process requires mapping the uncertainty in the observations into a set of decision heuristics. These heuristics are then utilized to determine if additional geometrical features - facets, vertices and edges - should be included into the estimated shape model. Applying this feature extractor algorithm to noise-free point cloud data yielded very good-quality shape models. A batch processor provided with the extracted shape and the raw point clouds converged to the true shape in only two iterations.

We are aiming towards combining our efficient ICP2P algorithm with the feature extractor to operate on real noisy point cloud data. This will demonstrate our capacity to autonomously create a shape model from an unknown target and use this shape model for navigation purposes in a realistic environment, independently from any external input.

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