Robust Tumbling Target Reconstruction through Fusion of Vision and LIDAR for Autonomous Rendezvous and Docking On-Orbit

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Abstract

I propose to develop an object reconstruction framework utilizing both vision and LIDAR data for tumbling target mapping in space. By fusing these two sensing modalities, my goal is to provide a robust target reconstruction algorithm suitable to target mapping in the harsh illumination environment of space.

1. Introduction

Target reconstruction is a necessary capability for safe and reliable autonomous rendezvous and docking capability on orbit. Vision is a natural sensor for object reconstruction as it is capable of providing frame-to-frame point correspondence and texture information. The field of structure from motion is a well-developed one, providing the capability to map a target (structure) and recover the camera motion, up to a similarity transformation (assuming calibrated cameras). This scale ambiguity is a problem for real operation on orbit, and cannot be resolved without more information.

Range data (LIDAR) provides 3D structure data directly, When using 3D LIDAR technology (e.g. Flash LIDAR), it is possible to solve for scan-to-scan correspondence through alignment of point clouds (typically, with a form of Iterative Closest Point algorithm). Conversely, line-scanning (2D) LIDAR can only solve the correspondence problem in loop closure situations. In terrestrial applications, the use of 3D LIDAR is most likely the correct choice. However, for applications on small satellite chaser vehicles, limitations on power, size, and weight may/will dictate use of the line-scanning LIDAR.

2. Proposal details

My proposed computer vision task is to intelligently fuse vision and line-scanning LIDAR data for accurate target reconstruction. This will entail modifying structure from motion algorithms to incorporate additional absolute depth data from LIDAR. At the very least, this will involve running standard structure from motion algorithms and resolving the absolute scale by minimization of distance from ranged points. A more involved solution may require tight integration of the ranged correspondence into the structure from motion optimization. This potential to improve the overall performance by inclusion of the absolute scale measurements in the SfM optimization is a key investigation that I propose.

To link correspondence between range points and image feature points, I will start by investigating how well I can search for vision features along the projection of the range scan line in the image plane (this will require camera-LIDAR calibration, which I have code in place for). For robust tracking of vision features in the SfM framework, I anticipate using SIFT or SURF features. However, for searching features along the range scan projection, it may prove more useful to search more dense features (e.g. Harris), in order to more fully exploit ranging benefit (but only track these dense features across the adjacent frame).

There is also a potential to investigate the projection of image texture onto the mapped 3D geometry. While there are standard software packages for doing this, I have the potential to explore the benefit of using the ranged 3D geometry to improve the disparity calculations for dense stereo reconstruction.

Furthermore, I plan to investigate the potential benefits of including the range data in bundle adjustment. By aggregating scans and matching point clouds in loop closure, standard vision-only bundle adjustment may be improved by the inclusion of range data.

Data sets will be collected with a calibrated camera-LIDAR system in the Aerospace Robotics Laboratory (my lab). Furthermore, much of the algorithm will be tested in a Matlab simulation environment I have been developing. Additionally, there is a vision-LIDAR dataset available from the PERL lab at the University of Michigan that I can draw on if my camera-LIDAR system is not up and running soon enough.

I will rely heavily upon “Multiple View Geometry” by Hartley and Zisserman, along with other structure from motion resources.

My anticipated final product will be a 3D reconstruction of a moving target. I am very excited about this work, as it is a stepping stone toward research work that I am moving toward. It is a lot to bite off in a quarter, and much of the new development is not specifically computer vision work, but this project will require that I learn a lot about computer vision, specifically in the structure from motion domain (and hopefully how this domain can be improved with additional range data).