Robust Sensing for Autonomous Rendezvous and Docking

Jose Padial
Aeronautics and Astronautics Industrial Affiliates Meeting
Stanford University
April 24, 2012
Motivation and Background

Related Missions

Intelsat VI

DSP-23

XSS 10

Orbital Express

ETS VII

DART

Asteroid exploration
Goal: Enable autonomous rendezvous and docking capability on a micro- or nano-satellite chaser for unstructured rendezvous situations

- Damaged and/or uncommunicative targets
- Targets undergoing complex, potentially tumbling, motion
- Targets for which we have little or no prior information

Small satellites introduce constraints

- Power consumption, weight, and size
- Sensor suite we are primarily considering
  - Monocular camera
  - Line-scanning (2D) LIDAR
Pose Estimation and Target Reconstruction through Fusion of Vision and Line-scanning-LIDAR data
Why Fuse Vision and LIDAR Data?

- **LIDAR is less sensitive to illumination**
  - Allows us to map the target in adverse lighting conditions

- **Dense reconstruction**
  - Line-scan projections allow for more dense reconstruction than that of a sparse visual landmark reconstruction

- **No Scale Ambiguity**
  - Monocular vision-only reconstructions can only be resolved up to a projective scale ambiguity
Data
Frame-to-Frame Vision Estimation
- Find frame-to-frame feature correspondence
- Estimate frame-to-frame rotation and translation

Solve for Multi-frame Pose and Target Geometry
\[
\begin{align*}
\text{minimize} & \quad \lambda, \epsilon & \quad \|M\lambda\|^2 + C\|\epsilon\|^2 \\
\text{subject to} & \quad A\lambda + \epsilon = 0 \\
& \quad D\lambda \geq \zeta
\end{align*}
\]

Incorporate LIDAR returns
- Project LIDAR points onto images
- Determine vision-range correspondence
Algorithmic Pipeline: Vision-Range Fusion

- **Images** (INPUT)
  - **Feature Correspondence (SIFT)**
  - **RANSAC Homography Estimation and Outlier Rejection**
  - **Essential Matrix Estimation** (8-point solution followed by nonlinear refinement)
  - **Frame-to-Frame Relative Pose (R,t) Estimation** (SVD solution followed by 2-frame BA)

- **Map Pixel Range Projections onto Neighboring Images** (Use homography estimates)
- **Project LIDAR Data onto Images** (INPUT)
- **LIDAR Scans**

**Output**
- **Pose Estimates**
- **Target 3D Geometry**

**Bundle Adjustment**
- **Upgrade to Absolute Scale** (Using correspondence between vision and range)
- **Projective Depths and Translation Scales Estimation** (Convex optimization)
Preliminary Experimental Results

10-frame reconstruction, no multi-frame smoothing/bundle-adjustment
ARL Hardware Platform

- R² manipulator
- Stereo IDS Imaging cameras
- Kinect™ sensor
- Hokuyo URG Line-scanning LIDAR
- Motion Capture IR Cameras
- Tumbling base motion simulator
Summary and Upcoming Work

- Have demonstrated proof of concept of Relative Pose Estimation and Target Reconstruction through Fusion of Vision and Line-scanning-LIDAR data

- ARL hardware platform up-and-running

- Coming soon:
  - Full 6DOF testing with ARL hardware platform
  - Incorporate estimate refinement (aka. Bundle Adjustment) into solution
  - Begin real-time algorithm development