Mapping Asteroids and Icebergs: Range Data Correspondence Detection for Natural Terrain

Objective
Create accurate 3D reconstructions of natural terrain, subject to unknown terrain motion and/or substantial vehicle inertial estimation errors.

Problem Description

Motivation: Asteroid exploration can provide clues about the origin of our solar system, but the uncertainty of asteroid spin rates and spin axes makes 3D reconstruction and subsequent terrain-relative navigation challenging. This research develops algorithms for asteroid missions and tests them on comparable Earth-based scenarios, such as drifting iceberg exploration and underwater vehicles with poor dead reckoning.

Issues:
- Poor Terrain-Relative Inertials
  - No GPS
  - Drifting Target
  - Poor Sensors
- Lack of Distinctive Features
  - Natural Terrain
  - No Man-Made Navigation Aids

Where does the problem come from?
ICP is commonly used to align point clouds, but substantial inertial errors can cause ICP to converge to local minima.

People have initialized ICP before. Why not use their methods? Most ICP initialization routines rely on easily identifiable and well localized features, i.e., from manmade objects with sharp corners or pre-placed fiducial markers.

Method Overview

High Level Algorithm:
Use Graph SLAM to correct the warped point cloud.

New Correspondence
Detection Algorithm:
To detect correspondences between one set of range data and another, use image processing to find matching subclouds.

Ongoing Improvements

Challenges
Initial experiments demonstrate the success of the algorithm in real terrain, but the reliance on RANSAC for matching presents three issues:
- Natural terrain can have relatively few distinctive features; RANSAC depends on a large quantity for successful matching
- A small number of closely-matched features can indicate correspondence; quantity of matched features is not a sufficient metric
- Computer memory is limited on spacecraft; reducing the minimum necessary quantity of features is preferred

Constellation Matching

For decades, spacecraft have been utilizing star trackers for attitude determination. Their constellation-matching algorithms have been designed for low computation and low memory requirements.

How Star Trackers Work ( & How it Applies to Range Data):
1. Take an image of stars (collect range data)
2. Locate stars within the image (locate point cloud features)
3. Search for a matching constellation in a starfield database (identify matching constellations of features in the “database” dataset)

Benefits:
- Fast database lookup
- Order of magnitude reduction of features
- Probabilistic model of match quality

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Bibliography

Further Information
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Figure captions
Sonar data was collected by an autonomous underwater vehicle, along two passes around Soquel Canyon in Monterey Bay, CA.

Feature Detector: SIFT
Feature Descriptor: SIFT
Feature Match Algorithm: RANSAC
Outlier Rejection: Hough Transform

Matches were determined by the quantity of RANSAC inliers. Varying the inlier threshold trades match quantity versus match accuracy. A Hough transform successfully identifies false matches.

Ground truth is shown in a green band. Accepted matches are shown in blue. Rejected matches are shown in red.

Success!