National Aeronautics and Space Administration

Multi-Phase Autonomous Vision-Based Navigation for Planetary and Small Body Exploration

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Program: FY22 SURP
Strategic Focus Area: Autonomous GNC, planning, scheduling, and execution

Objectives

Enable **robust** autonomous vision-based navigation for the approach, proximity operations, and landing on small bodies. Specifically, **detect**, **extract**, **track**, and **handle** surface landmarks across mission phases, subject to **variations** in scale, lighting, and observer's viewpoint.

Background

Navigation to/around small bodies is challenging, due to **large appearance changes** of its surface. Today, navigation heavily relies on operator engagement. This yields to lengthy and unscalable mission operations and higher overall mission cost.

Significance/Benefits

Provides key functions to enable autonomous access to **near-Earth Objects**, **main-belt asteroids**, **comets**, airless **planetary satellites**, **centaurs**, and **trans-Neptunian bodies**. It is part of a larger fabric to enable access to new destinations.

Approach and Results

Shadow-Based

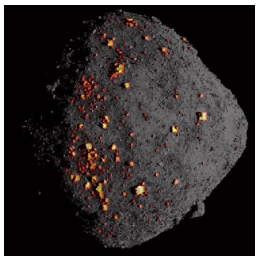
- Observing shadows to infer the location of the shadow-casting landmark
- Strong signal on the lit surface
- Robust to lighting, viewpoint, and scale
- Tested with both real and simulated imagery

Photometry-Based

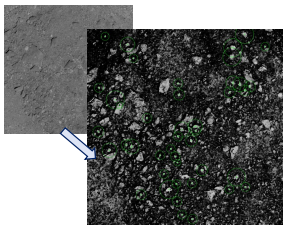
- Leveraging robust optical properties of natural features
- Removing shadowed pixels
- Robust to lighting, viewpoint, and scale
- Ideal for low-Sun phase scenarios

Landmark-based Features

Feature Detection

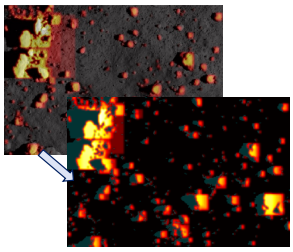


Probabilistic hazard maps based on shadow morphology.

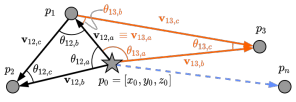


Enhancing signal of natural features based on surface variance and local brightness.

Feature Extraction

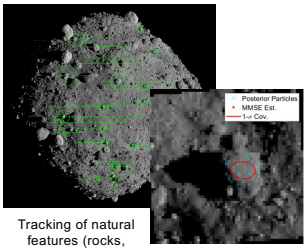


Hazard-based descriptors (local patches) encoding surface geometry (landmarks' relative location and size).



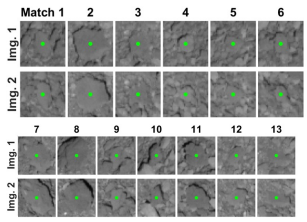
Graph-based descriptors leveraging geometric invariants. Features are matches within a database.

Feature Tracking/Matching



Tracking of natural features (rocks, boulders) using hazard maps.

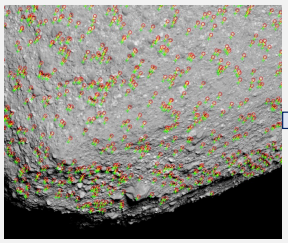
Localization and height estimation of landmarks using Bayesian estimation.



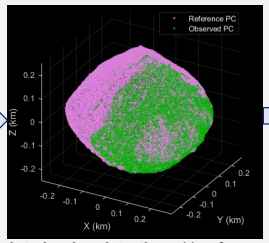
Proximity natural features are matched under different lighting and observing geometries.

Visual Point Cloud SLAM

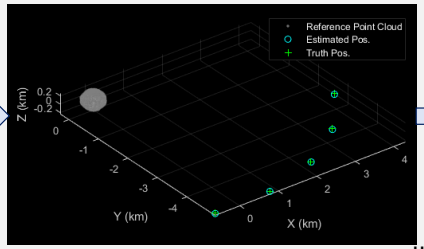
Agnostic to feature types; provides shape reconstruction and eventual localization; highly robust to most lighting, scale, and viewpoints.



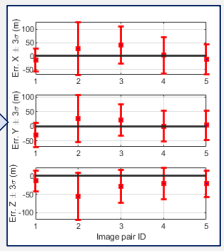
Feature tracking. Keypoints are triangulated using small stereo baseline to avoid drift from lighting and viewpoint change



Point-cloud registration with ref map (generated by VPC-SLAM). The scale bias in point cloud is estimated and corrected



Spacecraft localization based on point-cloud registration.



Uncertainty Quantification. Position estimates and associated covariance are fed into the orbit-determination filter.

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Publications:

1. J. Villa, et al., "*Autonomous Navigation and Dense Shape Reconstruction using Stereophotogrammetry at Small Celestial Bodies*", AAS Guidance, Navigation, and Control Conference, Breckenridge (CO), 2022
2. J. Villa, et al., "*Robust Landmark and Hazard Detection on Small Body Surfaces Using Shadow Imagery*", AAS/AIAA Astrodynamics Specialist Conference, Charlotte (NC), 2022
3. J. Villa, et al., "*Visual Point Cloud SLAM for Autonomous Navigation and Mapping at Small Celestial Bodies*", 3rd Space Imaging Workshop, GA, 2022
4. J. Villa, et al., "*Autonomous Navigation and Mapping at Small Celestial Bodies using Visual Point Clouds*", in prep, of Guidance, Control, and Dynamics

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