National Aeronautics and Space Administration

FY24 Strategic University Research Partnership (SURP)

Autonomous Navigation via Optical Measurements as Silhouettes for Primitive Bodies

Principal Investigator: Daniel Lubey (392), **Co-Investigators:** Courtney Hollenberg (392), Brandon Jones (University of Texas at Austin), Ryan Russell (University of Texas at Austin), Quinn Moon (University of Texas at Austin)

Objectives:

Demonstrate spacecraft relative **navigation** and small body **characterization** using only **silhouette measurements**. Specifically, combine image processing techniques to extract precise silhouette measurements, Gaussian processes for continuous surface representation of a body's shape, and extended Kalman filtering for estimation of the body spin, body shape, and spacecraft relative state.

Background:

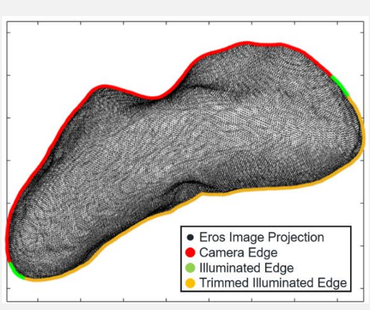
Current state-of-the-practice navigation in the proximity of primitive bodies relies heavily on ground analyst expertise and time. Studies have been conducted using autonomous navigation for orbiting and landing on small bodies assuming shape, spin, and gravity field are previously determined, however, there is a critical gap in connecting the autonomous cruise phase with autonomous orbit phase, i.e., **autonomous approach** to a small body.

Significance/Benefits:

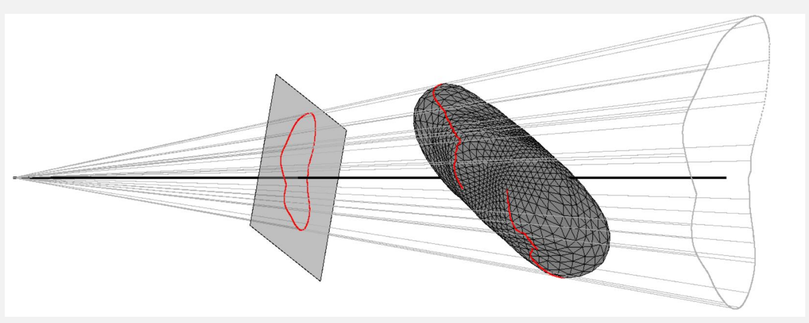
Autonomous missions greatly **reduce mission costs and timelines,** benefitting science missions and planetary defense. Beyond being ground-independent, this research supports autonomy efforts through its Monte Carlo-verified robustness.

Approach:

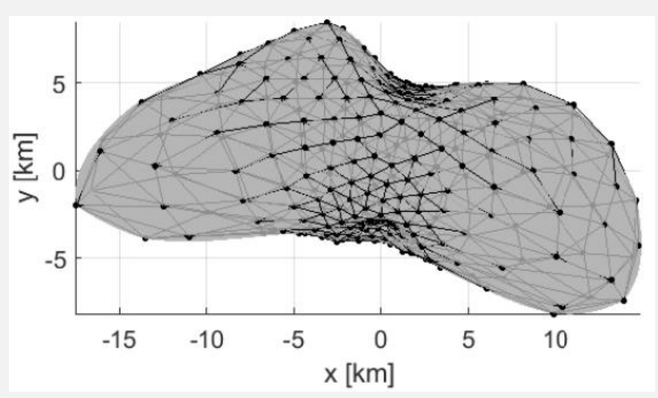
Extract observed silhouette from images



Compute expected silhouette from geometry

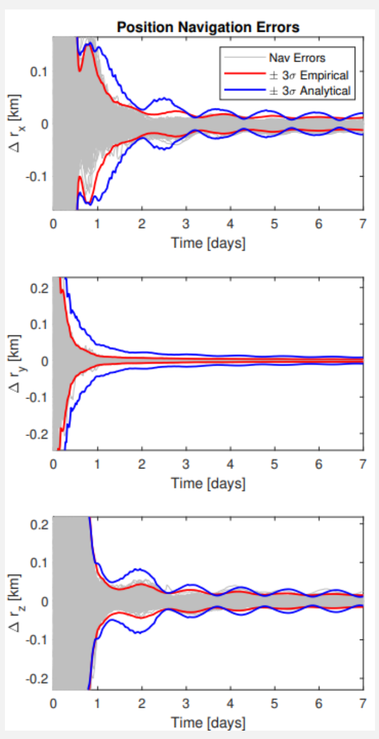


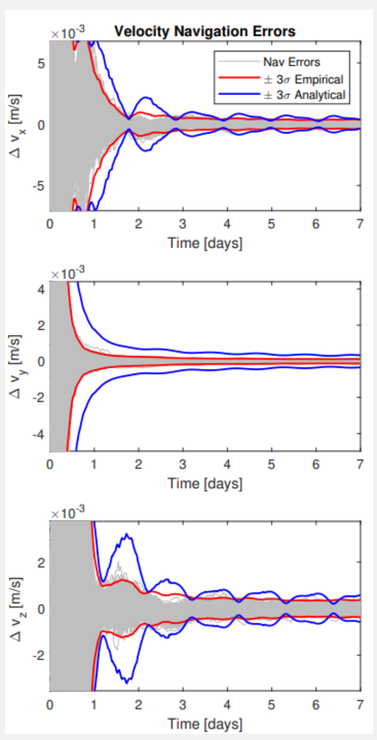
Perform Gaussian Process by augmenting state vector in extended Kalman filter

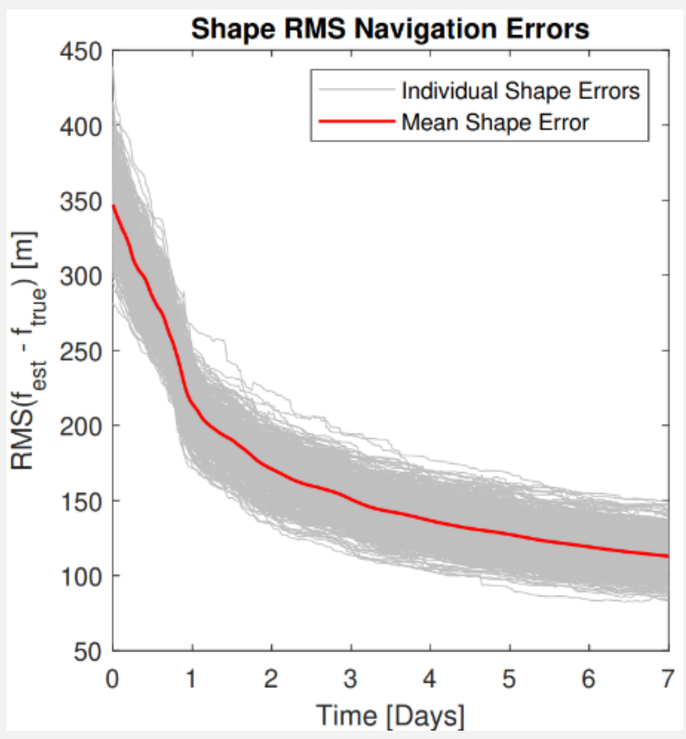


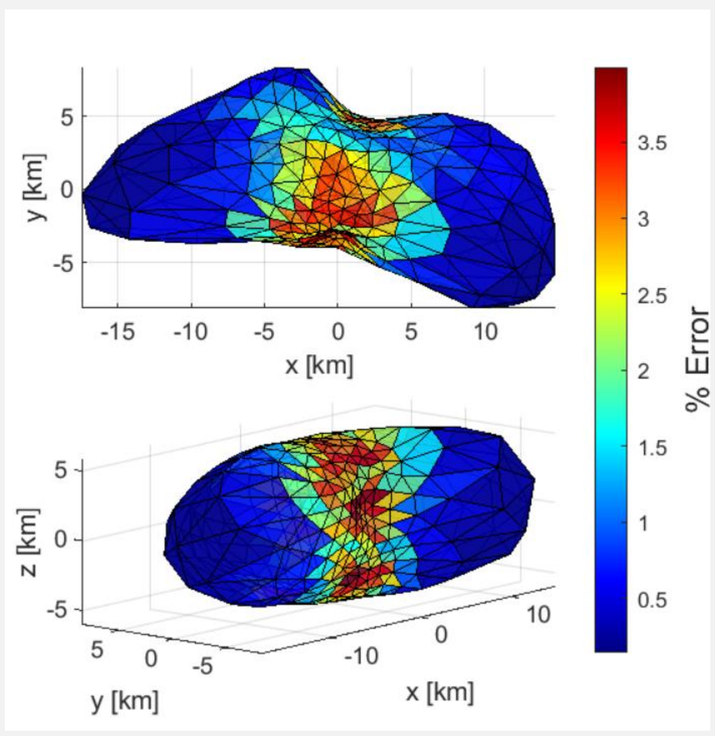
Results:

Monte Carlo simulations are loosely based on the Near-Earth Asteroid Rendezvous spacecraft around Eros, where the spacecraft is approximately in a 70×70 km near-polar orbit. The simulation takes places over 7 days with images taken every 30 minutes. Results indicate the filter is able to consistently converge perturbed state and shape parameters toward their true values with errors that are bounded by expected uncertainties.









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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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Publications:

[A] E. M. Zucchelli, B. A. Jones, and R. P. Russell, "Pose and shape estimation of a small body via extended target tracking," American Astronautical Society, Astrodynamics Specialist Conference, pp. 19–678, 2019.

[B] E. M. Zucchelli, N. Lifset, B. A. Jones, R. P. Russell, and S. Bhaskaran, "Towards limb-based autonomous navigation and mapping of primitive bodies," American Astronautical Society, Astrodynamics Specialist Conference, pp. 22–644, 2022.

[C] Courtney Hollenberg, "Horizon-Based Autonomous Navigation and Mapping for Small Body Missions," Master's Report, Department of Aerospace Engineering and Engineering Mechanics, The University of Texas at Austin, Austin, TX, 2023.

[D] Q. P. Moon, B. A. Jones, R. P. Russell, C. Hollenberg, D. P. Lubey, and S. Bhaskaran, "Silhouette based gaussian process batch filtering for simultaneous localization and mapping about small bodies," Denver, CO, Astrodynamics Specialist Conference, AAS-24-196, vol. 1, 2024.

[E] Q. P. Moon, C. Hollenberg, E. Zucchelli, N. Lifset, B. A. Jones, R. P. Russell, S. Bhaskaran, and D. P. Lubey, "Gaussian Process Sequential Filtering for Small Body SLAM with Silhouette-Based Measurements," Atlanta, GA, Space Imaging Workshop, 2024.

PI/Task Mgr. Contact Information:
Email: daniel.p.lubey@jpl.nasa.gov