National Aeronautics and Space Administration

FY25 Strategic University Research Partnership (SURP)

Autonomous Navigation via Optical Measurements as Silhouettes for Primitive Bodies

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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:

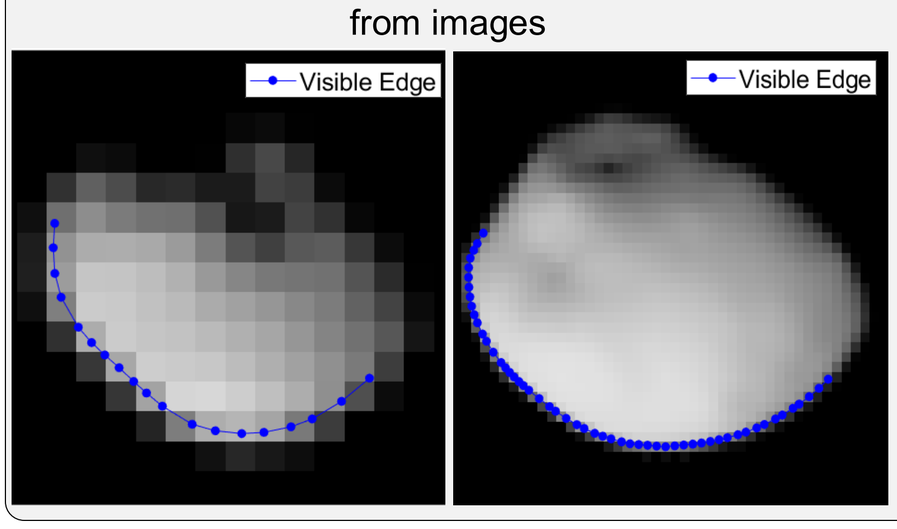
Current state-of-the-practice navigation in the proximity of primitive bodies relies heavily on ground analyst expertise and time. Studies have been conducted using autonomous navigation for orbiting and landing on small bodies assuming shape, spin, and gravity field are previously determined, however, 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:

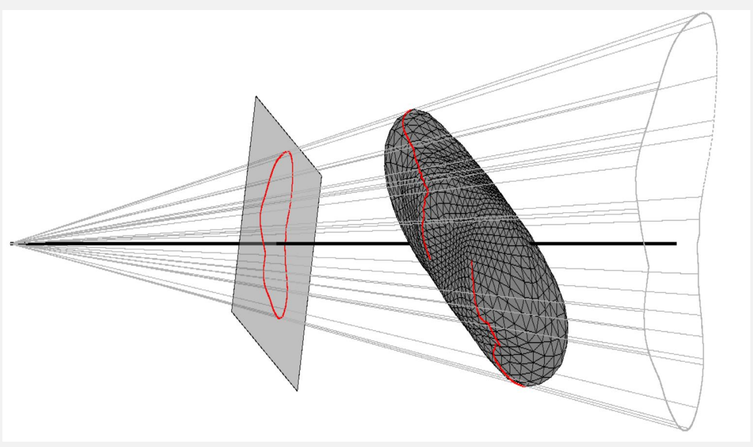
Autonomous missions greatly **reduce mission costs and timelines,** benefitting science missions and planetary defense. Autonomous mission will be able to explore unknown bodies and map them without ground operation assistance.

Approach:

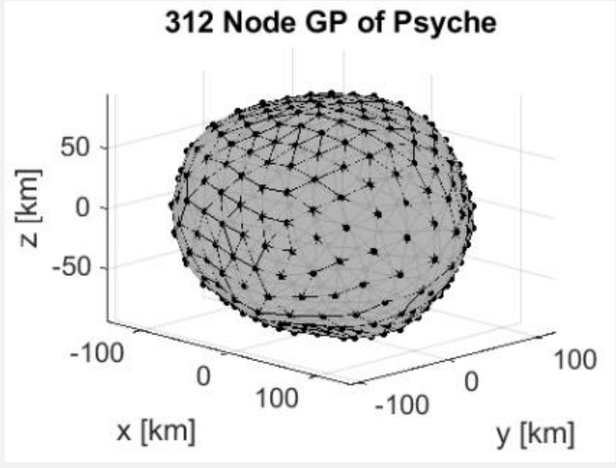
Extract observed silhouette from images



Compute expected silhouette from geometry

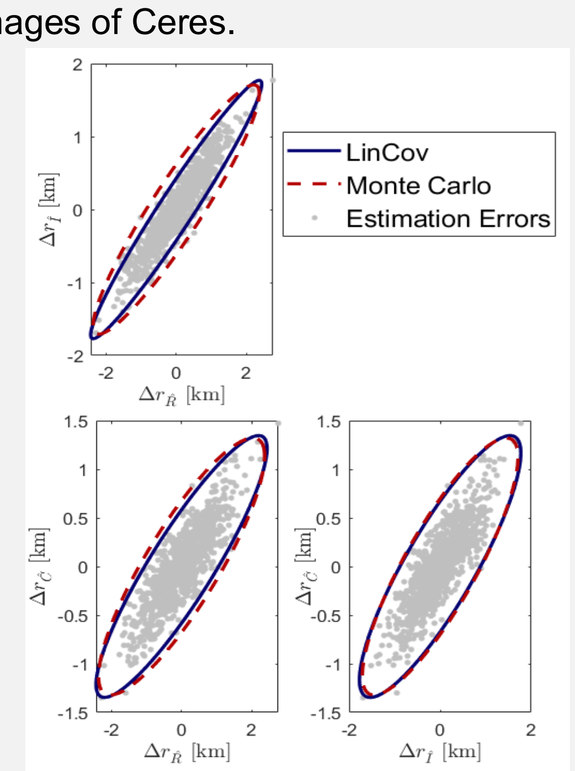


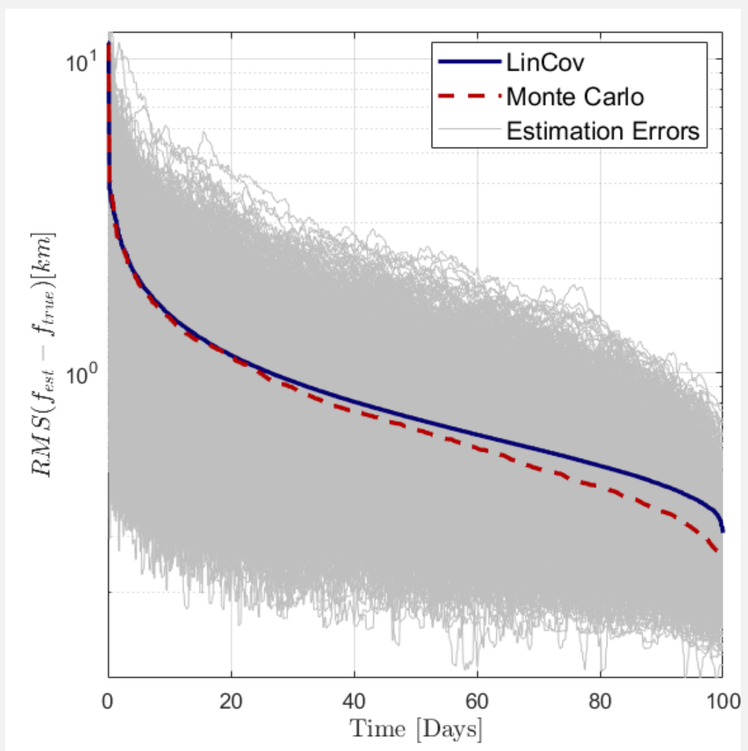
Perform Gaussian process by augmenting state vector in extended Kalman filter

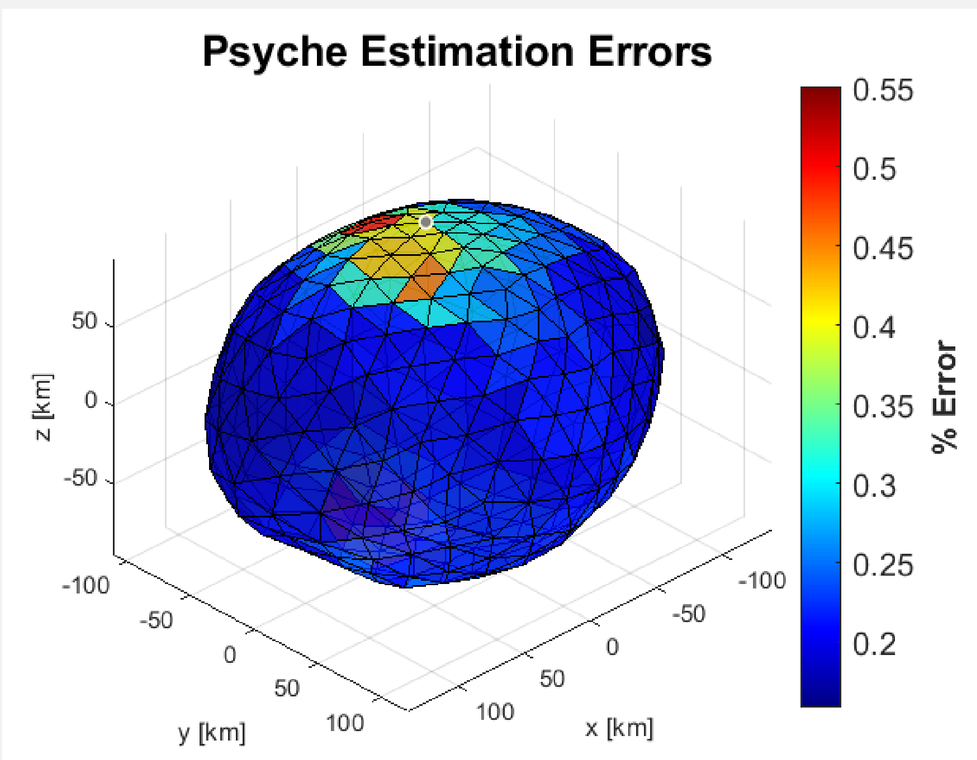


Results:

Monte Carlo simulations are performed on a 100-day approach to (16) Psyche. The approach ranges from 114,000 km to 811 km, taking images every six hours. Closed-loop maneuvers target orbit insertion at the final time. Simulations include true measurements generated using the Gaussian Process shape model and image extraction from Blender simulated images. Real image extraction and testing is also performed using the Dawn images of Ceres.







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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. AAS-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. AAS-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.
[F] Q. P. Moon, C. Hollenberg, B. A. Jones, R. P. Russell, S. Bhaskaran, and D. P. Lubey, "Gaussian Process Sequential Filtering for Small Body SLAM with Silhouette-Based Measurements," Journal of Astronautical Sciences, 2025.
[G] **(To Be Presented)** Q. P. Moon, B. A. Jones, R. P. Russell, D. P. Lubey, C. Hollenberg, and S. Bhaskaran, "Navigation with Shape Estimation During Small Body Approach," Spaceflight Mechanics Meeting, Orlando FL, 2026.

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