National Aeronautics and Space Administration

FY23 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:

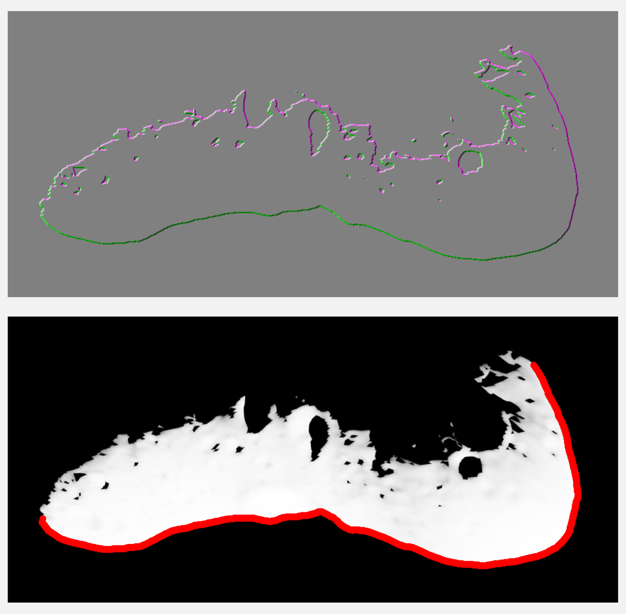
Current state-of-the-practice navigation in the proximity of primitive bodies relies heavily on ground analyst expertise and time. Studies have been conducted using autonomous navigation for orbiting and landing on small bodies assuming shape, spin, and gravity field are previously determined, however,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

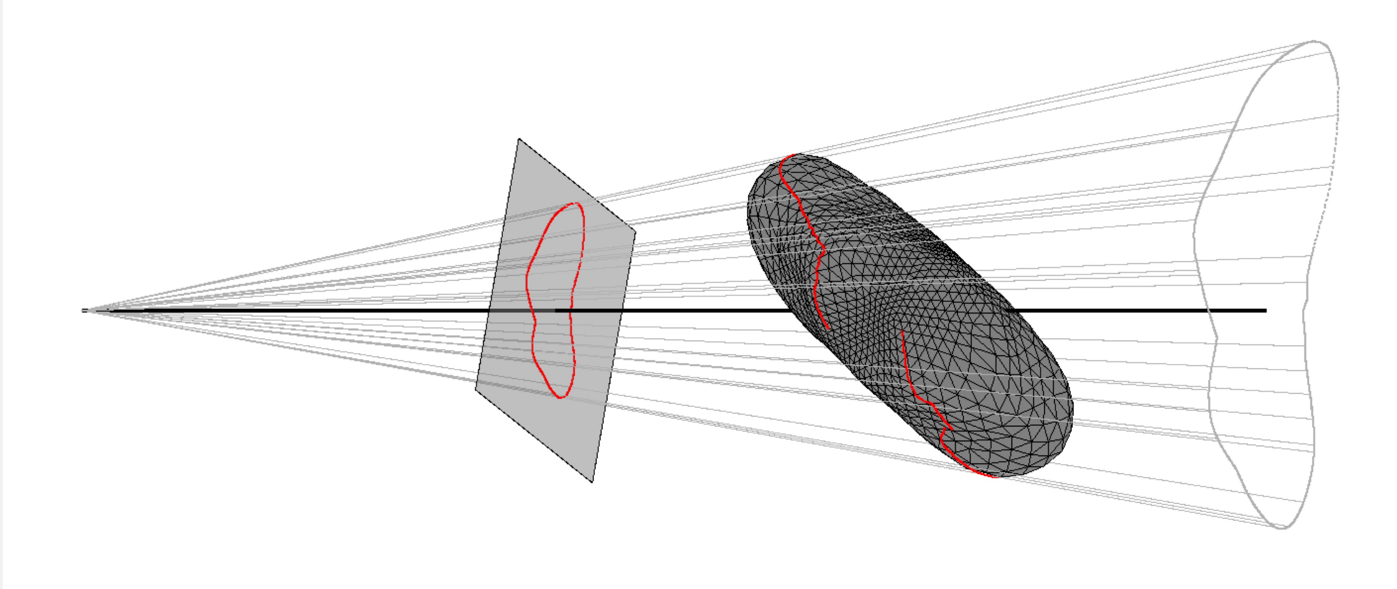
Automating the shape modeling/estimation process will greatly speed up operations, thus **reducing mission costs and timelines**. This will benefit both pure science missions and planetary defense missions to asteroids.

Approach:

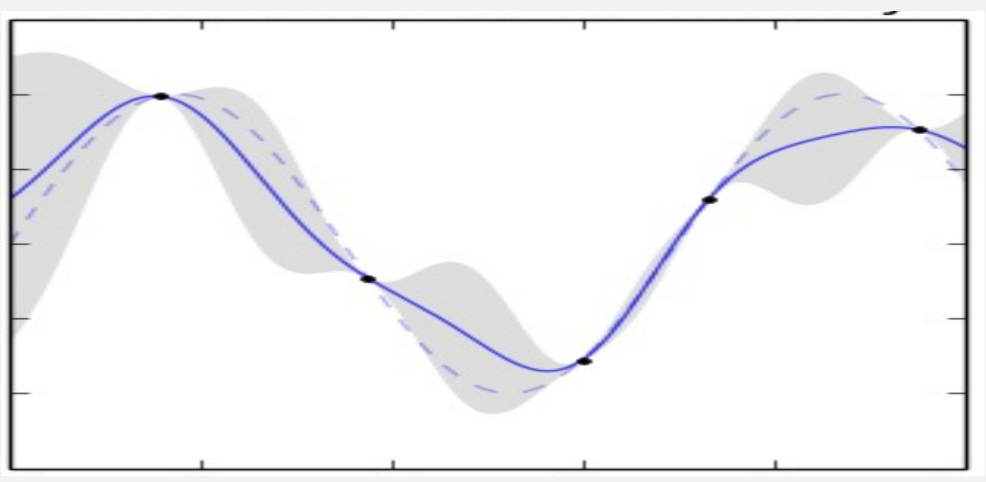
Extract observed silhouette from images



Compute expected silhouette from geometry



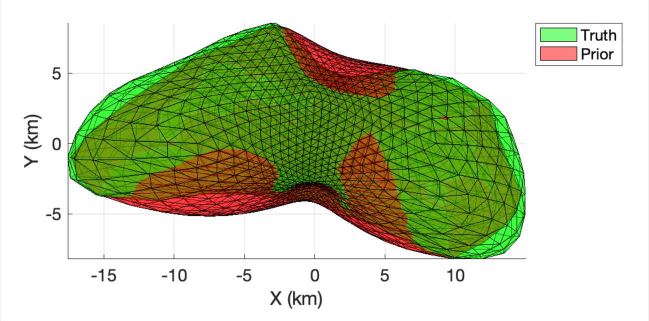
Perform Gaussian Process Regression on star-convex shape by augmenting state vector in extended Kalman filter

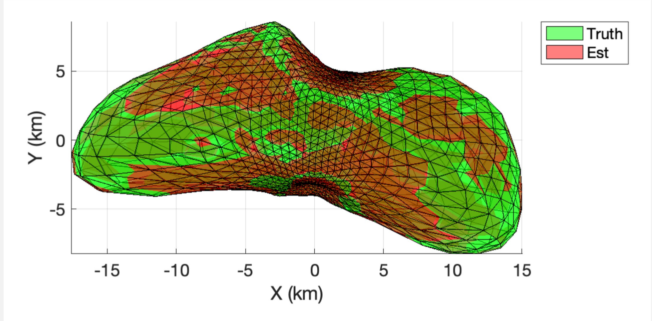


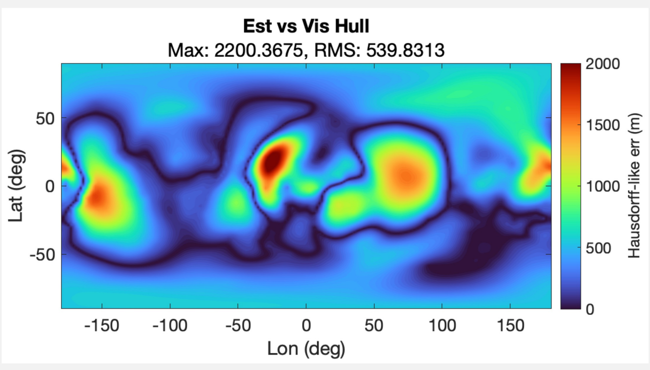
Results:

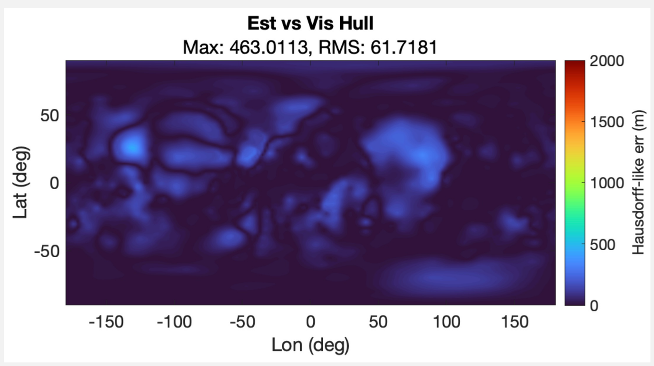
The simulation scenario is loosely based on the Near-Earth Asteroid Rendezvous spacecraft after initial orbit insertion around Eros, where the spacecraft is approximately in a 70×70 km near-polar orbit. The simulation takes places over 3 days with images taken every 30 minutes.

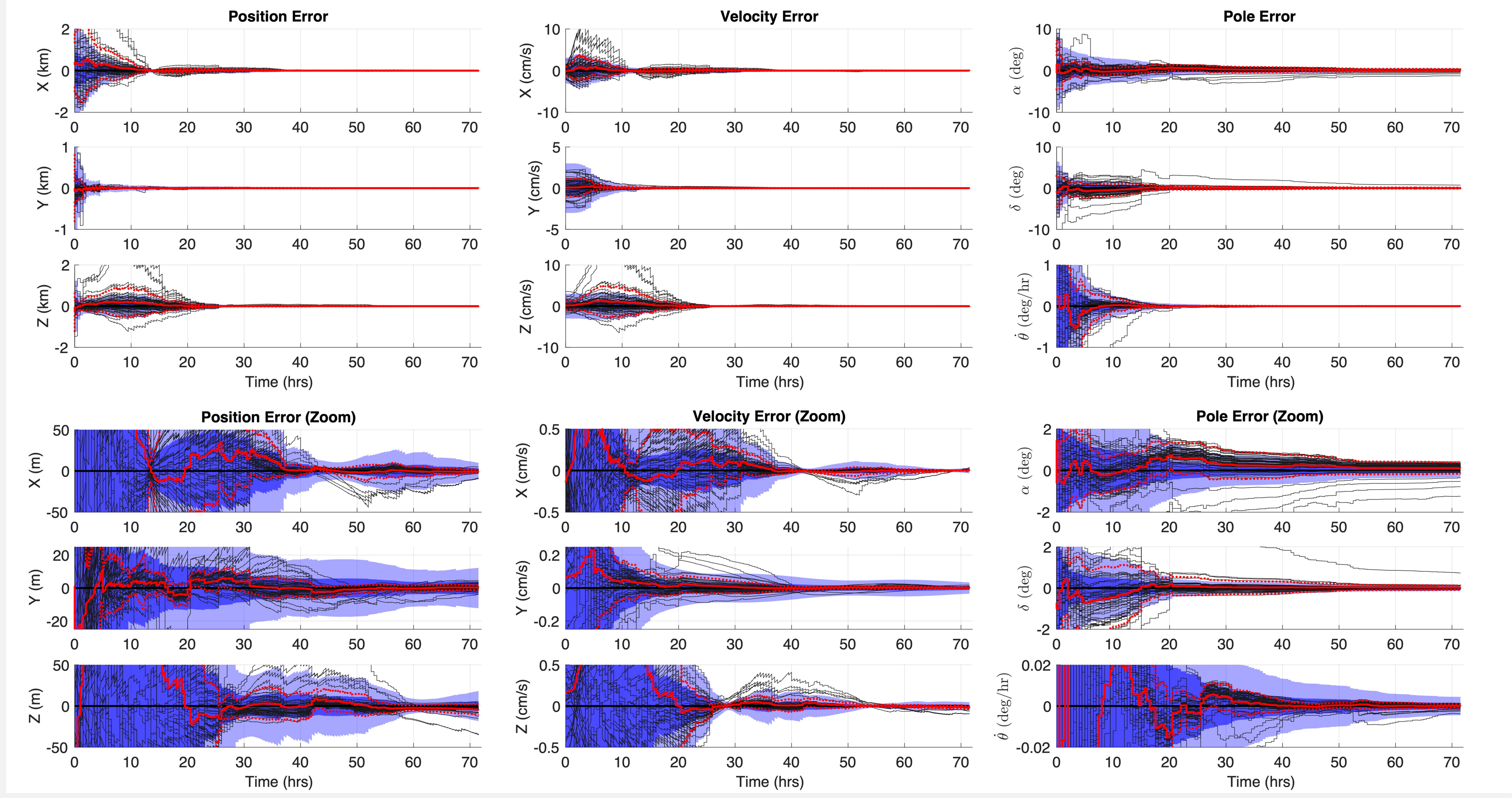
Parameter	Description	Initial Standard Deviation
$\boldsymbol{r}^I_{s/a}$	Spacecraft Relative Position	1 km
$\dot{\boldsymbol{r}}^I_{s/a}$	Spacecraft Relative Velocity	1 cm/s
α, δ	Asteroid Pole	4°
$\dot{\theta}$	Asteroid Spin Rate	68°/hr (2% of truth)
θ_0	Asteroid Prime Meridian Offset	1°
$\boldsymbol{f}$	Asteroid Shape	1.6 km











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Publications:

[A] 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.

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