National Aeronautics and Space Administration

End-to-End Autonomous Navigation via Optical Measurements at Primitive Bodies

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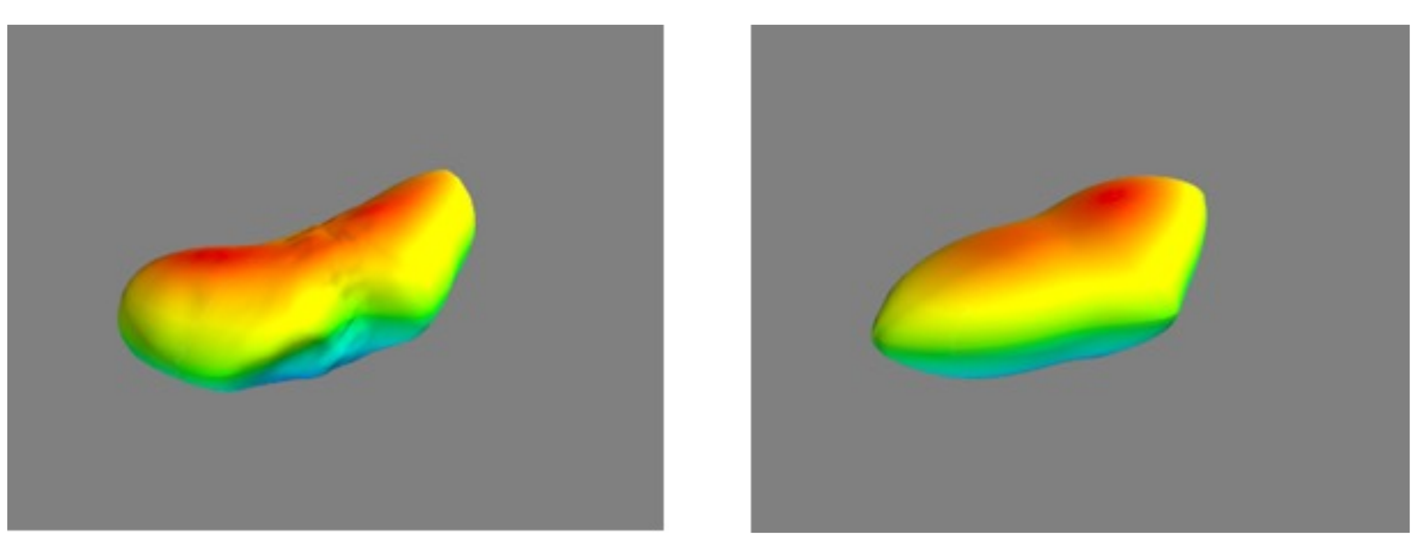
Strategic Focus Area: GNC and Mission Design

Objectives:

The primary technical objective of this work was to develop an approach to relative-state estimation using optical navigation and a Gaussian process for the body's shape.

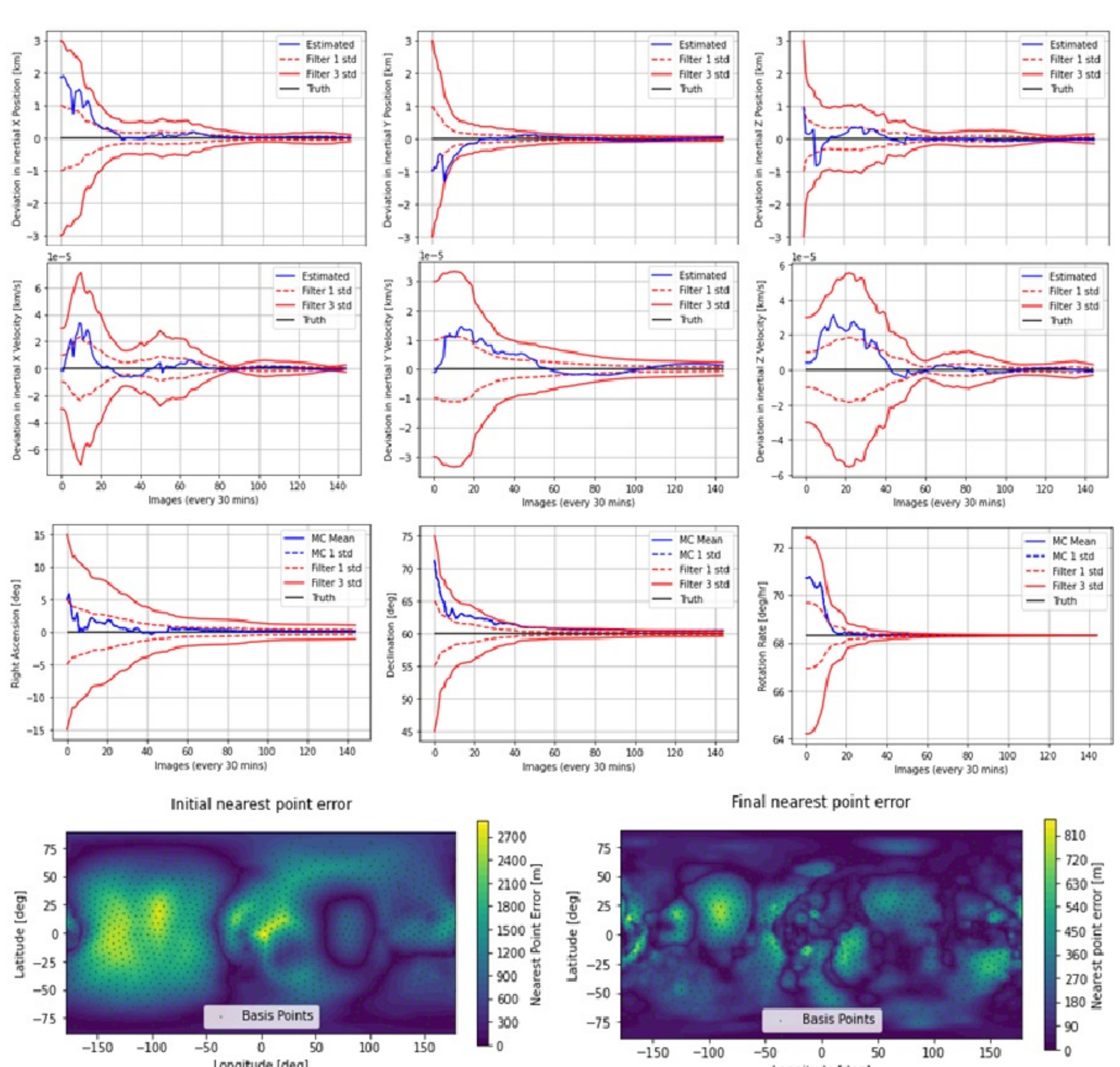
Background:

- Onboard autonomous navigation would significantly enhance and enable science return on missions to small bodies, but requires previous knowledge of physical characteristics.
- Current state of the art method (Stereo-Photoclinometry) relies heavily on ground expertise and time—nearly impossible to automate. We need a new approach.



Simulation:

- Spacecraft is orbiting around asteroid 433 Eros at 70 km.
- Images are taken every 30 minutes for a total of 143 images.
- Truth values for physical characteristics and relative state are preselected, then perturbed for estimator priors.

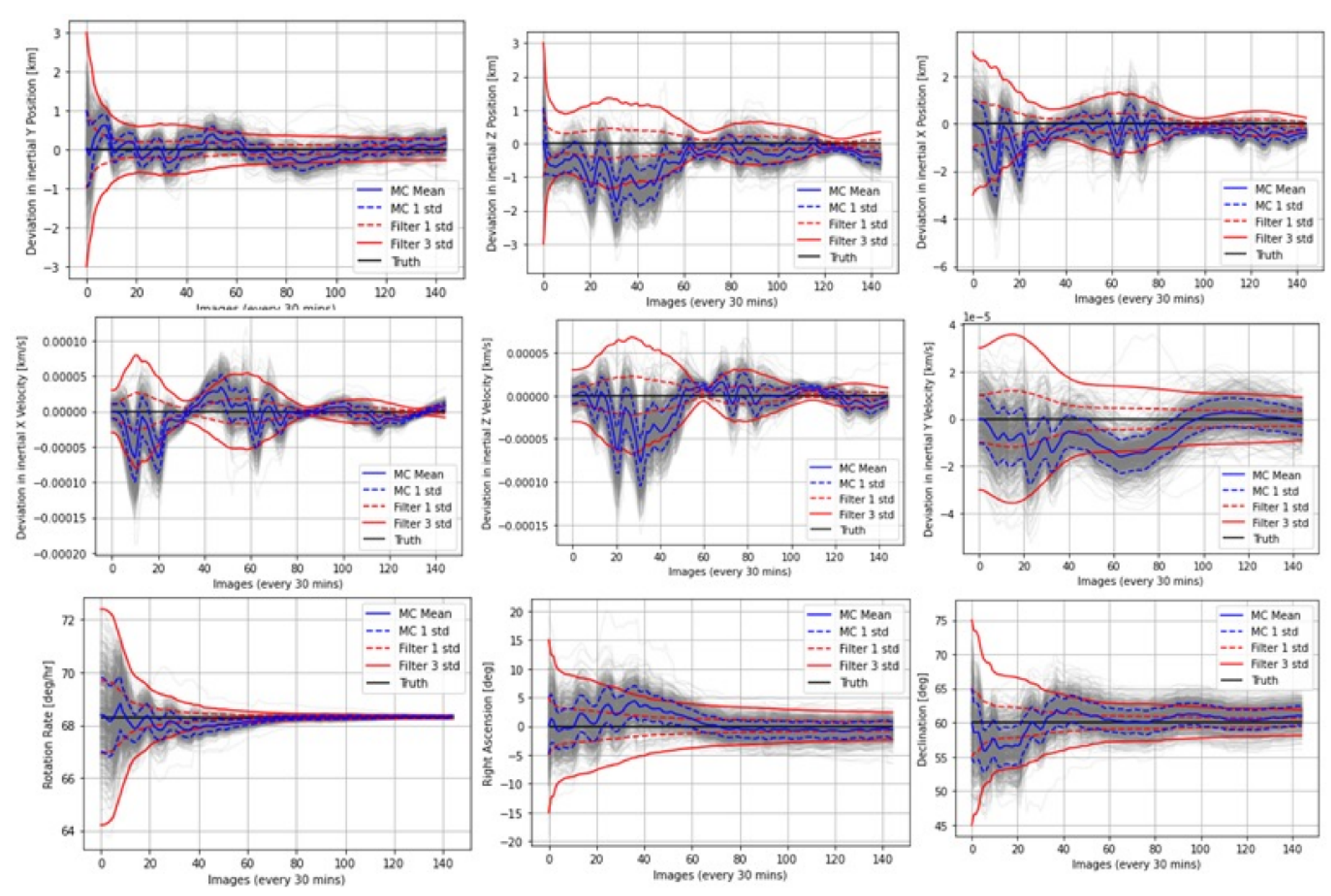


Approach:

- Simultaneous estimation of small body physical characteristics and relative spacecraft state using an Extended Kalman Filter
- Shape estimated using a Gaussian Process (GP)—allows for analytic description
- Asteroid silhouettes extracted from optical images and incorporated via GP regression
- Silhouettes are converted to 3D asteroid edge points in body-fixed frame

Estimated Parameter	Initial Standard Deviation Value
Asteroid Spin Axis RA/Dec [deg]	4 degrees
Asteroid Spin Rate [deg/hour]	68 degrees/hour (2% of truth)
Spacecraft Relative Position	1 kilometer
Spacecraft Relative Velocity	1 centimeter/second
Asteroid Shape	1.7 kilometers

Left: 3D rendering of asteroid true shape and shape prior. **Above:** STD values used for initial uncertainty and perturbed initial guess for each parameter. **Lower Left:** Results for single set of initial conditions (note different colorbar scales). **Below:** Results for Monte-Carlo (no shape shown due to lack of significant change)



Results and Next Steps:

- Single set of initial conditions show good convergence using hyperparameter tuning.
- Full pseudo-Monte-Carlo (600 runs) shows improvement in priors and uncertainty, but no convergence.
- Estimated shape very close to truth for single set, but no significant change for Monte-Carlo.
- Future work will deal with estimator robustness. Fix requires reformulation of measurement space to remove outstanding issue with measurement/prior correlation.

Significance/Benefits to JPL/NASA: Once methodology is proven to be robust, it would provide tremendous benefit to future missions to small bodies. Automation would significantly speed up operations and reduce cost/timelines.

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