FY24 R&TD Innovative Spontaneous Concepts (ISC)

Removing Navigation Biasing During Close Proximity Operations

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Strategic Focus Area: Innovative Spontaneous Concepts

Objectives

Goal: Develop an optical landmark-based navigation framework that consistently yields unbiased solutions and can be applied to all phases of prox ops. Research will involve:

- Leveraging OpNav Information Distillation Algorithm (OIDA)
- Developing data partitioning capability for reduced runtime
- Minimizing information loss with dataset partitioning
- Conducting thorough error analysis to identify lingering bias
- Validating approach against real flight data

Background

Standard optical landmark-based navigation yields biased solutions - degrading performance and increasing cost/risk. Unmodeled correlations in the information flow between OpNav and OD cause this (Fig. 1). The OIDA was developed to correct this problem; however, it leaves a small amount of bias and cannot process dense datasets.

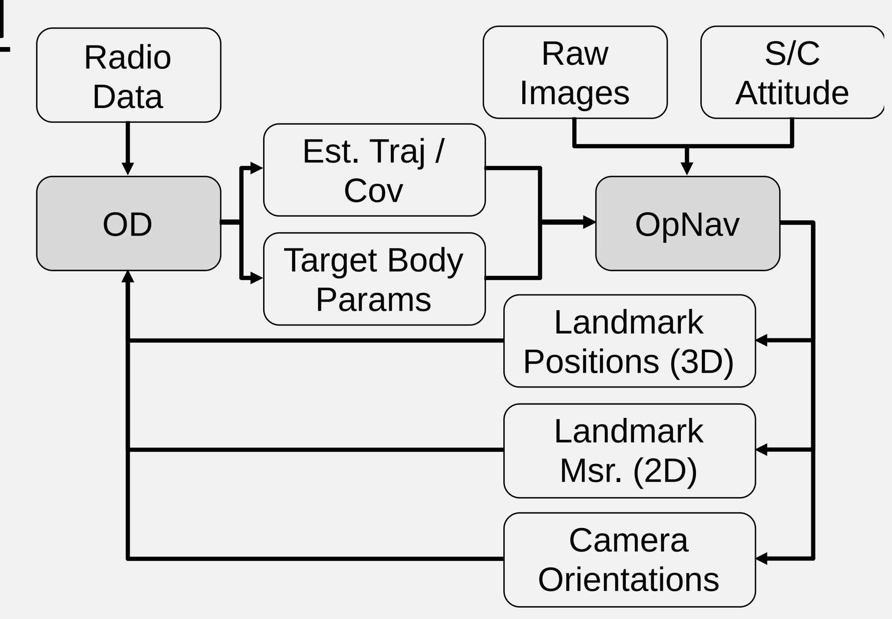

Figure 1: Standard OD-OpNav framework.

Approach & Results

We re-parameterized the OIDA to give it the ability to estimate with or without inertial attitude information. This provides estimation flexibility that can be used to identify potential biasing. We also developed a data partitioning algorithm called Landmark Community Tables (LTC, Fig. 2). With a LTC, datasets are depicted in a 2D binary table where the rows/columns can be interchanged to reveal information concentrations for optimal dataset partitioning.

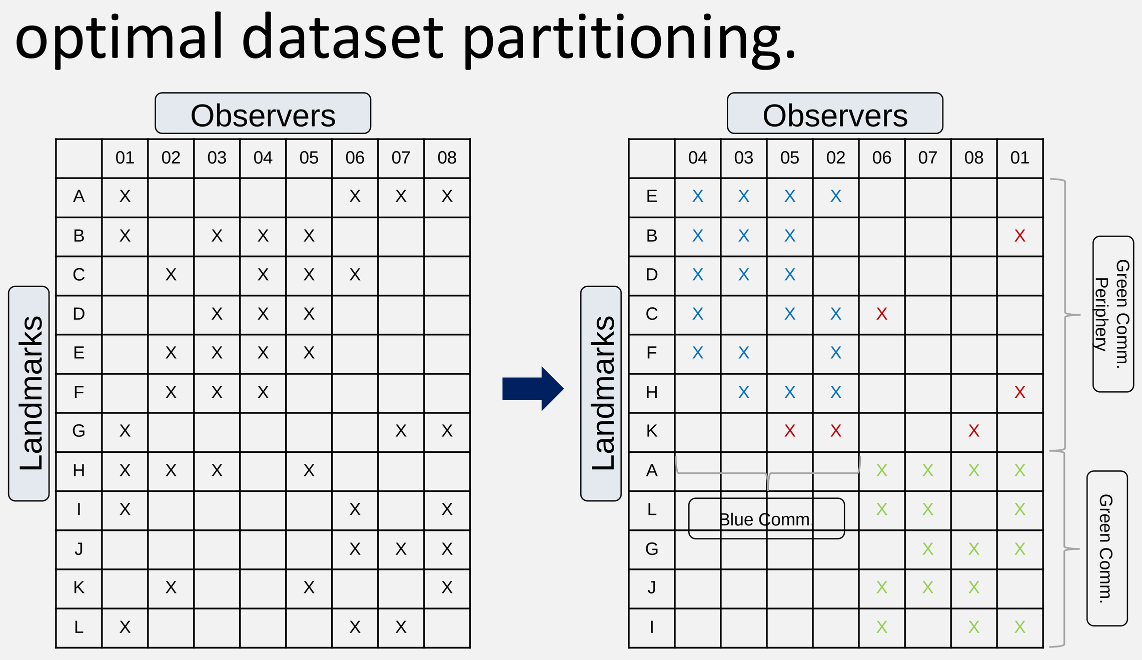

Figure 2: Landmark Community Tables.

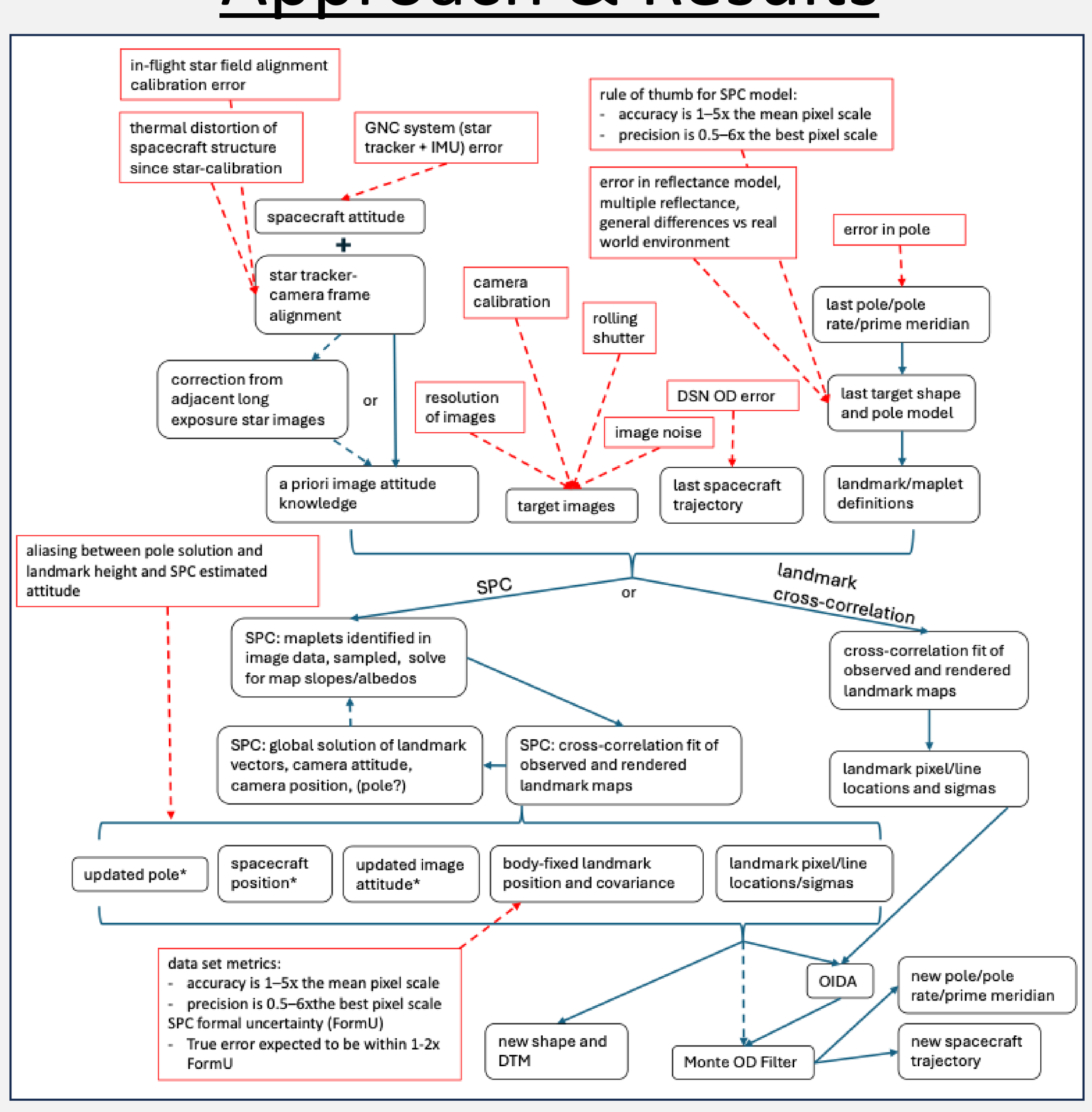

Figure 3: OpNav Error Flow Chart.

A complete error investigation was also performed as outlined in Fig. 3, which resulted in a novel per-landmark weighting scheme to reduce biasing.

Combining the re-parameterized OIDA, the LTC, and the novel optical data weighting scheme, we obtain the Information Sieve for Landmark (ISLAND) Navigation Framework. Applied to Dawn flight data (Fig. 4), the ISLAND completely removes solution biasing and drastically improves raw error relative to the state-of-practice (SOP). We have significantly decreased runtime (>100x) to enable usage for dense datasets throughout prox ops.

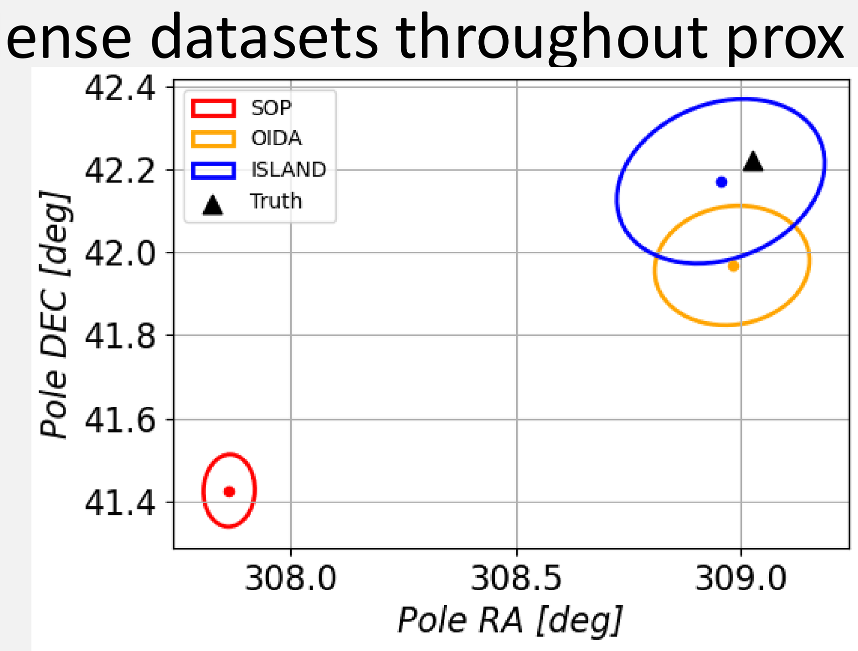

Figure 4: Vesta Approach Pole Estimate Comparison.

Significance / Benefits to NASA/JPL

We conclude that we have identified and removed the underlying cause of biasing with optical landmark-based navigation. This offers many benefits, including lowered development/ops cost, simplified requirements verification, and improved robustness/accuracy. This work will directly improve navigation for Psyche and MMX as well as future NASA/JPL missions. It also offers a pathway for more robust autonomous navigation.

References

[1] Lubey, Daniel and Bradley, Nicholas, “Improved Covariance Realism for OpNav-Informed Orbit Determination: The OpNav Information Distillation Algorithm,” IOM 392J-21-001, May 2021.
[2] Ernst, Carolyn M., et al. "High-resolution shape models of Phobos and Deimos from stereophotoclinometry." *Earth, Planets and Space* 75.1 (2023): 103.
[3] Mastrodemos, Nickolaos, et al. "Optical navigation for the Dawn mission at Vesta." *23rd International Symposium on Space Flight Dynamics, Pasadena, CA*. Vol. 29. 2012.

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Publications:

[A] Lubey, Daniel and Mages, Declan, “ISLAND: Removing Biasing from Optical Landmark-Based Navigation,” Hockney Seminar, Jan. 2025.

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