National Aeronautics and Space Administration

Improved Covariance Realism for OpNav-Informed Orbit Determination

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Objectives

Goal: Design, develop, and test a new method for processing landmark-based optical information from optical navigation (OpNav) in an operational orbit determination (OD) framework. The new method should ensure the following:

- Produces unbiased estimates with uncertainties that accurately reflect the information content of the available data
- Computationally efficient enough for use in operational spacecraft navigation framework
- Requires minimal updates to the existing OD and OpNav processes, which have significant design/flight heritage and validation

Background

While landmark-based OpNav is often critical for precise navigation in proximity operations, the current state-of-practice has consistently yielded biased solutions with over-optimistic uncertainty metrics – especially for pole (i.e., rotational axis) estimates [1, 2]. This impacts operational solution integrity as well as requirements validation for future missions (e.g., Psyche). We hypothesize the issue stems from unaccounted correlations between OD and OpNav, which currently exist in cyclic framework (Fig. 1) where the outputs of one process are inputs into the other.

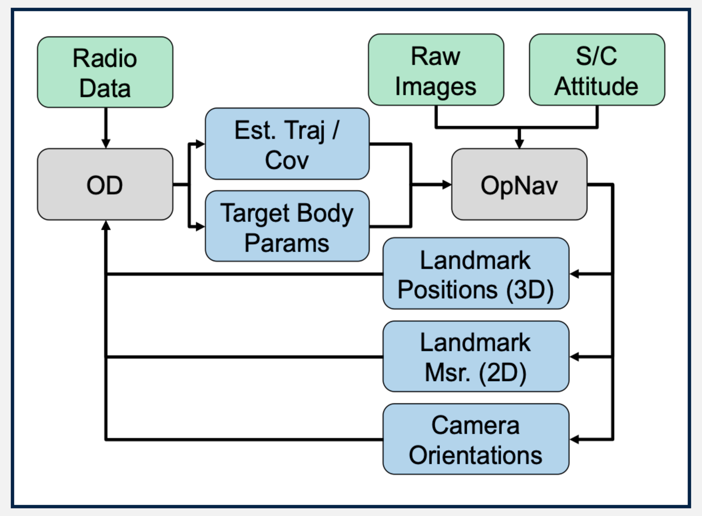

Figure 1: Standard OD-OpNav framework.

Approach & Results

To address this problem, we developed the OpNav information distillation algorithm (OIDA), which extracts the pure optical information content from OpNav outputs. It is a SLAM-like algorithm [3] that (among other parameters, Fig. 2) estimates observer and landmark positions in a scaleless state-space due to the observability restrictions of pure optical information. The scaleless observer positions and target orientation estimates from OIDA are then wrapped and fed to OD as a new measurement type that are uncorrelated with all other OD inputs and models. This updated framework (Fig. 3) succeeds in retaining the existing OD and OpNav processes while still addressing the root cause of the solution biasing and over-optimistic covariances.

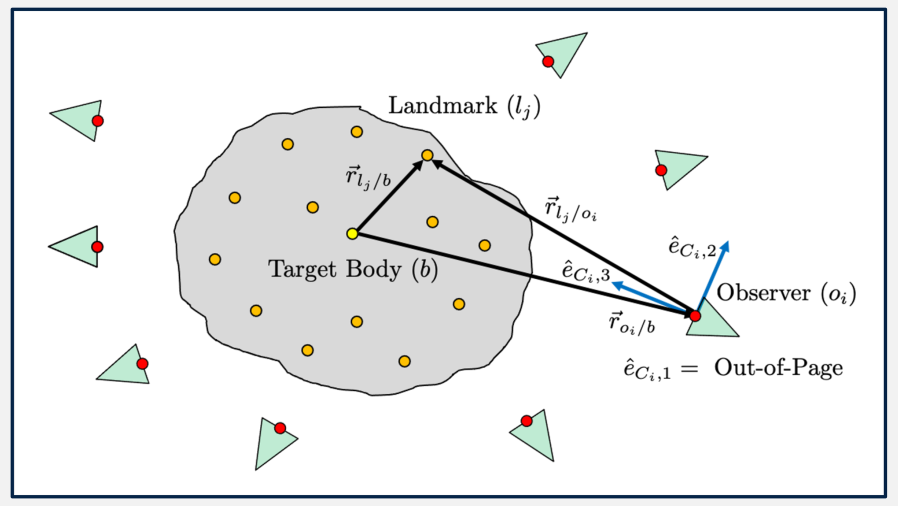

Figure 2: OIDA parameters of interest: observer/landmark positions, camera orientation, and target orientation

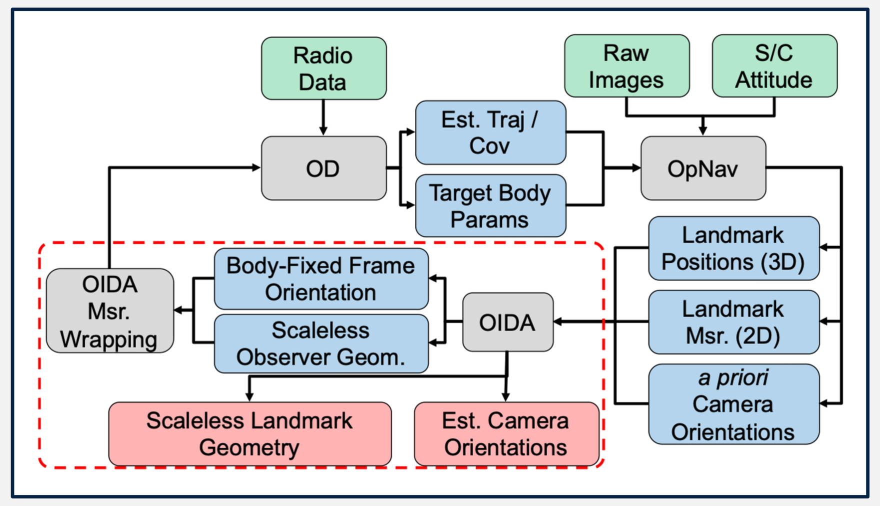

Figure 3: OIDA-Based OD-OpNav framework.

To validate the OIDA, we applied it to actual flight data from the Dawn and OSIRIS-Rex (OREx) missions. During Dawn's approach to Vesta, the standard OD-OpNav framework yielded Vesta pole estimates that jumped significantly from solution-to-solution. This culminated in a survey design pole estimate with a 66-σ error relative to the current best estimate of truth. Application of the OIDA to this same data set resulted in a solution with a much reduced statistical error of 4.5-σ (Fig. 4). Similarly, the standard framework for OREx yielded a 12-σ pole error during the Preliminary Survey phase, but application of the OIDA to the same data set yields a statistical error of 3.8-σ (Fig. 5). In each case, the OIDA-based estimates also have smaller raw errors, and slightly inflated uncertainties. This highlights the OIDA's ability to improve solution integrity while requiring minimal updates to the OD and OpNav processes.

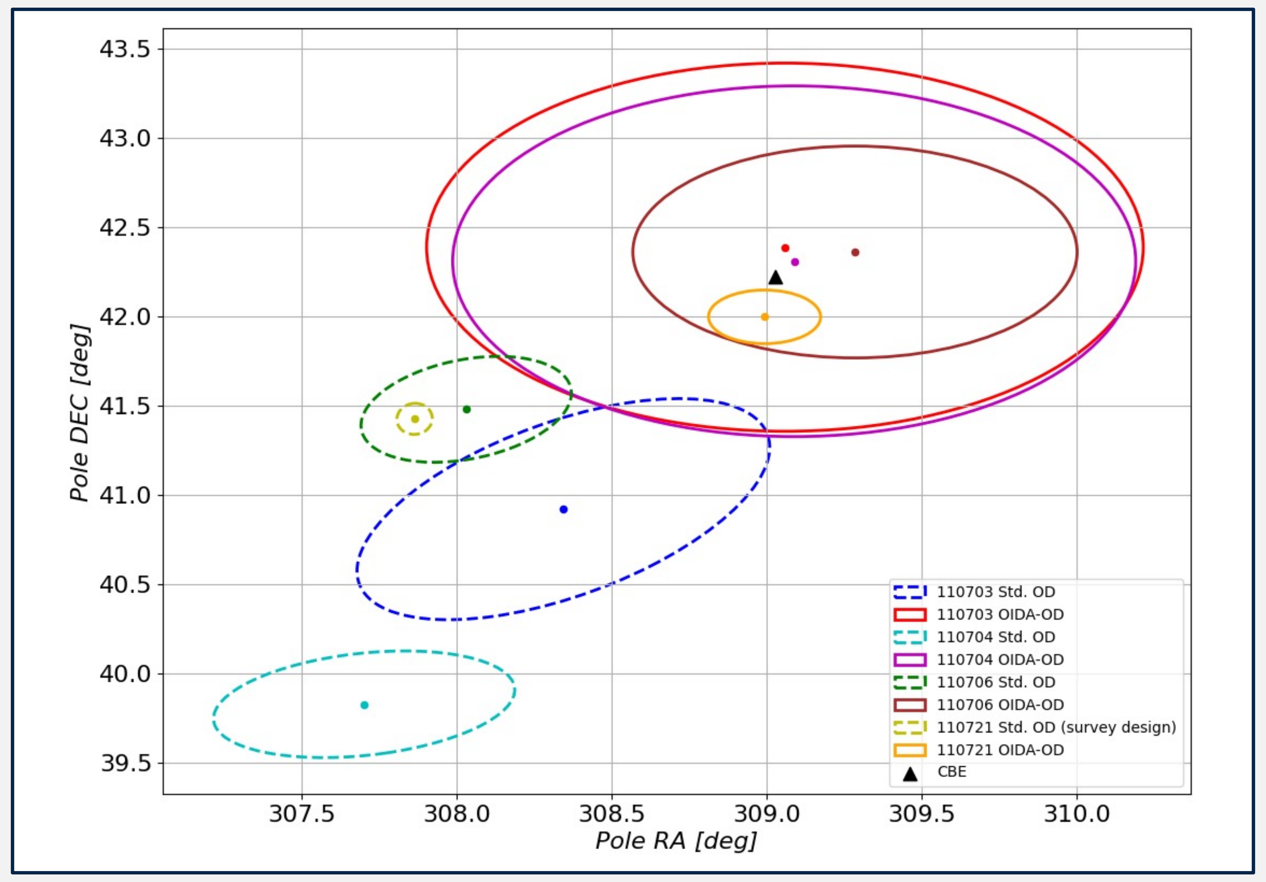

Figure 4: Vesta pole solutions (3-σ) during Dawn approach using standard (dashed) and OIDA (solid) approaches.

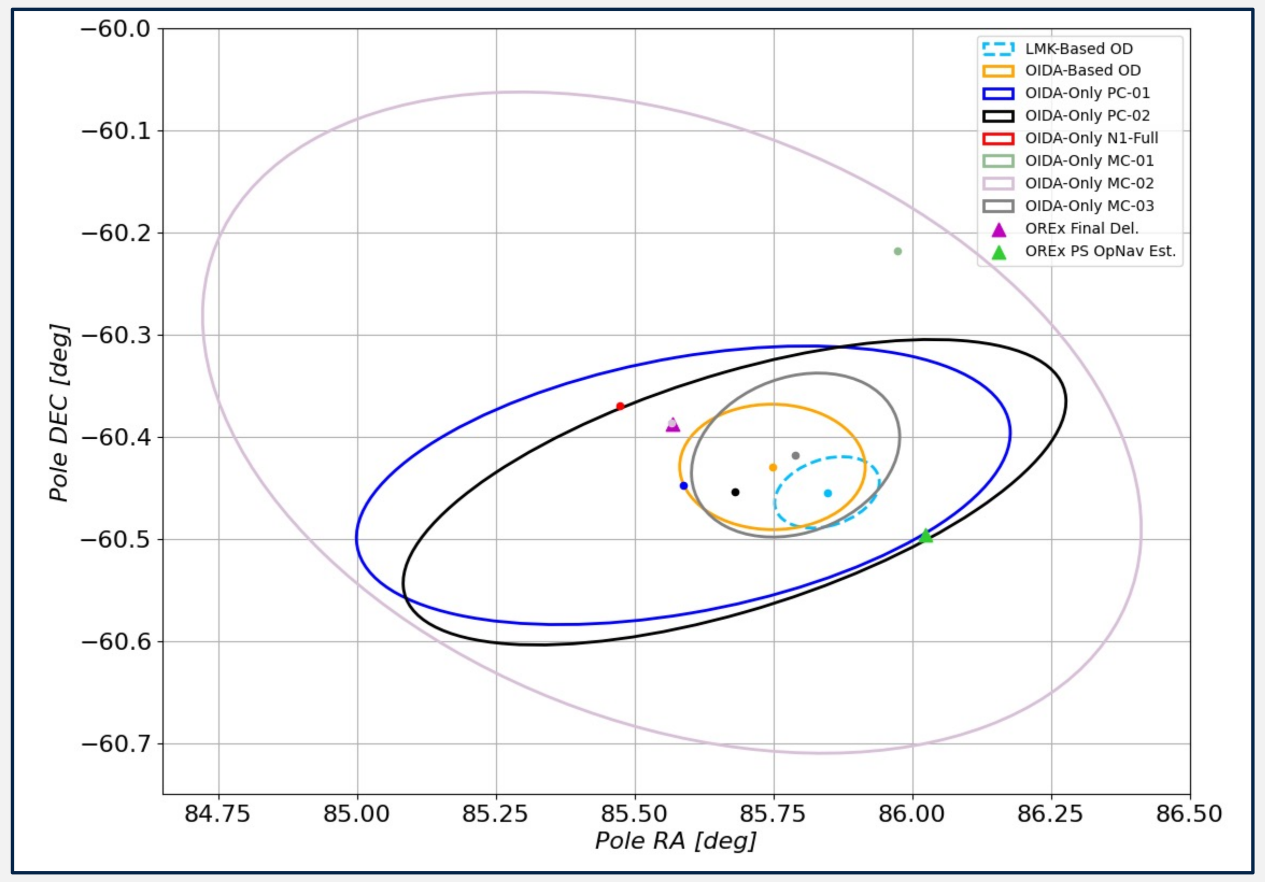

Figure 5: Bennu pole solutions (3-σ) during OREx Prelim. Survey using standard (dashed) and OIDA (solid) approaches.

Significance / Benefits to JPL & NASA

Our results demonstrate that the OIDA meets the goals of this research. It significantly out-performed the state-of-practice using flight data from Dawn and OREx, which establishes its potential for improved operational navigation in proximity operations. Furthermore, the OIDA requires minimal updates to OD/OpNav and it decreases both the data footprint and runtime for OD solutions. With more development, it could be expanded to cover navigation design studies too, where it could potentially support more effective requirements verification. Given its validation with flight data and implementation with operational software (MONTE), OIDA's path to operations is short. For these reasons, the Psyche navigation team plans to adopt the OIDA implementation in parallel with traditional OpNav processing to demonstrate its utility during operations.

Publications

[A] Lubey, D. P. and Bradley, N. E., "Improved Covariance Realism for OpNav-Informed Orbit Determination: The OpNav Information Distillation Algorithm," IOM-392J-21-001, The Jet Propulsion Laboratory, 2021.

References

[1] Kennedy, B., Abrahamson, M., Ardito, A., Haw, R., Mastrodemos, N., Nandi, S., Park, R., Rush, B., and Vaughan, A., "Dawn Orbit Determination Team: Modeling and Fitting of Optical Data at Vesta," 23rd AAS/AIAA Space Flight Mechanics Meeting, 2013.

[2] Mastrodemos, N., Rush, B., Vaughan, A., and Owen, W., "Optical navigation for the Dawn mission at Vesta," 23rd International Symposium on Space Flight Dynamics, 2012.

[3] Cocaud, C., and Kubota, T., "Autonomous navigation near asteroids based on visual SLAM," Proceedings of the 23rd International Symposium on Space Flight Dynamics, Pasadena, California, 2012.

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