PERFORMANCE OF LIMB-BASED NAVIGATION USING FLIGHT DATA FROM OSIRIS-REX AT BENNU

Andrew J. Liounis[1*] and Kenneth Getzandanner[1]; [1]Goddard Space Flight Center (8800 Greenbelt Rd, Greenbelt, MD 20771) [*][andrew.j.liounis@nasa.gov]

Abstract. *During approach to an unvisited body, particularly small primitive bodies, much time is spent characterizing the target and learning how to navigate with respect to it. The primary means of navigating with respect to these bodies typically involves some form of optical navigation (OpNav), where observables are extracted from images of the target and fed to a navigation filter to refine the relative position and velocity between the spacecraft and the target. We demonstrate the performance of a recently developed, limb-based OpNav technique for the approach time period by applying it to flight data from the Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) spacecraft's approach to asteroid Bennu.*

Introduction. In the initial approach to an unexplored, small, primitive body, relative navigation measurements between the spacecraft and the target body are essential to enable proximity operations. These measurements help to resolve uncertainty in both the spacecraft's and the target's state in the inertial sense, and also dramatically reduce the uncertainty in the relative state between them. Traditionally, these relative measurements have come from a process known as optical navigation (OpNav), where bearing and range observables to the target body are extracted from monocular images of the target.

During the earliest stages of approach, when the target body appears as unresolved in the image (with an apparent diameter typically less than 5 pixels), OpNav techniques nearly always involve some type of model fitting, where the observed unresolved object has some analytic model, which approximates the point spread function of the camera, fit to it to determine where the center of the object lies in the image. As the target begins to grow in the field of view to more than a few pixels, this technique quickly degrades and alternatives are used, typically either cross-correlation with a template or by finding the center of brightness and correcting based on the phase (Sun-target-spacecraft) angle.[1,2] Eventually, once the target becomes fully resolved, center of brightness techniques also quickly degrade in accuracy, leaving only cross correlation or limb-based techniques, where the observed, illuminated limb of the target is used to extract both the bearing and the range to the center of figure of the target.[3]

Traditionally, limb-based OpNav approaches have been limited to regular bodies (those well modeled by a tri-axial ellipsoid). Recently, however, a new limb-based technique capable of working with irregular bodies (those not well modelled by a tri-axial ellipsoid) was proposed.[4] This new technique works iteratively to refine the *a priori* estimate of the spacecraft to target position vector and the pairing of the observed limbs in the image with points on the surface of a shape model of the target. In the previous work, this method was demonstrated to work on a wide variety of irregular bodies using simulated images of the body, but it did not show the technique working on actual images of irregular bodies, nor did it demonstrate the effect the quality of the shape model used has on the performance of the technique. In this paper we address both of these issues through use of the rich data set generated by the Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) spacecraft during its approach to Bennu.[5,6]

Methodology. To further demonstrate the limb-based technique for irregular bodies, we apply the technique to monocular images captured by OSIRIS-REx during its approach to Bennu using the Goddard Image Analysis and Navigation Tool (GIANT).[7] Specifically, we consider images from PolyCam, MapCam, and NavCam across which Bennu spans from 50 pixels apparent diameter to several hundred pixels apparent diameter. This data set provides a wide range of viewing conditions in apparent size and phase angle and therefore supports extensive detailing of the performance of the technique.

In order to demonstrate the effect the quality of the available shape model of the target has on this technique, we also make use of different shape models that were developed by the OSIRIS-REx Altimetry Working Group during this time period. This includes the initial radar shape model that was used before in-flight characterisation of Bennu could occur, up through the shape model generated just as we entered into orbit at Bennu for the first time, representing a wide range in quality of shape models.[8] To demonstrate the technique in a true operational set up, we first restrict ourselves to only using the shape model that was available when an image was captured. We then also reprocess the data using the shape model that is available at the end of any given mission phase to demonstrate the "best case" performance for the technique. For each of these cases, we compared the observed relative position vectors from each image with the fully estimated trajectory from that time period to show accuracy. We also, if time permits, perform orbit determination solutions using the observables extracted from this technique to see how they compare to the officially delivered trajectories.

References.

[1] C. D. Jackman, D. S. Nelson, L. K. Mccarthy, T. J. Finley, A. J. Liounis, K. M. Getzandanner, P. G. Antreasian, and

M. C. Moreau, “Optical Navigation Concept of Operations for the OSIRIS-REx Mission,” in *27th AAS/AIAA Space Flight Mechanics Meeting, Washington, DC*, 2017.

[2] P. G. Antreasian, M. C. Moreau, C. D. Adam, A. French, J. Geeraert, K. M. Getzandanner, D. E. Highsmith, J. M. Leonard, E. J. Lessac-Chenen, A. H. Levine, *et al.*, “Early Navigation Performance of the OSIRIS-REx Approach to Bennu,” in *AAS Annual Guidance and Control Conference*, no. GSFC-E-DAA-TN66399, 2019.

[3] L. K. McCarthy, C. D. Adam, J. M. Leonard, P. G. Antresian, D. Nelson, E. Sahr, J. Pelgrift, E. J. Lessac-Chenen, J. Geeraert, and D. Lauretta, “OSIRIS-REx Landmark Optical Navigation Performance During Orbital and Close Proximity Operations at Asteroid Bennu,” in *AIAA SCITECH 2022 Forum*, p. 2520, 2022.

[4] A. J. Liounis, “Limb Based Optical Navigation for Irregular Bodies,” in *1st Annual RPI Workshop on Image-Based Modeling and Navigation for Space Applications, Troy, NY*, 2018.

[5] D. Lauretta, S. Balram-Knutson, E. Beshore, W. Boynton, C. Drouet d’Aubigny, D. DellaGiustina, H. Enos, D. Golish, C. Hergenrother, E. Howell, *et al.*, “OSIRIS-REx: Sample Return from Asteroid (101955) Bennu,” *Space Science Reviews*, vol. 212, no. 1, pp. 925–984, 2017.

[6] D. S. Lauretta, H. L. Enos, A. T. Polit, H. L. Roper, and C. W. Wolner, “OSIRIS-REx at Bennu: Overcoming challenges to collect a sample of the early Solar System,” in *Sample return missions*, pp. 163–194, Elsevier, 2021.

[7] A. J. Liounis, C. Gnam, J. Swenson, K. Getzandanner, J. Small, and J. Lyzhoft, “The Goddard Image Analysis and Navigation Tool,” 1 2022. https://github.com/nasa/giant.

[8] M. Al Asad, L. Philpott, C. Johnson, O. Barnouin, E. Palmer, J. Weirich, M. Daly, M. Perry, R. Gaskell, E. Bierhaus, *et al.*, “Validation of Stereophotoclinometric Shape Models of Asteroid (101955) Bennu During the OSIRIS-REx Mission,” *The Planetary Science Journal*, vol. 2, no. 2, p. 82, 2021.