NAVIGATION FEATURE GENERATION IN SUPPORT OF AUTONOMOUS NAVIGATION OF THE OSIRIS-REX MISSION.  E. E. Palmer1*, J. Weirich1, K. Lopez1, O. S. Barnouin2, M. G. Daly3, R. Gaskell4, C. Miller3, R. Olds4, C. Mario4, C. Norman4, D. A. Lorenz4 and D. S. Lauretta6, 1PSI, Tucson, AZ (epalmer@psi.edu), 2JHUAPL, Laurel, MD, 3York U. Toronto, Ontario, Canada, 4Lockheed Martin Space, Littleton, CO, 5NASA GSFC, Greenbelt, MD, 6Lunar and Planetary Laboratory, Univ. of Arizona, Tucson, AZ.

Introduction: The prime requirement of the OSIRIS-REx mission is the return of a sample from the surface of asteroid Bennu. In order to accomplish this, the spacecraft must navigate to the surface using au-tomatos navigation, conduct the “touch-and-go” sample acquisition maneuver (TAG) while avoiding hazardous terrain, and then return to a safe orbit [1].

The original plan for the mission was to depart from a terminator orbit and descend to the surface using a Flash LIDAR to measure the spacecraft-to-surface distance. The design for this technique was based on having a TAG site of 25 m radius. However, Bennu did not provide suitable TAG sites of this size, but instead had much smaller possible sites of only 5 to 8 m radius.

Natural Feature Tracking: A second method of autonomous navigation was developed for the mission by Lockheed Martin Space called Natural Feature Tracking (NFT), [2,3]. NFT allows the spacecraft to determine its location within 1 m during TAG operations, which makes it possible to use a considerably smaller site than originally planned. However, in order to accomplish a 1-m positional knowledge, exceptionally accurate and high-resolution digital terrain models (DTMs) are required. At the highest resolution, the DTMs have a 0.5-cm ground sample distance (GSD). Further, each DTM must be able to generate synthetic images realistic enough for on-board software to identify the DTM within the images from the navigational camera, NavCam. Stereophotoclinometry (SPC) [4] is an exception tool for generating high-fidelity synthetic images because it solves for topography and surface reflectance (albedo) (Fig. 1). The SPC-generated DTMs produce synthetic images that perform substantially better than any other technique we tested including using laser altimeter data overlaid with actual images and geometrically corrected images.

Pre-launch testing has shown that SPC can generate DTMs that have an accuracy of the same order as the source image pixel scale. For example, 2-cm images result in a mean error from a truth model of 2 cm [5]. Additionally, we can generate sufficiently accurate DTMs with a GSD extrapolated by a factor of 2 from the source images, e.g. 2-cm images can be used to generate 1-cm DTMs.

While only three images are needed to generate DTMs using SPC, testing has shown that the best DTMs are created with four topographically focused imaging stations (spacecraft position roughly north, east, west and south) to give the maximum topographic accuracy in both the x-slope and the y-slope. Additionally, albedo accuracy and topographic aliasing is minimized by having one observing station (albedo image) where the Sun is near local noon because that is when topography expression is minimized, so variations in amplitude are solely from surface reflectance.

During descent, the NavCam will take 31 images that have pixel scales starting at 16 cm and decreasing to 0.5 cm for the last image before TAG. NFT will correlate each image against a set of pre-generated “features” to identify where those features are located in the image. This information is used to autonomously compute the spacecraft’s position relative to Bennu and generate a state update for the OSIRIS-REx spacecraft’s navigation system. The NFT team at Lockheed Martin Space selected both the location and GSD of the features, so that each NavCam image would have five features in the field of view.

Each feature is a small DTM that is usually 125x125 pixels in size and has a GSD that closely matches the NavCam pixel size for the images to which it is compared. The feature needs both terrain geometry and albedo so that the DTM can be rendered to match the real images. These features are produced by the OSIRIS-REx Altimetry Working Group, part of the OSIRIS-REx science team, using procedures developed for scientific shape modeling and adapted for navigation. [4]

NFT Feature Generation: By the time of TAG, the Altimetry Working Group will have generated 111 NFT features using SPC [4]. The early part of the descent will have a field of view that is very wide, so features are spread out over a large amount of the surface. As the spacecraft descends, it needs images of progressively higher resolution, but NavCam's field of view covers progressively less of the surface, so the area of high-resolution imagery becomes more narrow.

Imaging Requirements. To support the generation of the new high-resolution DTMs, the mission adapted the original plan [1] to include phases Recon A (pixel size of 2 cm) and Recon B (pixel size of 1 cm), to focus on getting images of the NavCam’s field of view in the final portion of the descent profile when the needed pixel size was smaller than that captured in earlier mission phases.
The lowest-resolution features (8–16 cm) were generated with images from the Detailed Survey—Baseball Diamond mission phase, where the spacecraft performed south-to-north passes at 3–5 km range. Higher-resolution features (2–5 cm) were generated with images from both Baseball Diamond and Recon A mission phases, while the highest-resolution features will be generated from images taken during Recon A and Recon B using the factor of 2 extrapolation for the final feature at 0.5 cm.

**Evaluation:** The features were evaluated during generation using both objective and subjective methods. The geometric agreement of the data was evaluated by measuring the residual error between the prediction of all images and the DTM itself. Each feature was evaluated visually by rendering a simulated image matching an actual image, generating multiple stereo images, and generating synthetic images for every image in the region and evaluating how well it matched. (Fig. 1). Finally, we generated the correlation score for each real-image/synthetic-image pair.

The features were delivered to Lockheed Martin for their testing. They tested the DTM with a suite of tools for checking the performance of the features over the expected range of emission, incidence and phase angles that will be encountered during the actual mission profile.

Most of the features performed well beyond requirements and expectations. However, some of the features did not perform well. Four of the features needed additional processing; we worked to improve these features by adding images, removing any artifacts, and running more iterations. Five of the features were rejected and alternatives were selected. Features were rejected for two reasons. First, some features lacked sufficient imagery. For example, a 3-cm GSD was required but there were only two observation stations at 5 cm. Second, SPC struggles with very rugged topography (i.e. high slopes over a short distance). This typically results in boulders that have only 1/2 to 2/3 of their actual height and an overall muted slope. As such, shadows are reduced, so regions that will have a lot of shadows during the descent profile will perform poorly.

**Conclusion:** When presented with finer than expected accuracy requirements, the OSIRIS-REx mission adapted operational and scientific procedures to dramatically improve targeting accuracy. The science team is generating ~100 small “feature” DTMs to be used in targeting. Initial testing indicates that the delivered features meet requirements. The final test occurs in flight, where the spacecraft will fly the TAG descent profile until matchpoint using NFT for all navigation decisions.

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Figure 1. Example NFT feature, P3807, scheduled to be used on the 25th image of the descent. Lat: 57.640; Lon: 318.051. The feature’s dimensions are 125x125 pixels with 3.2 cm GSD. Fifty-five images from the Detailed Survey—Baseball Diamond and Recon A mission phases, which included all five requested observing stations, were used. a) PolyCam image at 2.8 cm pixel scale taken on 2019 April 4 (20190412T203658S749_pol_L1pan_V002.fits). b) Synthetic rendering of the same image using the both topographic and albedo channels of the feature. The mean correlation score between all of the source images and the rendered images is 0.822, well above the 0.6 operational requirement. c) Synthetic rendering of the same image using only the topographic channel. A comparison of (b) and (c) demonstrates that the representation is considerably better when the albedo channel is used. The mean correlation is 0.687, which is much lower than the topography and albedo version, showing that SPC provides a unique capability that increases accuracy of rendered images and operational margin.