

HIGH-RESOLUTION DIGITAL TERRAIN MODELS OF ASTEROID (101955) BENNU THROUGH STEREO-PHOTOGRAMMETRY OF OSIRIS-REX OCAMS IMAGES. M. Chojnacki¹, S. S. Sutton¹, D. N. DellaGiustina¹, K. Becker¹, C. A. Bennett¹, B. Carcich², D. R. Golish¹, B. Rizk¹, and D. S. Laurretta¹, ¹Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA (chojan1@pirl.lpl.arizona.edu), ²KinetX Space Navigation & Flight Dynamics Practice, Simi Valley, CA, USA.

Introduction: NASA's Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx) mission has the objective to analyze and return a sample of asteroid (101955) Bennu [1]. To characterize the surface of asteroid Bennu, we will use stereo-photogrammetry to derive high-resolution topography from geometric stereo images obtained by the PolyCam and MapCam imagers in the OSIRIS-REx Camera Suite (OCAMS) [2]. For this task, we developed photogrammetry pipelines (Fig. 1) using BAE Systems SOCET SET® software along with the United States Geological Survey's (USGS) Integrated Software for Imagers and Spectrometers (ISIS 3).

To date, we have tested various aspects of the pipeline successfully using OCAMS simulated stereo images and Earth gravity assist (EGA) flight data [3]. Current efforts are utilizing flight data of Bennu to test and improve the pipeline in producing useful digital terrain models (DTMs). Here we present details on the photogrammetry process, results, and future efforts generating high-resolution OCAMS DTM products.

Data Sets and Methodology: The OSIRIS-REx Image Processing Working Group (IPWG) at the University of Arizona is tasked to produce high-resolution asteroid DTMs. These following procedures are based on the established methods for other framing cameras, such as the Mercury Dual Imaging System (MDIS) [4] on MESSENGER, and push-broom cameras, such as the High Resolution Imaging Science Experiment (HiRISE) [5] on MRO.

OSIRIS-REx Camera Suite Stereo Images. OCAMS will be essential for collecting a sample from the surface of Bennu, identifying any surface hazards, and acquiring images for high-resolution topography [2]. For flyovers and mapping at a ~200-m altitude, PolyCam has an aperture diameter of 175 mm and a 2.9-arcsec field of view (FOV) that will resolve the surface of the asteroid at scales ≤ 30 cm/pixel. Initial testing and pipeline development was performed with MDIS data [4], simulated OCAMS images (Fig. 2) [6], and PolyCam and MapCam EGA data [3]. The EGA opportunity was particularly helpful for ISIS and SOCET SET® integration.

OSIRIS-REx Laser Altimeter (OLA). OLA is a scanning laser rangefinder (or lidar) that will measure the range between OSIRIS-REx and the Bennu surface, produce global-scale OLA shape maps, and provide critical context for other instruments [7]. Specifically,

OLA tracks allow us to precisely register stereo images to the surface of Bennu in an absolute reference frame.

Stereo Image Selection. We will use the ISIS program *ISISMiner* [9] to select candidate stereo images based on rigorous observational criteria, such as incidence, emission, and phase angles, ground sampling distance, shadow tip distance, and parallax/height ratio [8]. This tool will then generate a ranked list of the best stereo pairs based on a highly configurable set of parameters.

Preprocessing. Because we will obtain many thousands of OCAMS images and need to process them quickly to meet mission objectives, we have batch scripted most of the preprocessing portions of the pipeline. Scripts were developed at the University of Arizona with the support of ISIS developers at the USGS that complete all of these tasks and build the proper files

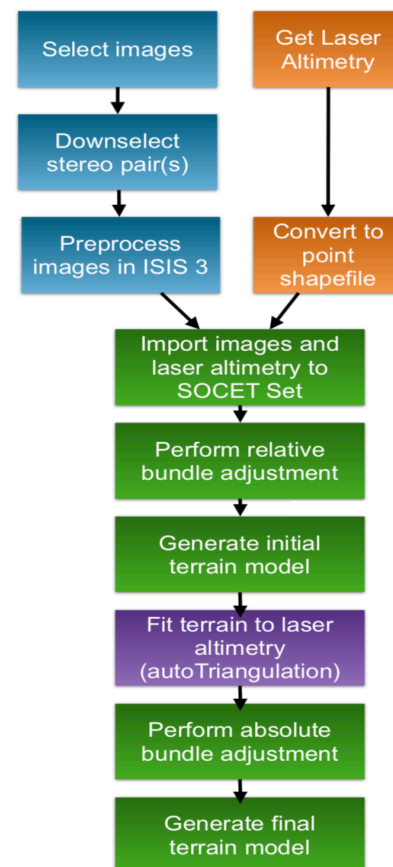


Figure 1. Workflow diagram for OCAMS digital terrain models production using ISIS3 and SOCET SET.

required by SOCET SET® v5.6 software. Specialized information about the OCAMS camera model was incorporated into the ISIS program *socetframesettings*, which translates the camera's focal plane coordinate system into the SOCET SET reference system. As part of workflow development and validation, these translated images were quantitatively compared to the parent ISIS data to insure no significant offsets of pixel coordinates occurred. Additionally, OLA data will be culled to an area of interest and preprocessed for ingestion into SOCET SET as track and point cloud shape files.

Relative Orientation. Following image ingestion into SOCET SET, each image is corrected for relative orientation to the other images in the stereo model. Typically, stereo images are linked by a set of ~6-9 tie-points by manually aligning and using the SOCET SET stereo viewer and a multi-sensor triangulation algorithm [10]. An acceptable root mean square (RMS) error for a stereo pair is <0.3 pixels, but testing has shown simulated image errors to approach ~0.1.

Absolute Orientation. The bundle-adjusted OCAMS images are initially manually controlled to the OLA tracks by registering them to Z-control (elevation) tie-points in the SOCET SET stereo viewer. These control points apply OLA elevation values, which places the stereo images in an absolute reference frame and can be included for bundle adjustments and terrain generation. The average difference, minimum and maximum difference (absolute values), and standard deviation of the error are reported and can be revised if necessary.

Following this initial pass, automated triangulation is performed by autoTriangulation software [11] to update and improve registration. This step fits a preliminary DTM to OLA data through a series of rotations and translations, then reports initial and final model error. Translations are then used to update XYZ-control coordinates within SOCET SET, automatically adjusting the stereo pair to the best-fit solution to the laser altimetry data. In practice with HiRISE DTM production, auto-Triangulation greatly reduces the time needed for the triangulation stage of DTM production and generally results in better registration to laser altimetry [11].

Terrain Extraction. The bundle-adjusted OCAMS images are then used with the Next Generation Automatic Terrain Extraction (NGATE) program in SOCET SET [12] to create a DTM at a ground sample distance (GSD) a factor of 4 greater than the pixel scale of the stereo pair images. For example, images acquired at 5 cm/px result in a DTM of 20 cm GSD. We expect a similar spatial scale will be eventually achieved with flight data of candidate sample sites [6]. If necessary, DTMs can be edited within SOCET SET to correct any terrain artifacts that may occur due to bland or shadowed terrain. Final products will include figure of merit (FOM)

maps that quantify confidence in the generated terrain and identify any potential artifacts (Fig. 2).

Orthophoto Generation. The final DTM is used to orthorectify the original OCAMS stereo images to remove distortions from topography and camera viewing angles. Orthoimages will be generated at both the DTM GSD and the native image pixel scale. Finally, DTM-related products are exported to the ISIS environment for analysis and conversion to Planetary Data System (PDS) format.

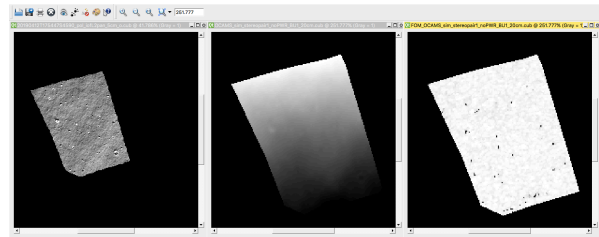


Figure 2. ISIS view of simulated PolyCam (left) orthoimages, (center) topography, and (right) FOM maps.

Ongoing and Future Work: During Bennu proximity operations, the IPWG will create high-resolution OCAMS DTMs and orthoimages that are critical inputs to sample site selection. Orbital A operations in December 2018 included acquisition of geometric stereo pairs that will satisfy at minimum a convergence angle of 10° to 30° (i.e. emission angles differ by >10°) and incidence angles 20° to 70° (incidence angles differ by <10°). These are the first flight data that we can use to validate the procedures developed using simulated and EGA data. The goal of this work is ultimately to produce photogrammetry products for sample site selection that will supplement OLA terrain models [6] and OCAMS stereophotoclinometry-derived DTMs [13]. High-level data products will be released into the PDS in PDS-4 format.

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