EPSC Abstracts
Vol. 13, EPSC-DPS2019-387-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Evaluation of the Bennu Global Digital Terrain Model for OSIRIS-REx

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Abstract

The accuracy of the global digital terrain model (GDTM) of Bennu obtained by the OSIRIS-REx mission to date has achieved global requirements earlier than anticipated. Additionally, a comparison between real images and synthetic images derived from the GDTM using normalized cross correlation show an exceptionally good match.

1. Introduction

The Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) mission is using stereophotoclinometry [1] (SPC) to generate a GDTM and local DTMs (LDTMs) of its target, Bennu. The GDTM is providing both scientific DTM information and landmarks used to calculate navigation solutions [2].

A primary concern for any operational use of a DTM is its quality. Evaluation of DTMs can be difficult because the absolute truth cannot be not known. Therefore, before OSIRIS-REx was launched, we conducted a large suite of evaluations using truth models with varying roughness and navigation errors. From this analysis, we identified which evaluation metrics were effective in measuring SPC's performance in meeting mission requirements.

2. Evaluation Methods

2.1 Geometry-Based Evaluation

The main metric for assessing the quality of a DTM is to calculate the agreement between the DTM and all the data (images, initial spacecraft trajectories, pointing) that went into developing it [1]. A highly accurate model has images, spacecraft position, and pointing perfectly aligned, and produces no errors between the stereo points with each DTM. The presence of errors lead to inconsistencies in measured height.

One benefit of this evaluation technique is that it requires no additional shape models or other data. Many missions do not have a laser altimeter to provide validation of the DTM. However, the value of this technique is limited because it is only an internal measurement of the error and cannot detect systematic errors. The connection to actual shape model quality becomes obscured.

2.2 Topographic Difference Evaluation

The next most common way to evaluate DTMs is to compare them with each other. This metric subtracts the one model from another and calculates the root mean squared differences (RMS) of every vertex. Models created using different techniques can be compared, such as was done for Vesta [4]. For OSIRS-REx, we are comparing the SPC-derived shape model with a lower-resolution but more accurate model derived from direct measurement of the surface of Bennu using a laser altimeter (OLA).

From our pre-launch testing experiments, we saw that the absolute error in the SPC solution was on the order of the pixel size of the highest-resolution images used. For example, if the images had a pixel size of 35 cm, the model would have an RMS of 35 cm. With large stereo angles (more than 45°), the error would be on the order of the dispersion of the image registration, which is typically about one pixel.

Our testing showed one surprising limitation in the RMS method. SPC can generate a model that is significantly better than can be described by the RMS calculations—meaning that the RMS will reach a minimum well before SPC is finished. While the RMS score that SPC achieves is very good, the image data provides sufficient information to make an even higher-quality DTM even though neither the geometry-based technique nor the topographic differences technique indicates improvement.

2.3 Cross Correlation Evaluation

Cross correlation evaluation compares how closely two images (an actual image and a synthetic image generated from the DTM) match one another. This process [5] translates the images into frequency space and runs a fast Fourier transform. This provides a normalized correlation score (max of 1.0 for perfect agreement) that can be used. SPC can use this technique because it calculates surface albedo, which makes generation of accurate synthetic images possible.

The navigation team uses cross correlation to identify the spacecraft's position relative to Bennu. The SPC DTM must be of high enough quality for the automated routines to identify key navigation landmarks with a navigation image. Further, those landmarks must have sufficient accuracy so that the spacecraft's 3D position can be identified [3]. Cross correlation is the key component of the navigation team's alignment process [1] and is also being used separately by the Lockheed Martin's natural feature tracking (NFT) system [6], which is providing the autonomous navigation to the surface for sample collection [7].

Once the DTM's accuracy (RMS height difference described earlier) approaches the images' pixel size, we uses cross correlation to measure both improvement and requirements [6]. The use of cross correlation in SPC supplements other internal SPC metrics and greatly improves our ability to assess the performance of a shape model in flight.

3. Bennu Encounter Results

During the mission, the shape model was improved as more and better data were collected. The model from Approach and Preliminary Survey data had images with a 35 cm pixel size over most of Bennu but 75 cm pixel size over the poles.

The geometry-based evaluation of this model indicated that the data agree with remarkable accuracy. The internal agreement among all the components, the residuals, was 46 cm. Additionally, the navigation team for OSIRIS-REx evaluated how their navigation images performed during Orbital A. Their residuals were approximately 35 cm for most of the asteroid, and higher residuals for the polar regions.

Topographic difference evaluation was performed with OLA laser altimeter data taken during Orbital A. Over the region where OLA data was obtained, the two DTMs had an RMS agreement of 35 cm.

Cross correlation evaluation provides a metric to see how well the images have been incorporated into the shape model. The DTM represents the data to a high degree with an average correlation score of 0.72. For global navigation, a correlation score above 0.5 is typically acceptable. Lockheed Martin's NFT requirement for autonomous navigation is 0.6. We will continue to improve the model with higher-resolution data, with the expectation of having an average correlation score above .80.

4. Summary and Conclusions

The shape model generated by SPC met all of OSIRIS-REx's global DTM requirements [8]. The two traditional metrics indicate that the SPC model met the mission requirements for both the 75-cm shape model and the 35-cm shape model.

Future work for the team is to generate NFT navigation features with an accuracy of 14 cm with a ground sample distance as small as 1/2 cm.

Acknowledgements

This work was supported by NASA contract NNM10AA11C. Our Canadian team was supported by the Canadian Space Agency.

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