Theoretical and Empirical Performance Evaluation of Stereophotoclinometry in Support of OSIRIS-REx.

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Introduction

Stereophotoclinometry (SPC) is a fusion of stereophotogrammetry and photoclinometry, which is used to calculate a digital terrain model (DTM; Gaskell, 2008). This technique leverages the strengths of each technique to mitigate the weaknesses of the other. Stereo provides a fixed position in 3D space for regional DTMs, while photoclinometry provides a pixel-to-pixel slope determination across the regional DTM that leads to estimating the surface height at higher resolution. Additionally, stereophotoclinometry calculates a system of three-equations for every pixel, resulting in the determination of not only x-slope and y-slope, but also relative albedo. By having a model containing albedo and topography, SPC uses that information to render a synthetic image in order to make direct comparisons to the original image.

SPC has been used extensively with numerous spacecraft data to estimate the topography of a wide array of celestial objects including Eros, Dione, Tethys, Mimas, Phoebe, Itokawa, Vesta, 69P/Churyumov-Gerasimenko, the Earth, Mercury, and the Moon. It will be used to develop the shape model for Bennu to be visited by the Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer (OSIRIS-REx) sample return mission and Ryugu, the target asteroid of the Hayabusa 2 mission. In the case of the OSIRIS-REx mission, it will be used in optical navigation. In the case of the Double Asteroid Redirection Test (DART), it will be used to model the shape of the Didymos A and B prior to impact, and determine the location of the impact location on Didymos B. Additionally, it is the shape model tool that will be used for the proposed CAESAR mission to sample 69P/Churyumov-Gerasimenko.

In support of OSIRIS-REx, we have conducted an extensive suite of tests and evaluations using synthetic data to understand the performance (accuracy, precision, residual error) of SPC in supporting operations. The tests consisted of both theoretical analyses to determine the sensitivity of input variables and processing techniques, as well as empirical analyses where the mission was simulated with various changes in operational parameters to verify that mission requirements were met. We summarize the key findings from these tests.

Key Test Findings

1 - Accuracy of the SPC model (defined as the root-mean-squared (RMS) between the mission model and the truth model) is typically the pixel size of the best images available, when suitable imaging conditions are achieved.

2 - RMS is an effective measurement of the quality of a model of most surfaces on the global scale, but is limited when it comes to high resolution DTM. Only two high-resolution images are needed to constrain the location of the center pixel of the MAPLET, which results in the RMS being insensitive to quality of imaging observations, number of images and amount of processing.

3 - Cross correlation between truth images and synthetic images rendered from the mission model provide a clear evaluation of the quality of the model. Optical navigation is based upon this technique, so while RMS provides an exact measurement of accuracy, correlation scores provide a better metric for the quality of a shape model.

4 - The quality of the observing stations is a key factor on the performance of shape model generation, especially when the cross correlation metric is used. SPC is able to use a wide variety of illumination and emission conditions, which allows it to benefit from most every image taken of the surface. SPC is able to extrapolate topographic information to a factor of three, although at a loss of accuracy. Stereo-image pairs are not required, but SPC does require at least three images, and typically, flight-mission imaging result in about 30 and 50 images for each pixel of a regional DTM. We have identified a minimum image suite needed to generate an optimum DTM: images that have low incidence angle to help constrain the albedo, and images with an emission angles from the four cardinal directions to enhance the slope-x and slope-y solutions.

5 - SPC is completely scaleable. Testing has shown that SPC can generate MAPLETs with scales from kilometers to millimeters, all depending on the pixel size of the imagery.

6 - SPC solves for the topography and albedo at every pixel of a MAPLET, and typically the ground sample distances of a MAPLET is set to match the pixel size of the source images. This results in a high-fidelity representation of the small features (i.e. SPC represents features that are only seven pixels in the source images), which is a significantly better performance than stereophotogrammetry. In general, large craters are represented very accurately when 3 or more MAPLETs are used to the make a larger regional DTM (called BIGMAP). Small craters and boulders (smaller than the width of the smallest MAPLET) can be under-represented by about 1/3.