EXAMINING THE IMPACT OF IMAGE GEOMETRIES IN GENERATION OF CONTROLLED GLOBAL MOSAICS OF ASTEROID (101955) BENNU N. Habib, D.R. Golish, C.A. Bennett, D.N. DellaGiustina, D.S. Lauretta. Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, 85721 (nhabib@orex.lpl.arizona.edu)

Background: OSIRIS-REx is a NASA New Frontiers mission led by the University of Arizona with the primary objective of returning a pristine sample of the surface of the carbonaceous asteroid (101955) Bennu. To select a viable sample site, we will first document and map the topography, mineralogy, and chemistry of the surface of Bennu [1].

The focus of this study is to determine the most efficient way of implementing feature based matching (FBM) for generating a controlled global mosaic (a compilation of spatially resolved images with corrected camera pointing and positioning information). Careful investigation of the FBM parameter space determines the relationship between the FBM efficiency, the control point network strength, the percent overlap between images in the mosaic, the bundle adjustment performance, and the photometric angles. Through this research, the Image Processing Working Group (IPWG) will use FBM techniques to produce a controlled global mosaic of Bennu in a timely manner.

Global mosaics are a vital image processing product because they allow scientists to visualize a full map with identified hazards, sampleable material, and geological features on the surface of Bennu. This information will be essential to guiding the sample-site selection decision and inform the Safety, Sampleability, and Science Value top-level maps. Developing software that can robustly automate the mosaicking process will play an important role for the OSIRIS-REx mission.

Feature Based Matching Algorithms: FBM algorithms generate a control network for a mosaic by identifying surface features within sets of images and then creating a series of tie points by finding feature matches between the images. FBM applications contain three fundamental processes; detection, extraction, and matching, which are performed by three individual algorithms, *detector*, *extractor*, and *matcher* respectively. The *detector* computes and finds the interest points in an image and makes local evaluations at each point to determine if there is an image feature. The *extractor* takes the interest point as an input and transforms it into a reduced representation set of features called the features vector. Finally, the *matcher* compares the feature vectors of two or more images and creates tie points between the images where feature points match [2].

To implement FMB and produce a controlled global mosaic, the IPWG will primarily use the Integrated Software for Imagers and Spectrometers version 3 (ISIS3), a specialized software package developed by the United States Geological Survey (USGS). The ISIS3 application *findfeatures* is used to implement FBM in this study (Figure 1). This function creates an ISIS3 control-point network using tools found in the Open-Source Computer Vision Library (OpenCV). Additionally, *findfeatures* will run an outlier detection procedure after the FBM algorithms are implemented, which searches and removes any points that are mismatched based on geographic positioning of the images.

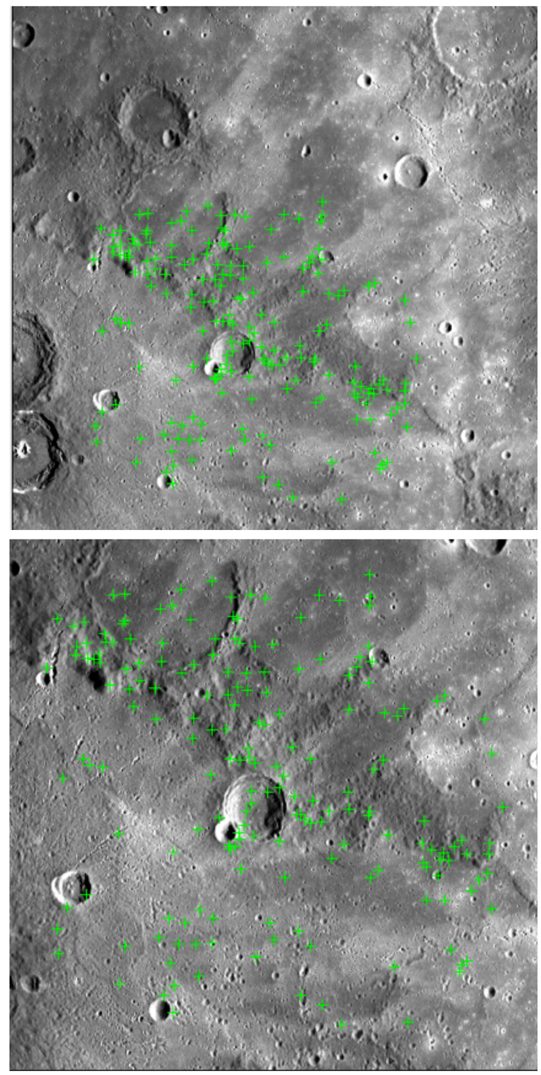

Figure 1 Control point network generated between two images of Kuiper Crater on Mercury using findfeatures

Preliminary Study: We performed the initial study of FBM implementation to generate a controlled mosaic in two steps. First, we researched *findfeatures'* parameter space to produce a general mosaicking pipeline. Second, we evaluated the efficiency and error of the mosaicking pipeline as a function of imaging parameters such as percent overlap between images in the mosaic, control point network strength, bundle adjustment performance, photometric angles, and stereo strength of the images in the set.

Producing the Mosaicking Pipeline: We used a set of five images of Kuiper Crater on Mercury from the MESSENGER data set to develop an image processing pipeline using ISIS3 applications to produce a controlled mosaic. We studied various ISIS3 image processing applications, the application implementation order, and the input parameters to the ISIS3 applications that perform subpixel registration and bundle adjustment based on the output from *findfeatures*. We optimized the final pipeline to reduce the bundle adjustment residual error and the *findfeatures* error. Additionally, the output mosaic was inspected to ensure the pipeline produced a mosaic with minimal or no mismatch between features at image seams.

To produce the controlled mosaic, the input images are first processed using *spiceinit* (which adds SPICE ancillary data such as nominal spacecraft pointing), *footprintinit* (which outlines the image footprint on the surface of the body), and *camstats* (which adds observation statistics to the image headers) to produce a controlled mosaic. We then use the updated images as an input to *findfeatures*, which generates a control point network for the images. This network file is updated using *pointreg*, which adds subpixel registration between images. The resultant network and images are then processed using *jigsaw*, which performs a bundle adjustment routine that refines the camera position and pointing based on the input control point network and updates the image headers and output control point network. These images are then map projected, photometrically corrected, and stitched together using *cam2map*, *photomet*, and *automos*, respectively, to develop the final control point network and image mosaic.

Examining the effect of image processing parameters on a controlled mosaic: To study the relationship between percent overlap of the images and the *findfeatures* and *jigsaw* efficiency, the base image, a single simulated image of Bennu, was used to generate sets of image pairs with a specific amount of overlap between them. To produce the manipulated image sets, the base image was copied and cropped to ensure a known percent overlap between the base image and the manipulated image. Additionally, the UTC in the image header of the manipulated image was offset by one second from the original base image. We then processed the image pair using the mosaicking pipeline to create a controlled mosaic. We repeated this process with manipulated images ranging from 5-95% overlap with the base image.

Preliminary Study Results The preliminary results show that the bundle adjustment residual error reached an acceptable value when there was at least 20% image overlap. Furthermore, at greater than 80% overlap jigsaw failed, and the bundle adjustment routine did not converge. This failure is likely due to the limitation of mosaicking the same image upon itself. By using the same image, there is not enough parallax between the image pair at these large overlaps.

In order to improve the robustness of the study and help reduce the limitations of using identical images to create a mosaic, we created a custom MATLAB graphical user interface (GUI) to produce images in a sequence with a user-defined amount of overlap between consecutive images. The GUI creates SUMFILES inputs for Bob Gaskell's stereophotoclinometry-based (SPC) image simulation program [4]. The GUI allows the user to define some imaging conditions including the starting UTC, the percent overlap between consecutively generated images, and the illumination conditions. This tool allows the IPWG to study the effect of incidence, emission, and phase angle, as well as stereo strength, on generating a controlled mosaic. Figure 2 shows the same image produced with three different incidence angles; this image set illustrates how illumination conditions effect FBM algorithms.

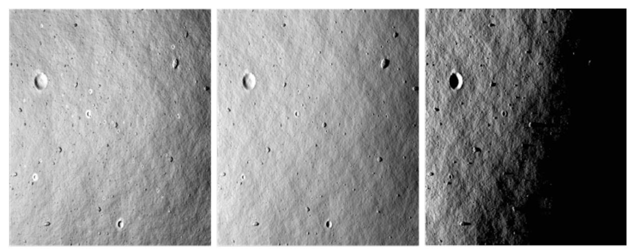

Figure 2 Simulated images show the effect of illumination conditions on the FBM algorithms.

Future Work: We are expanding this preliminary study using images simulated with additional imaging conditions. This effort will allow us to study the effect of photometric angles, stereo strength, and percent overlap on the bundle adjustment performance, *findfeatures* efficiency, and the overall quality of the final controlled mosaic.

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References: [1] Lauretta, D.S., et al. (2017). Space Science Reviews, 212, 925-984. [2] Becker, K. J. (2016) USGS*: ISIS Findfeatures Application Documentation*. Retrieved from URL. [3] Acton, C. (2017). The SPICE Toolkit. Retrieved from URL. [4] R.W. Gaskell et al. (2008) Meteorit. Planet. Sci. 43(6), 1049–1061.