USING IMAGES TO ESTIMATE THE MOTION OF PARTICLES DISTURBED DURING OSIRIS-REx SAMPLE COLLECTION AT BENNU

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Abstract. *On October 20, 2020, the OSIRIS-REx spacecraft autonomously navigated to the surface of the asteroid Bennu to collect a sample. During this event, the spacecraft fired nitrogen gas to mobilize surface material for collection and then fired hydrazine thrusters to back away. This resulted in the mobilization of Bennu surface particles that continued while the spacecraft was backing away. This presentation presents a method to characterize this particle motion using the spacecraft images collected throughout the sample collection and backaway event.*

Introduction. The OSIRIS-REx spacecraft successfully collected a sample from the asteroid Bennu during the fall of 2020 [1]. To do this, the spacecraft autonomously navigated from orbit to the surface [2], performed a Touch and Go (TAG) maneuver to collect the sample, and then backed away. During TAG, the firing of nitrogen gas to aid in sample collection and the spacecraft's hydrazine thrusters to back away mobilized surface material, which can be seen in the images collected by the spacecraft during TAG. The motion of these surface particles is important to understanding whether Bennu's surface responded as expected based on its estimated material properties. This presentation describes how we characterized particle motion using the images and presents our particle velocity results. Additional details on this approach and related science observations are provided in [3].

TAG Event. During TAG, the only part of the spacecraft to contact the surface was the sample collection mechanism. Approximately 1 second after initial contact, the nitrogen gas bottle fired to mobilize surface material that could be collected by the sample collection mechanism. At approximately 6 seconds after contact, the thrusters started firing to initiate the backaway burn. The thrusters remained on for ~26 seconds.

The spacecraft collected data with onboard cameras during TAG to aid in the reconstruction of TAG events. These cameras included SamCam, from the OCAMS camera suite [4], and NavCam 2, from the TAGCAMS camera suite [5]. SamCam has a field of view of 20.8° and images are 1024 x 1024 pixels. NavCam 2 has a field of view of 44° x 32° and images are 2592 x 1944 pixels.

During TAG, SamCam images were collected for approximately 5 minutes for a total of 82 images, starting at 25 meters above the surface and continuing through the backaway maneuver, with the final image collected at an altitude of 13 meters. Figure 1 shows examples of the SamCam images.

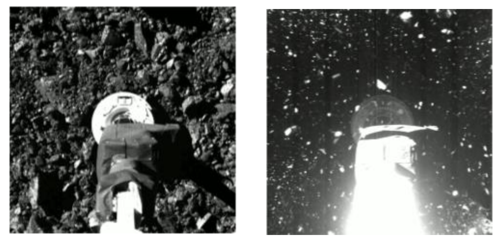

Figure 1. Images collected by SamCam during TAG. Credit: NASA/Goddard/University of Arizona.

NavCam 2 was used by Natural Feature Tracking (NFT) to autonomously navigate the spacecraft to Bennu's surface [5]. After the last image was processed by NFT, the camera frame rate was increased to capture the sample collection and backaway events. This image collection included 133 frames and started at ~45 seconds before contact at an altitude of ~3.7 meters. The last image was collected at ~88 seconds after contact, at an altitude of ~27.2 meters. Figure 2 shows examples of these NavCam 2 images.

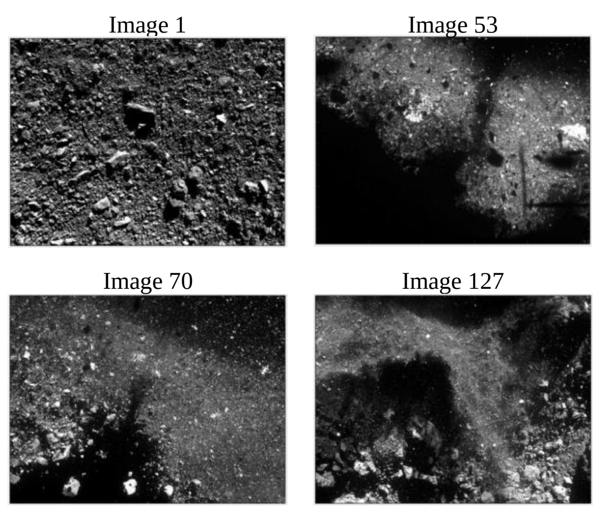

Figure 2. Images collected by NavCam 2 during TAG. Credit: NASA/Goddard/University of Arizona.

Method Overview and Results. To characterize motion of the surface particles disturbed during the TAG event, we used NavCam 2 images together with an estimated spacecraft trajectory. This trajectory was generated primarily by matching TAG images to known surface landmarks [7]. During parts of the trajectory where no landmarks could be identified due to images being obscured by particle motion, trajectory data were defined using spacecraft dynamics model and available IMU data.

Initial efforts to estimate particle velocities focused on tracking particles across multiple NavCam 2 images and solving for their positions and velocities, assuming the available trajectory data represented the true spacecraft trajectory. However, due to small errors in the trajectory, noise in the particle tracks caused by rotating particles, and limited camera perspectives to observe the particles, this method was unsuccessful. Instead, the final approach leveraged reference fiducials in the images to constrain the solution and solved for particle velocities for tracked particles that best fit these constraints.

In the NavCam 2 images, a shadow can be seen moving across terrain in the lower left corner that appears to be cast by particles along the ridge that formed towards the center of the images. While much of the terrain that this shadow moves across was disturbed during TAG, one rock that was visible in pre-TAG images remains undisturbed. This provided a known distance measurement to measure the shadow surface velocity. By simulating particle starting positions and vertical velocities, lateral particle velocities could be solved for using observed particle tracks from the images. The final particle positions and velocities were then determined by finding the particle tracks with projected surface shadow velocities that best matched the measured shadow velocity.

Figure 3 shows the particles that were tracked in NavCam 2 images for this analysis and Figure 4 shows the resulting tracks over sequential frames. While initial efforts focused on tracking particles across the entire scene, the final approach focused on this region due to the shadow constraint. This still provided valuable data to compare with thruster plume analysis as presented in [2].

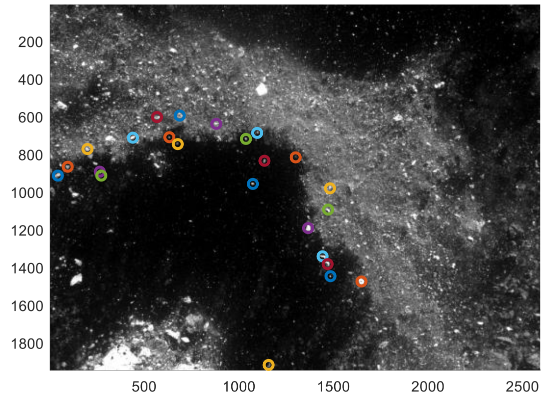

Figure 3. Tracked particles in NavCam 2 image collected during spacecraft backaway maneuver.

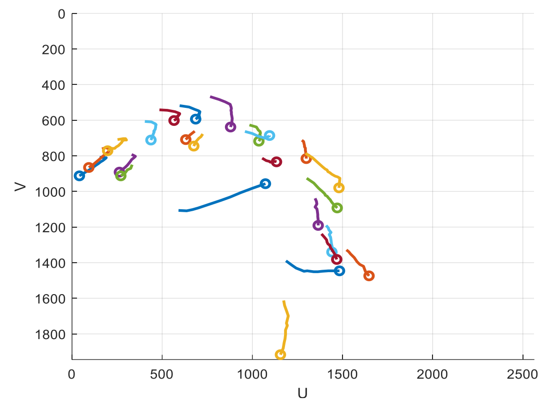

Figure 4. Particle tracks over all images. U and V represent image pixel coordinates. The dimensions shown in this figure correspond to the dimensions of the NavCam 2 image shown in Figure 3.

Figure 5 shows the resulting estimated particle tracks overlaid on the surface digital terrain model (DTM). Note that this figure is aligned with the Asteroid-Centered-Fixed (ACF) frame, centered at the TAG contact location. In this figure, the particle tracks are represented by the navy circles. The corresponding propagated surface shadows are shown by the red squares and are consistent with the shadow motion shown in the NavCam 2 images. Additional details on this approach and final particle velocities will be provided in the presentation.

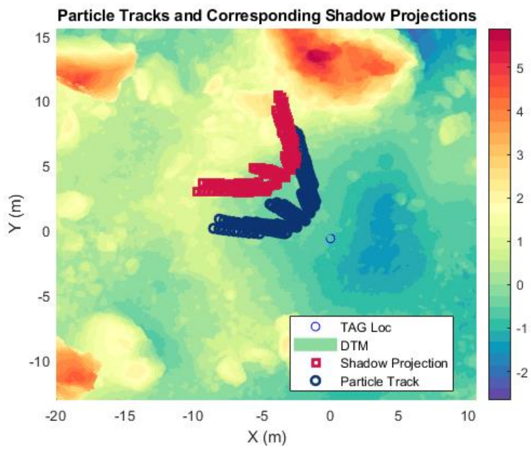

Figure 5. Resulting particle tracks and projected surface shadows.

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