On the Imaging Of Mobilized Regolith During Touchdown Events: A Technique To Study The Shape Distribution Of Millimeter-Centimeter Particles.

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Introduction: The recent space missions to Near-Earth asteroid [1,2] have revealed a rich array of resolved images of regolith particles during their sampling operations. Rather than constraining to the 2D topology of the surface, many mm-to-cm-sized mobilized particles are seen flying off in different trajectories, rotating for several frames, revealing their 3D profile [3].

The regolith particle's shape and irregularity are an important parameter in many models for interpreting light scattering [4], thermal scattering [5], mobility [6,7], and dynamics [8,9] in the context of geophysics of planetary surfaces. The derived shape frequency distribution from imaged particles may also provide a comparative and complementary information to the sample return to Earth [10]. Thus, with this work, we expect to contribute to the understanding of the formation of regolith on Bennu and Ryugu's surfaces.

We have therefore devised a methodology for the detection of translating and rotating irregular bodies, and the estimation of their effective ellipsoid axes, period and rotational axis from a sequence of frames. We investigated the success, uncertainties and issues related to the estimation of these parameters.

Detection: With the aid of Computer Vision tools [11], we extract every bright object from each frame that pictured the field of scattered mobilized particles (Fig.1). By considering the trajectories to be plane projected in straight line for short time scale, we reconnect the particles trajectories at different frames through a simple linear fit. Most importantly, we ensure that each particle profile was detected without losing information due to the faint borders. We set those for analysis that were in at least 3 frames.

Inversion technique: We first define an ellipsoid in free space, translating, in single-axis rotation, illuminated, and observed by a free camera. We then simulate a sequence of frames with a given rotational axis, period, dimension and observational configuration. We had in total 14 free variables.

The inverse technique consist of solving the posterior distribution for every free random variable to resolve the system's possible solutions, i.e., distributions that will reveal unique solutions, multiple solution and/or correlations. For such task, we apply Markov Chain Monte Carlo techniques as well as variational inference [12]. Our target log-likelihood function consist of the residue between simulate frame sequences and the profile of the original particle sequence. In general, chain with >10000 draws are needed for resolving the posterior distribution for every variable.

Looking for simplification, we split the process into two steps: since the ellipsoid axis as well as the period can be estimated directly from the sequences with good accuracy, we fix those variables in the first step. In this manner, we reduce the searching space and focused on the camera, illumination, and rotational state. In second step, we fix these variables and let the MCMC/VA technique solve for the ellipsoid and period only.

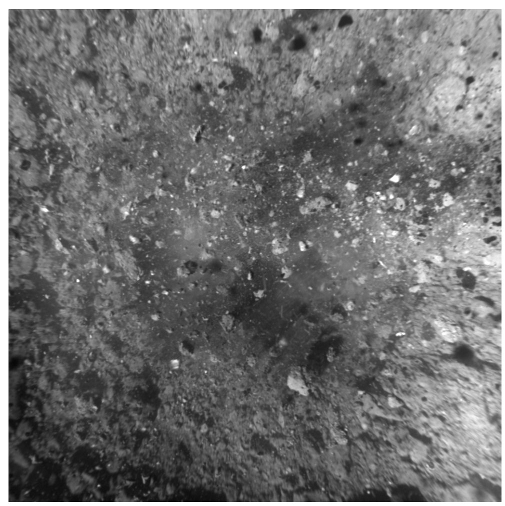

Fig. 1: JAXA/Hayabusa 2 ONC-W1 image at 2019-07-11 UTC 01:06:32, filter. About 12 seconds before the image, the retreating spacecraft temporarily meets the mean plume expanding speed, allowing many regolith particles to be capture in several frames.

Preliminary Results: We run tests for two kinds of virtual bodies: ideal ellipsoids and irregular bodies, with different noise levels and number of frames. While the ellipsoid axes, period, and rotational axis could be estimated with high accuracy, the camera vector and the rotational axis were generally correlated, leading to more than one solution. The lighting direction could be estimated with fair accuracy only if out of any "nuanced" light conditions, i.e., those expect for highly irregular particles or a lighting direction very close to camera direction. Furthermore, spherical particles and very slow rotators will suffer a degeneracy in estimating their period and third ellipsoid axis, respectively. The tests show that we can obtain their effective axes from field images, and even reconstruct their phase curves depending on favorable incidence and observation settings. Finally, we consider scaling the inversion technique to run for many particles as possible and apply it to real frame sequences.

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