Automated mapping of regolith microscopic properties for future Moon & Phobos exploration

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The increasing number of upcoming lunar missions demonstrates a renewed interest in the Moon. Several countries such as India or Japan are developing their own lunar missions, while multiple commercial entities are planning commercial services and industrial projects making use of lunar regolith for in situ resources utilization (e.g., Flahaut et al., 2023). Last year, the United Arab Emirates (UAE) sent their first rover to the Moon onboard the Ispace Hakuto-R lander, which unfortunately failed its soft landing in Atlas Crater. Equipped with a high-resolution microscopic camera CAM-M, the Emirates Lunar Mission (ELM) Rashid-1 rover aimed to better understand the lunar regolith characteristics, especially its grain size, distribution, color, heterogeneities, and geotechnical properties (Els et al., 2021). The Mars Moon Exploration (MMX) Idefix rover, carrying similar CASPEX high resolution pinned-photodiode CMOS image sensors with a 2048x2048 pixel array, available in color with a RGB bayer pattern, will attempt the first landing on Mars’　moon Phobos in the coming years (Michel et al., 2022). In the meantime, the UAE will reach for the Moon again with the Rashid-2 south pole mission (Almaeeni et al., 2023). Such new generation rovers equipped with high resolution imagers will send hundreds of images back to Earth that will need thorough analysis to extract relevant information regarding the surface properties.

The aim of this work is to develop and test a semi-automated analysis method for extracting grain characteristics (size, shape, color, distribution) from in situ microscopic images of the regolith surface. Similarly to the routine developed by Karunatillake et al. (2014) for martian soil granulometric analysis, our Python-based routine requires minimal human guidance to delineate individual grains in regolith images by segmentation. The algorithm starts by determining which parts of the image belong to the foreground and which parts belong to the background (when the operator indicates that such a foreground/background difference is visible on the picture). After some pre-processing steps (gamma correction, erosion, entropy filtering), Otsu (1979)’　s algorithm is applied to the image to proceed to the foreground segmentation by creating a binary image. The segmented foreground is then excluded with a mask before proceeding to the background segmentation. The background analysis process starts with sharpening to enhance edges (which is necessary because for background, due to a much higher number of particles, issues such as imbrication and juxtaposition obscuring grain boundaries are more common than for foreground), prior to a first segmentation with a watershed algorithm. Then, pixel values are multiplied by those of the background pre-segmentation, and the image is segmented a second time, morphologically. This double segmentation approach prevents the watershed algorithm from hyper-segmenting. In the end, the final segmented image is obtained by adding the segmented background to the segmented foreground.

This method was previously estimated to be as accurate, at least 10 times faster and more consistent than manual mapping from sedimentologists, with grain parameters determination being reliable at sizes > approximately 5 pixels (Karunatillake et al., 2010, 2014), with 5 pixels representing 150 microns at the resolution of the Rashid-1 CAM-M instrument. While the algorithm is still under development at the time of writing, validation on test images acquired on lunar simulants by the Rashid rover team, using the Rashid-1 engineering model and varying illumination conditions, will be presented at the conference time.

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