COMBINING PHOTOGRAMMETRY AND IMAGE SUPER-RESOLUTION TO INCREASE LUNAR AND MARTIAN DIGITAL ELEVATION MODELS RESOLUTION USING DESCENT IMAGERY.

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Introduction: Understanding the physical surroundings is a crucial part of ensuring the safety and success of manned and automated exploration missions. Although a great quantity and variety of information can be obtained from orbit, this data can have a resolution that is too coarse to be relied upon once on the ground. Having a detailed view of the landscaped that the operations will take place on is one such information that can often be lacking from orbital data. Digital Elevation Models (DEMs) derived from orbital sensors have a maximum resolution of around 0.5 meters to 2 meters for the Moon and 1 meter to 2 meters for Mars. To alleviate this problem, NASA rovers rely on a combination of orbital imagery and information from the rover itself to safely navigate the Lunar or Martian surface [1]. For some missions from the Chinese Space Agency, a method using descent imagery to create DEMs with resolutions of up to 5 cm for the area directly surrounding the landing site was successfully applied [2]. This resolution is obtained using photogrammetry, which allows to extract 3D information from a series of 2D images with varying observation perspectives.

The density of the point cloud created by photogrammetry is highly dependant on the quality of the input images since more detail can be extracted from higher resolution images [3]. Therefore, using descent imagery with a higher resolution should result in DEMs with a higher resolution as well. Recent advances in machine learning, more specifically super-resolution, allows to train a model to enhance the resolution of images to interpolate missing details more accurately than simple interpolation methods [4].

In this study, we compare photogrammetry and single image super-resolution to create a workflow that would allow for centimeter scale digital elevation models around landing sites of past, present and future missions. Our objectives are to (1) increase the spatial resolution of DEMs that can be generated from descent imagery and (2) increase the coverage of the DEMs that can be generated at a given spatial resolution.

Data and Methods: The general idea of the project is to evaluate the quality and precision of DEMs generated with standard and enhanced descent imagery. The photogrammetry methodology is based on the one presented by Liu et al. (2015) [2], whereas we will explore 2 main super-resolution solutions based on the methodology presented by Bing in 2021 [5]. The difference between the 2 solutions is concerning the scale factor used and how it is used. In the first scenario, a single scale factor of 4x, meaning the resolution of the image is enhanced by a factor of 4, will be applied on every image regardless of the acquisition altitude. In the second scenario, 3 scale factors will be applied on the images depending on the altitude of acquisition. By using higher scale factors for images that were acquired at a higher altitude, we want to reduce the variability of spatial resolutions between images of high and low altitude. The scale factors that will be used are of 8x for images between 2.4 km and 1 km, 4x for images between 1km and 500 m and 2x for images between 500 m and 10 m.

Figure 1. Example of descent imagery from the Mars 2020 mission taken during Perseverance's landing. This image was acquired at an altitude of approximately 1.7 km [7].

In order to achieve this objective, the data we will be using comprises of 5 missions that were equipped with descent cameras being Mars 2020 (Perseverance), Mars Science laboratory (Curiosity) as well as Chang'E 3 (Yutu), 4 (Yutu-2) and 5. Additionally, a validation mission in a sandpit near the University of Sherbrooke was conducted in December 2022 where a drone was flown to simulate the descent of a landing module. Ground lidar data of the same sandpit was also acquired to validate the precision of models generated using photogrammetry and quantify the error more precisely. Using machine learning requires substantial amount of training data for models to be preforming well. Since recent data from descent cameras are limited to the mentioned missions, data used in the training will also be used in the final creation of the point clouds. To limit the bias caused by using the same data for training and testing, the images from the validation campaign and the ones from Chang'E 5 will not be used in training and the conclusions of the study will mostly be based on those results. This leaves images from the Mars 2020, Mars Science Laboratory, Chang'E 3 and Chang'E 4 missions as well as potentially other sources such as HiRISE and LROC images to train the 4 super-resolution models. Before cleaning and selection of the final images, a total of more than 20,000 descent images are available by combining Lunar and Martian data.

Expected results: *(1) Increase the spatial resolution of DEMs*. In accordance with the literature, we expect to achieve DEMs with resolutions varying between 0.05 and 0.5 meters from imagery that has not been augmented. It is expected that areas further away from the landing site will have coarser resolutions caused by diminishing coverage of the images as the landing module gets closer to the surface. Since a handful of studies have tested the combination of super-resolution and photogrammetry, we have a general idea of what can be achieved in terms of point cloud density. In Burdziakowski (2020) for example, the density of the point cloud was increased by 337% by enhancing the input images used to generate it [6]. However, this paper used aerial imagery that was specifically acquired with photogrammetry in mind, meaning that the conditions were more favorable that what we can expect from descent imagery. Using a more conservative 200% increase in the point cloud density, we hope to achieve resolutions varying between 0.025 and 0.25 meters with enhanced images.

(2) Increase in the coverage of the DEMs that can be generated at a given spatial resolution. In Liu et al. [2], the area covered by the highest resolution (0.05 meters) was of around 260 m by 240 m around the landing site which represented only 2% of the total surface covered by their model. We therefore want to evaluate if the use of super-resolution can increase the area in which the maximum resolution is achieved.

In preliminary tests on Mars 2020 data, an increase of 42% in the point cloud density was achieved with an unspecialized Real-ESRGAN 4x super-resolution model [8] and Meshroom's default settings [3]. In these same tests, the area of high point density around the landing site is in fact significantly expanded in addition to the general increase in the total area covered by the model as shown in figure 2. Those results concur with our expectations but much can still be improved in the super-resolution and photogrammetry aspects of the project. With a current upper limit of around 1 point per square meter, the desired 2.5 cm (40 point/m^2) resolution is still far from being achieved in these early results.

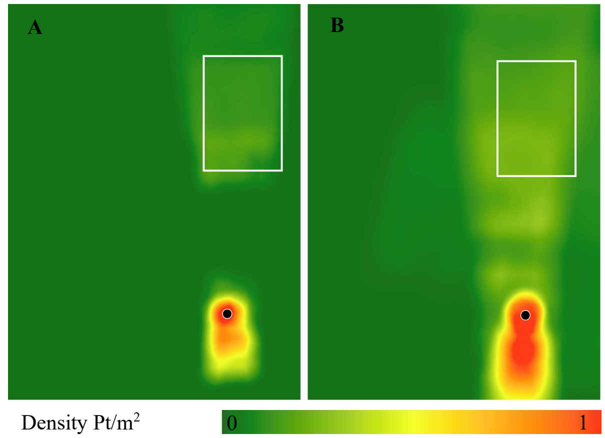

Figure 2. Point Cloud density generated using photogrammetry with the original Mars 2020 descent imagery (A) and enhanced imagery using the Real-ESRGAN model (B) [8]. The black dot indicates Perseverance's landing site. The white rectangles represents the outline of figure 1.

Conclusion: The goal of this research is to develop a methodology that would enable the creation of DEMs with a resolution of 2.5 centimeter in the direct vicinity of the landing sites of various missions. Using super-resolution and photogrammetry on descent imagery, these DEMs would allow for a level of detail unreachable with current orbital imagery and methods. This amount of detail would in term be useful for rover operations as well as for scientific purposes in order to create a more precise context for information acquired by the rover. Moreover, the trained super-resolution models themselves could be used to enhance imagery for other purposes such as identify geophysical features or areas of interest. Early results show that even though many improvements in the photogrammetry pipeline and super-resolution models are necessary, the project has the potential to significantly increase point cloud density.

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