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PHOTOGRAMMETRIC PROCESSING OF MSL IMAGES: A CASE STUDY AT THE MONT MERCOU OUTCROP IN GALE CRATER ON MARS. S. Schmauß^{1,2,*}, S. Le Mouélic¹, N. Mangold¹, G. Caravaca³, B. Seignovert², L. Cavalie¹, ¹Laboratoire de Planétologie et Géosciences, UMR 6112 CNRS, Nantes Université, France; ²Observatoire des Sciences de l'Univers Nantes Atlantique (Osuna), UAR 3281 CNRS, Nantes Université, France; ³Geosciences Environnement Toulouse (GET), Université de Toulouse, CNRS, IRD, CNES, France ; *corresponding author simeon.schmauss@hm.edu

Introduction: The *Curiosity* Mars rover spent more than 70 sols to investigate the Mont Mercou outcrop in Gale crater in 2021 [1], capturing a unique set of image data with wide spatial coverage and high overlap. This allowed us to create a high resolution 3D Digital Outcrop Model (DOM) using 6825 images from the rover's Mastcam and Navcam instruments with a Structure from Motion (SfM) process. This process is often difficult and time intensive, so we developed a new Python-based pre-processing pipeline to make the creation of large DOMs more straightforward.

Rover images preprocessing: One difficulty of working with rover images archived in the PDS is the handling of metadata and the conversion from the VICAR format into common image formats. The goal of our pipeline is the conversion of the PDS images into industry compatible image formats and the inclusion of metadata in standardized EXIF/XMP tags, making the converted images compatible with SfM and other image processing applications. Internally, images are read using The Planetary Data Reader (PDR) [2] and the location of each image is calculated by combining the CAHVOR camera model [3] with the rover localization from the PLACES PDS archive [4]. These metadata are converted to EXIF/XMP tags to describe the intrinsic and extrinsic camera model, allowing each image to be localized within 0.5 meters relative to the mission basemap [4] (Fig. 1). Our pipeline converts images to an intermediary Adobe DNG file, which holds the original PDS image array and additional metadata that describes how the image should be debayered and color processed [5]. Our pipeline can automatically convert these to TIFF files using RawTherapee, while applying zenith scaling and white balancing to homogenize the brightness and colors across the image set. Additionally, our pipeline converts available Navcam mask products to TIFF files, to enable masking of the rover in SfM reconstructions.

SfM workflow: We imported the converted images and masks into Agisoft Metashape [6] where they are automatically grouped into calibration groups and their prior focal lengths are set according to the EXIF/XMP metadata. Camera positions and orientations are automatically read from the XMP metadata and will act as constraints during the reconstruction, ensuring

correct scale and orientation of the DOM. Since all camera coordinates are specified for a planetodetic Mars system, we also changed the reference system in Metashape to Mars 2000 [7], by importing the specific WKT definition. A positional accuracy of 0.5 m and angular accuracy of 3 degrees were set for each image to constrain the reconstruction.

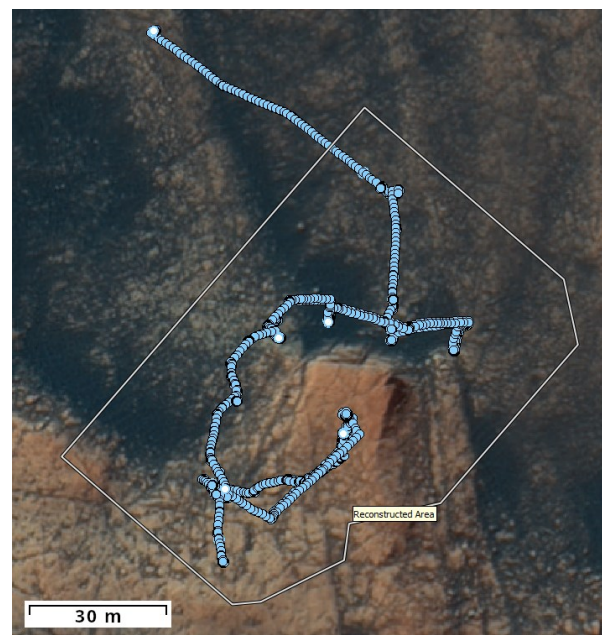


Fig. 1 *Curiosity* Mastcam and Navcam image positions (blue dots) between Sol 3047 and Sol 3117, displayed in Metashape on the HiRISE basemap. The white outline corresponds to the final reconstructed area of the DOM.

Even with the inclusion of positional metadata for each image, the multiscale nature of the rover images makes the reconstruction challenging [8] and sometimes requires placement of manual control points to improve the alignment [9]. We investigated several alignment settings in Metashape and found a method that repeatably produced good alignments with few required manual inputs for our image set. Even though Metashape can utilize the prior camera positions to speed up camera alignment, we found that any kind of preselection in Metashape significantly reduces the alignment quality and the number of matches between Navcam and Mastcam images. Instead, we found that a brute-force matching, with accuracy set to *High*,

increased *Key point limit* of 40,000 and *Tie point limit* of 10,000 led to the most reliable alignments (Fig. 2). This method usually results in the correct alignment of all Navcam images and most (~80%) of all Mastcam left and right images. Additionally, some groups of Mastcam images may be aligned incorrectly, which had to be filtered out manually.

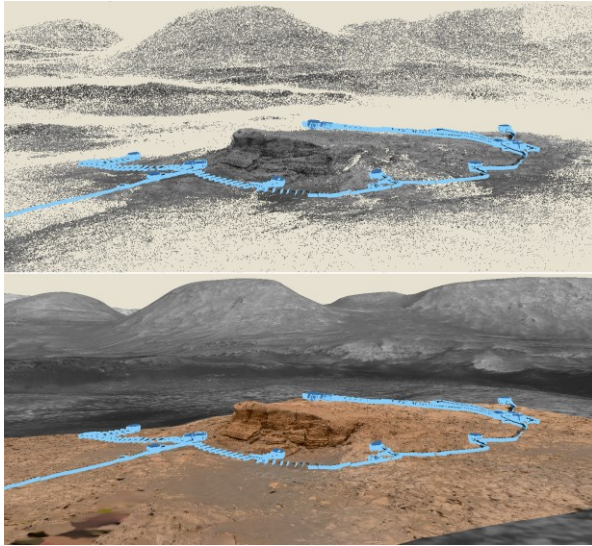


Fig. 2 Final, cleaned alignment tie points (top) and DOM reconstruction with 3D map view (bottom) in Metashape. Blue markers indicate the Navcam and Mastcam images.

Meshing and texturing: Once a good alignment was achieved, we reconstructed the model directly from depth maps using the *High* quality setting. The upper front edge of the Mont Mercou rockface could not be reconstructed accurately, since it was only seen edge on in images. Therefore, the bad geometry was removed and the resulting narrow gap was filled manually. Afterwards the model was textured as a tiled model using only the color Mastcam images with a texture resolution of locally 2.5 mm/pixel (Fig. 2 & 3). A lower resolution version of the Model has been uploaded to Sktechfab (<https://skfb.ly/psYyq>)

Scaling and accuracy control: In order to use this model for geologic interpretation, accurate scaling and orientation of the model is of high importance. We validated the accuracy by comparing the model against the HiRISE orthomosaic and DEM. Several sets of measurements ranging from 23 m to 56 m length between key features, present on the DOM and recognizable on the HiRISE orthomosaic, have been made. The resulting average error is 1%. By comparing the photogrammetric pointcloud to the DEM using the iterative closest point (ICP) algorithm we determined an orientation error of 0.3 degrees.

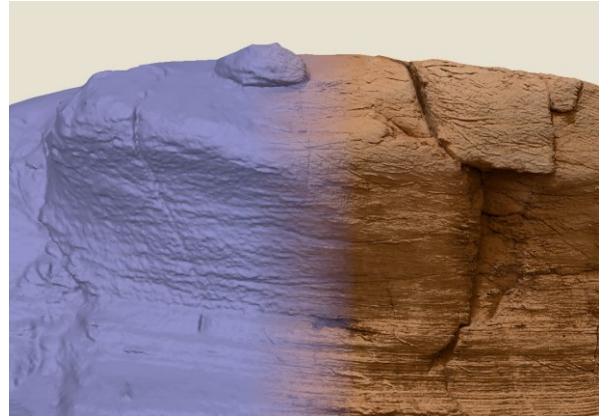


Fig. 3 Detail view of the final reconstructed Mesh (left) and textured Mesh (right) using the color Mastcam images.

Future work: Besides aiding geologic interpretation, large DOMs of Mars can also be an interesting medium for education and public outreach. For the latter, a seamless and immersive visualization is important, for example an integration of our model into a VR experience of Gale crater. An early version of this has already been developed in Blender (Fig. 4).



Fig. 4 Integration of the Mont Mercou DOM into a full-scale model of Gale Crater, created using orbital imagery. A model of the *Curiosity* rover is shown for scale.

Data Availability: Data for this work are available from NASA's Planetary Data System (PDS) (<https://pds-imaging.jpl.nasa.gov/volumes/msl.html>)

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