

# 3D Surface Models from Opportunity MER NavCam

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## Abstract

We present an automatic method for 3D surface modeling from planetary data and show the reconstruction of Endurance Crater computed from 58 images acquired by the Opportunity Mars Exploration Rover NavCam on sols 131, 132, 133, and 315.

## 1. Introduction

3D surface models provide a much better scene visualization than single images as having the model makes it possible to view the scene from an arbitrary viewpoint. Planetary data differ from the data of both urban and non-urban Earth scenes significantly and therefore bring new challenges to automatic 3D surface modeling from images, a rapidly developing area in the computer vision community. Furthermore, planetary image sets are usually much sparser and have lower resolution than usual Earth image sets due to the capacity limitations of the transmission channels.

## 2. The Pipeline

We demonstrate the performance of our 3D surface modeling method on 58 images acquired by the Opportunity Mars Exploration Rover NavCam provided by NASA [8] in IMG file format. The data consist of 12-bit monochromatic image data and of associated metadata containing internal camera calibrations and local external camera calibrations w.r.t. to the rover frame in CAHVOR format [1].

### 2.1. Image Data Pre-processing

Automatic feature point extraction, a part of the global external camera calibration step, heavily depends on the quality of input data. Therefore we (i) care to preserve the maximum possible dynamic range of the image by discarding 5% of the brightest pixels (Sun and/or overexposed areas) and 100 darkest pixels (possibly dead pixels) before quantizing the 12-bit input image data into 8-bit values required by our method and (ii) mask the areas containing parts of the rover to

prevent incorrect feature point matching between different rover sites. By using local external camera calibrations from image metadata and known rover dimensions, we are able to identify parts of the images which capture the rover itself. Feature detection in these areas is then restrained by applying a strong Gaussian blur.

### 2.2. Camera Calibration

First, internal camera calibrations are obtained by computing calibration matrices [3] from respective CAHVOR image metadata [1]. Secondly, the pre-processed images are converted to JPEG file format and EXIFs with focal length information extracted from the calibration matrices are attached. Such images can be input into Bundler [9], a publicly available Structure from Motion software which computes global external camera calibrations. Bundler performs SIFT [7] image feature detection and description followed by exhaustive pairwise feature matching and geometrical verification of the matches [2]. Global external camera calibrations are attained by sparse 3D model growing from the most promising image pair. To obtain even more accurate global external camera calibrations, we use the image feature tracks output from Bundler and perform an additional non-linear optimization step with exact internal camera calibrations using SBA [6].

### 2.3. 3D Surface Modeling

Our Multi-View Stereo (MVS) modeling, which employs global external camera calibrations obtained in the previous step, is similar to the technique proposed in [10]. First, we compute feasible camera pairs based on epipolar geometries as in [4]. Secondly, we detect and match SIFT features [7] in the feasible camera pairs using [11]. We triangulate matches and create seeds, i.e. 3D points with associated sets of cameras they were triangulated from. Next, we compute the minimal and the maximal depth based on the related seeds for each camera and use them to restrain plane-sweeping, similar to the state-of-the art [12],

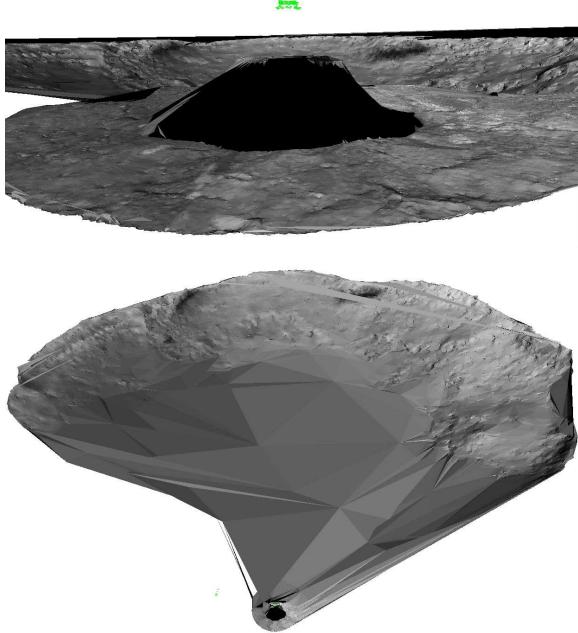


Figure 1: 3D surface model of Endurance Crater (images acquired by Opportunity MER NavCam on sols 131, 132, 133, and 315). Detailed (*Top*) and bird’s eye (*Bottom*) views of the reconstructed triangular mesh colored according to the input images. Camera poses extracted from global camera calibrations are denoted by green cones.

performed at several scales. The point cloud generated by plane-sweeping is used as the input to our implementation of the method proposed in [5]. Unlike [10], we do not perform mesh refinement but we do mesh smoothing as proposed in [5]. Finally, the resulting 3D surface triangular mesh is colored according to the pixel values in the pre-processed input images, see Figure 1.

### 3. Conclusions

We introduced a pipeline for automatic 3D surface modeling and presented a model reconstructed from 58 images acquired by Opportunity Mars Exploration Rover NavCam. As there are thousands of Opportunity MER NavCam images available, we hope to obtain even larger 3D surface models after modifying the pipeline in order to better fit the specifics of planetary data. The overall computation time on a standard Core2Quad PC with a CUDA-enabled GPU was around 3 hours while most of the time was spent in MVS modeling.

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