A PHOTOMETRIC APPROACH TO THE CONSTRUCTION OF LUNAR DIGITAL ELEVATION MAPS USING CHANDRAYAAN-1 M3 IMAGERY IN COMBINATION WITH LASER ALTIMETRY DATA.

A. Grumpe1 and C. Wöhler1,2. 1Image Analysis Group, Dortmund University of Technology, D-44221 Dortmund, Germany; {arne.grumpe | christian.woehler}@tu-dortmund.de; 2Geologic Lunar Research (GLR) group

**Introduction:** Many attempts have been made to construct digital elevation maps (DEMs) of the lunar surface. The most recent laser altimetry DEMs were provided by the Lunar Orbiter Laser Altimeter (LOLA). On small spatial scales, i.e. at a lateral resolution of a few hundred meters, however, the LOLA DEM does not always provide a reliable representation of surface details. Recently developed algorithms like automatic crater detection [1], however, require detailed DEMs with rich structural information of the surface. Recent works to compute high-resolution DEMs include stereo and multi-image photogrammetry [2] as well as multi-image shape from shading (SfS) requiring several images acquired under different illumination conditions [3]. A photometric stereo method for constructing a DEM of the lunar polar regions using multiple Smart-l images is proposed in [4]. Unfortunately, in many cases only a single image or multiple images with similar illumination geometries of the region of interest are available. As the basis of our approach, we therefore use the SfS scheme as proposed by Horn [5] to recover heights and gradients from single images. Most existing SfS methods (e.g. [3]) rely on the assumption of a uniform surface albedo throughout the image. This limits the field of application to small regions without significant variations in surface composition. The M3 image of our example region, comprising a part of the floor of the crater Alphonsus, is shown in Fig. 1a. Dark pyroclastic deposits around several small craters indicate a strongly non-uniform surface albedo, requiring a 3D reconstruction framework involving a non-uniform surface albedo since the assumption of a uniform albedo made by most related approaches is obviously not valid here.

**The 3D reconstruction scheme:** For the purpose of reconstructing the lunar surface we used a modified version of the SfS scheme proposed by Horn [5]. Instead of assuming a smooth surface [4], our approach enforces integrability of the surface gradient field. To maintain accuracy on large scales we added an error term to the optimization problem which describes the deviation of the resulting DEM from the initial DEM at a lower lateral resolution than the original image.

An initialization of our algorithm is computed from a low-pass filtered version of the laser altimetry DEM accompanying the M3 multispectral data set of ~140 m/pixel resolution released through the Planetary Data System (PDS) [6]. A weighted sum of the spectral channels provides the required radiance information. To avoid thermal radiation, the channels with center wavelengths above 2 µm are neglected. The M3 data are mapped to a cylindrical grid and resampled at a resolution of 300 pixels per degree. The surface reflectance is modeled using the Lunar-Lambert model with the phase parameter determined by McEwen [7]. To incorporate a non-uniform albedo into the 3D reconstruction algorithm, the solar irradiance and the physical surface albedo are combined into an effective albedo factor which is calculated for each pixel and blurred using a Gaussian filter. The initial kernel width is large, resulting in an almost uniform albedo with small variations. In an iterative manner, the DEM is reconstructed and a new effective albedo is computed using the resulting surface information. In each iteration the kernel width is reduced and the non-uniform albedo is recovered on decreasing spatial scales.

**Results:** As shown by the reconstructed image (Fig. 1b) and the resulting albedo map (Fig. 1c), the algorithm succeeds in constructing a DEM that retains most of the surface structure and yields an image very similar to the original one if applied to the Lunar-Lambert model. It separates the dark pyroclastic deposits from the surrounding surface and determines a strongly non-uniform effective albedo at the corresponding locations on the surface.

A comparison between the initial DEM (Fig. 1d) and our refined DEM (Fig. 1e) exhibits the lack of detail in the initial DEM. The elevation is measured as deviation from the mean lunar radius. Most of the small craters do not appear in the initial DEM, and there is barely an evidence of the long fracture. Our refined DEM clearly shows these structural features.

The most accurate global lunar DEM currently available is the newly released LOLA DEM with a resolution of up to 512 pixels per degree. To stress the structural features of the DEM, it is shaded using the illumination and viewing geometry of the corresponding M3 image in combination with the Lunar-Lambert model with uniform albedo (Fig. 1f). When compared to our refined DEM shaded in the same manner (Fig. 1g), it is obvious that the LOLA DEM does not display the same richness of structural features.

Since our algorithm minimizes the deviation of the refined DEM from the initial DEM on large spatial scales, and because the LOLA DEM does not reliably represent small-scale surface structures, the absolute accuracy of the refined DEM cannot be determined by comparison with existing DEMs. In our DEM, the
The depth of small bowl-shaped craters is in good correspondence with the expected value of about 1/5 of the diameter. Photogrammetrically constructed DEMs of very high lateral resolution [2], which are not available yet for large regions of the lunar surface, will allow a more detailed analysis of the absolute accuracy of our algorithm on both large and small spatial scales.

**Conclusion:** The proposed photometric method for constructing lunar DEMs is able to capture surface details on spatial scales comparable to the pixel resolution as well as to estimate the non-uniform surface albedo. In comparison to existing laser altimetry DEMs, the proposed algorithm preserves significantly more details of the surface structure. We are continuously processing further M³ data of other regions of the Moon. The results of ongoing data processing activities will be published at [www.bv.e-technik.tu-dortmund.de/Contents/FO_Planetary_DEM.html](http://www.bv.e-technik.tu-dortmund.de/Contents/FO_Planetary_DEM.html).

**References:**