HIGH RESOLUTION DIGITAL TERRAIN MODELS OF THE MARTIAN SURFACE: COMPENSATION OF THE ATMOSPHERE ON CTX IMAGERY. K. S. Wohlfarth[1,2], W. C. Liu[2], B. Wu[2], A. Grumpe[1], C. Wöhler[1], [1]Image Analysis Group, TU Dortmund University, 44227 Dortmund, Germany {kay.wohlfarth, arne.grumpe,christian.woehler}@tu-dortmund.de, [2]Department of Land Surveying and Geo Informatics, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong bo.wu@polyu.edu.hk, mo.liu@connect.polyu.hk

Introduction: The construction of accurate Digital Terrain Models (DTMs) of the Mars is important for a variety of tasks such as geomorphological analysis, spectral unmixing procedures, orthoimage rendering and landing site selection. Shape from shading on the Martian surface is especially challenging due to the existence of a thin atmosphere, which attenuates and offsets the measured TOA (Top of Atmosphere) radiance. Past works have solved this by applying an atmospheric model which compensates for the atmospheric effects. Nevertheless, these models require additional effort by processing external measurements and their performance depends on the availability of this data in general. We combine shape from shading and photogrammetry for in-situ model retrieval, resulting in two contributions: On the one hand, we are able to generate quick estimates of joint atmospheric and reflectance behaviour to overcome explicit atmospheric modelling and external data acquisition. This enables us to generate accurate DTMs based on Shape from Shading. Secondly, this scheme is applied to adaptive atmospheric compensation which is even able to provide good results in the presence of dust storms.

Related Work: Shape from shading [1], also known as 2D-photoclinometry [2], uses reflectance images to derive a high-resolution DTM. In order to enhance the quality of DTMs, previous approaches have successfully combined low resolution DTMs and Shape from Shading (SfS) on either the lunar [3-5] or the Martian surface [6-8]. These techniques leverage the advantages of photogrammetry and laser altimetry on the one hand and shape from shading on the other hand. Stereo vison and laser altimetry do not need a physical reflectance model but their lateral accuracy is mostly limited and artifacts occur frequently due to mismatching. Shape from Shading requires a reflectance model and a proper initialization, i.e., an initial DTM. This additional effort is justified by obtaining a DTM of pixel level resolution with a very accurate reconstruction of textureless areas. In [9] SfS of the Martian surface is performed without initialization.

Initially, the atmospheric distortions were ignored and no atmospheric correction was applied [6-7,9]. Jiang et al. (2017) [8] are the first to propose a scheme for shape from shading on Context Camera (CTX) images (approx. 6 m per pixel) to refine a DTM obtained from photogrammetry. They adopt the approach of [10] to build a throughout physical reflectance and atmospheric model b ased on additional Compact Reconnaissance Imaging Spectrometer (CRISM) measurements to estimate the model parameters. Despite the overall viability, several issues of the method can be identified: The main shortcoming is the requirement for external data for parameter estimation. As the analysis of the atmospheric conditions of the landing sites of Viking 1 and Viking 2 suggest, there are significant changes during the day and over the year [11]. Thus, the CRISM measurement and the CTX image should be taken at the same time or at least it should be ensured, that both measurements are taken under similar conditions for performing a meaningful atmospheric compensation. In most scenarios, these data are not always available.

Method: In order to overcome the aforementioned issues, we propose a simple and swift approach for in-situ retrieval of atmospheric compensation and the reflectance model. A photogrammetric reconstruction of the surface [12] serves as initial estimate and is used to retrieve the relation between slopes and image intensities of the CTX image, i.e., radiance measurements via regression. This is possible since the combination of reflectance and atmospheric models behave in a way which can be easily modeled by low order polynomials. The obtained relationship is subsequently applied to the full resolution CTX image, generating a dense slope map. An iterative integration scheme refines the initial DTM according to the slope estimates.

Results: The procedure is applied to several regions of the martian surface. In Figure 1, the renditions of the initial stereo DTM (left) and our refined DTM (middle) are shown next to the CTX image (right). The resolution of our refined DTM is increased to CTX pixel level resolution, craters are well apparent and the fibrous structures of the crater rim slippage are well retrieved. Note that the reconstruction along the illumination direction is more accurate than in the perpendicular direction, as the crater rims are sharper in the direction of illumination.

For the purpose of comparison, we eliminate any source of external errors which might arise from coregistration and image transformation. Therefore, we do not use a CTX stereo image as an initial DTM but smooth the HiRISE reference DTM with a broad

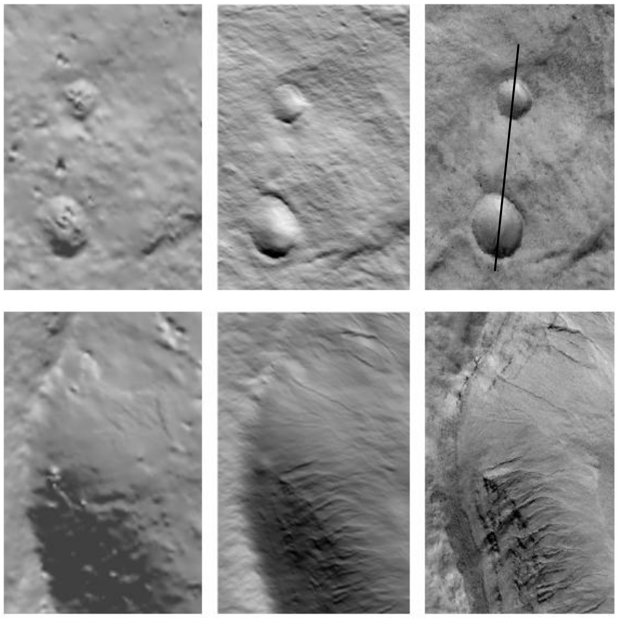

Figure 1. L: Shading CTX Stereo DTM. M: Shading of our refined DTM. R: Original CTX Image D10_031288_1410_XN_39S200W (6.26 m/pixel)

Gaussian kernel (σ=20 pixels). The profiles along the line shown in Figure 1 are plotted in Figure 2.

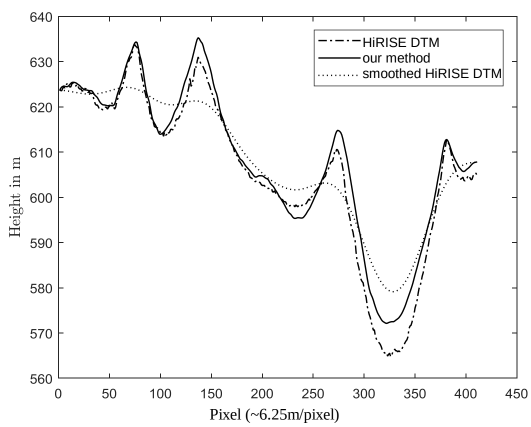

Figure 2. Comparison of height profiles.

Starting from the smoothed DTM, it can be observed that our algorithm yields a result which approaches the profile of the HiRISE reference DTM. The RMSE between the smoothed and the original HiRISE profile decreases from 6.22 m to an RMSE of 3.89 m between our result and the original HiRISE profile. Moreover, a significant improvement of slopes can be observed. The SfS procedure has a RMSE slope error between the smoothed and the original HiRISE DTM slopes of 8.66 cm/m and almost halves to 5.33 cm/m measured between the HiRISE-DTM slopes and our result.

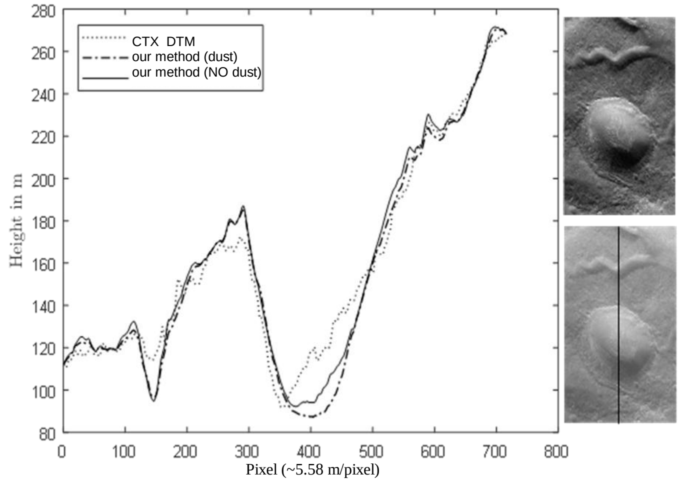

Figure 3. Left: Comparison of profiles. Right: Region from image B02_010226_1406_XI_39S103W (no dust) and B02_010292_1406_XI_39S103W (dust)

In Figure 3, the same crater can be seen at two states, i.e., normal (right top) and through a dusty atmosphere (right bottom). In general, dust leads to lower contrast and brighter images. Our algorithm is applied to the region using both images. The resulting heights along the centre profiles are depicted on the left of Figure 3. The RMSE between the reconstruction based on the dusty image vs. the non-dusty image is 4 m. Compared to the initial CTX Stereo DTM, we can see that both reconstructions are very close to each other. This supports the viability of our approach to compensate for the atmosphere even under difficult atmospheric conditions.

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