OVERCOMING TROUBLESOME STEREO ARTIFACTS: TOWARDS THE PERFECT DIGITAL TERRAIN MODEL OF MARS.

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Introduction: Digital Terrain Models (DTMs) are a versatile tool in the field of planetology. Geomorphology, spectral analysis, orthoimage rendering and landing site selection, among others, all benefit from accurate DTMs. Commonly used stereo algorithms such as the Ames Stereo Pipeline [1] and SOCET SET® [2], which rely on block-matching, suffer from a variety of artifacts which effectively reduce the resolution and the quality of the derived DTM. Stereo algorithms are prone to produce artifacts in textureless areas, due to mismatching pixels and generate stair-like structures termed pixel locking [3]. Shape from Shading (SfS, sometimes also termed 2D-photoclinometry) is, especially as a complementary method, suited to correct these artifacts and to substantially enhance the DTM quality. On Mars, special attention has to be given to proper physical modeling and the compensation of atmospheric influences on the measured Top of Atmosphere (TOA) radiance. Existing models [4] require additional measurements, which are not always available in the same region at the same time. Here we expand our previous approach [5] that combines stereo DTM generation with subsequent SfS refinement. For the SfS, we propose a new method which integrates Hapke based physical reflectance modeling and in-situ atmospheric parameter estimation with an established Shape and Albedo from Shading approach [6]. This is applied to HiRISE imagery and yields an effective DTM resolution of up to 0.25 m/pixel.

Related Work: Shape from Shading [7,8] uses reflectance images to derive pixel level resolution DTMs. Previous approaches have shown that including a low resolution reference surface as a constraint improves the stability of the algorithm. This was successfully applied to the Moon [6,9-10] and Mars [4,11-12]. Image-based photogrammetric stereo methods as well as laser altimetry yield accurate absolute heights, while Shape from Shading on the other hand can produce accurate slopes and can even reconstruct small features of the surface.

The first approaches to combine these methods for the Martian surface [11-13] did not include atmospheric compensation in the reflectance model. There are several approaches that describe the modeling of the atmospheric distortions [14,15]. Based on [14], Jiang et al. (2017) [4] have introduced a new method based on Shape from Shading that refines CTX photogrammetric DTMs to pixel level resolution of about 6m/pixel. The algorithm from [14] is used for reflectance modeling, which uses the multi angle CRISM measurements to estimate the surface and atmospheric parameters.

Method: Our approach falls into three steps: (1) Generation of an initial stereo DTM with the Ames Stereo Pipeline [1], (2) estimation of atmospheric parameters and (3) application of our Shape and Albedo from Shading method. To estimate atmospheric conditions, single scattering albedo and shape of the surface based only on the image and an initial DTM, we employ a procedure based on Hapke's modified isotropic scattering approximation (MIMSA) model [16]. The diffuse illumination of the surface from the atmosphere is modeled with the hemispherical directional reflectance derived from the MIMSA model. The attenuation of the incoming and outgoing light is modelled with Lambert-Beer law. Path scattered radiance is treated as a constant background illumination. Based on the initial stereo DTM the atmospheric parameters for the diffuse illumination, path scattered radiance and optical depth are estimated using a nonlinear optimization scheme. The single scattering albedo is then updated each step of the Shape and Albedo from Shading scheme. The SfS is implemented similar to [6]. Our previous method [5] was validated on CTX-derived DTMs of Mars and even works in the presence of severe atmospheric disturbances. The method in [6] was thoroughly validated on the lunar surface. For HiRISE derived DTMs there is no direct way of validation, because its resolution surpasses the other instruments, but we expect that the method scales well to these high resolution images.

Results: The new approach is applied to the HiRISE image pair ESP_036780_1985_RED and ESP_042622_1985_RED from the Oxia Planum region selected as the landing site for the ESA ExoMars rover [17]. Figure 1a shows the initial DTM created with the Ames Stereo Pipeline at full resolution. It can be seen that the hilltop shows significant missing values which indicate a larger area of failed stereo matching, as well as smaller mismatches present as spikes scattered over the whole region. The hillsides on the east and

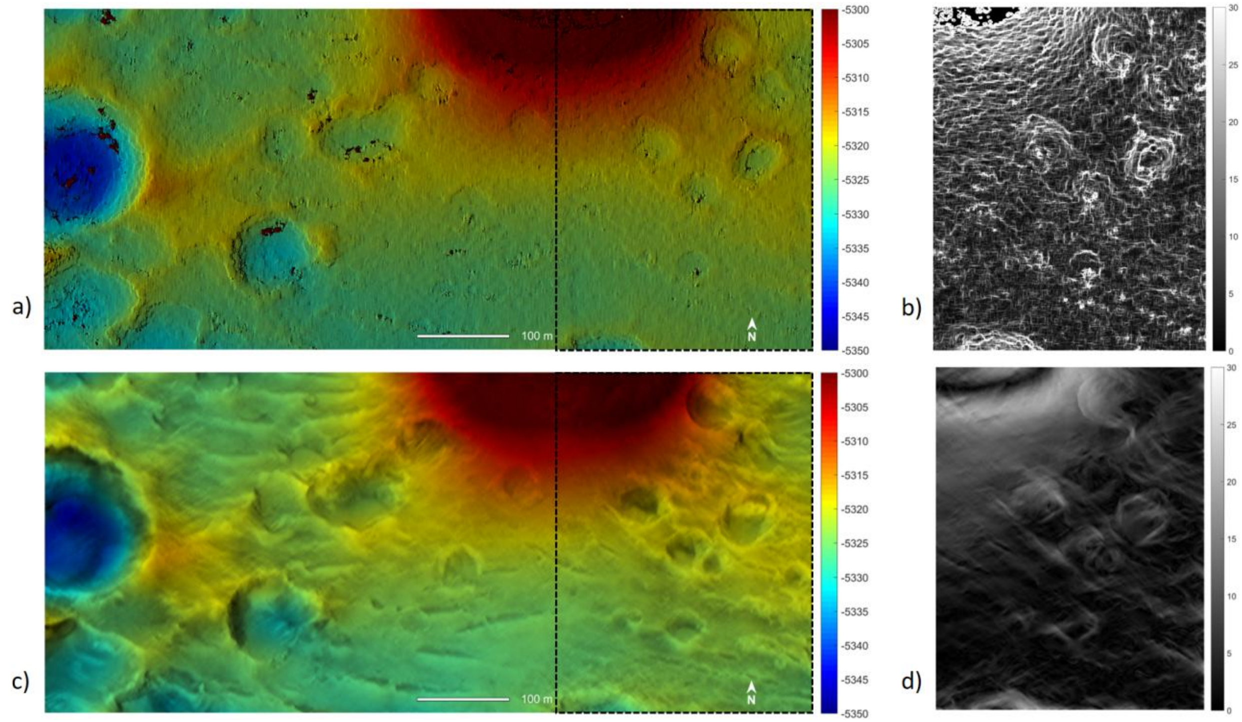

Figure 1 Comparison of HiRISE stereo derived DTM created with the Ames Pipeline (a) and refined DTM with the Shape from Shading approach (c). The left images (a,c) show color coded DTMs of the region of interest overlain with a shading of the surface. The right images (b,d) show the slope map of the eastmost part of the image in degree.

the larger craters in the west show unrealistic stair-like structures that are prevalent in stereo matching. This is reflected by the occurrence of high frequency undulations with exaggerated slope estimates in Figure 1b. The refined DTM is shown in Figure 1c. The artifacts in the west vanish and the Shape from Shading algorithm also reconstructs smaller details, such as the craters in the east and the eolian forms in the north west. The DTM becomes smoother and the slopes decrease, which is more realistic and corresponds to the details visible in the original images. All in all, our approach generates a convincing expansion of simple stereo processing with throughout physical modeling.

Conclusion: We have constructed a high-resolution DTM of a selected region within a landing site on Mars based on HiRISE data by applying a combined stereo and Shape and Albedo from Shading approach. Our method takes into account atmospheric effects, where the corresponding model parameters are estimated from the image data. The small-scale details in the refined DTM are found to be much more realistic than the abundant small spikes and stair-like artifacts appearing in the stereo DTM.

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