ASSESSMENT OF MICRO-RELIEF DERIVED FROM CURIOSITY'S MAHLI STEREO IMAGING.

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Introduction: The Mars Science Laboratory (MSL) [1,2] science payload includes the Mars Hand Lens Imager (**MAHLI**), which has been operated in a variety of configurations since early in the mission to provide stereo-overlap imaging. MAHLI observations have been used to support mission science goals associated with rock texture and other geologic properties as assessed in 2D images and stereo anaglyphs [2]. Here we focus on quantitative 3D stereo data products, in particular derived micro-relief **Q**uantitative **R**elief **M**odel (***QRM***) results that permit analysis of millimeter-scale texture. QRM's derived from MAHLI stereo images have been analyzed since early in the mission (**Fig. 1**). In this report we showcase a preliminary MAHLI stereo experiment designed to assess the quality of a derived QRM and the "noise floor" of the system by examining a pair of Sol 808 images of the REMS UV Sensor [3] box on the rover upper deck.

Background: 3D modeling of rock and outcrop surfaces is commonly applied in paleontology and archeology for non-destructive sample analysis and artifact documentation; 3D reconstruction of bedding features, stratigraphic and facies relations over distance; fracture analysis; and as part of the documentation of sample extraction sites for reproducible science as referenced to geographic and stratigraphic position. Micro-relief models also inform regarding rock weathering and potential as cryptoendolithic habitat or paleo-habitat. For Mars surface science, not only can quantitative surface relief models (QRMs) be applied for similar purposes (e.g., documentation of sample extraction sites, stratigraphic and facies relations within and between outcrops, on-Earth laboratory analysis of the 3D shape of an object), application to habitability assessment in terms of sub-millimeter-scale rock surface texture (i.e., present environment) and preservation potential for fossilized microbial communities (i.e., past environments).

MAHLI Stereo Imaging: The focusable color MAHLI camera can acquire sub-mm spatial resolution images of martian geologic materials from its location on the turret on the *Curiosity* rover arm. We have examined an initial MAHLI stereo pair acquired on Sol 88 (**Fig. 1**) that features a discrete clast approximately 5 cm in diameter. This example reflects the potential for measuring textures at ~0.1mm vertical scales for geologic materials of scientific importance. To date, MAHLI stereo pairs have been acquired for a variety of surfaces starting with the first contact science on Sol 46, and continuing until present. Further QRM's are planned after rigorous analysis of the vertical error budget intrinsic to the MAHLI stereo imaging configurations. Our focus here is on a first-order error analysis of QRM performance for a human-made object on the rover deck as a validation experiment.

Initial characterization/validation experiment: On Sol 808 a preliminary MAHLI stereo imaging experiment was conducted to evaluate the quality of derived QRM's for potential further utilization during the MSL Mission. The experiment was designed to allow for MAHLI stereo-overlap-imaging of the REMS UV Sensor box which is installed on the upper rover deck, and fully described by a CAD file provided by the REMS PI (from EADS-Astrium CRISA) [3].

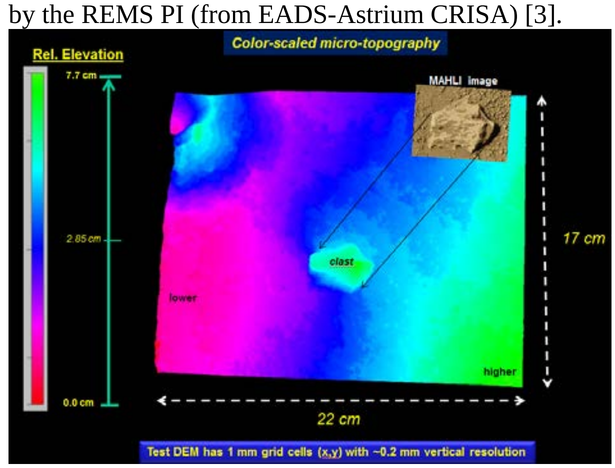

Figure 1: *Sol 88 MAHLI micro-relief model featuring a discrete clast with a few cm's of total relief. MAHLI image pixel scale is 66 μm and the frame was acquired from ~ 41 cm stand-off distance under near-nadir viewing geometry. The derived QRM has 1 mm grid cells and a vertical precision of ~ 0.2 mm.*

As illustrated in **Fig. 2**, the REMS UVS box [3] was successfully imaged from a stand-off distance of 16.8 cm under non-ideal solar illumination conditions (*i.e.*, with sun glints) on Sol 808 using an arm movement to achieve a large degree of stereo overlap. The pixel scale of the two overlapping MAHLI frames is 66 μm. The REMS UV Sensor box is 58 mm x 68 mm and approximately 19 mm in relief above the mounting plate on the rover deck. There are 6 circular UV-sensing photodiodes, each 8.5 mm in diameter arrayed on the upper plate of the REMS box [3]. Given the availability of the CAD model, we have been able to generate a highly precise "QRM" of the feature for use in absolute comparison to the QRM derived from the MAHLI stereo pair (**Fig. 2**).

Figure 2: *Color-scaled QRM from MAHLI stereo images acquired on Sol 808 from ~16.8 cm above that showcases the ~ 19 mm of total relief from the deck to the top of the REMS UVS Box (showin in Red). Black areas are those in shadow in the stereo pair. Color scale bar to Left.*

MAHLI QRM analysis: Our emphasis has been on evaluating the "noise" floor of the computed QRM in comparison with the 3D CAD model of the REMS UV sensor. This initial analysis showcases the potential vertical precision limits of the MAHLI stereo imaging for micro-relief, and can be used as a guide for scientists interested in using this approach for quantitative texture analysis in the future.

The difference between the REMS UV sensor "QRM" (from the CAD model) and the preliminary MAHLI QRM was computed after careful registration of the two models. **Figure 3** illustrates the differences and suggests that the "vertical noise floor" of the MAHLI QRM is ~0.1 mm on a spatial grid scale of 0.3 mm. This indicates that textures with relative relief of 0.2-0.3 mm can be detected effectively for certain geologic targets at mm spatial scales (for the 1st time).

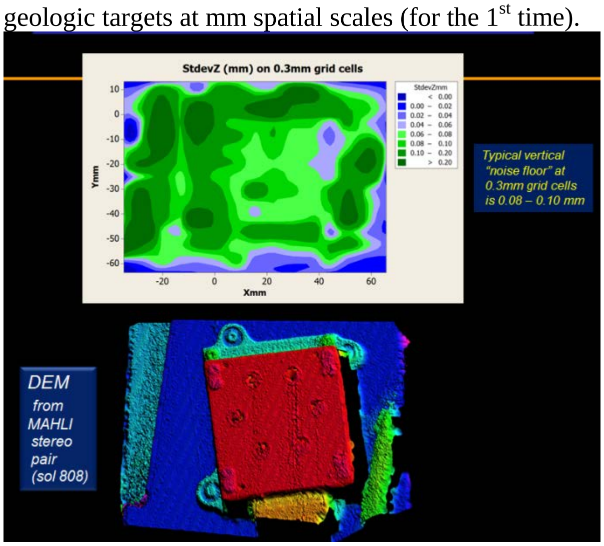

Figure 3: *Statistical analysis of "vertical noise" levels in the computed MAHLI QRM. At the top is a color contoured map of vertical errors cast as standard deviation of local relief at 0.3mm grid scales, with the color-coded MAHLI QRM shown below. Typical values are ~0.1 mm.*

Differential Analysis: It is instructive to compare the QRM's from the REMS UVS CAD model and the MAHLI stereo pair after sub-grid scale registration to examine the distribution of errors under the illumination and geometric conditions of the Sol 808 experiment. **Figure 4** depicts the distribution of local topographic differences between the two QRM's for the upper plate of the REMS UVS box. For this smooth upper plate, the measured variation is ~0.1 mm, while larger variations can be seen in the UV photodiode "pits" mostly due to shadowed illumination and image saturation. More than 80% of the statistical differences are $\leq$ 0.2 mm on a grid scale of 0.3 mm (**Fig. 4**). This suggests that martian rock sample textures at such scales can be reliably measured, especially if illumination conditions are optimized.

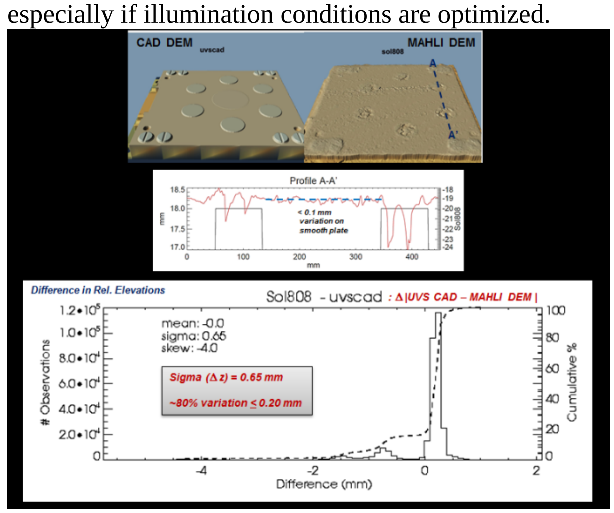

Figure 4: *Sol 808 MAHLI QRM differential relief analysis. At top are perspective views of the REMS UVS box from the CAD model next to the MAHLI QRM. A profile through the MAHLI QRM is shown in the middle panel relative to the CAD model. A histogram of local topographic variations between the CAD model and the MAHLI QRM is in the lower panel. See text for details.*

Conclusion and Future Work: Even under non-ideal imaging conditions, the preliminary MAHLI QRM for Sol 808 illustrates vertical precision levels better than 0.2 mm. Quantitative analysis of such QRM's is a step beyond routine, qualitative anaglyph evaluation, and offers the possibility of new boundary conditions for micro-relief analysis of rock textures.

References: [1] Grotzinger, J. P. *et al.* (2012) *Space Sci. Rev. 170*, 5–56. [2] Edgett, K.S., et al. (2012), Space Sci. Rev., doi:10.1007/s11214-012-9910-4. [3] Gómez-Elvira, J. *et al.* (2012) *Space Sci. Rev. 170*, 583–640, doi:10.1007/s11214-012-9921-1. [JBG is grateful to Drs. J. Grunsfeld and C. Scolese for support].