Systematic Photometric Modeling for Correcting Topographic Shading Effects on HRSC Imagery
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Introduction

The High-Resolution Stereo Camera (HRSC, [1,2]) onboard the European mission Mars Express is a high precision photogrammetric camera which delivers color imagery and accurate height model information of the planet Mars. Recent improvements in the orbit and pointing data of the camera [3] together with refinement of the 3D surface reconstruction at high resolution [4] allow global mosaicking of digital terrain models with grid spacing of up to 50 m per pixel and orthoimages with up to 12.5 m resolution. We want to use the exact orientation information resulting from bundle adjustment together with the pixel-based surface orientation to derive a synthetic photometric model and compare it with the recorded HRSC image. This model can then be used for several purposes, one of which would be to correct the acquired image to standard lighting and viewing geometry for merging the image into a global orthoimage mosaic with uniform viewing geometry.

Derivation of Pixel-Scale Illumination Conditions

The orientation data derived by either reconstructed orbit data or bundle adjustment consists of the 3 components for the position of the spacecraft/camera in the Mars-fixed coordinate system and three angular pointing components that define the rotation matrix to the actual camera system. Geometric camera calibration data contain the interior orientation of the focal length and CCD positions in the focal plane as fixed values for every CCD line. This information is used together with CSPICE toolkit functions of the Planetary Constants Kernel subsystem (PCK, [5]) and routines of the VICAR Run-Time Library [6] to calculate unit vectors of the Sun and the pixel’s position in the Mars-fixed coordinate system for every single pixel. They are saved in floating-point images exactly aligned to the original HRSC level 2 image sequence. These floating-point values representing sun and observer directions can be transformed to the VICAR level 4 image geometry of the map-projected HRSC DTM. This way, we are able to rotate these vectors about the slope and aspect angles of the surface, resulting in the illumination angle $\iota$ of the sun’s incidence and the emergence angle $\epsilon$ of the observer to the surface normal representing the exact orientation of the pixel in the map-projected coordinate system.

Photometric Surface Model

Téillet et al. [7] describe a simple but robust correction method for multispectral scanner data suitable for the systematic derivation of a photometric surface model. Minnaert’s law is given by:

$$ r_M(\iota, \epsilon, \psi) = A_M \mu_0 \mu^{k-1} $$

with $r_M$ being the reflectance on the surface depending on the angles $\iota$, $\epsilon$ and the wavelength $\psi$, $A_M$ the Minnaert Albedo, $\mu$ and $\mu_0$ the substitutions for $\cos(\epsilon)$ and $\cos(\iota)$. The parameter $k$ can be determined empirically by linearizing Equation 1 logarithmically, leading to Equation 2:

$$ \log(r_M \mu) = \log(A_M) + k \times \log(\mu_0 \mu) $$

To consider the atmospheric contribution, we subtract an estimated shadow value from the real image before performing the fit. A scatter plot of this regression for an example image sequence of HRSC is shown in Figure 1.

Figure 1: Scatter plot for the empirical determination of the Minnaert index $k$ (HRSC orbit 3207)
For the same orbit (Figure 2 a), the derivation of slope/aspect-corrected incidence angles are shown color-coded in Figure 2 b. Higher incidence angles are shown in red to white. Part c is a representation of the synthetic model for the same subset, calculated by use of Eq. 1 and the k parameter from the linear regression. Part d shows the division of the haze-corrected HRSC image by the synthetic model (contrast stretched). As expected from the slope/aspect correction, the three-dimensional relief impression of the image has been reduced while albedo differences have been isolated from the shading of the bright and dark slopes.

Figure 2: Original image, subset of HRSC orbit 3207 (a), color-coded incidence angles (b), synthetic Minnaert-based topographic model (c), topographically corrected albedo image (d)

Outlook

As Veverka et al. [8] point out, the linearization of the Minnaert equation could lead to improper weighting of the data points. To address this issue, the initial guess of the k parameter could be refined by a subsequent non-linear fit.

For a systematic approach, the atmospheric contribution has to be determined more precisely. Hoekzema et al. [9] describe robust methods to derive the optical depth of the Martian atmosphere.

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References