GEOMETRIC AND RADIOMETRIC MODELING OF THE MARTIAN SURFACE BASED ON OBJECT SPACE MATCHING AND PHOTOCLINOMETRY

Stephan Gehrke [1,2]

[1] Technische Universität Berlin, Geodesy and Geoinformation Science,
Straße des 17. Juni 135, D-10623 Berlin, Germany
[2] North West Geomatics, Pixelgrammetry Group, Suite 212, 5438 11th Street NE, Calgary, AB T2E 7E9, Canada,
E-mail: stephan.gehrke@pixelgrammetry.com

Keywords: Planetary Cartography, Radiometry, Matching, Visualization, DEM/DTM, Orthoimage, Atmosphere

Abstract:

The High Resolution Stereo Camera (HRSC) on board of the European Mars Express mission is imaging the Red Planet since January 2004. After almost four years, HRSC is still unique regarding its ability to provide multiple stereo as well as full color within each imaging sequence. Altogether, this line scanner features nine bands in different stereo angles between ±18.9°, five of them panchromatic and four colors: red, green, blue, and infrared. The entire data set is converted into Digital Terrain Models (DTM) and orthoimages, which form the basis for map products and various scientific researches. Besides this systematic processing, several photogrammetric approaches have been investigated with HRSC imagery and recently compared in the HRSC DTM Test, almost all of them involving either image matching or photoclinometry (shape-from-shading).

An entirely different approach for HRSC data processing is investigated by the author: Facets Stereo Vision, an algorithm for matching in object space, which has been developed since the late 1980s. It integrates the traditionally consecutive steps of (image) matching, point determination, surface reconstruction and orthoimage generation and thus implicitly allows for regarding the interconnections between geometric (DTM) and radiometric surface properties (basically, an orthoimage). First results for comparatively small areas of the Martian surface have already been published.

In the context of this paper, significant enhancements of the Facets Stereo Vision approach, which are especially necessary but also very promising when applied on planetary surfaces like Mars, are suggested. As the basic algorithm becomes weak in smooth regions comprising only few texture or small contrast differences – i.e., areas that frequently occur on the dust-covered Martian surface –, the adjustment has to be stabilized by additional assumptions. This is usually realized by conditions on surface curvature. While such regularization significantly reduces noise and overcomes outliers in the resulting DTM, in particular when weighted individually on the basis of local surface properties, the conditions are literally fictitious. This lack could be overcome by fully using all radiometric image information, i.e., the observed radiance factors of each pixel, and to combine matching in object space with photoclinometry. Based on a reflectance model, additional conditions on height changes can be formulated and readily integrated in the existing adjustment for object-space matching. Such an approach nicely combines the advantages of both matching, which results in reliable absolute heights for well textured image parts, and photoclinometry, which leads to relative heights and is therefore suited to bridge matching gaps. This is achieved, again, through the area-dependant weighting between the two.

A simple and widely used reflectance model is given by Lamberts cosine law; a physically meaningful description of planetary surfaces can be achieved by the more complex, bi-directional Hapke model. However, depending on surface properties (such as relief energy), image resolution as well as illumination and viewing geometries, the up to nine model parameters tend to be highly correlated and their derivation along with DTM and orthoimage will very likely fail. Therefore, the empirical Lunar-Lambert-Model – it has proven a suitable mathematical approximation of Hapke's formula throughout various investigations – is chosen as the radiometric surface description in this context. In addition to the Martian surface, the attenuation of the atmosphere (the optical depth) and the influence of ambient light are to be adequately parameterized. Here lies the strength in the combination of object space matching and photoclinometry along with the use of HRSC multiple stereo imagery as data source: It allows for the integrated estimation of such radiometric properties, leading to a comprehensive geometric and radiometric least squares adjustment that allows for the joint derivation of surface models: DTM, material properties (reflectance), and orthoimage as well as atmospheric optical depth and the contribution of ambient light to diffuse surface illumination. Based on the resulting Lunar-Lambert parameters, the Hapke model can be retrieved afterwards. It provides the link to further interpretation of surface material properties.

The integrated algorithm has been adapted to Mars Express orbit and HRSC line scanner geometry and implemented in MATLAB; it has been applied to several regions of Mars using HRSC imagery of different resolution obtained under various illumination and viewing geometries. As a result, the benefit from combining matching with photoclinometry is clearly visible in the derived DTMs, especially in comparison to the HRSC DTM Test data, which had been derived using either method. For small regions (described by approximately 60x60 DTM posts), fine structures of the Martian surface can be modelled in very high resolutions of up to 2x2 image pixels per DTM facet.

In this presentation, a 25x25 km area of hills and smaller mesas located in the south of Gusev crater will be discussed in-depth. As the Mars Exploration Rover (MER) Spirit landing lies in this crater, it has been imaged by HRSC multiple times under different conditions, e.g., during orbit 648 from very high altitudes. This inevitably leads to comparatively low ground resolutions (>160 m/pixel) but, most important for modeling radiometric properties, also to large variations in imaging geometry, namely viewing angles larger than 30° (HRSC features nominal stereo angles of 18.9°). Accordingly, besides the geometry reasonably good radiometric results have been obtained from this image data concerning both surface material properties and atmospheric optical depth. Hapke parameters that have been derived based on the integrated approach nicely match with findings of independent photometric studies, in which HRSC data but also very high resolution Mars Orbiter Camera (MOC) images had been analyzed.

In conclusion, the combination of object space matching and photoclinometry, integrating geometric and radiometric modelling of the surface along with atmospheric parameters, indicates to be a powerful approach in particular with regard to quality: high DTM resolution, modeling of fine surface details, and simultaneous derivation of material properties. Further investigations will be necessary, especially when aiming for an operational algorithm in order to process larger areas or even entire HRSC image sequences.