HRSC DATA PROCESSING BY MATCHING IN OBJECT SPACE, II. EFFECTS OF IMAGE AND DTM FILTERING. S. Gehrke, C. Bischoff. Technische Universität Berlin, Germany (stephan@igg.tu-berlin.de).

Introduction: The High Resolution Stereo Camera experiment (HRSC) on Mars Express orbiter provides imagery in full color and five stereo angles, well suited for systematic derivation of Digital Terrain Models (DTM) and orthoimages [1]. Consequently, a variety of photogrammetric approaches for HRSC data processing has been investigated [2-5].

With the future goal of the combined derivation of geometric and radiometric surface properties, HRSC data have been exemplarily processed by Facets Stereo Vision, i.e. matching in object space [6,7]. The application to selected small regions on Mars (5-10 km in size) basically lead to promising results [8-10] – see also companion presentation, part I [11], for joint DTM and orthoimage derivation for a crater rim. However, in shadows or areas of only sparse texture, few DTM artifacts are caused. While it has already been shown that outliers can be reduced by DTM filtering during subsequent processing (see below), the effects of different filters and filter sizes are compared in the following. In addition – since DTM quality can also be affected by image noise – smoothing of HRSC data is investigated.

Facets Stereo Vision is a powerful approach for multi-image matching in object space that integrates the derivation of DTM and orthoimage; it is flexible for modeling further parameters, such as surface reflectance [6,7]; the algorithm has been adapted for HRSC data processing and implemented in MATLAB [8]. Based on HRSC nadir and stereo channels, orthoimage and DTM are derived in combined least-squares adjustments with respect to spatially regular grids, i.e. facets. Depending on initial height quality, subsequent downsizing of DTM facets – using the (filtered) results as starting values for the next step – has proven a capable method, i.e., for each DTM facet size (each calculation step), least squares adjustments are carried out iteratively [9,10]. Thus, from high resolution HRSC data (15 m/pixel in nadir, 30 m/pixel in the two outer stereo channels), a 150 m/post DTM has been collected with an average height RMS of 17.8 m [11].

Test Area: The effects of DTM and input image filtering have been studied for different regions on Mars; it is exemplarily shown for a small area in the Nanedi Valles complex (5.0x5.0 km^2; see Figs. 1 and 2), which has been covered by HRSC during Mars Express orbit 905. Due to the low solar elevation, most valley walls feature rich texture while shadows occur on opposite slopes; the valley floor appears comparatively smooth. In such heterogeneous data, outliers are likely to appear during DTM derivation.

DTM Filtering: For the application of Facets Stereo Vision on Mars, some DTM smoothing is useful for two reasons: First – and most important –, height results of subsequent calculations have to suffice as initial values for the next step with smaller DTM facets. Therefore, peaks in coarser DTMs that eventually cause outliers [9], have to be reduced. Second, noise in the final DTM can be smoothed by Gaussian or mean filtering. This is common practice – also for HRSC DTMs [e.g. 2,4] – and also leads to meaningful contour lines [12]. All DTM results in this context have been slightly smoothed using a Gaussian filter with $\sigma = 0.6$ (FWHM = 1.4).

The first issue has been investigated in detail, particularly considering the following aspects:

- Filter type – mean, Gaussian, or median?
- Filter size (magnitude of smoothing)?
- Filtering after each iteration or only after each step?

For comparison, the Facets Stereo Vision algorithm was initially carried out with no DTM filtering. Then mean, Gaussian, and median filters have been applied in various sizes and configurations. It turned out that the median produced

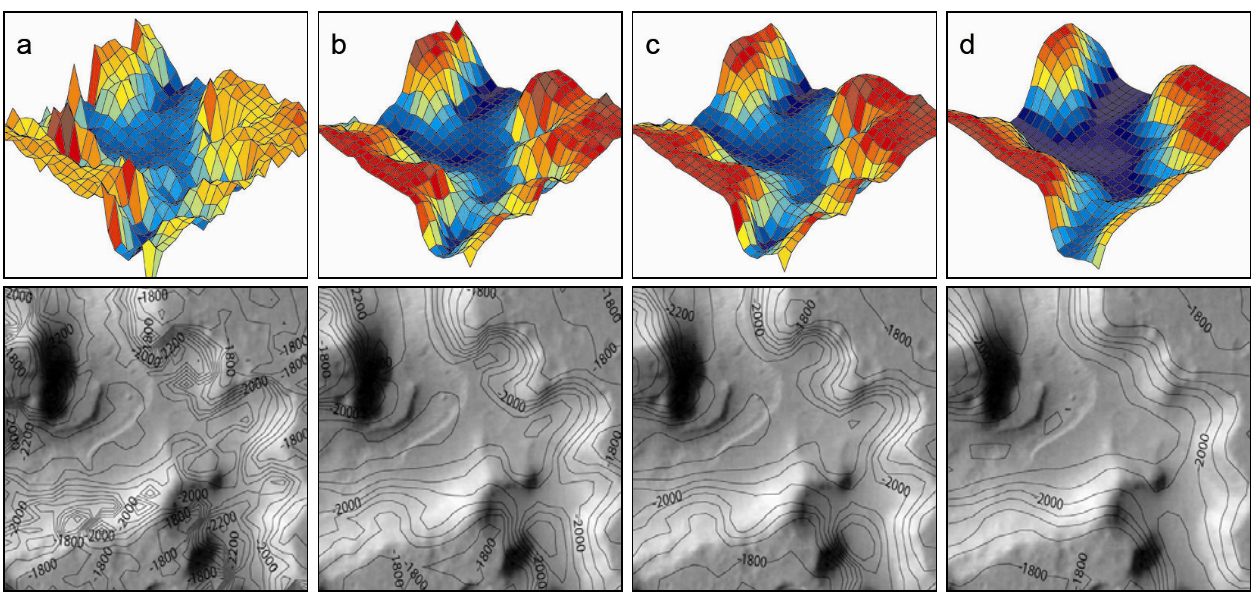

__Fig. 1:__ Results of Facets Stereo Vision – Perspective DTM views and orthoimages with derived contour lines: a) Calculation with no DTM filtering, b) 3x3 median filtering after each step, i.e., applied to the final DTM of a particular facet size, c) 3x3 median filtering after every least squares iteration, d) 5x5 median filtering after every least squares iteration.

the best results, since it eliminates outliers that are only flattened by the other filters. Fig. 1 gives an overview of DTMs and corresponding orthoimages that have been collected by applying the "plain" algorithm and by additional DTM smoothing after each step or iteration, for the latter case with different filter sizes. Without filtering, outliers are clearly visible, e.g., in shadows and the radiometrically smooth valley floor. Such artifacts are significantly reduced by filtering after each step and, more effectively, after each iteration. As expected, increased filter sizes lead to further smoothing and, therefore, reduce both artifacts and topographic detail. Contour lines that are based on either 3x3 or 5x5 DTM median filtering are generally in good agreement with the orthoimage but run rather straight in shadow areas (compare southern valley wall). Nevertheless, these results nicely fit with the DTM that "yielded the best overall results in terms of accuracy and fine detail" during the HRSC DTM Test [4].

In conclusion, DTM and orthoimage derivation by Facets Stereo Vision can be stabilized by DTM median filtering after every iteration of the least squares adjustment. Filter size has to be chosen under consideration of image texture and relief energy. It should be remarked that, due to filtering, adjusted height corrections do not converge to zero. But, more important, the DTM collected during a certain calculation step (with respect to a particular facet size) suffices for starting the next step (with respect to smaller facet size).

Image Filtering: In general, matching results can be improved by low pass filtering of input images. Thus, various filters have been investigated along with processing of HRSC or comparable data [3,4,13-15]. While all approaches aim for noise reduction, some allow for local contrast enhancements, e.g., in order to sharpen edges. However, other HRSC processing methods involve no prior image filtering [2,4,5].

In contrast to classical image matching, which is based on certain features – the quantity of which (i.e. completeness) can be increased by appropriate filtering –, all image pixels are used in Facets Stereo Vision; modeling is a priori complete. The above-mentioned adjustment of image contrasts may allow for averaging the accuracy of the derived DTM (see discussion below) but cannot improve it in total. Radiometric changes are even out of the question for the estimation of reflectance properties with Facets Stereo Vision.

Nevertheless, potential impacts of image noise can be reduced by low pass filtering. Following the experiences of Gwinner et al. with HRSC data processing [3,4] we applied Gaussian filtering with σ = 0.75 (FWHM = 1.8) and σ = 1.5 (FWHM = 3.5) and carried out the Facets Stereo Vision algorithm with 3x3 DTM median filtering after each iteration; results are shown in Fig. 2. While the orthoimages are clearly smoothed (cp., e.g., the inner valley in Figs. 1 and 2), DTM artifacts increase with filtering. Outliers occur, especially in the northeastern plain. This effect can be explained by the reduction of both noise and fine detail during image filtering – while then some dense but weakly constrained DTM results from Facets Stereo Vision, image matching would lead to only few object points and an interpolated, smooth DTM. In this configuration (e.g., without regularization), Facets Stereo Vision cannot be improved by Gaussian image filtering.

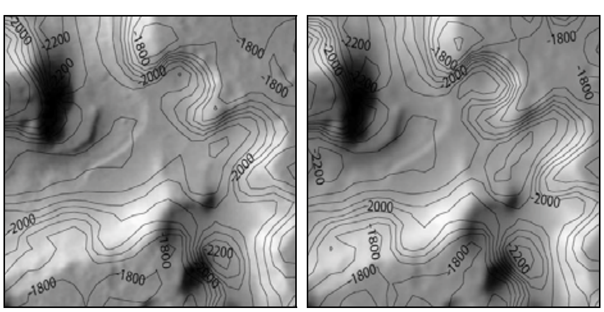

Fig. 2: Facets Stereo Vision results from smoothed images and 3x3 DTM filtering after each iteration (cp. Fig. 1c). Left: Gaussian filter, σ = 0.75. Right: Gaussian filter, σ = 1.5.

Discussion and Outlook: The investigations with regard to input image and DTM filtering indicate the necessity of some regularization in Facets Stereo Vision, especially in regions that show only little texture. The strong dependence of DTM accuracy from image texture is illustrated in Fig. 3 (left): Besides edges and corners of the investigation area the valley floor, the northeastern plain, and shadows are least constraint and, without any DTM filtering, outliers occur – although it should be remarked that DTM filtering reduces artifacts but doesn't improve accuracies, since least-squares adjustment configuration is unaffected. However, the adjustment may be stabilized by accuracy-dependent constraints on surface curvature: Regions of little texture are forced to be straight and curvature is allowed (but not forced) vice versa.

Fig. 3 (right) shows changes in accuracy after Gaussian image filtering. While significant increases can bee seen in "problem areas" (cp. left), most RMS values slightly decrease by lees than 10 m. Therefore, image filtering might improve the HRSC DTM and orthoimage obtained by Facets Stereo Vision, if appropriate regularization is applied.

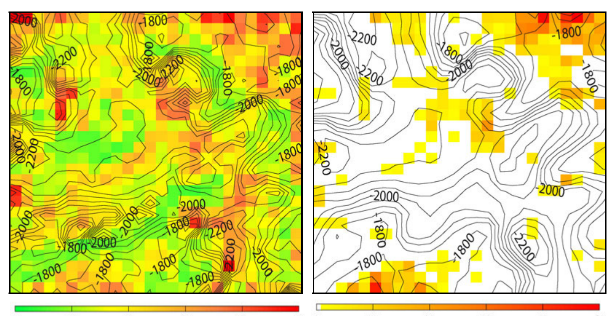

Fig. 3: Height RMS' in [m] from Facets Stereo Vision. Left: Calculation without any filtering (cp. Fig. 1a). Right: RMS increase after image smoothing, carried out with 3x3 DTM filtering (cp. Figs. 1c and 2, right).

References: [1] Neukum G. et al. (2004) *ESA SP-1240*. [2] Scholten F. et al. (2005) *PE&RS*, 71(10). [3] Gwinner K. et al. (2005), *PFG*, 5/2005. [4] Heipke C. et al. (2006) *ISPRS TC IV Symp.*, Goa. [5] Kirk R.L. et al. (2006), *ISPRS TC IV Symp.*, Goa. [6] Wrobel B.P. et al. (1987) *Fast Proc. of Photogramm. Data*, Interlaken. [7] Weisensee (1992) *DGK-Reihe C*, #374. [8] Haase I. (2007) *Diploma Thesis*, TU Berlin. [9] Gehrke S. et al. (2006) *Turkish-German Joint Geodetic Days*, Berlin. [10] Gehrke S. & Haase I. (2006) *ISPRS TC IV Symp.*, Goa. [11] Gehrke & Haase I. (2007) *ISPRS Extraterr. Mapping Workshop*, Houston [12] Gehrke S. et al. (2006) *ISPRS TC IV Symp.*, Goa. [13] Schmidt et al. (2006), *ISPRS TC IV Symposium*, Goa. [14] Schmidt et al. (2007), *ISPRS Extraterr. Mapping Workshop*, Houston. [15] Pateraki M. et al. (2002) *Map Asia*, Bangkok.