QUALITY CHECK OF MOMS-2P ORTHOIMAGES OF SEMI-ARID LANDSCAPES

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ABSTRACT:
From 1996 until 1999 DLR operated the first 3-line along-track stereo scanner in space. This MOMS-2P camera was mounted onto the Russian space station Mir. It had its own navigation system consisting of GPS receiver and gyros. The orbit and attitude data derived from their measurements had already a very good relative accuracy in sub-pixel range. But absolute biases and drifts of exterior orientation and also some parameters of the interior orientation have to be estimated via bundle adjustment. Ground control points (GCP) have to be provided for this task. This always was a bottleneck of MOMS stereo evaluation. For large areas in Afghanistan, Jordan and Libya geocoded Thematic Mapper imagery was available. On one hand, these data have been used for automated GCP extraction via image matching. On the other hand, they are also used here to check the MOMS orthoimages produced by DLR's MOMS stereo workstation software along with the digital elevation models which are a prerequisite of orthoimage generation. This check is done via automatic image matching. Mean and standard deviations of the shifts are found to be in sub-pixel range. The internal fit of the MOMS orthoimages of the off-nadir looking stereo channels of MOMS is also checked via image matching. The standard deviations of the shifts are in the order of $1/5^{th}$ pixel which allows the color composites of good radiometric quality and the use of the orthoimages in multispectral evaluation.

1 INTRODUCTION

Software development of the MOMS stereo workstation was triggered by the three-line along-track stereo scanner projects at DLR. After some in-house experience the MOMS camera (Modular Opto-Electronic Multispectral Stereo Scanner) was designed in a cooperation of DLR with the Chairs for Photogrammetry of several German universities and an industrial partner (Dasa, now part of EADS) which finally built the camera under the supervision by DLR. It was first flown as MOMS-02/D2 during the German D2 shuttle mission in 1993. In 1996 it was put on a new Russian module Priroda of the space station Mir (see [1] for a description of instrument and mission). MOMS on Mir had its own navigational package consisting of GPS receiver and gyros. The relative accuracy of orbit and attitude information is already in sub-pixel range (1 m and 1-2 arcseconds, respectively). Figure 1 shows the residuals of the attitude angles after subtraction of a second order polynomial to illustrate the finer oscillations. By comparison of digital elevation models (DEM) generated from MOMS data with existing DEM it has been proved that all the fine oscillations larger than 1-2 arcseconds are real attitude motions. In contrast, absolute accuracy which is coupled to the attitude of Mir station is not better than a few hundred meters compared to a ground pixel size of about 17 m square. That is the reason why still ground control is needed. Additionally, some parameters of the interior orientation of the MOMS scanner which consists of several lens systems have to be adjusted by self-calibration in bundle adjustment. The provision of ground control turned out to be the bottleneck of MOMS stereo data evaluation. In one of the stereo evaluation projects georeferenced Thematic Mapper (TM) data had been made available by the customer and extraction of ground control could be done successfully with image matching. Three MOMS-2P data takes are involved: T0893 - Scene 43 (Libya, imaged on April 8, 1998), T08E8 - Scene 15 (Amman/Jordan, imaged on June 16, 1998) and T0940 - Scenes 50-54 (Afghanistan, imaged on August 18, 1998). All three were acquired in imaging mode D: 2 inclined panchromatic channels and 2 nadir looking color channels (blue and NIR). A MOMS scene comprises an area of about 100 km by 100 km. The Landsat-5 TM scenes date from 1987 (Libya, Jordan) and 1990 (Afghanistan). The geocoded images have a ground pixel size of 28.5 m. The indicated MOMS scenes are the areas for which DEM and orthoimages were required. A coarse DEM with a grid spacing of 100 m for GCP height extraction was also provided.

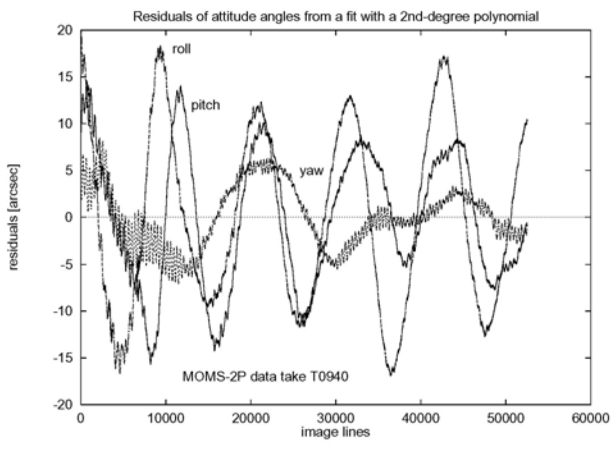

Figure 1: Oscillations on pixel scale of MOMS attitude angles measured by gyros (MOMS pixel: 8 arcseconds IFOV)

2 MOMS ORTHOIMAGE GENERATION

The main steps of the processing chain which transforms MOMS stereo data into DEM and orthoimages are:

1. Matching for generating primary tie points between the three looking directions of MOMS stereo data for input to bundle adjustment and as seed points for Otto-Chau region-growing
2. Preprocessing of orbit and attitude data: orbit is derived from on-board processed GPS data by approximation with a satellite orbit model; attitude is reconstructed from gyro measurements and start values given by Mir attitude
3. Measurement of ground control points (GCP): this is normally a very tedious manual process with the additional big problem of retrieving maps of appropriate scale (about 1:25000), up-date status, and distribution over the strip
4. Bundle adjustment (BA) for the estimation of the absolute values of interior and exterior orientation of the camera during imaging of the current data strip. The BA is done with the software package CLIC of the Chair for Photogrammetry of Technical University Munich (see [4]). It is based on the concept of orientation images for reducing the number of unknowns which are to be estimated for stereo scanner imagery. The results of the BA are the exterior orientation for each image line and some adjusted values of the interior orientation. In order to exploit the full accuracy potential of 3-line stereo scanning the region of interest is kept in the middle of a data strip with one extra base length (about 8000 image lines) on both ends. The coordinate system used for MOMS is a local topocentric system (LTS) centred in the middle of the evaluation strip.
5. Matching for a very dense tie point distribution using Otto-Chau region-growing method with mass seed points from previous matching process; in mode D the matching is performed between the off-nadir looking panchromatic channels and the blue channel (only in regions with snow and ice or forests the addition of the NIR channel can help to fill gaps)
6. Forward intersection to compute the ground coordinates of the triple conjugate points based on the reconstructed interior and exterior orientation
7. Generation of a regular DEM by two-dimensional interpolation (normal grid spacing for MOMS is 25 m)
8. Calculation of orthoimages based on the regular DEM and the orientation data (normal grid spacing for MOMS is 15 m)

Threefold imaging is exploited for blunder reduction in all image matching steps and in forward intersection. A more detailed description of the MOMS stereo workstation software is given in [2].

2.1 GCP extraction by matching

The first step is the approximate transformation of MOMS panchromatic channel 6 into TM image space. This is done via an affine transformation based on a few manually found tie points. The MOMS stereo viewer software is used to get the tie points. An example of such an input pair for matching is shown in figure 2. This transformation reduces the scale differences and the rotation angles to acceptable values for the matching.

The transformed MOMS image is now matched with a TM synthetic channel which is derived from the original TM color image by averaging of the 3 given TM channels. DLR software for matching in image space is used to get tie points with sub-pixel accuracy (see [3] for more details). The procedure is based on an image resolution pyramid (6 pyramid levels have been used). On each level of the pyramid an interest operator will first find the patterns which are suited for digital image correlation. For each such pattern two intensity based image matching methods are used to try to extract a conjugate point:

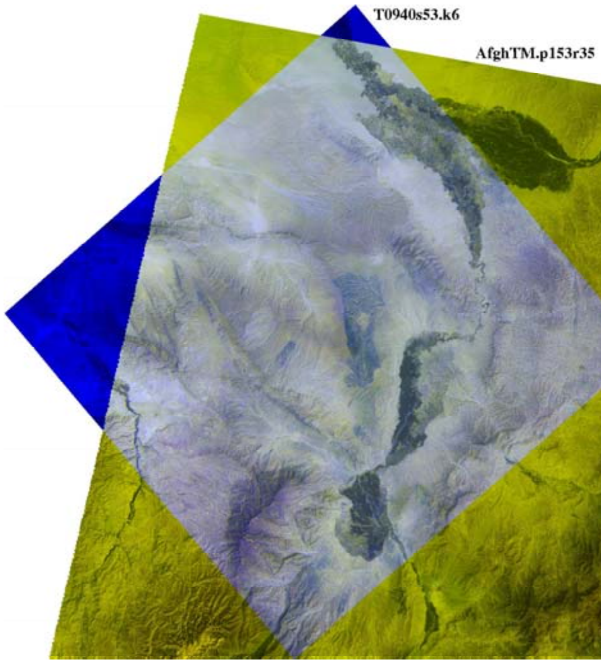

Figure 2: Example for geocoded TM and rotated MOMS scenes (Afghanistan)

1. maximum of cross correlation coefficients between pattern area and search area located in the stereo images (the software allows for the simultaneous matching of up to 3 stereo partners); a conjugate point found by this process will have an accuracy of about 1 pixel and will enter the next matching step:
2. local least squares matching (LLSQM) is used to refine the conjugate point coordinates to sub-pixel accuracy (accuracy limit about 0.1 pixel); 6 affine and 2 radiometric transformation parameters between image chips of a stereo pair are estimated by iterative least squares adjustment; the convergence radius of this method is 1-2 pixels which demands for another method (here (1)) for getting good approximations.

By interchanging the roles of template and transformed image of the image pairs in LLSQM and analysis of the resulting shifts the best matching results are selected.

The TM image coordinates can now directly be used to compute the object space coordinates of the GCP (UTM coordinates from geocoded images, terrain height by interpolation in given DEM, and transformation to LTS).

The MOMS channel 6 image coordinates are back-transformed to original MOMS image space. By automatic matching they are completed to full MOMS stereo tie points (coordinates in two inclined and the blue channels). This is done by LLSQM for which good approximations for the channel 1/7 coordinates are estimated by least squares adjustment from the already available mass stereo tie points for the MOMS strips. Once more, only the best points are selected. The number of points kept after all these processes is given in table 1.

Table 1: Number of GCP found by matching

MOMS data take	Strip length (km)	GCP from matching	GCP into BA
T0893	300	5722	2490
T08E8	600	8320	3280
T0940	900	17980	7510

2.2 Bundle adjustment

Part of these GCP are selected via a regular grid and entered into bundle adjustment (BA). Of course, a few percent of the points are removed from BA because of the estimated deviations in object or image space. Additional input to BA are stereo tie points, preprocessed exterior orientation, and initial values of interior orientation. All observations are input with appropriate standard deviations for weighting (similar to those given in [2] except for the GCP: standard deviation is set to 20 m in X and Y, and 30 m in Z). The distance of orientation images is put to 70 lines for T08E8 and T0940 in order to be able to model the fine oscillations of the attitude angles. In case of T0893 it had to be set to still acceptable 140 lines because of the low density of tie points in larger desert areas. The result of BA are the improved orientation values.

With this improved orientation the remaining GCP can be used as check points: through forward intersection their image coordinates are transformed to object space coordinates which can be compared to those derived from TM imagery and input DEM. The result for the three MOMS data takes is shown in table 2. The standard deviations are in sub-pixel range and correspond in lateral directions x, y well with the standard deviations found by matching in table 3. For the Afghanistan strip the standard deviation in z is much higher. This long strip contains the Hindukush mountains with a height variation of more than 6000 m. Larger errors in the coarse input DEM can be expected.

Table 2: Residuals (in m) at check points

Data take	check points		Mean	Standard deviation	Min	Max
T0893	2124	X	0.1	6.0	-27	20
		Y	0.5	4.7	-18	24
		Z	-0.2	6.8	-31	37
T08E8	4839	X	-0.2	8.3	-40	28
		Y	0.5	7.5	-24	26
		Z	-1.5	8.4	-36	47
T0940	8085	X	0.5	9.0	-83	43
		Y	0.2	6.6	-25	28
		Z	0.4	24.9	-321	279

2.3 DEM generation

Otto-Chau region growing with a step size of one pixel is used to get a dense set of 3-fold tie points from the primary tie points used as seed points. The available 3 stereo pairs are used for checking which of course leads to 50% increase in computation time but the number of miss-matches is efficiently reduced. The resulting tie points are fed into forward intersection using the reconstructed exterior and interior orientation. Here too, a check for 3-fold tie points is made via the corrections to the observed image coordinates found by the least squares adjustment. The irregular set of object space coordinates resulting from forward intersection is interpolated to a regular DEM with 25 m cell size.
The increase of details in MOMS DEM compared to the coarser input DEM for GCP height extraction is shown in figure 3.

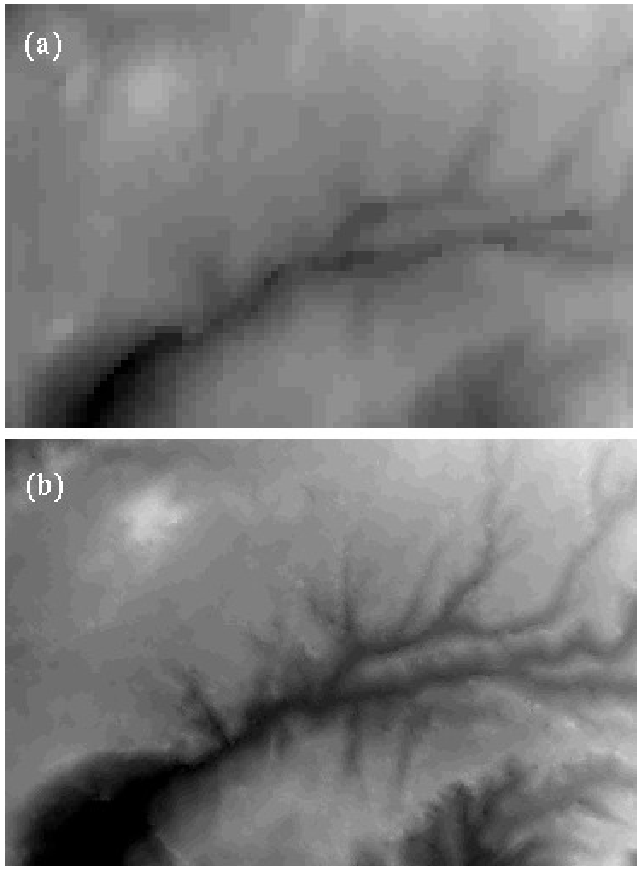

Figure 3: Comparison of DEM subarea (9 km x 6 km) of Afghanistan strip: input DEM used for GCP height extraction (a) versus MOMS DEM (b)

2.4 Orthoimage generation

The MOMS DEM and the improved orientation data from BA are now used for orthoimage production. The software written at DLR employs the direct projection of triangles from image space onto DEM to derive the position of the corresponding triangles in output space. Radiometric values are then transferred from the corners of the triangle in input space to all pixels contained within the triangle in output space by nearest neighbor or bilinear interpolation (see [5] for details on orthoimage processing).

For each data take two sets of orthoimages with resolutions 28.5 m for matching with the given TM images and with 15 m (normal resolution of MOMS orthoimages) for checking the fit between the orthoimage channels have been produced. The UTM projection and WGS84 datum have been used as output system which is identical to the coordinate system of the TM images.

3 CHECKS VIA MATCHING

Two independent checks have been performed. Matching of orthoimage channel 6 of MOMS with the pan-simulated TM imagery and matching between the off-nadir looking orthoimage channels of MOMS (channels 6,7). The shifts measured by image matching are influenced also by radiometric differences which are present in TM/MOMS pairs (multi-sensor/multi-temporal/aspect angle) and also in off-nadir looking channels of MOMS because of differences of reflectance values for the two inclined looking directions. It is tried to keep the influence of radiometry low by selecting only points with high radiometric similarity, i.e. a correlation coefficient beyond 0.7 in case of TM/MOMS and 0.9 in case of MOMS/MOMS matching at the final stage of LLSQM (still more than 90% of all available points). Because of the good fit of the image pairs to be matched here no resolution pyramid has been used here for the matching.

3.1 Matching between MOMS and TM

Pixel resolution for this matching is 28.5 m (resolution of TM imagery). Channel 6 orthoimage in each of the three cases was matched with an adequate subimage of the corresponding averaged TM channels. The results are described in table 3. They show a good fit between MOMS and TM orthoimages. Standard deviation is in the order of $1/3^{rd}$ of a pixel (9.5 m).

3.2 Matching between orthoimages of the off-nadir looking MOMS channels

The resolution of the orthoimages is 15 m in this case. In order to check the quality of the orthoimages the shifts between the orthoimage channels of the off-nadir looking MOMS channels 6 and 7 are assessed. These channels should in case of DEM and orientation errors show the maximum shifts and they are both panchromatic channels which minimizes the influence of radiometry. Results are given in table 4 and histograms of the shifts for data take T08E8 in figures 4 and 5. Standard deviation is in the order of $1/5^{th}$ of a pixel (3 m).

Conclusions

It is shown that the MOMS stereo evaluation process can be fed with ground control from the matching of MOMS data with geocoded Landsat TM images. Because of the low density of needed GCP a large time gap between MOMS and TM imagery can be tolerated, at least for the semi-arid regions of this investigation. The resulting orthoimages fit well with the given TM imagery. The fit between the MOMS orthoimage channels is in the order of $1/5^{th}$ of a pixel even for those produced from the images of the off-nadir looking MOMS channels. Thus, color composites of good radiometric quality can be generated.

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Table 3: Shifts between TM and MOMS orthoimage channel 6 (in pixel)

MOMS Data take	**Number of points**	**Mean shift**		**Standard deviation**		**Line shift**		**Column shift**	
		Lines	*columns*	*Line shift*	*col. shift*	*Min*	*Max*	*Min*	*Max*
T0893	5726	-0.42	-0.46	0.22	0.34	-1.38	0.80	-1.78	2.23
T08E8	10643	-0.40	-0.38	0.30	0.29	-2.41	1.90	-4.71	2.31
T0940	24563	-0.70	-0.30	0.45	0.36	-2.49	2.45	-2.68	3.07

Table 4: Shifts between MOMS orthoimage channels 6 and 7 (in pixel)

MOMS Data take	**Terrain Heights (m)**	**Number of points**	**Mean shift**		**Standard deviation**		**Line shift**		**Column shift**	
			Lines	*columns*	*Line shift*	*col. shift*	*Min*	*Max*	*Min*	*Max*
T0893	0 - 510	23095	-0.03	-0.11	0.18	0.17	-0.94	0.95	-0.84	1.01
T08E8	-350 - 1200	177154	0.08	0.03	0.15	0.15	-1.24	1.22	-1.17	1.31
T0940	330 - 4060	266310	0.01	-0.08	0.21	0.22	-4.61	2.73	-3.15	3.69

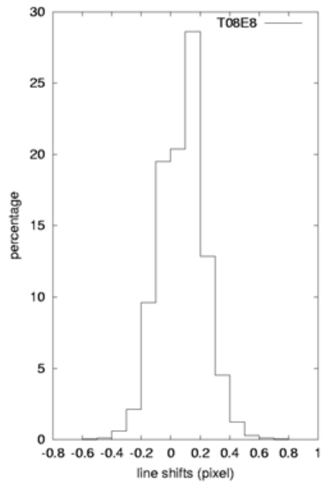

Figure 4: Histogram of line shifts between channels 6/7 for MOMS data take T08E8

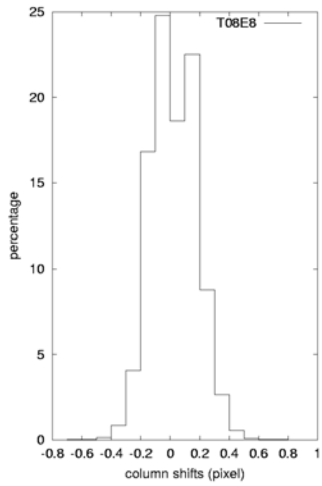

Figure 5: Histogram of column shifts between channels 6/7 for MOMS data take T08E8