D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

IMPROVEMENT OF THE AUTOMATIC MOMS02-P DTM RECONSTRUCTION

Dieter Fritsch [1), Michael Kiefner [1), Dirk Stallmann [1), Michael Hahn [2)

[1) Institute for Photogrammetry (ifp)
University of Stuttgart
Geschwister-Scholl-Straße 24
70174 Stuttgart
GERMANY
email: *firstname.familyname*@ifp.uni-stuttgart.de

[2) Faculty of Surveying and Geoinformatics
College of Applied Sciences (Fachhochschule)
Schellingstrasse 24
70174 Stuttgart
email: m.hahn.fbv@fht-stuttgart.de

Commission IV, Working Group 4

KEY WORDS: MOMS02-P, Mir Space Station, High Resolution Satellite Imagery, DTM Reconstruction, DTM Validation

ABSTRACT

Using high resolution optical satellite imagery for automatic DTM generation the validation of the digital terrain model becomes an issue. This problem is easily to overcome if a DTM already exists, as given in various European countries. For the validation of the MOMS02-P camera experiment the outcome of the data take M2P083C of March 14th, 1997 is compared with the archived DTM of the Bavarian state survey department. The reconstructed MOMS-DTM has a size of 50*km*x178*km*, within an estimated overall accuracy of about 11.6*m*. Investigations have shown, that this figure can be broken down taking into account various landscape types. This is necessary to come close to the expected height accuracy of the MOMS02-P experiment, what should be in the order of 6-7*m*.

1 INTRODUCTION

The Institute for Photogrammetry (ifp) of the University of Stuttgart serves as 'Principal Investigator' in the optical remote sensing project MOMS02. The MOMS project startet already in the 70s, when first experiments were made for digital data acquisition. MOMS is an acronym for 'Modular Opto-electronic Multispectral Stereo-Scanner'. The current camera system of 2nd generation has proven its capability for simultaneous high resolution panchromatic (PAN) and multispectral (MS) image date acquisition during the 2nd German Spacelab experiment (26.4.-6.5.1993). Thereafter it was slightly redesigned to operate on-board the Russian Space Station Mir for a 2 years term. Since May 1996 MOMS02 is on-board of the Mir's remote sensing module PRIRODA . After testing and calibration a first data collection phase started from October 1996 lasting till April 1997. Due to well-known technical failures of the Mir space station (and also of the MOMS02 power supply) the data stream stopped for about 1 year. As it seems today, the phase 2 data collection which started in January 1998 will last until the total download of Mir, estimated towards the end of 1999.

During the phase 1 about 13 mio km² image data could be collected in both modes, PAN and MS. These data are available to the MOMS Science Team and German pilot project applications, funded by the German Aerospace Research Institute (DLR). First evaluations have shown, that the overall aim of the mission serving for topographic and thematic mapping at scales 1.50.000 and 1:100.000 could be fulfilled. A first DTM validation is given by D. Fritsch et al. (1998), with an overall accuracy in height of 11.6*m.* These results are confirmed by other members of the MOMS Science Team (cf. H. Ebner et al. , 1998).

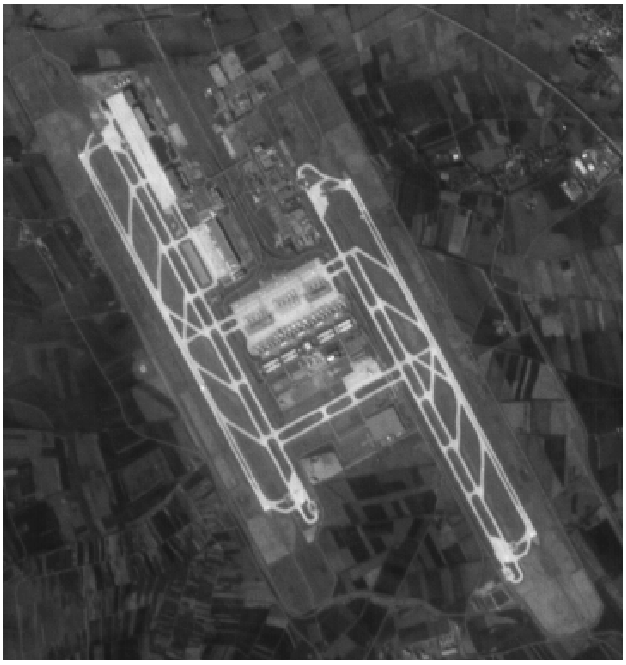


Figure 1: Airport Munich collected by the FW channel (GSD 17*m*)

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

The optical camera system MOMS02-P provides 4 data collection modes: mode A for triplet stereo using the PAN channels 5,6,7 only, mode B delivering all 4 MS data channels simultaneously (1,2,3,4), mode C offers high res MS imaging (5A PAN, 2,3,4), and mode D serves for simultaneous stereo and multispectral capability.

For the automatic DTM reconstruction in this paper, only mode A with the forward and backward looking channels 6 and 7 is used. Unfortunately, an operating error blurred the data collection of the high res channels 5A,B, thus these data could not be integrated. Looking at the imaging geometry for a flying height of about 350*km* a base-to-height-ratio of 0.8 can be expected. This finally results from the inclination of the stereo lenses (± 21.4*deg).*

Mir moves along a very smooth and stabil orbit what causes less distortions in the imagery. A typical scene collected from a flying height between 380 to 400*km* represents an area of about 50*km* in width. Its repetition rate varies between 3 to 18*days*. The GSD for the stereo lenses 6,7 is about 15-18*m* – the image strip has an extension of 2976 pixels.

Our first experiment for DTM data validation deals with the data take M2P083C, scenes 27-30, collected on March 14, 1997. This data take is mostly located in the southern part of Germany and, therefore, offers the first opportunity for a thorough data validation. As it is well-known, Germany is well-covered by the ATKIS digital terrain model available in grid mode at 50*m* spacing. A comparison can easily be made between the MOMS DTM and the ATKIS DTM, as described in D. Fritsch et al. (1998). The test site investigated in this paper covers an area of 178*km* length and 50*km* width.

The expectations on that comparison could not yet be fulfilled. During the evaluation phase of the MOMS02-D2 mission we learned that an overall accuracy for DTM data of 4.2*m* could finally be reached. A prediction for the Mir flying height comes to a 6*m* level. On the contrary, results reached so far indicate an overall height accuracy of 11.6*m*. The goal of this paper is therefore to improve the latter figure, in more detail, to examine the residuals depending on the terrain type. For this reason, the test site is subdivided into three different landscape forms: open area, forest area, and urban area.

2 AEROTRIANGULATION

One main problem with MOMS02-P imagery consists in the measurement of Ground Control Points (GCP). As said before, because of the technical failure during the data take, measurements only for the for and back channel are available. Therefore the GCPs were only measured in the for and back channel with the limited resolution of 18*m* GSD. To check our results of the aerotriangulation we also measured some check points. Both groups of validation points, the control as well as the check points were digitized in topographic maps of scale 1:25.000 and measured in the raster images of the two stereo channels. Figure 2 shows an example of a typical point identification and visibility. In this example a crossing

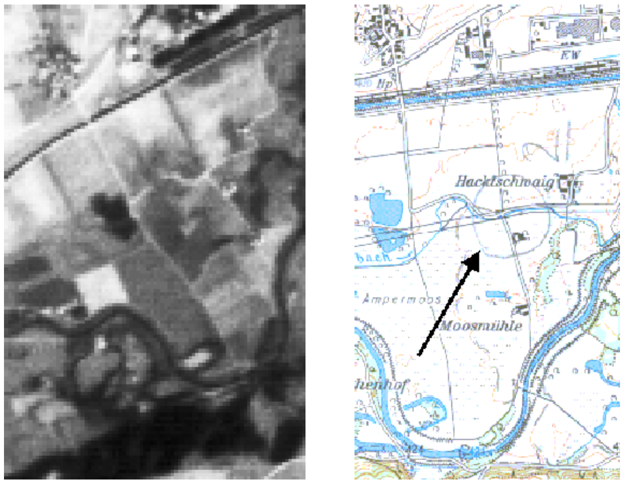


Figure 2: Example of a ground control point

of 3rd order roads was identified being a GCP. This example shows quite well the difficulties for point identification.

The aerotriangulation was carried out with the Spotcheck+ program of Kratky Consulting. During the investigation we used two orientations. One set of orientation parameters covers the whole area of 178*km* by 50*km*, a second set consists only of the upper half of the computed strip.

Table 1 shows the results delivered by the Spotcheck+ program. The results for the whole DTM area indicate, that using 10 GCPs and the quadratic attitude model the accuracy of the GCPs comes close to σ_0 = 5.5μm. Therefore the measurement precision of the image coordinates is of about 0.5*pixels* adequate with 8.5*m* in object space. Due to the measurement conditions this result is quite satisfactory. A detailed view of the inner accuracy of the GCPs and Check Points (CPs) is shown by the values $\bar{\sigma}_x, \bar{\sigma}_y$ and $\bar{\sigma}_z$ in this table. The exterior accuracy of the Check Points is also outlined. For the whole area root mean square errors (rms) can be differentiated in rms_x = 11.2*m*, rms_y = 11.4*m* and rms_z = 13.7*m*. Moreover, Table 1 shows the results of the orientation of the upper half of the examined area. Obviously these results do not differ very much from the results of the orientation of the whole examined area.

	GCP	Check points	σ_0 [μm]	$\bar{\sigma}_x$ [m]	$\bar{\sigma}_y$ [m]	$\bar{\sigma}_z$ [m]	RMS_x [m]	RMS_y [m]	RMS_z [m]
Whole DTM area	10	24	5,5	6,7	5,5	5,5	11,2	11,4	13,7
Upper half of DTM	9	35	6,1	7,0	5,9	6,9	11,8	13,5	13,1

Table 1: Results of the aerotriangulation (whole area 178*km* x 50*km* and upper half area)

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

3 DTM DATA COLLECTION AND VALIDATION

3.1 Data Collection

For the DTM data collection a least squares matching module was started with the following parameters: DTM grid of 5x5*pixels* grid distance and matching window size of 21x21*pixels*. In case of failed matchings the window is increased to 31x31*pixels* and finally to 41x41*pixels*. The implemented self diagnosis was set to a precision of 0.1 pixels by default. The computed area of the DTM has a size of 178*km* by 50*km*.

About 1.2 million points had to be matched in a dense regular grid. The approximation values were of about ±40*pixels*. Therefore the point transfer was done by using a coarse-to-fine approach with 5 pyramid levels and the original image level. All points which could not be matched by the default window were again transferred with the alternative window sizes. Experimentally a success rate of 97.73% was obtained. There are two different explanations for this excellent matching quota. On the one hand the comparison of the MOMS-2P images with those of the MOMS02-D2 shows a much better radiometric quality, on the other hand with the new strategy of using multiple window sizes the success rate of the point transfer increased from 73% to the already mentioned 97.73%. This means that only 2.27% of all points could not be matched. Most of those points belong to areas of low texture.

3.2 Overall DTM Validation

For almost all MOMS scenes processed so far the validation of the derived DTM was quite difficult because of the absence of sufficient ground truth data. Fortunately for our test site a complete ATKIS DTM exists with a grid size of 50*m* and a height accuracy of better than 5*m*. This reference DTM has been made available by the Bavarian State Surveying Department. The comparison of ground heights between the ATKIS DTM and the overall MOMS DTM finally yields the following accuracies:

Mean offset:	+6.3*m*
Rms:	13.2*m*
Unbiased rms:	11.6*m*

3.3 Reconsideration of DTM Validation

The results above of the overall DTM accuracy do not meet the expectations. Therefore, a further investigation was made by classifying the errors in two types of landuse. Previous experiences have shown that the MOMS-DTM produces big errors in forest areas.

Two classes for the more detailed investigation were chosen. The first class consists of forest areas and the second of open and urban areas. Since no multispectral image data for a thematic classification was available, only these two classes were manually generated. An operator used orthophotos with a pixel size of 20*m* for the classification. It was especially difficult in some cases to detect the correct class. To obtain the accuracy in urban areas, a specific investigation with four city regions (Erding, Freising, Ingolstadt and Landshut) inside the examined DTM was carried out.

With this more detailed investigation a better understanding of the error distribution inside the DTM should be possible. Figure 3 shows the results. Using these two classifications on the whole examined area of the DTM the accuracies will not change significantly . For

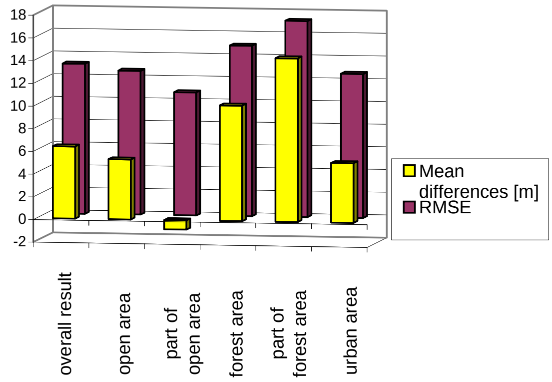
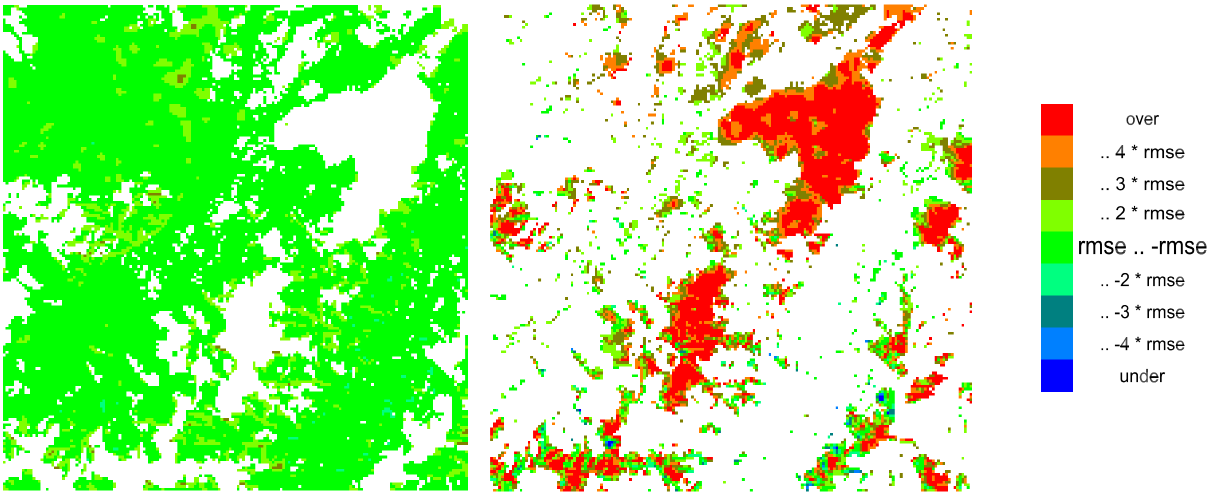


Figure 3: Detailed accuracies of the MOMS-DTM

open land and urban areas the rms only improves to 12.7*m*, and the mean error in height only to 5.2*m*. The accuracy of forest areas also changes not that strict one would expect (rms = 15.0*m*, mean differences = 10.2*m*). Figure 4 shows parts of these difference images. Especially the part of forest areas shows that the used classification is fuzzy. Most of the middle grey points in Figure 4 (range –rms to rms) indicate a wrong classification. This means that the differences which belong to open areas, and therefore show only small figures, are used for the calculation of forest areas by mistake. Therefore only little parts of the DTM were used for the examination. Manually, three classes were chosen. Open land, which contains only a few small cities, forest areas with big contiguous plains and an urban area, which contains the four named cities. The accuracies of these areas are shown in Table 2 (see also Figure 3). For open land a systematic error of –0.8*m* with an rms of 10.8*m* was obtained. This is an equivalent result with respect to the exterior orientation. The other two results are also quite satisfying. Forest areas are measured systematically too high. This leads to the mean error of 14.4*m* and to the rms of 17.3*m*. For urban areas, a systematic of 5.3*m* and a rms of 12.7*m* were obtained. Please notice, that the number of used observations for the urban area is quite small.

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.



Open and urban area Forest area

Figure 4: Accuracy shown for examples of the classified regions (open and urban area, forest area)

	Overall results (no classes)	Open area		Forest area		Urban area
		whole DTM	chosen parts	whole DTM	chosen parts	
Number of observations	474426	370415	131999	104011	70284	4685
Mean differences [m]	6,358	5,285	-0,815	10,180	14,419	5,259
RMS [m]	13,213	12,658	10,839	15,026	17,279	12,696
Unbiased RMS [m]	11,583	11,502	10,808	11,052	9,520	11,557

Table 2: Number of used observations

Removing the systematic effects of forest areas the rms of 11.6*m* shows approximately the accuracy of the MOMS-2P DTM. Included in this number is the uncertainty of the reference DTM. Thus a MOMS DTM accuracy of about 10*m* is verified by this DTM ground truth test.

4 ORTHOPHOTOS

With the derived DTM and the images of the forward and backward looking channel respectively orthophotos with a size of 9125*pixels* by 5725*pixels* were computed. The GSD of these orthophotos is 20*m*. Figure 5 shows again the area around the airport Munich within the orthophoto of the forward looking channel. The DTM could be checked by carrying out again a point transfer with the least squares matching modul. Within the two orthophotos it is expected that the parallaxes in x and y direction are zero.

Figure 5: Zoom into the orthophoto of forward looking channel (pixel size 20*m*, airport Munich)

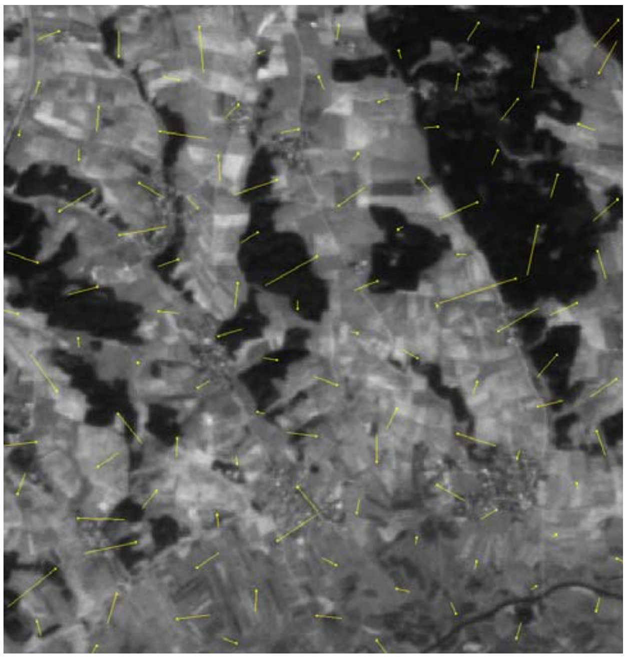


Figure 6: Orthophoto with superimposed parallax vectors

For this application again a regular grid was used with a grid width of 10*pixels*. The result was quite satisfactory. Over 99.46% of all points could be matched which shows that the whole area could be taken into account for this verification. Figure 6 shows a section of the orthophoto with overlayed vectors of the parallaxes. One can see, that the vectors are randomly distributed what means that no large systematic errors are availabe. The following two figures show some other visualizations of the results. Figure 7 indicates an orthophoto superimposed with a topographical map. Surely, this figure could not exactly verify the result. But it shows quite well that no big errors exist inside the computed orthophotos. Forest areas, streets and rivers fit quite well between the overlayed topographical map and the orthophoto. Another result is

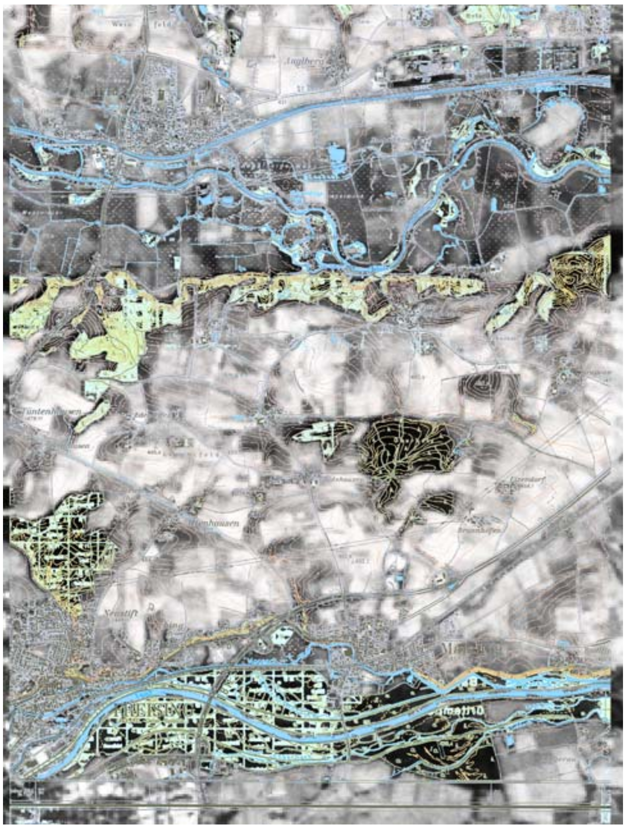


Figure 7: Orthophoto with superimposed topographical map

shown in Figure 8 where the topographical map is superimposed over the DTM. The bright regions represent the areas of high altitude and the dark ones stand for the lower height respectively. Again one can see that the contour lines correlate with the MOMS DTM.

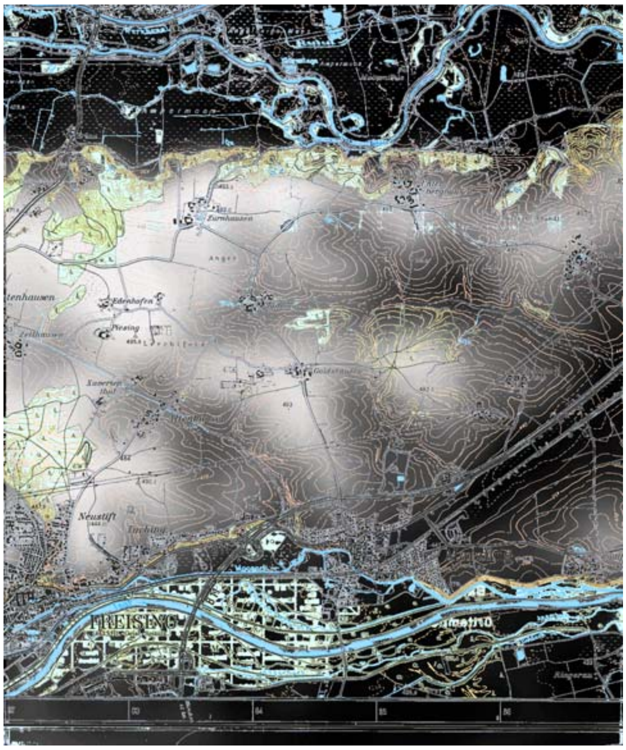


Figure 8: DTM with superimposed topographical map

5 CONCLUSIONS AND OUTLOOK

Fortunately, for the comparison of the derived MOMS-2P DTM a reference DTM with 50*m* grid size and an accuracy in height of better than 5*m* was available. We processed only the scenes 27 to 30 of the data take M2P083C which covers a southern part of Germany. With these scenes a DTM was reconstructed with an extension of 178*km* by 50*km* and a grid size of 100*m*. The achieved accuracy of the MOMS DTM is close to 10*m*. Some systematic errors are observed and shown by the histogram in Figure 9. These errors mainly result from the forest areas. To generate a more accurate DTM one has to include routines into the DTM generation process which automatically detect those critical regions. The test with the computed orthophotos has also shown that the DTM derivation works quite satifactory.

An alternative solution for the determination of the exterior orientation of MOMS-2P images is currently under investigation. Instead of the conventional aerotriangulation GPS, INS and star sensors can be used for direct determination of position and attitude data of the MOMS camera. This solution will facilitate the aerotriangulation

D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

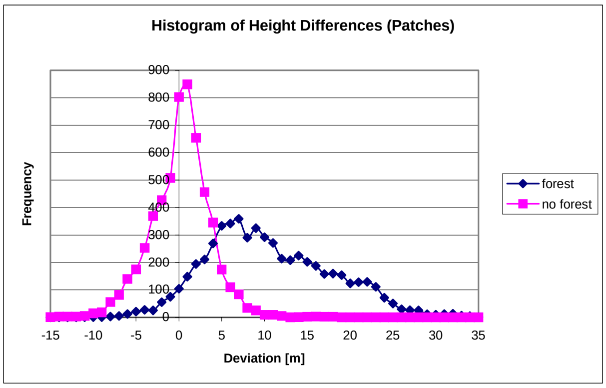


Figure 9: Histogram of height differences in forest and other areas

and ground control point measurement processes certainly again. We are quite optimistic that this will result in a further improvement of the quality of the exterior orientation and directly benefits the DTM reconstruction process.

Acknowledgement

The generous support given by the Bavarian State Surveying Department is gratefully acknowledged.

Furthermore, we thank the DLR section “Project Management” (former DARA) for funding the MOMS02-P project.

6 REFERENCES

Fritsch, D. (1996): MOMS, Fortschritt in der optischen Fernerkundung, In: Geowissenschaften, 14(10), pp. 399-408

Fritsch, D., Hahn, M., Schneider, F., Stallmann, D. and Kiefner, M. (1996): Experiences in processing MOMS-02/D2 Stereo Image Data. In: Proc. ISPRS Congress Comm. IV, XXXI/B4, pp. 267-272

Fritsch, D., Kiefner, M. and Schneider, F. (1997): MOMS-02/D2 DTM Generation Using Intensity Based Least Squares Matching Techniques In: Proceedings of SPIE: Integrating Photogrammetric Techniques with Scene Analysis and Machine Vision III, Vol. 3072, pp. 132-142

Fritsch, D., Hahn, M., Kiefner, M. and Stallmann, D. (1998): Comprehensive Ground Truth Evaluation of MOMS-2P DTM Reconstruction In: Proceedings of ISPRS: Object Recognition and Scene Classification from Multispectral and Multisensor Pixels, Vol. 32, Part 3/1, pp. 325-330

Kornus, W., Lehner, M., Ebner, H., Fröba, H. and Ohlhof, T. (1998): Photogrammetric Point Determination and DEM Generation using MOMS-2P/Priroda Three-Line Imagery In: Proceedings of ISPRS: GIS - Between Visions and Applications, Vol. 32, Part 4, pp. 321-329

Seige, P., Reinartz, P. and Schroeder, M., (1996): The MOMS-2P Mission in the MIR Station. In: Proc. ISPRS Symposium Comm. I, Vol. XXXII, Part 1, pp. 204-210.

Schneider, F., Hahn, M. [1995]: Automatic DTM Generation using MOMS-02/D2 Image Data. In: *Photogrammetric Week '95*, Fritsch, D., Hobbie, D. (Eds.), pp. 85-94, Wichmann Verlag, Heidelberg, 1995.