First Results on Accuracy Analysis for DEM and Orthoimages Derived from SPOT HRS Stereo Data over Bavaria

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ABSTRACT

ISPRS and CNES announced the HRS (High Resolution Stereo) Assessment Program during the ISPRS Commission I Symposium in Denver in November 2002. 9 test areas throughout the world have been selected for this program. One of the test sites is located in Bavaria, Germany, for which the PI comes from DLR. The goal is to derive a DEM from the along-track stereo data of the SPOT HRS sensor and to assess the accuracy by comparison with ground control points and DEM data of superior quality. For the derivation of the DEM, the DLR own stereo processing software, developed for the MOMS-2P three line stereo camera is used. As a first step, the interior and exterior orientation of the camera, delivered as ancillary data (DORIS and ULS), which should lead to an absolute orientation accuracy of about 30 meters, are extracted. No bundle block adjustment with ground control is used in the first step. A dense image matching, using every pixel as a kernel center, provides parallaxes for every pixel. The quality of the matching is controlled by forward- and backward matching of the two stereo partners using the local least squares matching method. Forward intersection leads to points in object space which are then interpolated to a regular DEM of the region in a 20 meter grid. As a second step, orthoimages are generated from the images of the two looking directions, using the derived DEM. The orthoimage and DEM accuracy is determined by using the ground control points and the available DEM data of superior resolution (DEM derived from laser data). As the original image data were received with delay by mid of July 2003 only very preliminary results can be given in this paper.

Keywords: Digital elevation models, SPOT HRS, along track stereo, image matching, orthoimages

1. INTRODUCTION

The derivation of terrain models from along track stereo data from space has up to now only been possible with the German MOMS-2P (Müller et al. 2001) and the American ASTER sensor on TERRA (Toutin et al. 2001). Both of them have lower resolution (15-18 meter pixel size) than the new HRS sensor on SPOT 5. HRS produces image stereo pairs with two optics looking forward and backward with ±20 degrees with respect to the nadir direction. It has a spatial resolution of 10 meter across track and a 5m ground sampling distance along track for obtaining higher accuracy of the parallaxes for the DEM generation. The swath of the HRS is 120 km (12000 CCD elements) and one acquisition sequence is 600 km along track.

After the ISPRS Commission I Symposium in Denver in November 2002, the HRS Scientific Assessment Program has been established. This program gives the user community the opportunity to test HRS data, which are usually not available, for generating DEM and for comparison with other DEM generation methods. Further it should provide CNES an international scientific performance assessment of the HRS which will be taken into account for future programs. For the investigations 9 test areas around the world with corresponding PIs and co-investigators have been selected. Only those areas have been selected, where the PIs could provide a sufficient data set of ground control points and a high precision DEM for comparison and accuracy checking of the derived HRS-DEM.

The data which have been provided by SPOT IMAGE contain the following parts:

- 8 bit image data (size 12000 x 12000 pixel = 120 km x 60 km) of the Bavarian test area from two viewing directions in TIF format
- XML-files containing all additional information regarding time synchronization, position (DORIS), attitude (star sensors), inner orientation
- ASCII text files containing information on the delivered data.

The data have been acquired on October 1st 2002 with a sun elevation of 38 degrees and nearly no clouds, which promises sufficient image matching possibilities.
The data set was distributed by CNES in mid of July 2003, therefore not all planned evaluations could be performed until the delivery of this paper. In this paper only very preliminary results will be given. The investigations will continue until the end of 2003 and more detailed results will probably be given at the ISPRS Istanbul congress in 2004.

2. TEST AREA AND GROUND REFERENCE DATA

The test area chosen by DLR is a region of about 40 x 50 km² in the southeastern part of Bavaria. The elevations range from 400 to 2000 meters in a mostly hilly, post-glacial landscape including some lakes and also mountains of the German Alps. This selection allows the comparison of DEM for different land surface shapes, including forest and steep terrain. The ground reference data chosen for this test area are the following:

- Four regions have a pixel spacing of 5 meters and an overall size of about 5 km x 5 km, derived from airborne laser scanning. The height accuracy is better then 0.5 meter.

- One region (area of Inzell, total: 10 km x 10 km, 25 meter spacing) consists partly of laser scanner data (northern part). The height accuracy is here better then 0.5 meter.
  The southern part of the DEM is derived from contour-lines 1:10 000. The height accuracy is about 5 meter due to the mountainous area and the method used.
- A large region (50 km x 30 km) is covered by a coarser DEM with 50 meter spacing and height accuracy of about 2 meters
- 81 ground control points (fix points) are listed in a pdf document, with detailed description of the exact location of each point.

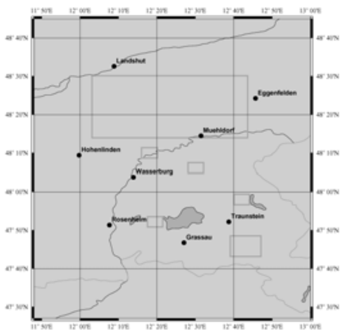

Figure 1: HRS test area: Chiemsee

Fig. 1 shows the location of the test area at the most southeastern part of Germany.

3. EVALUATION OF ANCILLARY DATA

The delivered SPOT 5 HRS Level 1A product consists of the image data in standard TIF format and the meta data in DIMAP format. The following information is extracted from the XML ancillary file for further processing:

- the ephemeris data containing position and velocity of the satellite measured by the DORIS system every 30 seconds with respect to the ITRF90 (International Terrestrial Reference Frame 1990) system during the data take and at least four times before and after image data acquisition,
- the corrected attitude data with respect to the local orbital coordinate frame measured by the star tracker unit ULS with 8Hz,
- the look direction table for the 12000 CCD pixel elements expressed within the body fixed coordinate frame and
- the data used for time synchronization like sampling period and scene center time.

According to the „SPOT Satellite Geometry Handbook“ (SPOT IMAGE 2002) Lagrangian interpolation of the ephemeris data and linear interpolation of the attitude data are used to calculate data sets for every scan line. Further processing leads to the exterior orientation (position and attitude) for every scan line expressed in a local topocentric system (LTS) with a fundamental point located at the center of the image scene which serves as input for our processing software.

4. IMAGE MATCHING

The first matching of the two images is performed purely in image space with DLR software. Details on this software are described in Lehner et al. 1992. It relies on a resolution pyramid and applies intensity matching in two forms: normalized correlation coefficient for pixel accuracy and subsequent local least squares matching for refinement to subpixel accuracy (0.1 to 0.2 pixel accuracy). First interest points are generated with a Förstner operator and the homologous points are searched for in the other image. Only points with high correlation and quality figure are selected as tie points for bundle adjustment (see chapter 6.) and a lower criterion is valid for the usage as seed points for the subsequent Otto-Chau region growing dense matching procedure (Heipke et al 1996). This local least squares matching starts with template matrixes of 13 x 13 pixels around the seed points with a step of 1 pixel in each direction. For cross checking a backward match is performed for all points found. For the HRS stereo pair, the 12000 x 12000 pixel scene was divided into chips of 3500 x 3500 pixels with 500 pixels overlap. Table 1 shows the amount of pixel matched in forward and backward directions for 12 image chips. From the differences of the image coordinates a standard deviation of about 0.14 pixel is found. Points showing differences higher than 0.5 pixel in the backward matching are eliminated. The high matching performance is due to the good image quality and to the selection of a landscape with high contrast. In the regions of lower contrast (lake, mountain shadow, forest) in the last chip, the amount of detected points is much less.

Table1: Matching of HRS stereo pair, percentage of matched points (each chip contains 12,250,000 pixel)

Chip number	forward match [% of pixel]	backward match [% of pixel]	Total matched [% of pixel]
01/01	87,7	93,8	82,2
01/02	81,8	93,6	76,5
01/03	84,1	94,3	79,3
01/04	85,0	94,8	80,5
02/01	82,7	92,8	76,8
02/02	79,4	93,2	74,0
02/03	71,4	94,4	67,5
02/04	73,3	91,4	67,0
03/01	76,7	93,0	71,3
03/02	81,4	94,7	77,1
03/03	78,0	94,1	73,4
03/04	55,1	86,6	47,7
All chips	**78,3**	**93,3**	**73,1**

5. ORTHOIMAGE GENERATION AND ACCURACY ANALYSIS

To get an impression on the accuracy of the position and attitude data, a first step is to derive orthoimages using an already available DEM. This is done to get an estimation of the necessity to improve the ancillary data by bundle adjustment or other methods.

The inputs for the orthoimage production are the interior orientation (extracted from the meta data file), the six parameters of the exterior orientation with respect to an unique coordinate frame for each image line (interpolated from the sampling points) and the digital elevation model (DEM). The used DEM has been derived by DLR from several ERS 1/2 Tandem pairs, the accuracy is in the order of 5 to 10 meter in flat and hilly terrain and 10 to 50 meter in mountainous terrain. Therefore the more reliable part of the orthoimages is found north of the foot of the Alps.

The principle of the orthoimage production is based on the forward intersection of the actual sensor viewing direction (pointing vector) and the DEM applying the rigorous collinearity equation. The orthoimage processor calculates the object points within the intermediate local topocentric system and then transforms them to the desired coordinates of a map projection using geodetic datum transformation parameters (Müller et al. 2002).

After generation of the two orthoimages without any ground control information, a check of the accuracy using 11 of the ground control points has been performed. The measuring accuracy of the control points is better than ½ pixel size. Table 2 shows the deviation in x an y direction for the orthoimage in comparison to the control points.

Table 2: Difference of orthoimage points and ground control points in meter in Gauss-Krüger coordinate system

Table for forward looking image

TK25 Nr.	Point number	Diff. (m) x	Diff. (m) y
7740	017 25	-10	4
7838	084 00	-6	-3
7841	066 00	-8	-9
7940	011 25	-1	4
8040	107 00	2	6
8138	030 00	-8	9
8140	136 00	-5	3
8141	153 00	-17	-2
8141	169 00	-9	-8
8142	098 00	-6	-4
8239	066 25	-7	7
	RMSE	8,7	6,2

Table for backward looking image

TK25 Nr.	Punktnummer	Diff. (m) x	Diff. (m) y
7838	084 00	-7	24
7841	066 00	-21	20
7940	011 25	-15	25
8040	107 00	-6	28
8138	030 00	-14	39
8140	136 00	-7	22
8141	153 00	-19	21
8141	169 00	-12	20
8142	098 00	-9	27
8239	066 25	-9	34
	RMSE	14	28

The upper table contains the data for the forward looking image. The result shows that even without any ground control, the absolute georeferencing accuracy of the HRS sensor is better than the pixel size of 10 x 10 meter. This is much better than expected. The backward looking channel shows less absolute positioning accuracy. Mainly in flight direction there is an offset of 2 to 3 pixel. While the differences in x direction (mainly across track) are similar for both images (about –10 m), the differences in y direction (mainly along track) have a nearly constant offset of about 30 meter.

An automatic matching of the two orthoimages reveals that the difference vectors show a very homogeneous behavior, mean length is about 30 meter (Fig. 2). Only in the region of the mountains, where the used DEM is of less performance there is a little deviation to that constant offset.

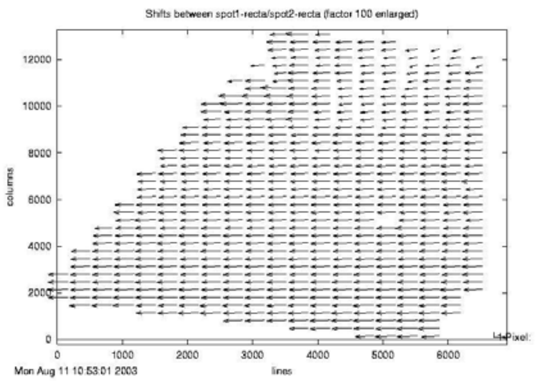

Fig. 2 Shifts between the two orthoimages derived from forward and backward looking channels of SPOT HRS (mean values in a regular grid)

The reason for this nearly constant offset and how it can be modeled in the evaluation process has to be further analysed.

6. FUTURE WORK

Having the mass points of correlation from the matching process as well as the exterior and interior orientation of the camera system, the surface heights can be calculated using forward intersection. This is done by least squares adjustment for the intersection of the image rays. However exterior and interior orientation can be improved beforehand in using the best tie points, some ground control points and the method of bundle block adjustment. For the bundle adjustment the software package CLIC, developed at the University of Munich will be used (Kornus et al. 1999). The results for the changes in interior orientation will be compared to the publications by IGN and SPOT IMAGE.

The irregular distribution of points in object space after the forward intersection has to be regularized into a grid of about 20 x 20 meter pixel size. The interpolation process is performed by a moving plane algorithm (Linder 1999). This derived surface models will be compared by several methods regarding: height accuracy, location accuracy, single events, error budget depending on surface properties etc., with the high precision DEM from Laser data and with the lower resolution DEM (2 meter) from contour lines.

The improved interior and exterior orientation is used to produce orthoimages with the derived HRS-DEM.

7. REFERENCES

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