GEOMETRIC CHARACTERISTIC OF DIGITAL FRAME CAMERAS

Volker Spreckels[1], Andreas Schlienkamp[2] and Karsten Jacobsen[3]

1. RAG Aktiengesellschaft, Dept. Geoinformation/Engineering Survey (BG G), D-44623 Herne, Germany; volker.spreckels@rag.de
2. RAG Aktiengesellschaft, Dept. Geoinformation/Engineering Survey (BG G), D-44623 Herne, Germany; andreas.schlienkamp@rag.de
3. Leibniz University Hannover, Institute of Photogrammetry and Geoinformation, D-30167 Hannover, Germany; Jacobsen@ipi.uni-hannover.de

ABSTRACT

In this contribution the geometric characteristics of a digital photogrammetric aerial camera are discussed for the generation of digital elevation models (DEM) and stereo plotting. Due to legal restrictions the German hard coal mining company *RAG Aktiengesellschaft* (RAG), successor of the *Deutsche Steinkohle AG*, is obliged to conduct a monitoring on earth surface changes caused by mining activity. To fulfil legal demands in effective manner process chains using photogrammetry, remote sensing and Geo Information Systems (GIS) have been established. Photogrammetric methods are used to generate high resolution DEMs from which - in combination with subsidence information - geometric changes to the topographic surface are deduced. For mine site areas from about 100 km² up to 200 km² DEMs have to be generated by means of digital photogrammetric stereo-workstations with a standard deviation of ±10cm for the height. This accuracy up to now could be attained with analogue wide angle cameras at an image scale of 1:4000 and 80% end lap together with a high number of ground control points.

In March 2006 an aerial flight campaign had been performed with the Microsoft Photogrammetry UltraCamD because only this camera is able to take images with 80% end lap, 10cm ground sampling distance (GSD) and a theoretical possible height accuracy of about ± 8 to 9cm. DSK noticed that the stereo-measurements in neighbouring UltraCamD models, having 60% end lap, did not fit very well to each other in height. For this reason the stereo plotting was mostly done in the center parts of models with 40% end lap. The flown 80% end lap made it possible to calculate two DEMs from image combinations with 60% end lap: one DEM with even and one DEM with odd image numbers. The comparison of these DEMs resulted in height differences up to 30cm. Compared to the DEM of an analogue flight it could be shown that the height differences are based on systematic image errors of the UltraCamD that led to not negligible model deformation.

For this reason the images have been processed again based on the original sub-images using new Microsoft Photogrammetry software, which shall respect the effects of the temperature to the camera geometry. The differences between the varying DEMs with and without temperature correction are presented, as well as the systematic image errors and model deformations determined by the Hannover program system BLUH. Also the analysis of the a posteriori corrected DEMs based on the resampling of the images with the program IMGEO for accurate stereo-measurements is presented.

INTRODUCTION

Since 2004 three photogrammetric aerial flights have been made for RAG with the same UltraCamD (Spreckels et al 2005). In 2006 a large block of about 120 km² and 2.800 images was flown for the generation of a 5m-DEM and additional refinement by stereo plotting of topographic structures (see figure 1, left). The flight was performed with 80% end lap, 35% side lap and ground sampling distance of 8cm to 11cm depending on the flying height above ground. 185 ground control points (GCP) served as ground reference.

Like in the flight campaigns before the stereo plotting showed differences in height of about 30cm for neighbored 60% stereo models based on systematic effects in the digital aerial images. RAG noticed that usual commercial digital photogrammetric workstations were not able to handle systematic image errors determined by bundle block adjustment. The model deformations were acceptable for the horizontal coordinate components, but in the height, deformations exceeded the accuracy limit. The stereo plotting was mostly done in the center parts of models with 40% end lap that showed minimal differences for connecting the measurements (Spreckels et al 2007).

Microsoft Photogrammetry modified the cameras and data handling and in 2007 the virtual UltraCamD images have been generated again with the improved merging software based on the original sub-images. A sub-block of 108 images has been triangulated in a pan-sharpened colour channel and once more with RGB-images (level 3) (see figure 1, right). The new generated DEMs have been compared to each other (60% odd image number DEM to 60% even image number DEM) and to an analogue RMK TOP 15 DEM based on a flight in 2005.

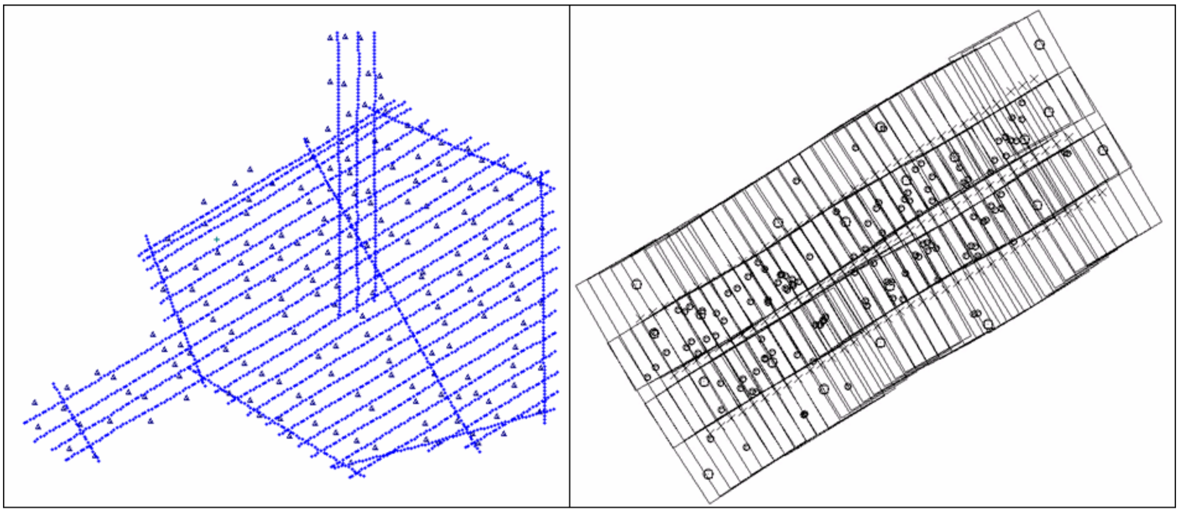

Figure 1: Left: UltraCamD flight campaign 2006 with projection centres and ground control points. Right: sub-block with used control points (large symbols) and 125 check points (small symbols).

METHODS

For digital aerial camera data different ways for data processing exist. Usually the RGB or CIR images are delivered and the aerotriangulation (AT) and DEM matching are performed in one pan-sharpened colour channel, usually the green channel. The analysis of the colour channels images showed large height errors caused by the green channel so RAG used the red colour channel for data processing (Spreckels et al 2007).

If level 2 data are available, it is possible to use only the panchromatic channel that is not influenced by the camera geometry of the colour channels. But daily practice shows that the photogrammetric operators do not really prefer measuring in panchromatic stereo images if colour images are available. RAG performed the AT and DEM matching with the images corrected with the new Microsoft Photogrammetry merging software and compared the resulting DEMs to each other, to the DEMs matched with the old software and to the analogue DEM. To exclude the regions with maximum deformation at the border areas RAG reduced the models with 40% end-lap in longitudinal and lateral direction. The new merging software reduced the large discrepancies in height but still systematic image errors occur. For this the sub-block (figure 1 right) was handled again to detect the systematic image errors and to determine the model deformation in pan-sharpened red-channel and in RGB images with the Hannover program system BLUH.

Detailed analysis with BLUH

In the pan-sharpened red channel sub-block only 15 control points are available, so the analysis of check points is limited to 5 independent check points and 10 ground control points (GCP). The averaged image residuals are indicating systematic image errors nevertheless these are smaller compared to the images based on the old software (see figure 2).

In the RGB sub-block only 11 original not well distributed control points were available. For this reason additional identical points from the adjustment of the whole block, based on the images mosaiced with the old software in 2006, have been used. Now 20 control points and 125 check points were available.

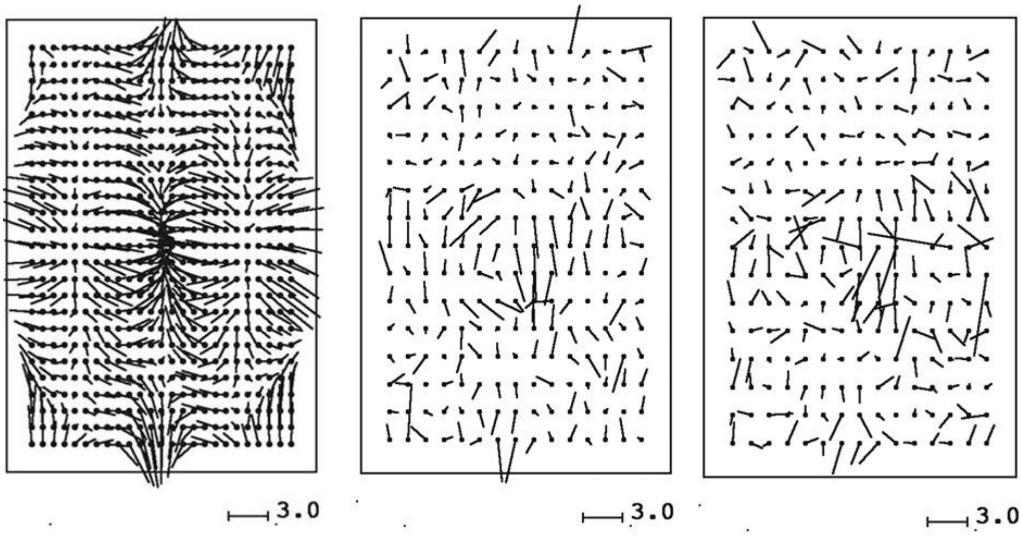

Figure 2: Averaged residuals of block adjustment without self calibration: old software (left), new software, pan-sharpened colour channel (mid), new software, RGB images (right).

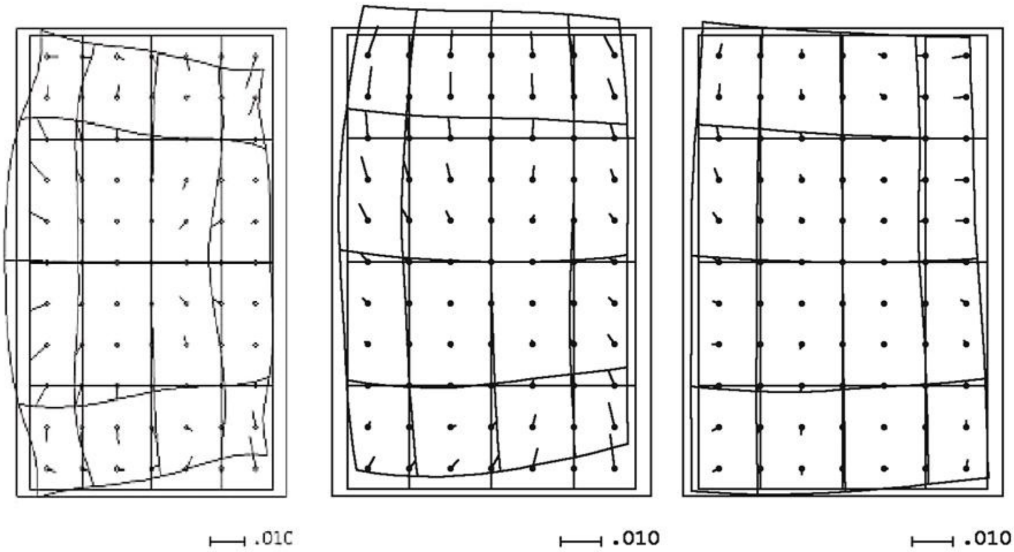

Figure 3: Systematic image errors, additional parameters 1-12: old merging software (left), new software, pan-sharpened colour channel (mid), new software, RGB images (right).

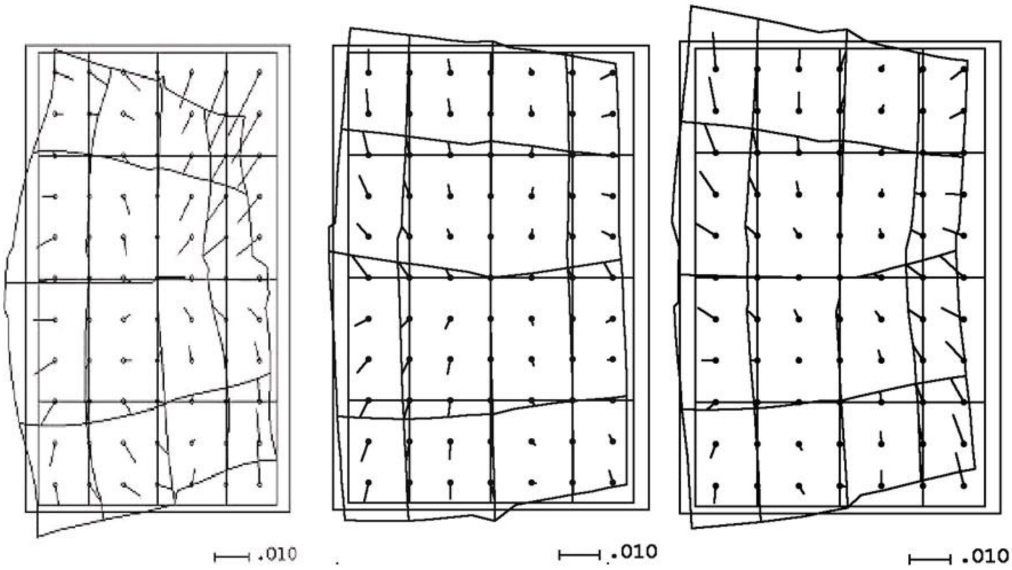

Figure 4: Systematic image errors, additional parameters 1-12 and 42-73: old software (left), new software, pan-sharpened colour channel (mid), new software, RGB images (right).

The systematic image errors (difference of image geometry against the mathematical model of perspective geometry) are smaller than in the case of the image matching based on the old software. Additionally the discrepancies do not emerge very much in x-direction and for this reason they are not that much influencing the height. The y-parallaxes still effect the measurements in stereo-view in the border areas of the stereo model.

Table 1: Pan-sharpened images: root mean square discrepancies (10 control and 5 check points).

	sigma0	RMS at control points [cm]			RMS at check points [cm]		
Add. Par.	[µm]	RMSX	RMSY	RMSZ	RMSX	RMSY	RMSZ
without	2.66	4.5	4.6	6.8	4.3	7.2	7.3
1-12	2.61	4.0	4.1	14.2	4.7	6.9	6.4
1-12 and 42-73	2.57	3.7	3.8	10.8	4.7	6.8	7.5
GSD = 9.5cm							

Table 2: RGB-images: root mean square discrepancies at 20 control and 225 check points.

	sigma0	RMS at control points [cm]			RMS at check points [cm]		
Add. Par.	[µm]	RMSX	RMSY	RMSZ	RMSX	RMSY	RMSZ
without	3.34	3.1	3.1	5.0	4.1	4.1	6.5
1-12	3.32	3.2	2.8	4.8	3.9	4.0	6.7
1-12 and 42-73	3.28	2.7	2.6	3.7	3.8	4.0	6.5
GSD = 9.5cm							

Because of the limited number of control and check points for the pan-sharpened images the result should not be over-interpreted. Nevertheless there is a small trend that by using the standard additional parameters 1–12 best results are reached, while without self-calibration the results are not that good. With self-calibration by 12 standard parameters plus 32 UltraCam-specific parameters an over-parameterization cannot be avoided. In general in relation to the 9.54cm GSD for such a limited block, the results are satisfying.

The results from the RGB images are more realistic than the results achieved with the small number of control and check points for the panchromatic images. In panchromatic images just 5 points, corresponding to the block adjustment 2006 could be identified. In RGB images with the full number of additional parameters the best results could be achieved, but the differences are small. The accuracy of the check points is depending upon the number of images per point (see figure 5).

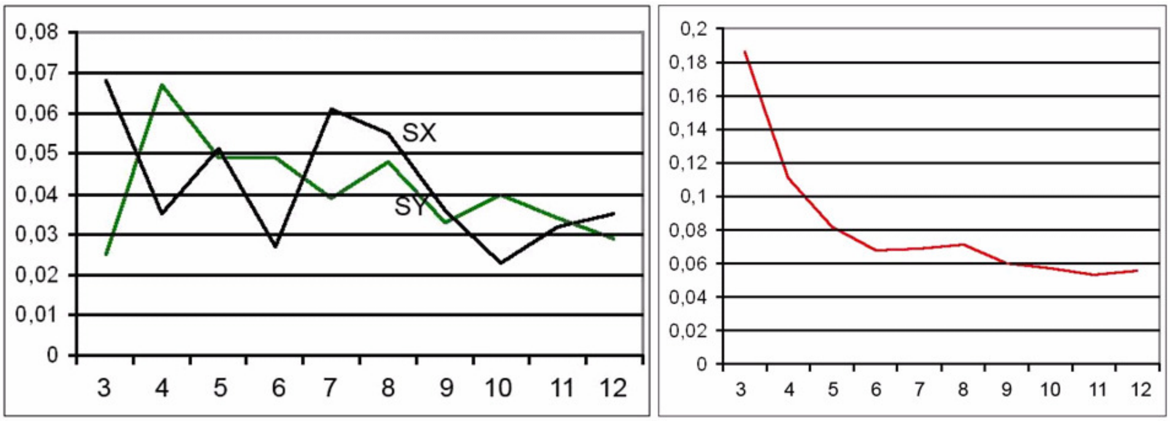

Figure 5: SX, SY (left) and SZ (right) at independent check points as function of number of images per point.

The systematic image errors are leading to deformations of optimal oriented models like shown in the following figures. For the adjustment with the **additional parameters 1-12** the extreme values are:

-20cm and +12cm,	*old merging software, 60% endlap,*
-16cm and +2cm,	*old merging software, **40%** end lap,*
-5.0cm and +1.7cm,	RGB-images, 60% endlap,
-11.1cm and +5.8cm,	pan-sharpened images, 60% end lap,
-12.3cm and +6.1cm,	pan-sharpened images, **40%** end lap,

while it is for the **additional parameters 1–12 plus 42–73**:

-35cm and +23cm,	*old merging software, 60% endlap,*
-21cm and +9cm,	*old merging software, **40%** end lap,*
-11.3cm and +9.1cm,	RGB -images, 60% endlap,
-10.1cm and +6.7cm,	pan-sharpened images, 60% end lap,
-7.9cm and +5.6cm,	pan-sharpened images, **40%** end lap.

With the height to base relation of this model of 4.51 (height above ground = 1077m, base = 238m), the largest model deformation of 11.3cm corresponds to 0.26 GSD, which is in the range of the vertical accuracy.

For the additional parameters 1–12 the model deformation based on the images merged with the new software is limited – the corresponding systematic image errors, shown in figure 3, mainly can be compensated with an optimal image orientation. The model deformation caused by the additional parameters 1–12 plus 42–73 are, for RGB-images, smaller by the factor 2 and for the pan-sharpened images smaller by the factor 3 than the model deformation based on the old software for image merging.

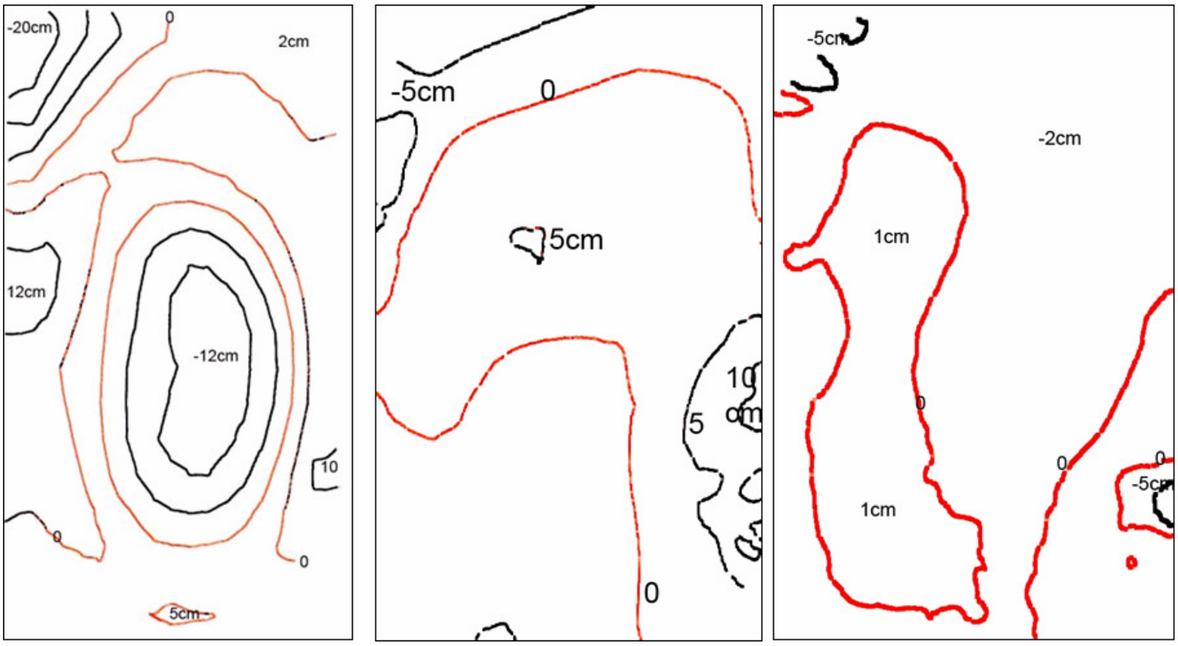

*Figure 6: Model deformation at **60% end lap**, additional parameters **1-12**: old merging software (left), new merging software, pan-sharpened colour channel (mid), new merging software, RGB-images (right).*

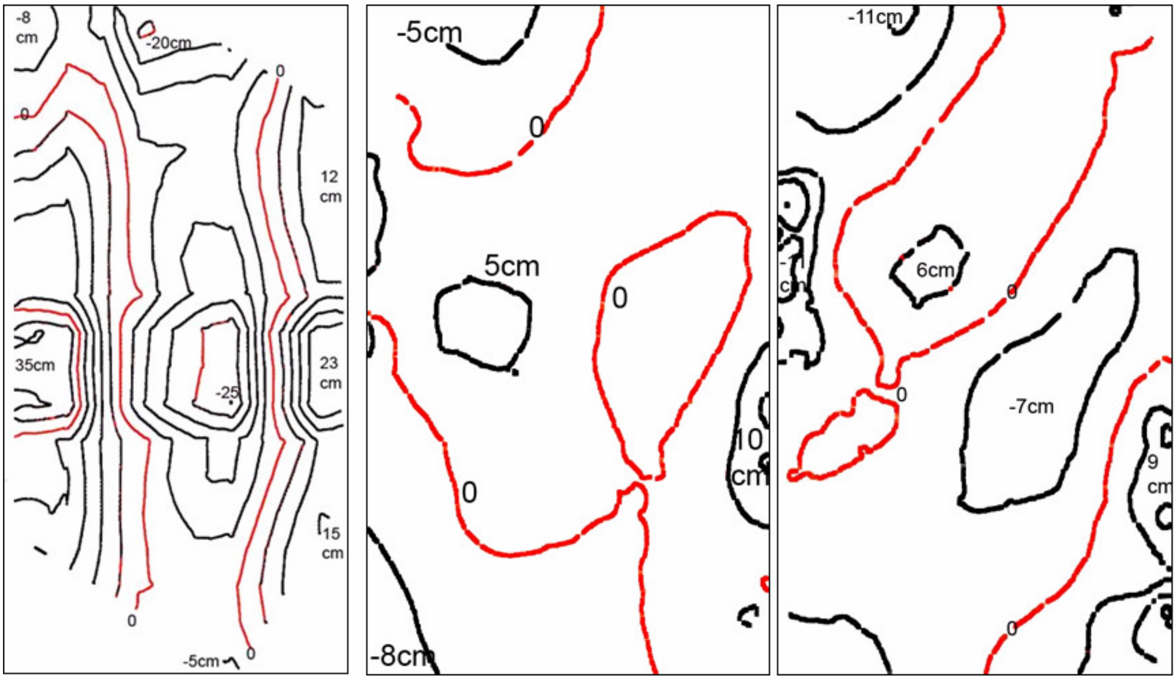

*Figure 7: Model deformation at **60% end lap**, additional parameters **1-12 and 42-73:** old merging software (left), new merging software, pan-sharpened colour channel (mid), new merging software, RGB-images (right).*

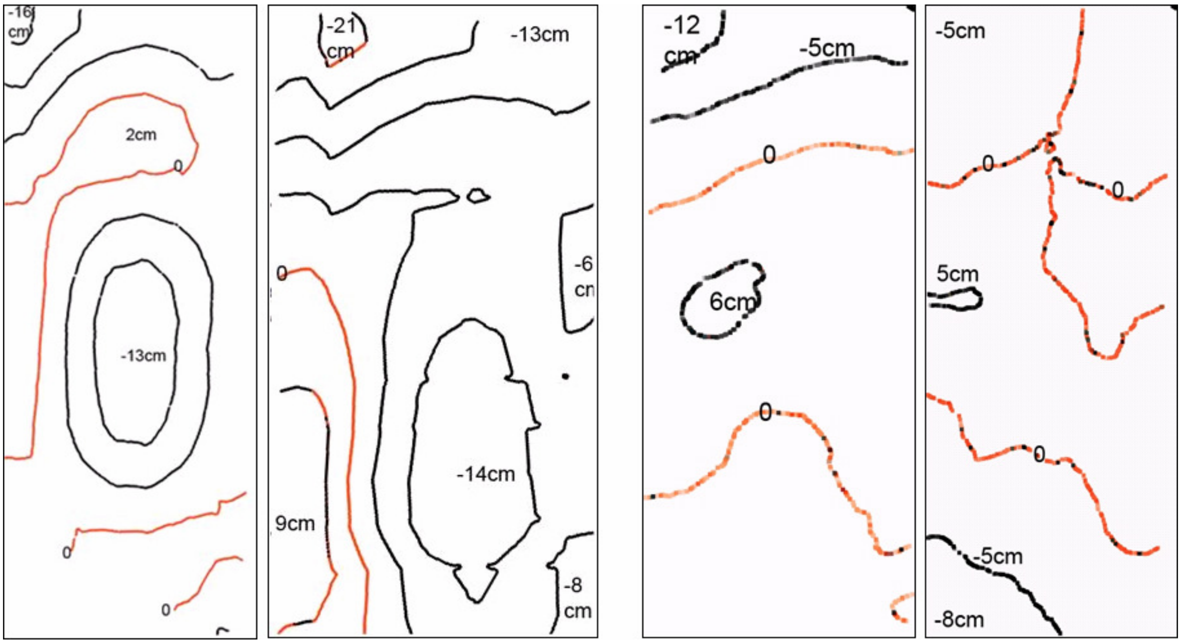

*Figure 8: Model deformation at **40% end lap.** From left to right: additional parameters **1-12** and **1-12 plus 42-73**, **old** merging software; additional parameters **1-12** and **1-12 plus 42-73**, **new** merging software, pan-sharpened colour channel.*

DEM Comparison

RAG computed the 40% end lap DEMs from images with odd and DEMs from images with even image numbers that had been generated with the new Microsoft Photogrammetry software. These DEMs have been compared:

- to each other and
- to the UltraCamD DEM generated with the old software and
- to the DEM from the analogue RMK TOP 15 DEM (flight campaign 2005).

Figure 9 shows an overview of the 2006 orthophoto with the 80% end lap stereo models (left) and the orthophoto from the analogue flight campaign 2005 (right).

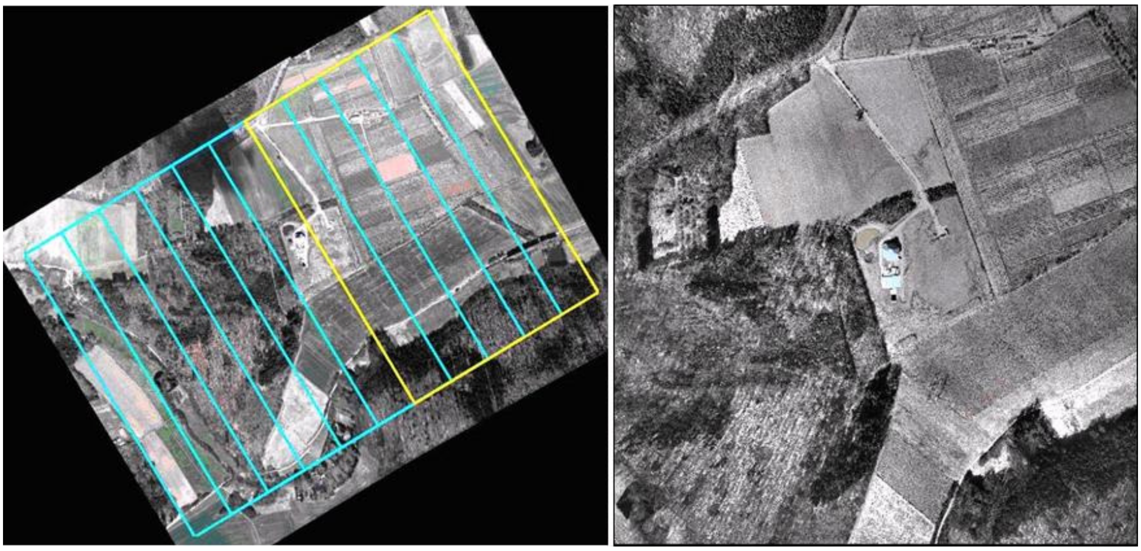

Figure 9: Left: UltraCamD orthophoto with 80% end lap stereo models 2006. Right: analogue RMK TOP 15 orthophoto, flight campaign 2005.

Due to the required accuracy in height of ±10cm, the camera design and the experience made in the years before, RAG decided to perform the stereo plotting in the 40% end lap stereo models. The following analysis points out that and why this approach was reasonable.

Figure 10 shows 60% (upper row) and 40% end lap DEM (lower row). The DEM grid size is 1m. The left and mid column present DEM differences that were calculated from a stereo model with **odd** image numbers and a stereo model with **even** image numbers. Left there are the DEM differences from DEM calculated with the **old** software, to the mid the DEM differences from DEM computed with the **new** software. The right column presents the difference between DEM matched with the new merging software minus DEM matched with the old software. It is obvious that the new software smoothes and levels the local pattern of the height differences but an over-correction with opposite sign seems to be adapted. At the model borders the relative model deformation increases to ±50cm for **60%** end lap while this amount decreases to ±20cm for **40%** end lap DEM difference.

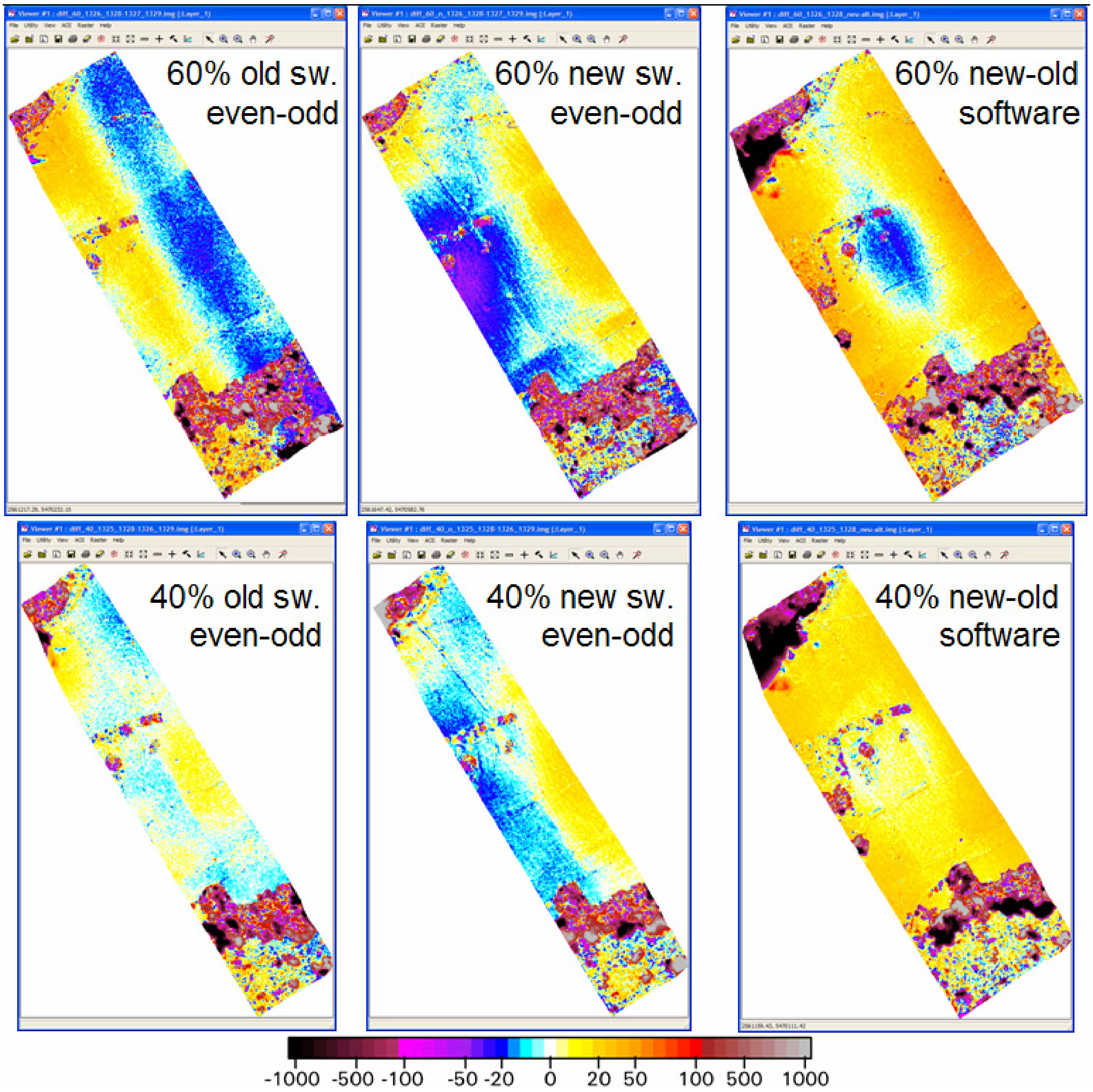

Figure 10: UltraCamD DEM-differences [cm], upper row 60% end lap, lower row 40% end lap. Left column: even minus odd image number DEM, old merging software. Mid column: even minus odd image number DEM, new merging software. Right column: new merging software DEM minus old merging software DEM.

The right column of figure 10 shows that the centre of the **60%** end lap DEM matched with the **new** merging software lies up to 35cm lower while the border areas lie up to 50cm higher compared to the old DEM. For the **new 40%** end lap DEM the center part heights equal the old DEM heights but the border areas lie up to 35cm higher compared to the DEM that were matched with old merging software.

The procedure to compare the DEM calculated from images with odd and even numbers delivers relative differences for this special flight campaign and the DEM matching with the old or the new merging software. For an independent check of absolute height differences these UltraCamD DEMs are compared to a DEM from an analogue photogrammetric flight with the film camera RMK TOP 15 (see figure 11). The comparison of both DEM differences shows that all in all the height differences are reduced but even in the border areas an over-correction can be detected.

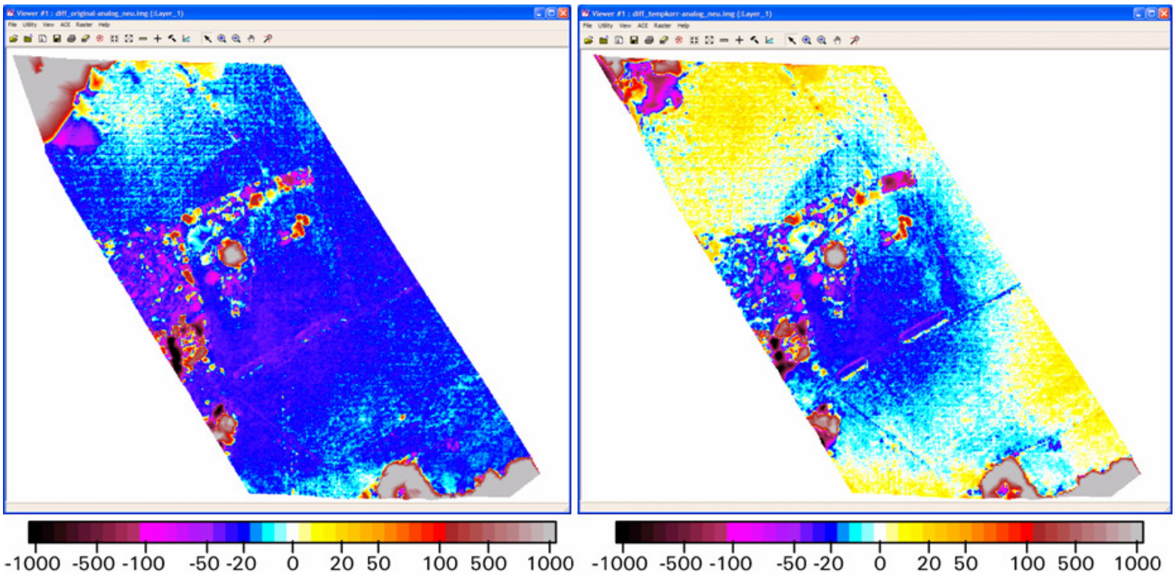

*Figure 11: DEM differences [cm]: UltraCamD to analogue RMK TOP 15 DEM. Left **old** merging software. Right: **new** merging software.*

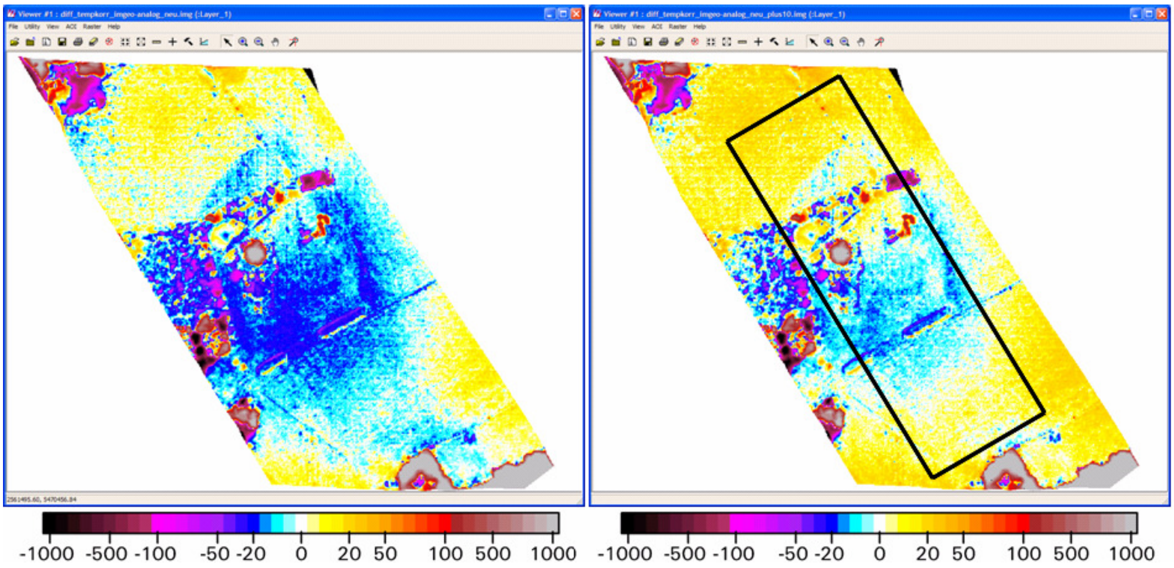

Figure 12: DEM differences [cm]: new UltraCamD DEM to analogue RMK TOP 15 DEM. Left: IMGEO correction. Right: IMGEO correction and offset-correction (+10cm) with borderline of stereo measurements.

The largest model deformation was eliminated with the new software, but still systematic image errors effect the DEM matching. A correction of the image data with IMGEO from the Hannover program system BLUH was performed and the DEM differences of the resulting DEM to the analogue DEM were calculated (see figure 12, left). RAG added another correction: the GCP measurements contained an offset of about 10cm between the measurements in 2005 to 2006. If this is respected, the height and IMGEO corrected DEM difference between the UltraCamD DEM processed with the new software and the analogue DEM lies between ±15cm for the central parts wherein RAG performed the stereo plotting (see figure 12, right). The IMGEO corrected images were displayed in stereo view on the digital photogrammetric workstation. Points of the old DEM grid were used as check points for a new stereo plotting. The height differences between the old DEM and stereo view in maximum reached about +27cm in the northern and southern parts and of about -15cm in the mid parts (see figure 13).

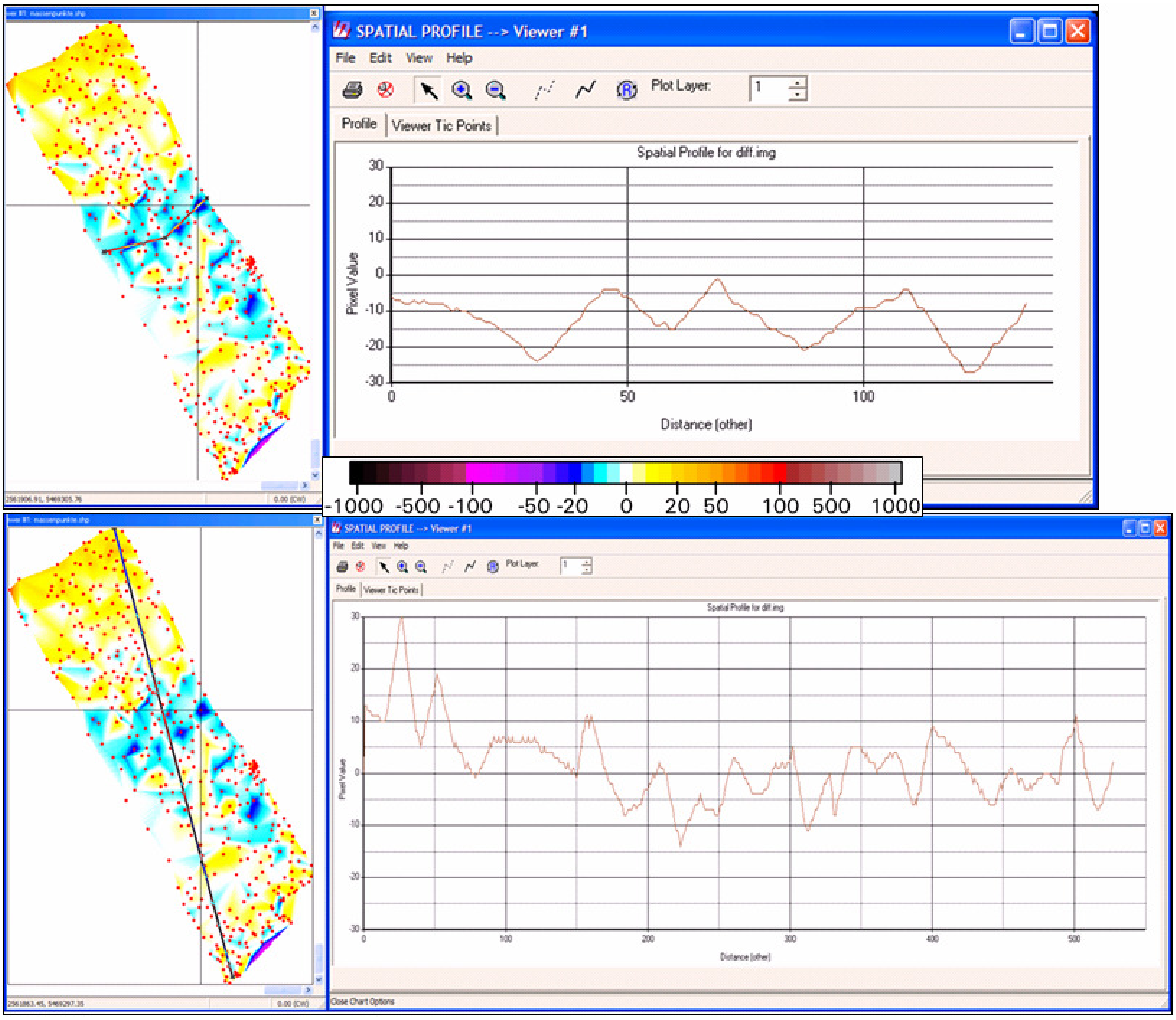

Figure 13: DEM-differences [cm] between the DEM generated with the old software (red dots) and re-measurement (stereo plotting) in IMGEO corrected stereo model (left). DEM difference profiles (right).

Y-parallaxes still exist and have a noticeable influence to the determination of the object heights. That is an additional reason why the stereo plotting has to be done in the centre parts of the stereo model (see figure 3 mid and right and figure 12, right).

The influence of the model deformation at the model borders can be improved by reducing the model area within the DEM matching. Figure 14 shows the influence of the model deformation for the whole 40% stereo model and for reductions of -15%, -20% and -35%. Using -35% the amount of the model deformation has reached an optimal balance between the size of the stereo model and the model deformation. The remaining model deformations cause height differences that can be tolerated for the production purposes of RAG.

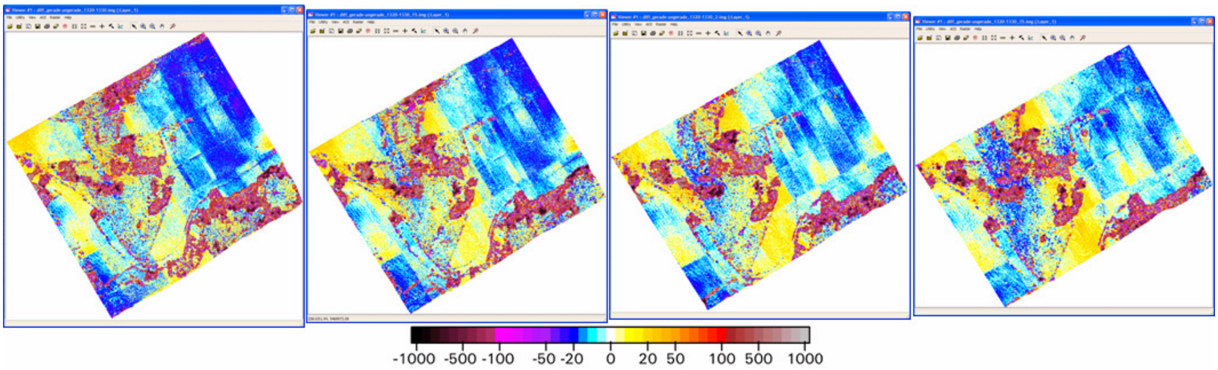

Figure 14: Reducing the area for DEM matching in 40% end lap stereo models: From left to right: whole model area, reduction of 15%, reduction of 20% and reduction of 35% in longitudinal and lateral direction. DEM differences [cm].

CONCLUSIONS

Under operational conditions for highest accuracy the process chain from image data to DEM measurements still is not homogenous because the AT and DEM matching cannot be performed in the same image data set that is used for stereo plotting on digital photogrammetric stereo-workstations. AT and DEM matching work on one colour channel of the image data, stereo plotting is done in RGB stereo images. The current workflow at RAG is that AT and matching use a pan-sharpened colour channel, but in the current case not the green channel for it is distorted too much. To guarantee the required height accuracy the matching is done in 40% end lap models – due to this reason the aerial flight campaigns have to be performed with 80% end lap. Stereo measurements are done in RGB-images.

The analysis with BLUH showed that the new Microsoft Photogrammetry merging software reduces the systematic image errors significantly. The results of the area-wide DEM comparison were of similar shape like the model deformation in BLUH. Still large model deformations exist at the border areas of stereo models. The systematic image errors can be detected and reduced by self-calibration e.g. with the program system BLUH. The x-parallaxes could be reduced but in the model border areas remaining x-parallaxes lead to height differences exceeding the required accuracy and y-parallaxes blur the stereo effect. These areas can be avoided by minimizing the matching area and stereo measurements to the centre parts of the stereo models.

Using the new merging software, self-calibration and the restriction of stereo plotting within the centre parts of stereo models RAG is able to reach high accuracy for stereo measurements with UltraCamD-imagery.

REFERENCES

i. Spreckels, V., A. Schlienkamp, L. Syrek, 2005: Photogrammetric Stereoplotting Capabilities of Vexcel UltraCamD Digital Aerial Imagery. In: Proceedings of ISPRS Hannover Workshop 2005 “High-Resolution Earth Imaging for Geospatial Information“, May 17-20, 2005, Hannover, Germany. On CD-ROM.

ii. Spreckels, V., A. Schlienkamp, K. Jacobsen, 2007: -Model Deformation- Accuracy of Digital Frame Cameras, ISPRS Hannover Workshop 2007, IntArchPhRS. Vol XXXVI, Part 1/W51. On CD-ROM.