GEOMETRY AND INFORMATION CONTENTS OF
LARGE SIZE DIGITAL FRAME CAMERAS

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ABSTRACT:

Large size digital aerial frame cameras like Intergraph DMC and Vexcel UltraCam are becoming standard for photogrammetric application. It is difficult to compare the information contents of such cameras with this of analogue photographic cameras. Also the rules for project planning have to be checked if the old relation between photo scale and map scale is still valid. The photo scale has no longer any meaning for flight planning because it is depending upon the pixel size in the camera; the important figure is the ground sampling distance (GSD). The image quality of digital cameras usually is quite better like the image quality of scanned photos, disturbed by photo grain. The comparison of digital images taken with different GSD and scanned analogue photos are leading to the result, that digital images have the same information contents like analogue photos scanned with 20µm pixel size having a GSD smaller by the factor of approximately 1.5. That means 15cm GSD from a digital camera is corresponding to 10cm GSD from analogue cameras scanned with 20µm pixel size. So the information contents of a DMC- and also an UltraCamD-image exceeds the information contents of an analogue aerial photo.
Block adjustments with digital camera images are resulting in sigma0 values of 0.15 up to 0.3 pixels. This high accuracy potential cannot be reached by analogue photos. But it has been shown, that self calibration by additional parameters is still required also for original digital images. Because of the small field of view, the systematic image errors are causing not negligible model deformation. If the systematic image errors can be used in the processing chain, the full accuracy potential of the digital cameras can be used. A program for geometric improvement of the images by the systematic image errors and a program for the improvement of height models by the model deformation have been developed in the Leibniz University Hannover.

1. INTRODUCTION

Large size digital frame cameras are becoming standard for mapping purposes; this also can be seen at the fact that the large size digital cameras in USA are booked during the main flight season and no free capacity is available. The better image quality, high accuracy and the not required scanning of analogue photos supports the change to digital cameras. Because of the better signal to noise relation, CCD- and not CMOS-sensors are used. It is not so simple to compare the information contents of a standard analogue photogrammetric photo with a digital image. In the frame of a diploma thesis, intensive tests of mapping with analogue photos and digital images with different image scales and different ground sampling distance (GSD) have been made in the same area (Oswald 2006). The result was quite clear – the same information contents, that means the identification of details, has been achieved in original digital images having approximately 1.5 times larger GSD than analogue photos scanned with 20µm pixel size, so analogue photos with a side length of 230mm have comparable information contents like digital images, having 7700 x 7700 pixels. This is still less than expected few years ago, but CCD-arrays with such a dimension are not available for affordable price, fast read-out time and suitable image quality. By this reason the Intergraph DMC and the Vexcel UltraCam are based on a combination of smaller CCD-arrays which have to be merged to a virtual image.

Another alternative solution is the use of CCD-line cameras like the Leica ADS-40, but with the disadvantage of scene accuracy dependency from the direct sensor orientation, based on relative kinematic GPS-positioning and inertial measurement units (IMU). Under operational conditions the direct sensor orientation is limited to a standard deviation of approximately 15cm. The handling of CCD-line scanner images also requires special software for the photogrammetric workstation. For mapping purposes usually CCD-array cameras are preferred, while for large size ortho images the CCD-line scanner is used more often.

2. INTERGRAPH DMC

The Intergraph DMC is based on 4 convergent arranged sub-cameras (Doerstel et al 2002) (figure 1). This has the advantage of a small field of view for the sub-cameras, optimal for imaging quality. The sub-images are individually merged by tie points in the overlapping area and transformed to a homogenous virtual image. This transformation respects the calibration of the sub-cameras including the lens distortion, so by simple theory the virtual image should be free of any systematic error. But in reality the flight conditions may change the geometry of the sub-cameras even if they are more solid like usual analogue aerial cameras.
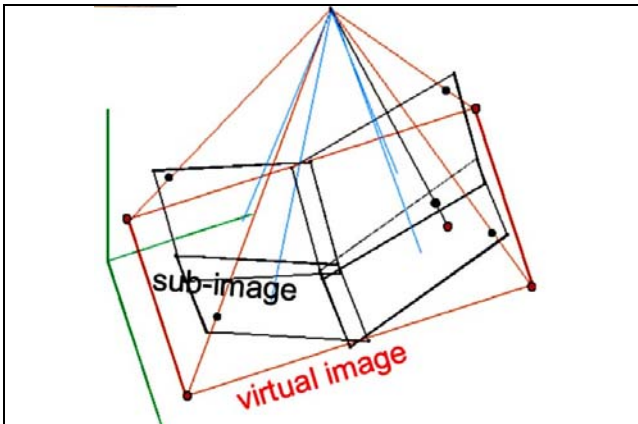
Figure 1: relation of DMC sub-images to homogenous virtual image

3. DMC-BLOCK GHENT

The block Ghent has been flown by Hansa Luftbild, Muenster, Germany over the city of Ghent, Belgium. The block has 80% end lap and 60% side lap; it has been flown in a height level of 796m. Together with the average ground height of 12m the photo scale 1 : 6440 exists, corresponding to 77mm ground sampling distance (GSD). Two crossing flight lines are stabilizing the block, allowing a reduction of the number of control points.
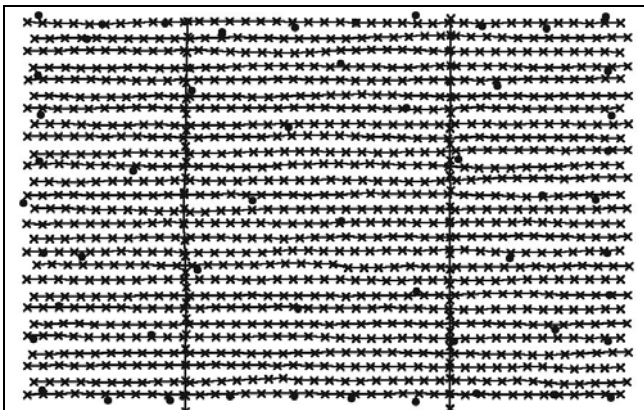

Figure 1: block Ghent 80% end lap, 60% side lap, 77mm GSD 1105 photos, 11899 object points, 102132 image points, up to 21 images/object point

From the original 53 control points, 23 are not used for the block adjustment, instead of this they are used as independent check points. Only with independent check points correct information about the reached object point accuracy can be computed. The inner accuracy of the block adjustment usually is to optimistic and does not respect systematic errors.

A bundle block adjustment without self-calibration leads to not optimal results for the point height. Such effect in a block with not dense control usually is caused by "systematic image errors" – or more precise, the image geometry does not agree with the mathematical model of perspective images. An analysis of the bundle block adjustment residuals – the remaining discrepancies of the image coordinates – indicates systematic image errors. The residuals of all observations are overlaid corresponding to the image coordinates and averaged in small sub-areas to reduce the random image errors. Such averaged residuals only indicate the systematic image errors

because parts of the systematic errors are compensated by the adjustment.
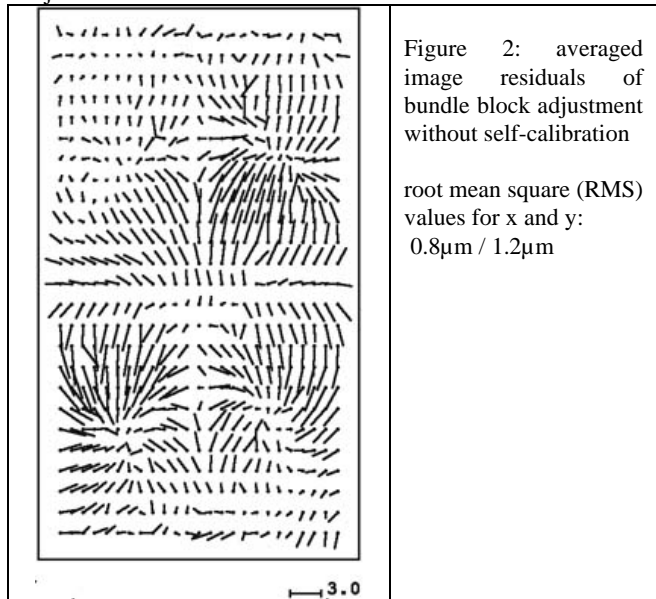

Figure 2: averaged image residuals of bundle block adjustment without self-calibration

root mean square (RMS) values for x and y: 0.8µm / 1.2µm

The averaged residuals (figure 2) indicate systematic errors of the virtual images caused by geometric problems of the sub-images.

4. BLOCK ADJUSTMENT WITH SELF-CALIBRATION

The bundle block adjustment has been made with the Hannover program system BLUH. BLUH handles the self calibration of standard aerial images with 12 additional parameters (Baz et al 2007). For handling the special DMC geometry, special additional parameters have been introduced. The parameter 29 can determine eccentricity errors caused by a not correct introduction of the flying height to the merge of the 4 sub-images (Doerstel et al 2002). This parameter was not significant for all handled data sets, showing that no problem with eccentricity errors exist. The additional parameters 30-33 can determine synchronization errors of the sub-images, the parameters 34 – 41 can determine perspective errors of the sub-images and parameters 74 – 77 can determine radial symmetric errors (r^3) of the sub-images. Under the condition that all 4 sub-cameras are influenced by the same change of the focal length, parameter 78 can compensate the influence of a changed field of view to the virtual image (figure 3a). Also under the condition that all sub-images are influenced by the same radial symmetric error (r^3), parameter 80 can compensate this (figure 3b).

Bundle block adjustments of block Ghent with the following combination of additional parameters have been made:

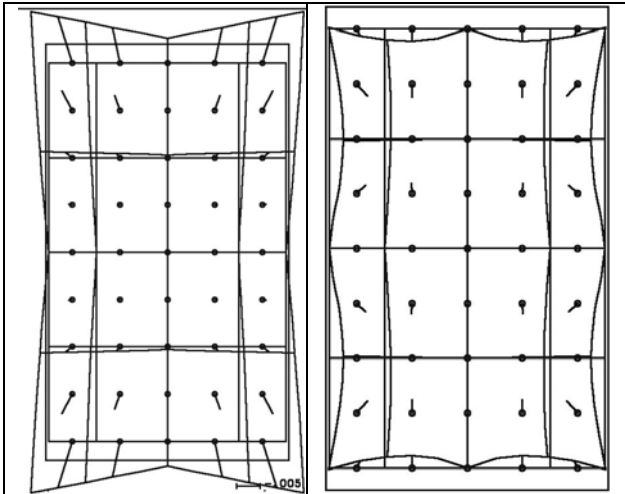|	additional parameters	
1	0	no self-calibration
2	1- 12	standard parameters of BLUH
3	30-41, 74-77	special DMC-parameters
4	1-12, 30-41, 74-77	standard parameters of BLUH + special DMC-parameters
5	78, 80	common change of all sub-images by field of view + r³
6	1-12, 79, 80	standard parameters of BLUH + common change of all sub-images
Table 1: used parameter combinations		

Figure 3a: effect of additional parameter 78

Figure 3b: effect of additional parameter 80

Program BLUH checks the additional parameters for significance, individual and total correlation and removes the not usable parameters automatically from the adjustment. So the final iteration of the bundle block adjustment will be made with a reduced set of additional parameters, guaranteeing the use of only the parameters which can be determined and which are not too strong correlated to each other.
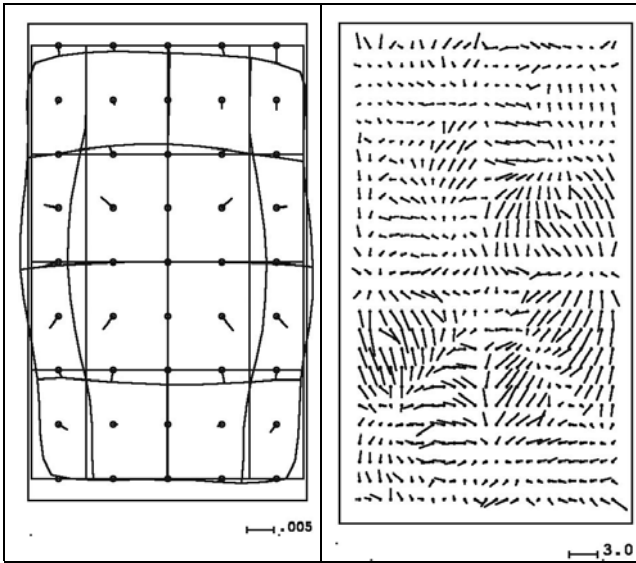

Figure 4: systematic image errors of block adjustment with parameters 1-12 (left) and corresponding averaged residuals (right)

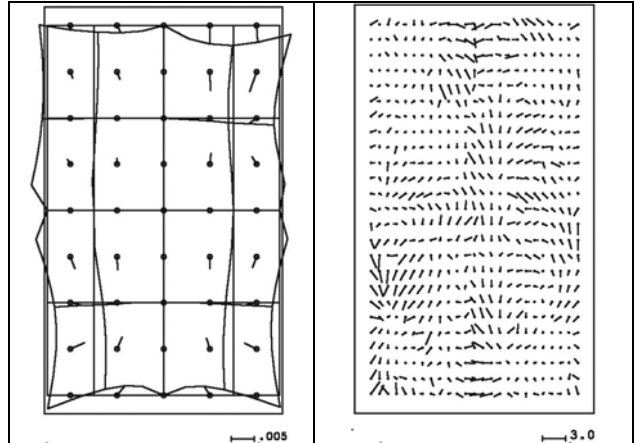root mean square error (RMS) of residuals: 0.6µm / 0.8µm

Figure 5: systematic image errors of block adjustment with parameters 30-41 + 74-77 (left) and corresponding averaged residuals (right) RMS of residuals: 0.4µm / 0.5µm
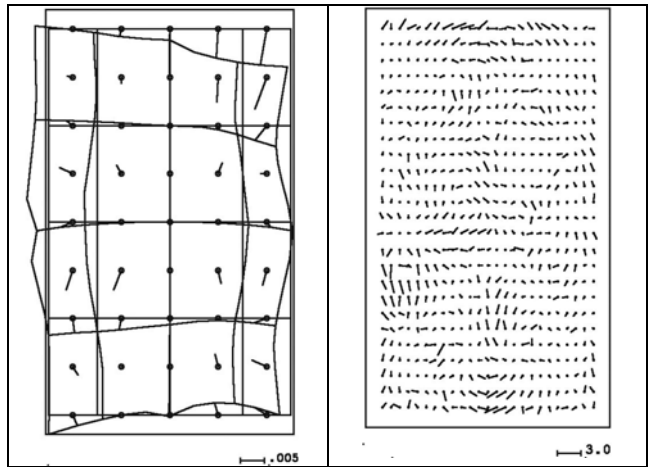

Figure 6: systematic image errors of block adjustment with parameters 1-12 + 30-41 + 74-77 (left) and corresponding averaged residuals (right) RMS of residuals: 0.3µm / 0.4µm
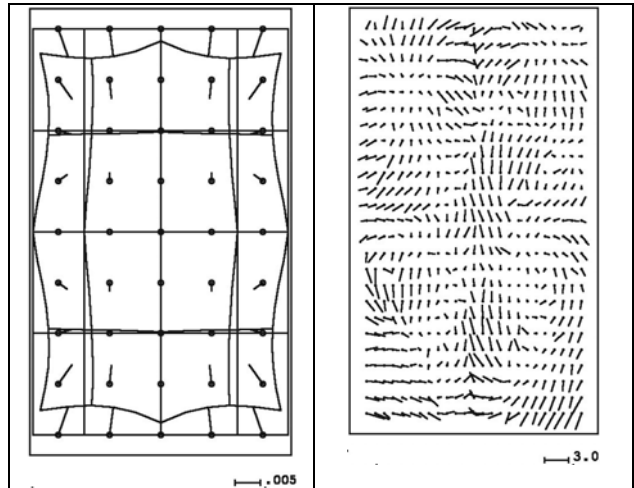

Figure 7: systematic image errors of block adjustment with parameters 78 + 80 (left) and corresponding averaged residuals (right) RMS of residuals: 0.5µm / 0.8µm
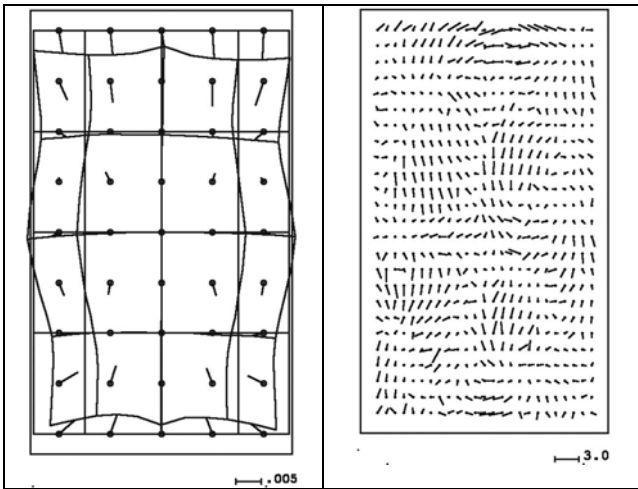
Figure 8: systematic image errors of block adjustment with parameters 1-12 + 78 + 80 (left) and corresponding averaged residuals (right) RMS of residuals: 0.4µm / 0.6µm

It may happen that the systematic image errors are changing within the block. By this reason, the block has been divided into 2 equal parts and the block adjustment has been made for the whole block, but handling the images as taken by different cameras. The systematic image errors of both parts are nearly identical with root mean square differences of the systematic image errors in the range of 0.5µm up to 1µm – this is within the accuracy range under the condition of the correlation to the exterior orientation.

The averaged residuals of the adjustment without self calibration have root mean square values for x and y with 0.8 and 1.2µm. By self calibration with the parameter configuration 1-12, 30-41, 74-77 (configuration 4, table 1) it is reduced to 0.3 and 0.4µm, the other results are within between. But also with configuration 4 small remaining systematic errors exist – neighboured vectors are correlated by r=0.26 for x and r=0.31 for y. At a distance of 15mm in the image the vectors are not more correlated. Without self-calibration, neighboured vectors are correlated by r=0.4 and the correlation goes to 0.0 for a distance of 27mm within the image.

case	control points [cm]		sigma0 [µm]	check points [cm]	
	SXY	SZ		SXY	SZ
0	2.7	9.3	2.08	2.7	15.5
1-12	2.6	2.6	1.75	2.5	5.9
30-41,74-77	2.6	2.6	1.65	2.7	6.1
1-12 + 30-41,74-77	2.5	2.2	1.59	2.5	5.8
78+80	2.6	3.4	1.75	2.7	7.0
1-12 +78 +80	2.5	2.6	1.63	2.5	5.8
Table 2: results of bundle block adjustments DMC-block Ghent					

The best results have been achieved with the combination of the general additional parameters (1-12) and special DMC-parameters. It is interesting, that the same accuracy at the independent check points has been reached with the combination of the general parameters with just the 2 additional parameters 78 and 80 like with the individual DMC-parameters. So the same accuracy has been reached with finally 12 parameters in the last iteration like with 24 parameters. That means there is a tendency that there is a simultaneous change of the optics under flight conditions. Intergraph is investigating this and likes to generate improved camera calibrations so that the major influence of the systematic image errors is removed from the virtual images.
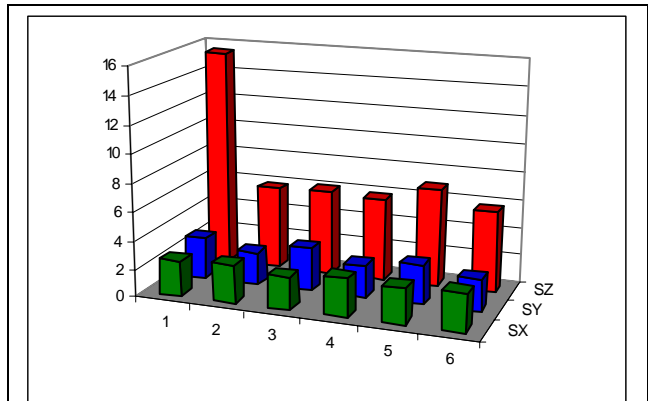

Figure 9: root mean square discrepancies at independent check points – block Ghent, case 1-6 see table 1 and 2

5. DMC-BLOCK RUBI

Also the block Rubi of the Cartographic Institute of Catalonia (ICC), Spain, has been analyzed in detail. The block with 426 photos having 80% end lap, approximately 40% side lap and 3 crossing flight lines, 7763 object and 45464 image points, has been matched with the Intergraph software. The image scale 1:8180 leads with the pixel size of 12µm in the image to 9.8cm GSD. 17 control points with distances up to 12 base lengths, in relation to 60% end lap, are used and 21 independent check points. The control and check points are announced with a standard deviation of 2cm for X and Y and 4cm for Z.
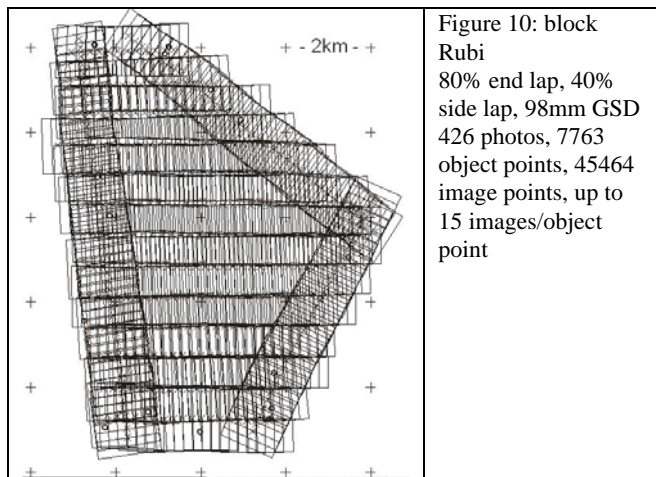
Figure 10: block Rubi
80% end lap, 40% side lap, 98mm GSD 426 photos, 7763 object points, 45464 image points, up to 15 images/object point

parameters	sigma0	RMSX	RMSY	RMSZ
0	1.87	3.2	2.6	40.3
1-12	1.80	2.1	2.3	6.9
30-41,74-77	1.76	2.5	2.9	7.4
1-12,30-41,74-77	1.73	2.2	2.6	6.9
78 + 80	1.79	2.8	3.3	11.3
1-12 + 78 + 80	1.74	2.2	2.7	6.4
Table 3: results at independent check points, DMC-block Rubi				

The results of the DMC-block Rubi are similar to the block Ghent. The sigma0-value – the accuracy of the image coordinates - is in the same range and also the tendency of the dependency upon the additional parameters agrees. But in this case the combination of the general additional parameters (1-12) together with the special DMC-parameters 78 and 80 with the common change of the sub-images are leading to the optimal results. Also some other blocks show the same tendency.

6. VEXCEL ULTRACAMD

For the panchromatic band the Vexcel UltraCamD has 4 separate cameras parallel to each other with 1 up to 4 smaller CCD-arrays (figure 11). The master image includes 4 CCD arrays located in the corners, 1 camera includes the left centre and right centre CCDs, one the upper centre and lower centre and the last camera has just the centre CCD. By means of the overlapping parts, the sub-images of 3 cameras are transformed to the master image with the 4 corner CCDs (Leberl et al 2002).

M = master image
    (4 CCD-arrays)
1 = configuration 1
    (2 CCD-arrays)
2 = configuration 2
    (2 CCD-arrays)
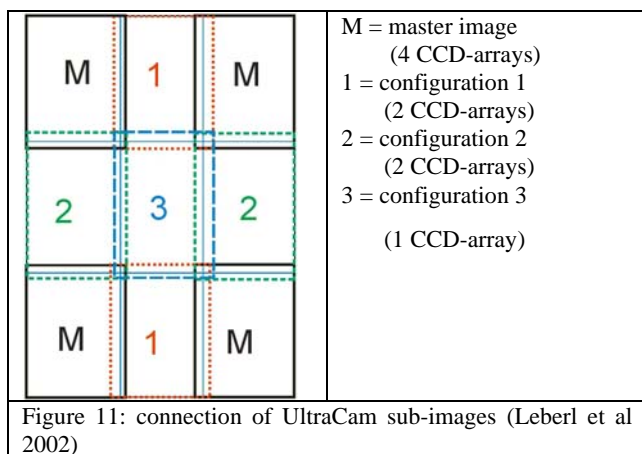3 = configuration 3

    (1 CCD-array)

Figure 11: connection of UltraCam sub-images (Leberl et al 2002)

Corresponding to the special parameters for the DMC, the program system BLUH includes special additional parameters for handling the geometric problems of the UltraCam. In relation to the centre image the 8 other sub-images can be changed like a similarity transformation respecting the situation that no gaps between neighboured sub-images are allowed (table 4).

additional parameters	function
42-49	scale parameters
50-57	shift in x-direction
58-65	shift in y-direction
66-73	rotation
table 4: special additional parameters for UltraCamD	

7. EXPERIENCE WITH ULTRACAMD

Details of the experience with the Vexcel UltraCamD are shown in Baz et al 2007 and Spreckels et al 2007. With the UltraCamD similar problems like with the DMC exist, that the camera is changing under flight conditions, requiring self-calibration. The standard set of additional parameters (1-12) is not sufficient, so the special UltraCam-parameters have to be used. Like Intergraph, also Vexcel is just investigating

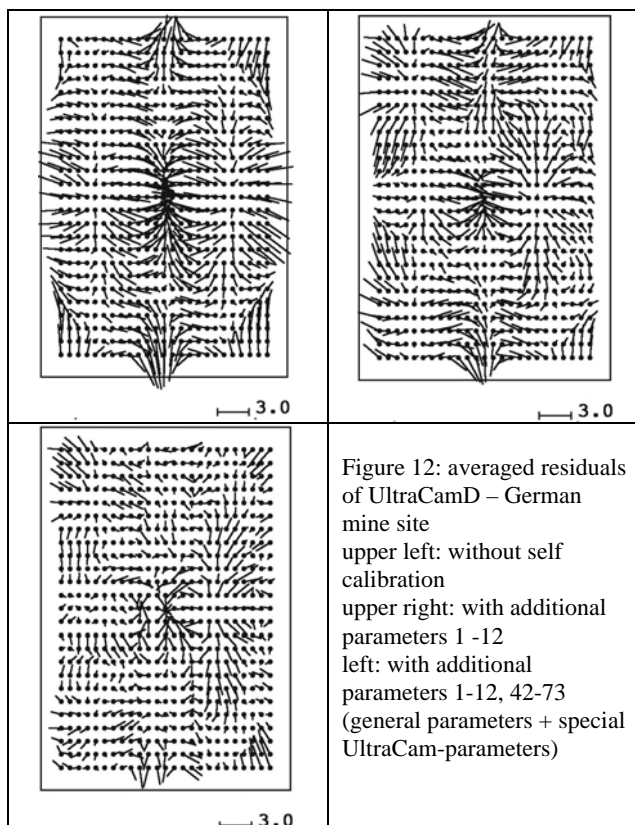possibilities for a-priori corrections or improved camera calibration.

Figure 12: averaged residuals of UltraCamD – German mine site
upper left: without self calibration
upper right: with additional parameters 1 -12
left: with additional parameters 1-12, 42-73
(general parameters + special UltraCam-parameters)

The averaged residuals shown in figure 12 are demonstrating the problem – without self-calibration there is a clear indication of systematic image errors and only with the combination of the general additional parameters (1-12) and the special UltraCam-parameters (42-73) the major part of the systematic errors can be removed.

additional parameters	sigma0	RMSX [cm]	RMSY [cm]	RMSZ [cm]
without	2.66	3.8	3.7	7.6
1 – 12	2.44	3.5	3.4	5.6
1-12,42-73	2.26	3.2	3.0	5.4
Table 5: UltraCamD block mine site, block adjustment with self calibration, 9.0cm GSD, 80% end lap, 60% side lap				

additional parameters	sigma0	RMSX [cm]	RMSY [cm]	RMSZ [cm]
without	3.01	2.2	2.8	16.8
1 – 12	2.76	2.2	1.9	7.6
42 - 73	2.85	2.3	2.7	8.9
1-12,42-73	2.75	2.3	2.0	7.5
Table 6: UltraCamD block large scale Istanbul, block adjustment with self calibration, 8.6cm GSD, 80% end lap, 60% side lap (Baz et al 2007)				

Also the block Istanbul (table 6), as well as others, shows the same behaviour that for the optimal accuracy a bundle block adjustment with self-calibration, using the general set of additional parameters as well as the special additional parameters for the UltraCam, are required.
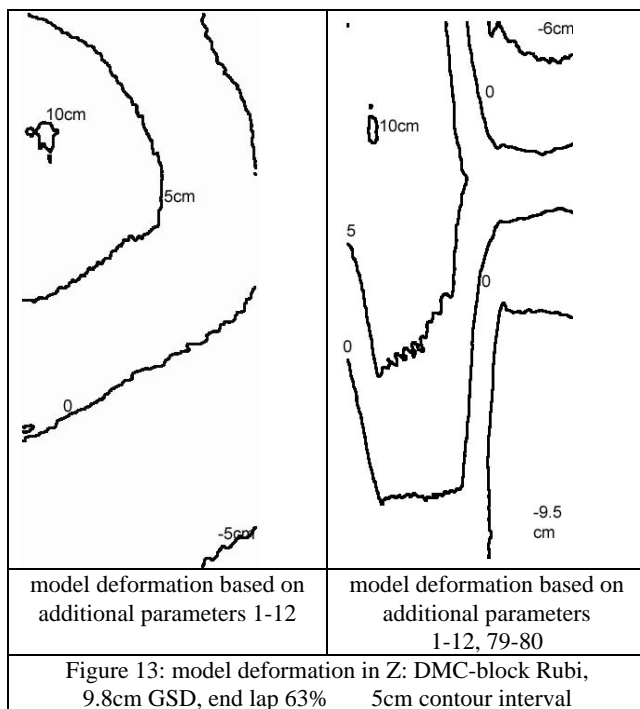
8. MODEL DEFORMATION

The bundle block adjustment with self-calibration is not a problem; this can be handled like for analogue photos. The problems appear with the handling of stereo models. For the handling of analogue photos usually systematic image errors are ignored, even if the influence may influence especially the height. For a horizontal mapping the systematic image errors can be ignored for analogue like for the large frame digital cameras. This is obvious in the shown accuracy range – the standard deviation in X and Y is not so much influenced by the self-calibration.

The DMC has for 60% end-lap a height to base relation of 3.26, the UltraCam 3.8. If (like usual) the standard deviation of the x-parallax corresponds to the accuracy of the image coordinates, the vertical accuracy corresponds to the accuracy in X and Y multiplied with the height to base relation (formula 1).

$$SZ = \frac{h}{b} \bullet Spx$$
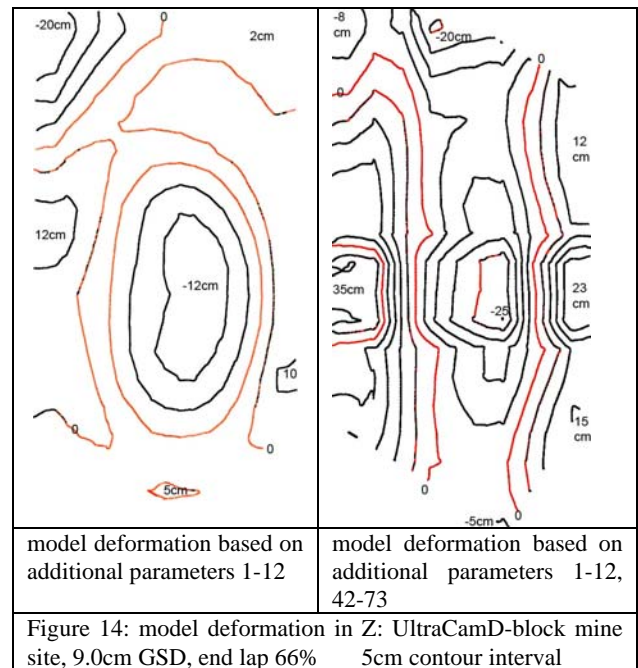
Formula 1: standard deviation of Z

h=height above ground   b=base
Spx = standard deviation of x-parallax

The height to base relation is valid also for the height deformation caused by systematic image errors – this leads to the model deformation. The model deformation is not a new topic for digital images; it exists as well for analogue photos.

model deformation based on additional parameters 1-12	model deformation based on additional parameters 1-12, 79-80

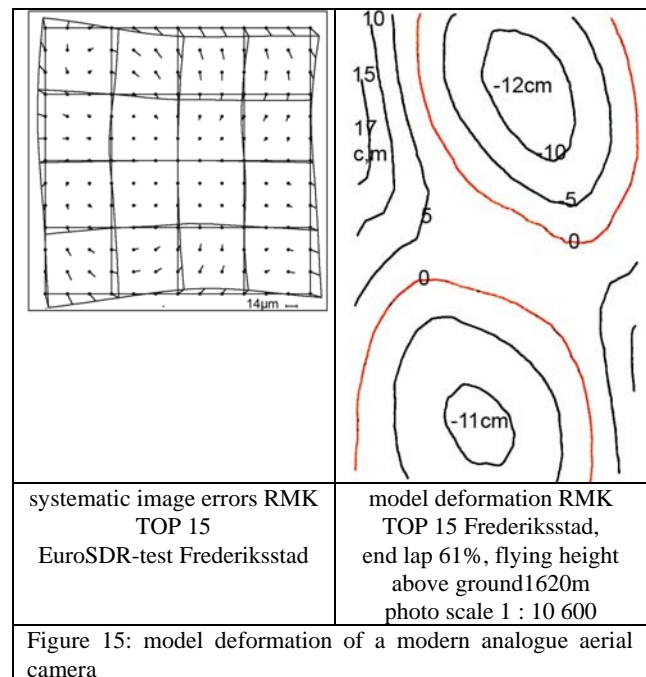Figure 13: model deformation in Z: DMC-block Rubi, 9.8cm GSD, end lap 63%   5cm contour interval

The vertical model deformation determined at the DMC-block Rubi is typical for the handled DMC-data sets. The expected vertical accuracy of well defined points corresponds to the sigma0 multiplied with the height to base relation; that means approximately 2µm * image scale * 3.26 = 5.3cm. The average height deformation is in the same range; in the extreme case it reaches 10cm. Of course the systematic image errors could be respected on-line during model handling, but this is not

standard for digital photogrammetric workstations. Another possibility is the change of the image geometry by the systematic image errors like possible with Hannover program IMGEO, or a change of the generated digital elevation model like with Hannover program DEMCOR.

model deformation based on additional parameters 1-12	model deformation based on additional parameters 1-12, 42-73

Figure 14: model deformation in Z: UltraCamD-block mine site, 9.0cm GSD, end lap 66%   5cm contour interval

The model deformation based on the UltraCamD shown in figure 14 are even larger based on a similar GSD. This is also confirmed by other UltraCamD-blocks. As mentioned before, this is not a new thing for digital cameras; it exists also for analogue cameras.

systematic image errors RMK TOP 15 EuroSDR-test Frederiksstad	model deformation RMK TOP 15 Frederiksstad, end lap 61%, flying height above ground 1620m photo scale 1 : 10 600

Figure 15: model deformation of a modern analogue aerial camera

The model deformation of the block Frederiksstad exceeds the expected vertical accuracy of the RMK TOP 15. As rule of thumb for analogue photos the vertical accuracy is in the range of 0.1‰ of the flying height above ground, corresponding to

16cm for topographic points or 9cm for well defined points (based on +/-5µm for Spx). This demonstrates that the model deformation is not a new problem; it is an old, but mostly ignored problem.

9. INFORMATION CONTENTS OF DIGITAL IMAGES

For mapping purposes in most cases the information content of the mages is the limiting factor and not the accuracy. It is not so easy to compare the information content of analogue with digital cameras. Often this is made based on the resolution of aerial cameras, having under operational conditions a resolution of 40 line pairs / mm, corresponding to 12.5µm pixel size. Under this condition the information contents of an analogue aerial camera would correspond to 80 x 230 pixels or 18 400 pixels in one direction. In reality analogue photos are scanned usually with approximately 20µm pixel size, corresponding to 11 500 pixels in one direction. The major reason for scanning with 20µm pixel size is the disturbance of the detail information by the film grain in the case of smaller pixels. This is not a correct base for comparing the information content of analogue with digital images. By this reason within the frame of a diploma thesis (Oswald 2006) the information content has been compared between analogue and digital images available in the same area with different ground resolution. The possible object identification as function of the ground resolution has been used for the comparison. Digital images are not disturbed by film grain, simplifying the object identification beside better conditions for automatic matching and more information in the shadow areas. As clear result the following relation has been found: the information content of digital images corresponds to analogue images having 1.5 up to 2.0 times larger GSD under the condition of a scan of analogue images with 20µm pixel size. Or in other words: analogue images having 30 – 40µm pixel size correspond to the information contents of digital images. This test was based on DMC and UltraCamD images.

So the information content of an analogue aerial image corresponds to 5750 x 5750 up to 7590 x 7590 pixels. The UltraCamD has 7500 x 11500 pixels while the DMC has 7680 x 13824 pixels. That means the information content of an UltraCamD and a DMC-image is better than the information content of an analogue aerial image. The information content of the UltraCamX has not been analyzed, but here not only the number of pixels is important – smaller pixels may cause a reduced image quality.

10. CONCLUSION

Also the large frame digital cameras Intergraph DMC and Vexcel UltraCamD have some problems with systematic image errors. For reaching the best accuracy, a combination of the standard additional parameters used also for analogue photos and special parameters for the camera type have to be used. The major part of the systematic image errors can be determined and respected with the standard set of additional parameters, the special parameters are only improving the result slightly. In the case of the DMC the systematic errors common for all 4 sub-images together can cover the largest part of the systematic errors, this is an important fact for an improved camera calibration which may reduce the systematic effects in advance. In the bundle block adjustment no problems exist with the handling of these data, problems may occur with model deformation during model handling. Under operational conditions this is limited to the height determination; the effect to the horizontal position is very limited.

The systematic image errors may be respected as on-line correction in a photogrammetric workstation, but most software solutions do not allow this. Another possibility is a posterior correction of the images or a correction of digital elevation models by the influence of the systematic image error. It should not be forgotten that this is not a special effect for digital cameras, model deformation exist as well also for analogue photos. In addition the possible accuracy which can be reached with digital cameras is quite better than the accuracy reachable with analogue cameras.

The high accuracy level of the digital frame images, as well as the easier increase of the image overlap, allow an extension of the control point distance.

It has been shown that the information contents of a single DMC and UltraCamD image is better than the information contents of a single analogue aerial image.

Intergraph and Vexcel are just working in improved calibration methods, so the described problems may be solved in near future.

Even with the mentioned limitations, also today the potential of the large frame digital cameras is better like the potential of analogue cameras.

ACKNOLEDGEMENT

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