GEOMETRIC HANDLING OF LARGE SIZE DIGITAL AIRBORNE FRAME CAMERA IMAGES

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ABSTRACT

The photogrammetric data handling today is done by digital photogrammetric workstations. Analog photos have to be scanned, causing a loss of accuracy and information contents. The degrading of the quality can be avoided in using directly digital sensors. The large size digital frame cameras Intergraph DMC and Vexcel UltraCam are becoming more and more popular. The geometric advantage of the digital cameras against the analogue film cameras is well known in the meantime. But detailed geometric analysis by bundle block adjustment with self calibration showed systematic image errors caused by the merge of the sub-images. At least within the same photo flight these geometric effects are stable, allowing compensation by self calibration. For the exact handling of the special geometric problems of the DMC and the UltraCam special additional parameters corresponding to the image composites have been developed. For a complete determination of all geometric effects caused by the merge of the sub-images 17 additional parameters for the DMC and 32 for the UltraCam can be introduced into the Hannover program BLUH, but detailed investigation showed that for the DMC just 2 additional parameters in addition to the general set of 12 additional parameters of the program system BLUH are enough to fit the geometric problems. Intergraph and Vexcel are working at the improvement of the image geometry, but for existing data the geometric problems have to be solved by special handling.

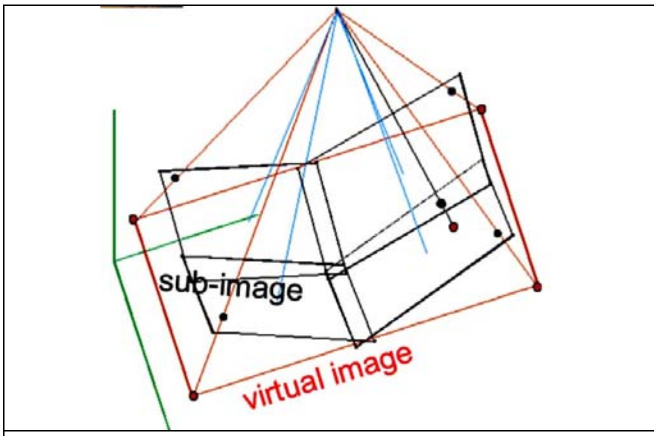
In the block adjustment the geometric characteristics of the digital cameras can be respected. More difficult is the influence to the data handling of stereo models. It would not be a problem if the systematic image errors, determined by self calibration, could be respected in the photogrammetric workstations, but most commercial systems do not have such functions and no standardization of correction grids including the influence of the systematic image errors exist. The systematic image errors are causing model deformations which cannot be neglected for the height values. The manual measurement of digital elevation models based on the UltraCamD in overlapping models of a photo flight with 80% end lap was leading to height discrepancies in the range of 25cm, while a standard deviation of the models in the range of 10cm was expected. This can be explained by the model deformation causing +12cm Z-shift in a location where the overlapping model has a shift of -12cm.

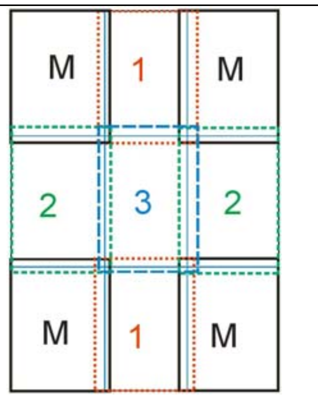
The model deformation is not a special problem of large size digital frame cameras; it exists also for analogue cameras, but in most cased it is ignored.

Because of missing functions to respect the systematic image errors in photogrammetric workstations, the program IMGEO has been developed, able to correct the geometry of the digital images by the systematic image errors. As another possibility with program DEMCOR always generated digital elevation models can be corrected by the model deformation.

1. INTRODUCTION

CCD-arrays with a sufficient quality and a short read out time have a limited size, not corresponding to the information contents of analogue aerial photos. By this reason the large size digital frame cameras Intergraph DMC and Vexcel UltraCam combine medium up to large size CCD-arrays, available in 4 sub-cameras, to one homogenous virtual image (figure 1). The merge of the sub-images is using tie points in the overlapping area to guarantee optimal sub-image connections. The transformation of the sub-images to the virtual image respect the laboratory calibration of the sub-cameras, so by theory the virtual images should be exact perspective images without any systematic errors, but under flight conditions the cameras are changing the geometry against the situation in the laboratory. Some systematic image errors of the digital large frame cameras have been reported (Alamus et al 2005, Honkavaara et al 2005, Baz et al 2006), having mainly an influence to the object height because of the limited height to base ratio of the digital cameras.





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 1a: combination of DMC sub-cameras to a homogenous virtual image

Figure 1b: connection of UltraCam sub-images (Leberl et al 2002)

2. SELF CALIBRATION BY ADDITIONAL PARAMETERS

Systematic image errors, or more precise the difference between the mathematical model of perspective geometry and the real image geometry, can be determined and respected with additional parameters in the bundle block adjustment. Different sets of additional parameters are in use and lead to satisfying results for analogue photos. In the Hannover program BLUH a combination of physical justified and mathematical parameters are used (table 1).

x, y = image coordinates normalized to maximal radial distance 162.6mm (scale factor: 162.6 / maximal radial distance) $r^2 = x^2 + y^2$ b = arctan (y/x)

1. $x' = x - y \cdot P1$	$y' = y - x \cdot P1$	angular affinity
2. $x' = x - x \cdot P2$	$y' = y + y \cdot P2$	affinity
3. $x' = x - x \cdot \cos 2b \cdot P3$	$y' = y - y \cdot \cos 2b \cdot P3$	
4. $x' = x - x \cdot \sin 2b \cdot P4$	$y' = y - y \cdot \sin 2b \cdot P4$	
5. $x' = x - x \cdot \cos b \cdot P5$	$y' = y - y \cdot \cos b \cdot P5$	
6. $x' = x - x \cdot \sin b \cdot P6$	$y' = y - y \cdot \sin b \cdot P6$	
7. $x' = x + y \cdot r \cdot \cos b \cdot P7$	$y' = y - x \cdot r \cdot \cos b \cdot P7$	tangential distortion 1
8. $x' = x + y \cdot r \cdot \sin b \cdot P8$	$y' = y - x \cdot r \cdot \sin b \cdot P8$	tangential distortion 2
9. $x' = x - x \cdot (r^2 - 16384) \cdot P9$	$y' = y - y \cdot (r^2 - 16384) \cdot P9$	radial symmetric r^3
10. $x' = x - x \cdot \sin(r \cdot 0.049087) \cdot P10$	$y' = y - y \cdot \sin(r \cdot 0.049087) \cdot P10$	radial symmetric
11. $x' = x - x \cdot \sin(r \cdot 0.098174) \cdot P11$	$y' = y - y * \sin(r \cdot 0\ 0.098174) \cdot P11$	radial symmetric
12. $x' = x - x \cdot \sin 4b \cdot P12$	$y' = y - y \cdot \sin 4b \cdot P12$	

Table 1: general additional parameters of program system BLUH

For the DMC and the UltraCam special additional parameters are used in program BLUH, able to respect problems in generating the virtual images based on the sub-images. For handling the special DMC geometry, 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 2a). Also under the condition that all sub-images are influenced by the same radial symmetric error (r^3), parameter 80 can compensate this (figure 2b). For the UltraCam corresponding additional parameters have been introduced into program BLUH. In relation to the center image, the 8 other sub-images can be changed like a similarity transformation respecting the situation that no gaps between neighbored sub-images are allowed. The parameters 42 – 49 are corresponding to the scale, 50-65 to shift in x and y and 66-73 to a rotation.

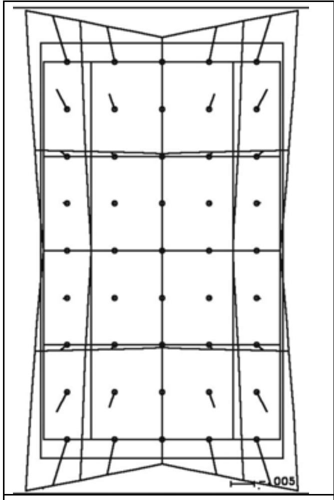


Figure 2a: effect of additional parameter 78 (common DMC)

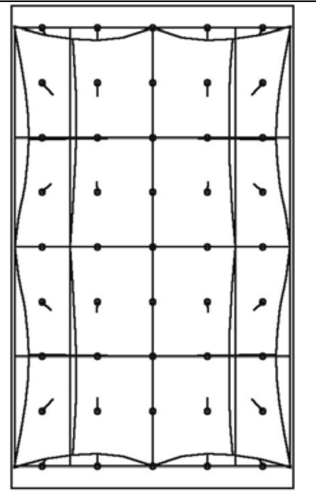


Figure 2b: effect of additional parameter 80 (common DMC)

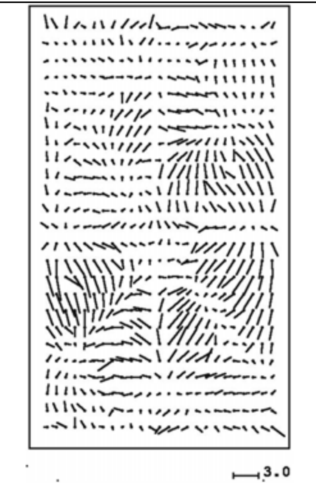


Figure 2c: averaged residuals DMC-block Ghent

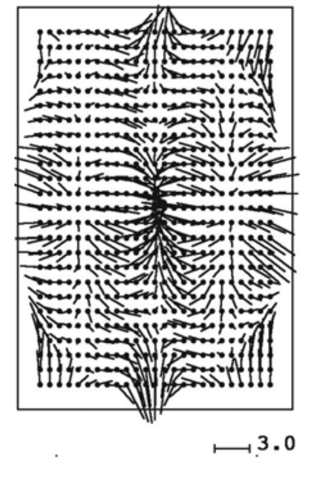


Figure 2d: averaged residuals UltraCamD-block "mine site"

Systematic image errors are influencing the residuals (remaining image coordinate errors) of a bundle block adjustment, or reverse the residuals can be used as indication for systematic image errors. The residuals of all observations are overlaid corresponding to the image position and averaged in small sub-areas to reduce the random image errors (figures 2c and 2d). Such averaged residuals only indicate the systematic image errors because parts of the systematic errors are compensated by the adjustment, but in the case of a strong overlap the shape of geometric problems is shown well. Neighbored averaged residuals as shown in figures 2c and 2d are correlated, so systematic image errors are present.

3. INTERGRAPH DMC

3.1 Block Ghent

The block Ghent, flown by Hansa Luftbild, has 80% end lap, 60% side lap and a photo scale 1:6440 corresponding to 77mm ground sampling distance (GSD). Two crossing flight lines are stabilizing the block, allowing a reduction of the number of control points. From the original 53 control points, 23 are only 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.

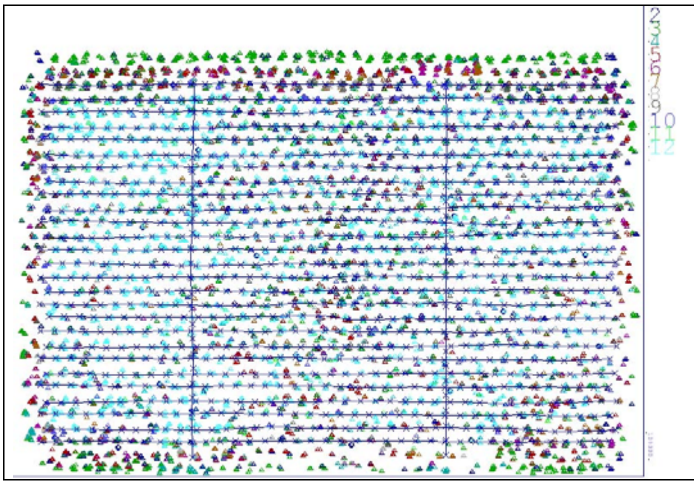
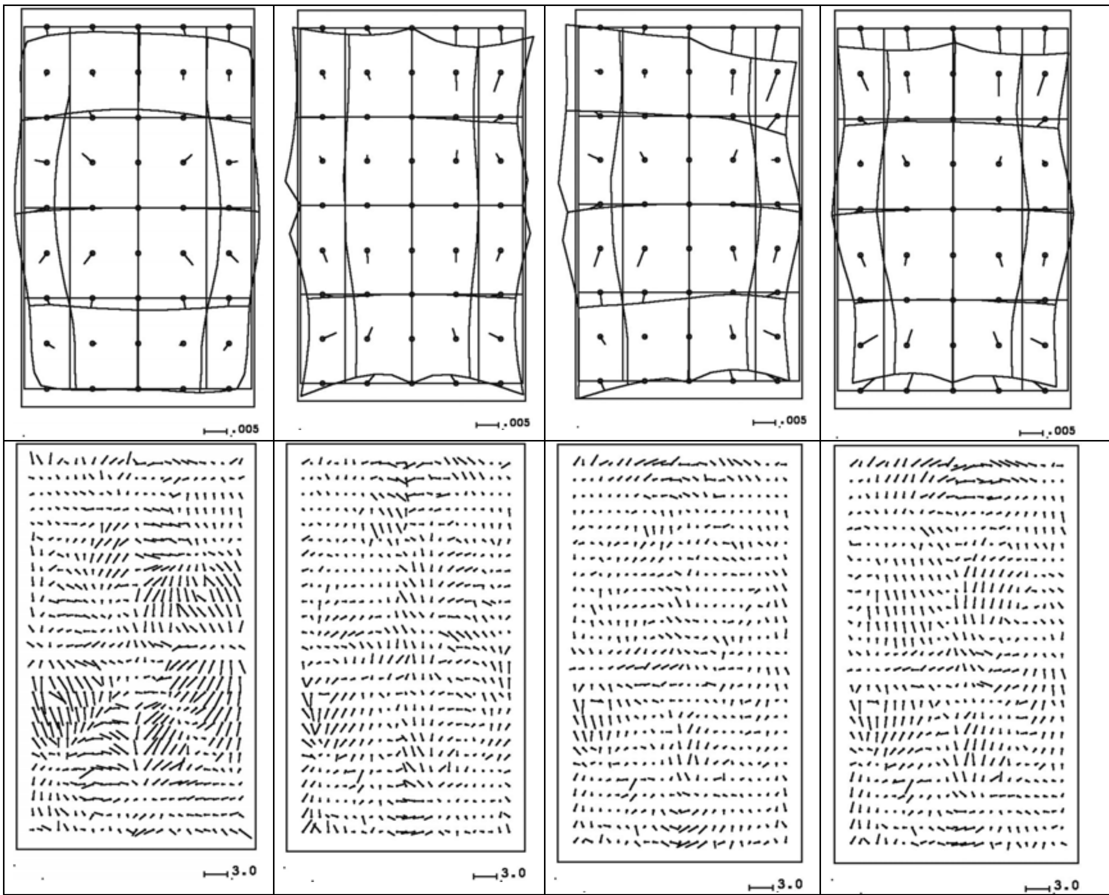


Figure 3: DMC-block Ghent

80% end lap, 20% side lap
7.7cm GSD

color coded number of images/point
≥ 12 images/point = blue
up to 21 images/point
11899 object points, 1105 photos
102 132 image points
in average 8.6 images / point



Systematic image errors

Averaged residuals

(overlay of all images)

3a: Additional parameters 1-12 = standard parameters	3b: parameters 30-41 + 74-77 = special DMC parameters	3c: parameters 1-12 + 30-41 + 74-77 standard + DMC	3d: parameters 1-12 + 78 + 80 standard + common DMC

Figure 3: systematic image errors and averaged residuals DMC-block Ghent depending upon used additional parameters

The trend of the systematic image errors based on the used combination of additional parameters (figure 3, upper part) is similar. In the first view the systematic image errors based on the combination of the standard parameters, used also for analog photos, plus the special DMC-parameters (figure 3c) seems to have a perspective deformation, but this is caused by correlation to the exterior orientation.

The averaged residuals of the adjustment without self calibration (figure 2c) have root mean square values for x and y of 0.8 and 1.2µm. By self calibration with the parameter configuration 1-12, 30-41, 74-77 (configuration 3c) it is reduced to 0.3 and 0.4µm, the other results are within between.

Used additional parameters	control points [cm]		sigma0 [µm]	check points [cm]	
	SXY	SZ		SXY	SZ
Without self calibration	2.7	9.3	2.08	2.7	15.5
1-12 (standard parameters)	2.6	2.6	1.75	2.5	5.9
30-41, 74-77 (special DMC parameters)	2.6	2.6	1.65	2.7	6.1
1-12 + 30-41,74-77 (standard + special DMC)	2.5	2.2	1.59	2.5	5.8
78+80 (only common DMC parameters)	2.6	3.4	1.75	2.7	7.0
1-12 +78 +80 (standard + common DMC parameters)	2.5	2.6	1.63	2.5	5.8

Table 2: results of bundle block adjustments DMC-block Ghent SXY=average of SX and SY

Especially the vertical discrepancies at check points are sensitive for systematic image errors. Nearly the same accuracy at the check points has been reached with the standard set of additional parameters, also used for analog photos, with the standard set plus the special DMC-parameters and also with the combination of the standard parameters with the two parameters handling a common change of the focal length as well as the radial symmetric distortion for all sub-cameras together. There are still small differences in the averaged residuals, but they are not influencing the results.

3.2 Block Rubi

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

Additional parameters	sigma0 [µm]	RMSX	RMSY	RMSZ
Without self calibration	1.87	3.2	2.6	40.3
1-12 (standard parameters)	1.80	2.1	2.3	6.9
30-41, 74-77 (special DMC parameters)	1.76	2.5	2.9	7.4
1-12 + 30-41,74-77 (standard + special DMC)	1.73	2.2	2.6	6.9
78+80 (only common DMC parameters)	1.79	2.8	3.3	11.3
1-12 +78 +80 (standard + common DMC param.)	1.74	2.2	2.7	6.4

Table 3: results at independent check points [cm], 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, modelling the common change of the sub-images, are leading to the optimal results. Also some other blocks show the same tendency.

4. VEXCEL ULTRACAMD

With the UltraCamD similar problems like with the DMC exist, the camera geometry 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.

A photo flight with the Vexcel UltraCamD version 2.1.3, number 8, was made for the German Coal Mining Company 'Deutsche Steinkohle AG' (DSK) in the area of a mine site. This camera did not include the improved temperature handling, which is available since UltraCamD version 2.2. A subset of 2282 images has been analyzed. The images do have an end lap of 80% and a side lap of approximately 60%. The image scale 1:10046 corresponds to 9cm GSD. The block is stabilized by crossing flight lines.

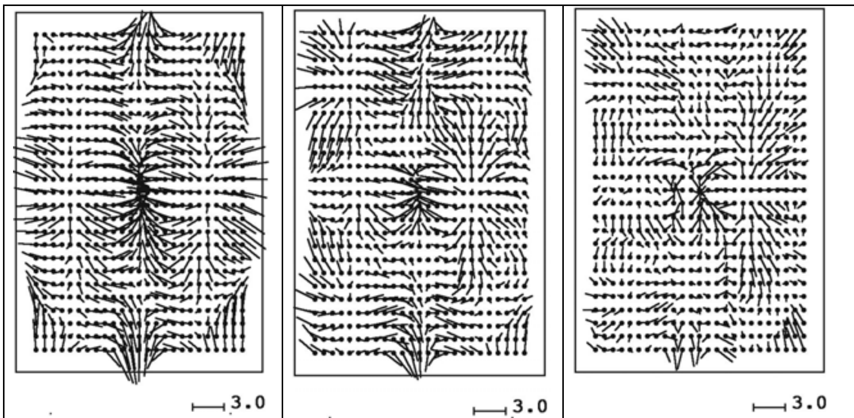
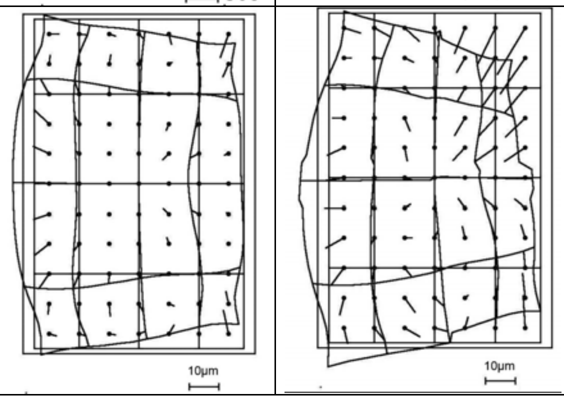


Figure 4: averaged residuals of UltraCamD – German mine site

left: without self calibration
center: with additional parameters 1 –12 (standard set)
right: with additional parameters 1-12, 42-73 (general parameters + special UltraCam-parameters)

"mine site"
80% end lap
60% side lap
crossing flight lines
9cm GSD
2282 images



Corresponding systematic image errors

additional parameters	sigma0 [µm]	control points			check points		
		RMSX [cm]	RMSY [cm]	RMSZ [cm]	RMSX [cm]	RMSY [cm]	RMSZ [cm]
without	2.66	3.6	3.4	2.9	3.8	3.7	7.6
1 - 12	2.44	3.3	3.1	2.5	3.5	3.4	5.6
1-12,42-73	2.26	3.0	2.8	2.3	3.2	3.0	5.4

Table 4: UltraCamD block "mine site", block adjustment with self calibration, 9.0cm GSD results of bundle block adjustment – root mean square discrepancies at 117 control points and 40 check points

Like for the DMC, the systematic image errors are also stable for the UltraCamD - at least within the block. A handling of two sets of images together in one block adjustment was leading to negligible differences of the systematic image errors between both sub-blocks.
Like with the other data a block adjustment with self calibration is required. Also for the UltraCamD-block "mine site" only a very limited improvement of the results at the check points is reached with the special additional UltraCam-parameters, even if the averaged residuals (figure 4 above, center) are indicating remaining systematic image errors if only the standard additional parameters 1 – 12 are used. 3.1cm at the check points are corresponding to 0.34pixels and 5.4cm in Z to hypothetical 0.16pixels for the x-parallax of a model with 60% end lap.
The results of the block Istanbul, like also other blocks, are similar to the block "mine site" – self calibration by additional parameters is necessary, the averaged residuals indicate remaining systematic image errors if only the standard additional parameters 1 – 12 are used, with the special

additional parameters for the UltraCam the size of the averaged residuals can be reduced, but this is only slightly influencing the results achieved at check points.

additional parameters	sigma0 [µm]	control points			check points		
		RMSX [cm]	RMSY [cm]	RMSZ [cm]	RMSX [cm]	RMSY [cm]	RMSZ [cm]
without	3.01	0.8	2.1	23.4	2.2	2.8	16.8
1 - 12	2.76	0.8	0.8	6.5	2.2	1.9	7.6
1-12,42-73	2.75	0.8	0.8	5.1	2.3	2.0	7.5

Table 5: UltraCamD block Istanbul, results of bundle block adjustment
8.6cm GSD, 80% end lap, 60% side lap, crossing flight lines, 1608 images
root mean square discrepancies at 31 control and 17 check points

5. MODEL DEFORMATION

The systematic image errors can be determined and respected by bundle block adjustment, but for the following handling of stereo models, most digital workstation do not allow the use of the determined systematic image errors. Without correction, model deformations are caused by this. This is not a new topic for digital cameras, we do have it also for analogue images, but usually this is ignored.

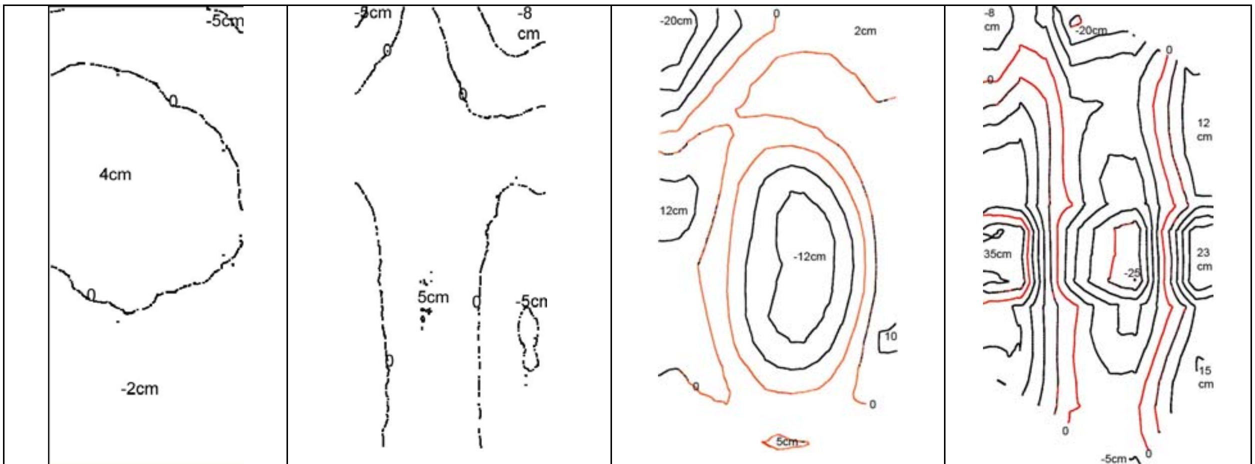


Figure 5a: parameters 1-12	Figure 5b: parameters 1-12, 78-80	Figure 5c: parameters 1-12	Figure 5d: parameters 1-12, 42-73
model deformation in Z: DMC-block Rubi, 9.8cm GSD, end lap 63% 5cm contour interval		model deformation in Z: UltraCamD-block mine site, 9.0cm GSD, end lap 66% 5cm contour interval	

The influence of the model deformation shown in figure 5 is not negligible in relation to the expected vertical accuracy of 7.6cm for the DMC-block Rubi and 9.2cm for the UltraCamD-block "mine site". The influence to the height is more complex and local for the UltraCamD, while it is smoother and not too far away from acceptable for the DMC. Usual commercial Digital Photogrammetric Workstation cannot respect the systematic image errors, so the generated object coordinates are influenced by the model deformation. The influence of the model deformation cannot be accepted for DEMs, by this reason the program DEMCOR for a posterior height correction of DEMs has been developed by the Leibniz University Hannover, solving the problem of the model deformation. In addition a function in the program IMGEO is able to change the image geometry corresponding the systematic image errors. After the change of the image geometry, the images can be handled as perfect perspective images.

As it can be seen in the example from a modern analogue camera (figure 6), model deformations are available in a similar size in analogue cameras.

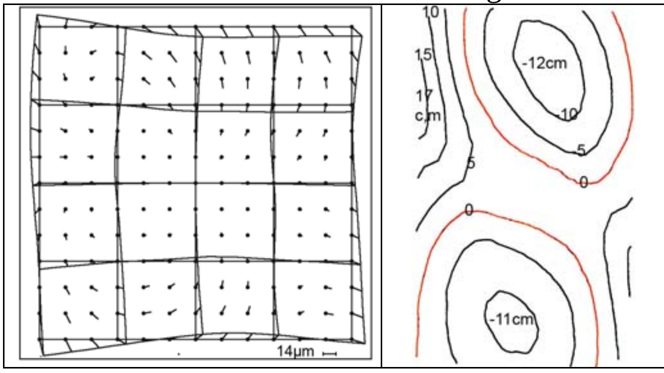


Figure 6: systematic image errors (left) and model deformation (right) for analogue camera RMK TOP 15

end lap 61%
flying height above ground1620m
EuroSDR test flight Frederiksstad for photo scale 1 : 10 600
expected vertical accuracy: 9cm for well defined points, 16cm for other points

CONCLUSION

Caused by geometric change under flight conditions, also the large frame digital aerial cameras DMC and UltraCamD require a block adjustment with self calibration. For the complete elimination of the systematic image errors, special camera specific additional parameters are required, but they have only a limited influence to the object coordinates if they are used in addition to the required standard additional parameters. The systematic image errors can be respected in the bundle adjustment, but usually not during the following data handling in models, causing model deformations especially in the height. The influence of the model deformation to the horizontal coordinates is nearly negligible. With a change of the image geometry by the systematic image errors or a correction of achieved height models by the model deformation, this can be respected. The analysis is describing the current situation; Intergraph and Vexcel are just trying to improve the image geometry, so that the unavoidable model deformation is coming to an acceptable small size.

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