ACCURACY ANALYSIS OF LARGE SIZE DIGITAL AERIAL CAMERAS

R. Passini*, K. Jacobsen**

*BAE SYSTEMS GP&S
124 Gaither Dr.,Suite 100, Mount Laurel, NJ 08054, USA,Ricardo.Passini@baesystems.com
**Institute of Photogrammetry and Geoinformation,Leibniz University Hannover,jacobsen@ipi.uni-hannover.de

Commission I, WG I/4

KEY WORDS: Photogrammetry, Digital, Geometry, Calibration, Block, Accuracy

ABSTRACT:

A test area north of Philadelphia was flown with Vexcel Imaging UltraCamD, UltraCamX and Z/I Imaging DMC digital frame cameras as well as with the 3D-CCD-line scanner camera Leica ADS40 and the analogue RC30. The frame images have 60% overlap in both directions. The object resolution is approximately the same with ~ 5cm ground sampling distance (GSD). 42 well defined control and check points are available with sufficient accuracy. Even if the nominal GSD is approximately the same, this must not correspond to the effective object resolution. This has been investigated by edge analysis – a sudden change of the grey values in the object space is causing a continuous change of the grey values in the image. A differentiation of the grey value profile leads to the point spread function and from the point spread function the effective resolution can be determined. Corresponding to the information about the modulation transfer function in the calibration report, UltraCam-images have in the corners a lower modulation transfer function. In the case of pan-sharpened UltraCam images in general a loss of up to 30% of the image quality against original panchromatic images has been seen. The aerial image, scanned with 13 microns, has a factor for the effective resolution of approximately 1.4; that means it corresponds to an image scanned with 18 microns pixel size. The large size digital frame images are merged from 4 separate panchromatic cameras and the colour cameras. The image deformation of the sub-cameras, determined by laboratory calibration, is respected by the generation of the homogenous virtual images. So by theory they should not show any systematic image errors. In reality an analysis of the image residuals of block adjustments shows very clear systematic image errors corresponding to the merge of the sub-images. The Hannover bundle block adjustment program BLUH has been updated by special additional parameters fitting to the geometric problems of the individual cameras. So by self calibration the exact shape of the systematic image errors – the difference between the mathematical model of perspective geometry and the real image geometry – has been determined. The root mean square discrepancy at independent check points is not so much dependent upon the chosen additional parameters; also with the standard parameters of BLUH approximately the same accuracy could be reached. This is not possible with the Ebner set of additional parameters, here the Gruen set with 44 parameters is required, but such a high number of additional unknowns may cause a loss of accuracy. The block adjustment with the DMC-images is resulting in a sigma0 of approximately 3.5µm (1/3 pixels), while for the UltraCam it is in the range of 4µm. For the DMC this is larger like usual, but it can be explained by the very large scale. The accuracy achieved at independent check points with +/-2cm for X and Y is in the range of the given information about the check point accuracy. For this good result it was necessary to check the exact pointing of every object point with the available field image of the control and check points. With ADS40 images a horizontal accuracy of 2 – 3cm and a vertical accuracy in the range of 3cm has been reached

1. INTRODUCTION

Digital aerial cameras are replacing analogue photogrammetric cameras faster than expected few years ago. The large size frame cameras are based on a combination of sub-cameras, influencing the image geometry. The systematic image errors caused by the image merge have to be respected for projects with high accuracy level as well as for the height determination. Not all sets of additional parameters, used in bundle block adjustment programs, are able to handle the special geometric characteristic of the large size digital frame cameras, so special additional parameters, different for any camera type, have to be analysed.

The 3D-CCD-line cameras, like the ADS40, use a quite different method for the generation of 3D-information. Any CCD-line has a different exterior orientation, determined by direct sensor orientation. This was analysed in the same test area with similar GSD.

2. USED TEST DATA

Organized by BAE SYSTEMS, Mt Laurel, NJ, USA, photo flights with the DMC, UltraCamD, UltraCamX, ADS40 and a RC30 over the test field Franklin Mills have been made (tables 1 and 2). Approximately 42 control points with a standard deviation of the coordinate components not exceeding 2cm are available. With the exception of the ADS40 the flights have approximately 60% end and 60% side lap.

In addition experiences from block adjustments with the DMC in the test block Ghent from Hansa Luftbild (7.7cm GSD, 1105 images), Rubi and Amposta from ICC Barcelona (9.8cm / 9.0cm GSD, 426 /140 images) and with UltraCamD images in "Mine Site" from German Coal Mining (9cm GSD, 2282 images), in Istanbul (8.6cm GSD, 1608 images) as well as DMC-, UltraCamD- and analogue images from the EuroSDR-test Frederikstad have been used (Jacobsen 2007a and 2007b).

camera	f [mm]	image size x [pixel]	image size y [pixel]	pixel size [µm]	(sub-) camera field of view x	(sub-) camera field of view y
DMC	120.0	7680	13824	12.0	23.1°	39.4°
UltraCamD	105.2	7500	11500	9.0	35.6°	52.4°
UltraCamX	100.5	9420	14430	7.2	37.3°	54.7°
RC30	151.3	18400	18400	12.5	74.5°	75.5°
ADS40	62.7	-	12000	6.5	-	63.8°

Table 1. technical data of cameras used in test area Franklin Mills

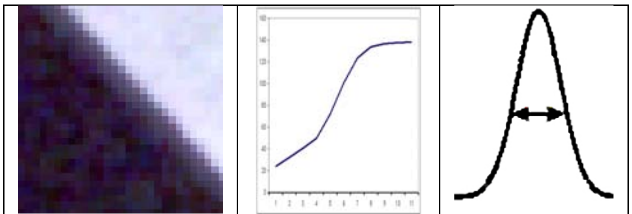
camera	flight	Images	GSD
DMC	July 2007	72	54mm
UltraCamD	February 2006	66	42mm
UltraCamX	April 2007	66	37mm
RC30	September 2007	35	49mm
ADS40	September 2007	5 lines	53 x 91mm²

Table 2. photo flights over test area Franklin Mills

The ADS40 is limited to a sampling rate of 800 lines/sec, determining the GSD in flight direction independent upon the flying height. 91mm GSD in flight direction corresponds to a flight speed of 142 knots or 262 km/h, which is a usual flight speed of photo flights. Across the flight direction the GSD is depending upon the flying height above ground.

3. IMAGE QUALITY BY EDGE ANALYSIS

The GSD computed by the pixel size in the image and the image scale is only the nominal value about the details which can be identified in the images. The relation between the nominal and the real GSD, corresponding to the image quality, can be checked by edge analysis. An abrupt change of brightness in the object space causes a continuous change of the grey value profile perpendicular to the edge in the image. The differentiation of the grey value profile leads to the point spread function. The width of the point spread function shows the effective resolution of the image. The function of the grey value change at edges is mainly dependent upon the optical system including the CCD-array or photo, but it may be influenced also by pan-sharpening.



edge in RC30-image	grey value profile	point spread function

Figure 1. edge analysis

In the Hannover program EDGE, all grey value profiles across an edge, specified by 2 points in the image, are averaged and after differentiation a scale factor for the effective pixel size is computed. This scale factor estimates the information contents, verified by mapping based on corresponding analogue photos, DMC and UltraCamD images (Oswald 2007).

camera	Sun elevation	Image type	Factor for effective pixel size
DMC	43°	pan	0.92
UltraCamD	27°	pan-sharpened	1.16
UltraCamX	27°	pan-sharpened	1.23
UltraCamX centre	27°	panchromatic	1.03
UltraCamX corner	27°	panchromatic	1.24
RC30	46°	RGB colour	1.43
ADS40	46°	pan forward 2°	0.99
ADS40	46°	pan after 14°	0.95
ADS40	46°	pan forward 27°	1.11

Table 3. factor for effective pixel size, Franklin Mills - corresponding to information contents

The images of the test area Franklin Mills have been checked for the effective pixel size (table 3). The RC30 images are scanned with 12.5µm pixel size, so the effective pixel size corresponds to 12.5 ∗ 1.43 = 18µm pixel size. In addition to this, scanned analogue images are affected by film grain and have a limited contrast in relation to original digital images. In the diploma thesis of Oswald 2007, confirmed by additional investigations (Jacobsen 2007a), it became clear, that the same object details which can be identified in analogue images, requires a 1.5 times smaller GSD for scanned analogue photos than for digital images. So the 18µm pixel size has to be multiplied with this factor 1.5, leading to effective 27µm pixel size in digital images. That means, the whole information contents of an analogue photo of 230mm x 230mm corresponds to 8520² pixels, which is below the information contents of the DMC and the UltraCamX and approximately similar to the UltraCamD (more details in Jacobsen 2008).

The factor for the effective pixel size by theory should not be below 1.0, but it can be influenced by contrast enhancement. The contrast enhancement can be seen at the grey value profiles. All investigated images have approximately the same contrast enhancement.

The image quality is not directly influencing the geometric property, this is only the case for pointing control and check points which are not so well defined.

4. SELF CALIBRATION

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 by self-calibration with additional parameters in the bundle block adjustment. Different sets of additional parameters are in use and lead to satisfying results for analogue photos. The additional parameters may be based on a pure mathematical solution or they may be physically justified. Ebner (1976) developed a set of additional parameters, able to compensate the systematic image errors in the 9 Gruber points of a photo (regular grid of 3 x 3 points). This mathematical justified set of parameters was extended by Grün (1979) to a set able to compensate the systematic errors in a regular grid of 5 x 5 image points. Jacobsen (1980) use in the Hannover program system BLUH physical justified parameters, supported by some mathematical justified (Passini, Jacobsen 2008).

DMC-, as well as UltraCam-images, are based on a combination of 4, respectively 9 CCD-arrays from 4 cameras. The merge of the sub-images to homogenous virtual images respects the calibration of the sub-cameras, so by theory the virtual images should be free of systematic errors. In reality this is not the case. The main source of errors is caused by thermal influences; the camera cones and the CCD-arrays, fixed on ceramic, have different thermal coefficients. In addition the temperature gradient within the optics may cause additional geometric distortions. Such errors are causing the same image deformation of a larger group of images - usually this is the same for the whole block.

In the case of a block adjustment without self-calibration, the systematic image errors are influencing the image coordinate residuals. The residuals of a block can be overlaid corresponding to the position of the image point. In small sub-areas the residuals can be averaged, reducing the random error. A plot of such overlaid and averaged residuals gives an impression about systematic image errors.

The overlaid and averaged residuals are indicating very well the systematic image errors. With the standard set of additional parameters the influence of the image merge cannot be expressed precisely. By this reason special additional parameters for the DMC and the UltraCam have been introduced into program BLUH.

The parameters 30 – 33 can detect and respect synchronisation errors of the 4 DMC pan-cameras, while 34 - 41 are improving the perspective relation between the 4 panchromatic DMC sub-cameras. Parameters 74 – 77 are respecting a radial symmetric distortion of the DMC sub-cameras. Investigations with the mentioned large blocks showed similar effects of the DMC specific parameters for all sub-cameras, justifying a common handling. So with parameter 79 the effect of a common change of the focal length of all 4 slightly oblique sub-cameras can be determined and respected and by parameter 80 the same change of the radial symmetric distortion of the sub-cameras can be handled. Parameters 79 and 80 (figure 2) together could replace all other DMC specific additional parameters.

For the UltraCam with the additional parameters 42 up to 73 shifts in x and y, scale changes and rotations of the 8 CCD-arrays in relation to the centre part can be determined. They respect the connection of sub-images by means of tie points. In any case, in addition to the camera specific parameters the standard set of the 12 BLUH-parameters have to be used. For small blocks this may lead to over-parameterisation, requiring only the use of the justified parameters. In program BLUH, based on a T-test, check of the correlation and the total correlation, the set of chosen additional parameters is reduced by the program to the necessary set. That means even if in following tables a larger number of additional parameters are specified, this is only the start set, the final adjustment has been made with a reduced set of additional parameters.

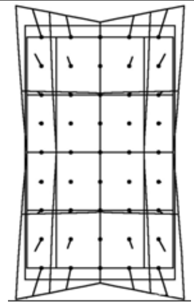


Figure 2a. effect of additional parameter 79 to image geometry (common change of focal length; DMC)

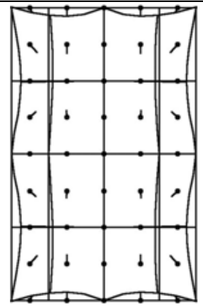
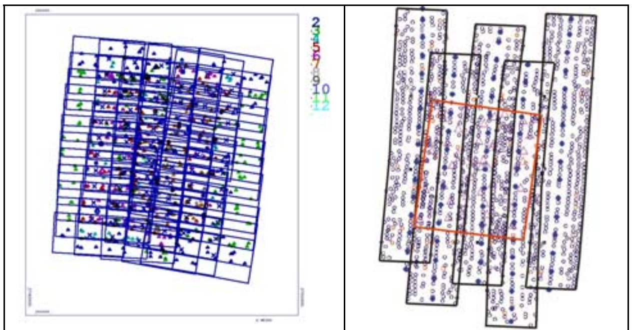


Figure 2b. effect of additional parameter 80 to image geometry (common radial symmetric distortion; DMC)

5. BLOCK ADJUSTMENTS

The determination of the tie points of the test area Franklin Mills has been made for the frame cameras with LPS and for the ADS40 with ORIMA. The manual control point measurement was time consuming because of the 60% side lap and 60% end lap of the frame cameras. In the DMC and UltraCam blocks the control points have been measured in the average in 5.4 up to 6.4 images, in the RC30 block in 9.1 images and in the ADS40 block in 5.0 images. The control point definition required for any point the check of the precise point location based on field images, because sometimes the centre of lines on a large parking place and sometimes the corners have been used.



DMC | ADS40

Figure 3. block configurations Franklin Mills with colour coded number of images per point for the frame cameras

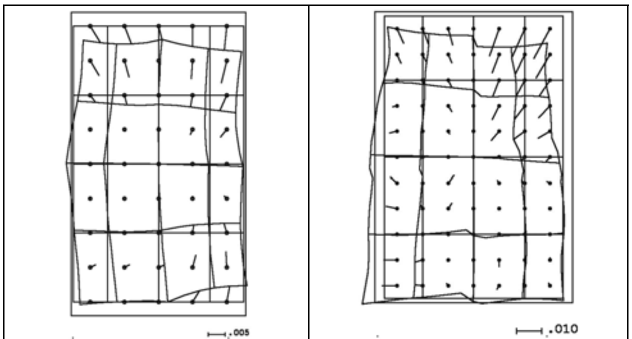
Figure 3 shows the block configurations of the test field Franklin Mills. The configuration for the UltraCam is not shown, because it is similar to the configuration of the DMC.

DMC	RMSX	RMSY	RMSZ	sigma0
without self calibration	2.5 cm	1.8 cm	3.4 cm	3.51 µm
parameters 1-12	2.4 cm	1.7 cm	3.4 cm	3.49 µm

parameters 1–12, 79-80	2.4 cm	1.7 cm	3.0 cm	3.48 µm
add. par.1–12, 30-41,74-77	2.5 cm	1.8 cm	3.4 cm	3.48 µm

Table 4. root mean square differences at independent check points - block adjustment of DMC-images with 8 control points; 54mm GSD ; 1.7cm = 0.31 GSD, 1.4cm = 0.26 GSD

Also block adjustments with all and with 15 control points have been made in addition to the results shown in table 4. In general there is only a limited improvement of the results at independent check points by self calibration. The optimal results have been achieved with the standard set of the BLUH parameters (12 parameters) plus the common DMC parameters 79 and 80. The main reason for the limited influence of the self calibration is caused by the limited block size together with 60% side lap. This was different for the Hansa Luftbild block Ghent, having 1105 DMC-images. In this large block the accuracy at vertical check points could be improved from 19.1cm without self calibration to 5.7cm with self calibration (Wu 2007). The self calibration avoids the block deformation especially in the vertical component. A combined adjustment with relative kinematic GPS-positions of the projection centres reduces the effect of the self-calibration.



DMC, based on parameters 1 – 12, 79, 80	UltraCamD, with parameters 1 – 12, 42 – 73

Figure 4.systematic image errors; vector length of systematic image errors: DMC: 5µm, UltraCamD: 10µm

UltraCamD 42mm GSD	RMSX	RMS Y	RMSZ	sigma0
no self calibration	4.3cm	3.0cm	8.3cm	4.32µm
add. par. 1 – 12	3.2cm	2.6cm	7.9cm	4.27µm
1–12, 42-73	3.8cm	2.5cm	8.0cm	4.18µm

Table 5. root mean square differences at independent check points - block adjustment of UltraCamD-images with 8 control points 3.2cm = 0.76 GSD 2.5cm = 0.58 GSD

Also the block adjustment of the UltraCamD-images (table 5) shows only a limited advantage of the self-calibration, even if the systematic image errors are not negligible (figure 4).

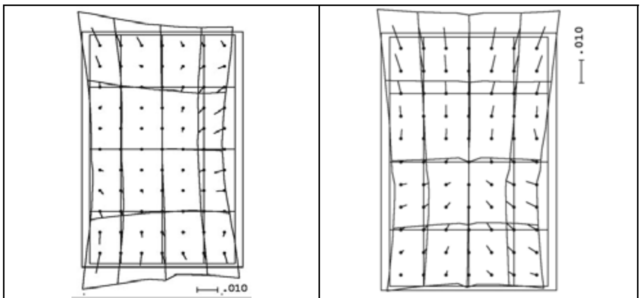
At first only pan-sharpened UltraCamX images have been available for the test area Franklin Mills. Later on Vexcel Imaging merged the sub-images again and gave us from the new calculated data set also panchromatic images. Vexcel Imaging also determined the tie, control and check points with INPHO Match AT. With this a sigma0 of 1.0µm was reached by BLUH instead of 3.0µm with tie points based on LPS, but because of the high number of tie points per image this did not influence the results determined at independent check points. An additional measurement of the check points by the experienced operator of the Leibniz University Hannover, together with a matching with LPS, improved the results against the measurements by Vexcel Imaging even with the quite higher sigma0-value.

UltraCamX first data set	RMSX	RMS Y	RMSZ	sigma0
no self calibration	4.3cm	3.0cm	8.3cm	3.06µm
add. par. 1 – 12	2.0cm	1.6cm	3.8cm	2.98µm
add. par. 1–12, 42-73	2.8cm	1.7cm	4.2cm	2.99µm

Table 6. root mean square differences at independent check points - block adjustment of first data set of UltraCamX pan-sharpened images with 8 control points 37mm GSD 2.0cm = 0.54 GSD 1.6cm = 0.43 GSD

UltraCamX second data set	RMSX	RMS Y	RMSZ	sigma0
no self calibration	2.8cm	1.9cm	8.7cm	2.98µm
add. par. 1 – 12	1.5cm	1.4cm	4.7cm	2.94µm
add. par. 1–12, 42-73	1.6cm	1.4cm	5.3cm	2.88µm

Table 7. root mean square differences at independent check points - block adjustment of second data set of UltraCamX panchromatic images with 8 control points 37mm GSD 1.5cm = 0.40 GSD 1.6cm = 0.43 GSD



parameters 1 – 12, 42 – 73 first data set pan-sharpened	parameters 1 – 12, 42 – 73 2nd data set panchromatic

Figure 5. UltraCamX-block Franklin Mills

With the new calculated images the horizontal components at independent check points have been improved (tables 6 and 7). This may be caused also by the better image quality of the panchromatic images, making the precise pointing easier. In the Z-component there was no improvement. For the UltraCamX-images the self-calibration is very important, improving not only the height, but also the horizontal components.

The systematic image errors of the UltraCamX-images (figure 5) did not change their size based on the new merged images, but the systematic image errors of the second data set are smoother and more regular. This improved especially the horizontal component of the adjustment without self-calibration.

The ADS40-images have been handled with ORIMA. The same control and check points have been used like for the frame cameras. With the 3D-CCD-line scanner a quite different imaging concept is used, leading to image strips (see figure 3). The ADS40 has with 53mm x 91mm the largest GSD of the used images.

Caused by the imaging geometry the self-calibration is not so important for the ADS40-data, only 2 parameters for affine improvement have been used, but they did not show a clear improvement. More important is the weighting relation between the direct sensor orientation and the control points. The finally reached accuracy of 2cm – 3cm (table 8) requires a strong fit to the ground control points. The sigma0-value for all adjustments with quite different weight relations was always in the range of 4.9µm up to 5.0µm.

	RMSX	RMSY	RMSZ
1 GCP	5.2 cm	2.7 cm	4.5 cm
4 GCP	2.3 cm	2.5 cm	3.1 cm
8 GCP	2.1 cm	2.4 cm	3.1 cm
15 GCP	2.0 cm	2.2 cm	2.7 cm

Table 8. root mean square differences at independent check points - block adjustment of ADS40-data, depending upon a different number of ground control points (GCP)

With the exception of an adjustment with just one control point, the accuracy is not so much depending upon the number of control points, but it has to be respected, that the ADS40-data are supported by relative kinematic GPS-positioning and IMU-data. Such a support, which is especially improving the height, has not been used for the frame data, so a direct comparison of the ADS40-data with the frame data is not possible.

The image coordinate accuracy of the wide angle RC30 is with approximately 6µm (table 9) in the level of operational block adjustments. The systematic image errors of the used camera are with maximal 10µm smaller than usual. With analogue cameras systematic image errors up to 20µm are not unusual.

	RMSX	RMSY	RMSZ	sigma0
without self calibration	2.4cm	3.6cm	4.1cm	6.02µm
additional parameters 1-12	2.6cm	3.7cm	4.5cm	5.94µm

Table 9. root mean square differences at independent check points - block adjustment of RC30-data based on 8 GCP

The results achieved with the different sensors have to be compared in relation to the GSD (figure 6) which varies between 3.7cm and 7.2cm (average for ADS40). But it has to be respected, that the standard deviation of the control and check points is specified with not exceeding 2cm, so no better accuracy can be confirmed for the results below 2cm standard deviation and reverse the very good result as function of the GSD for the ADS40 could be reached easier because of the larger GSD. So also the absolute values of the root mean square differences at the independent check points have to be seen (figure 7).

Of course the Franklin Mills blocks are not so large, so the advantage of the self calibration with additional parameters is limited, nevertheless especially the height is sensitive for systematic image errors, but in the case of the UltraCamD and UltraCamX also the X- and Y-components are improved by self calibration. In general for the small blocks, the camera specific parameters have only a limited influence even if there is a clear reduction of the averaged image coordinate residuals. Also in larger blocks the improvement by the camera specific parameters was limited, but this is only the case for the parameter set used in program BLUH. An adjustment of the DMC-block Ghent with the Ebner parameters (Ebner 1976) did not result in satisfying object point accuracy, the high number of 44 Grün-parameters (Grün 1979) were necessary to reach a similar accuracy level like with the 12 BLUH-parameters (Wu 2007).

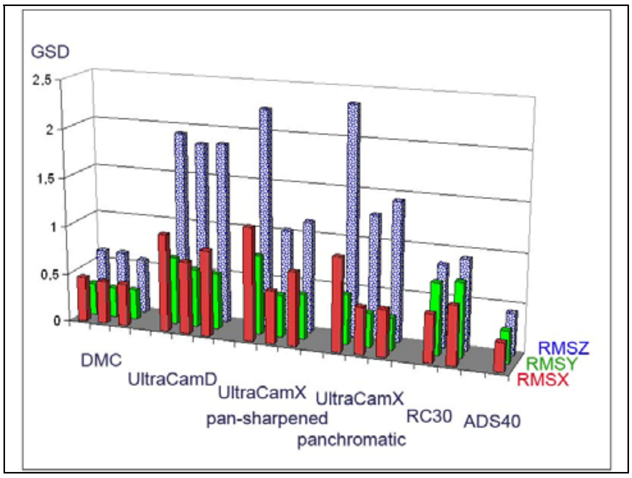


Figure 6. comparison of results at independent check points of block adjustments with 8 control points achieved in test area Franklin Mills **[GSD],** Within the groups: from left without self calibration / with parameters 1 – 12 / with parameters 1 – 12 + camera specific parameters

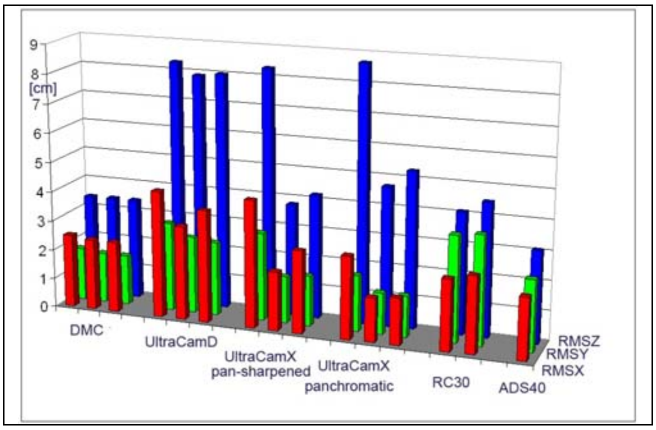


Figure 7. comparison of results at independent check points of block adjustments with 8 control points achieved in test area Franklin Mills based **[cm]** Within the groups: from left without self calibration / with parameters 1 – 12 / with parameters 1 – 12 + camera specific parameters

6. MODEL DEFORMATION

The systematic image errors are determined and respected in the block adjustment; here they are not causing any problem. In most cases this is different for the handling in the photogrammetric models, often the systematic image errors cannot be respected, but there is a trend to include the possibility of respecting the systematic image errors in commercial software. Under standard conditions, the influence to the horizontal coordinate components is limited and can be accepted in most cases, this may not be the case for the height. If the height is important for the data acquisition, the model deformation should be checked at least.

	
UltraCamD Min: -5cm max: 8cm	UltraCamX 2nd data set panchromatic Min : -7cm max : 8cm

Figure 8. model deformation in Z caused by systematic image errors, based on additional parameters 1 – 12 + camera specific parameters, data set Franklin Mills, contour interval 1cm

The figures 8 shows the model deformation of the Z-component caused by not respected additional parameters for the data set Franklin Mills. For the DMC it is between -1.5cm up to 2 cm, and for the RC30 between -4cm up to 3cm. The model deformation has been computed in the object space for a specific model and rotated to the base direction. Based on 0.5 pixels standard deviation of the x-parallax in a photogrammetric model, the expectation for the vertical accuracy for the DMC is 8.6cm, for the UltraCamX 6.8cm, for the UltraCamD 7.8cm and for the RC30 4cm. The varying values are depending upon the GSD and the height to base relation which is 3.1 for the DMC, 3.7 for the UltraCam and 1.6 for the wide angle RC30. The estimated standard deviations are not identical to the results of the block adjustments, because in a model only 2 images are used and not the large over-determination of the block. The model deformations for the DMC and the RC30 are below the estimated standard deviations, while this is not the case for both UltraCam. Nevertheless also for both UltraCam the model deformation exceeds just slightly the estimated standard deviation and no negative influence to data acquisition in a model would exist, if the software is able to handle the systematic image errors. Another solution would be the change of the image geometry based by the systematic image errors like realized in the Hannover program IMGEO or the a posterior change of determined height values like realized in the Hannover program DEMCOR. Both methods have been used successfully for DEM-generation in coal mining areas (Spreckels et al 2008).

In cooperation with the German hard coal mining company “RAG Aktiengesellschaft” (RAG) a block flown with an UltraCamD for the determination of subsidence has been handled. The UltraCamD-images have been merged at first with the old software from Vexcel Imaging and later computed again with the new software, which is respecting some geometric problems in a more precise manner. The UltraCamD-images based on the new merging software of Vexcel Imaging show quite smaller systematic image errors than the same images based on the old software. Corresponding to this, also the model deformation has been improved by the new merged images from the range -25cm up to 35cm. to the range -8cm up to 9cm.

7. CONCLUSION

The high accuracy level of the digital cameras has been confirmed. With similar GSD the DMC, the UltraCamX and the ADS40 are reaching a better accuracy in X and Y than the wide angle RC30. The DMC and the ADS40 are also better in the vertical direction than the results based on the wide angle RC30.

The just 2 camera specific additional parameters for the DMC are improving the result achieved at independent check points. The UltraCamD images, generated with the old merging software, have some geometric problems, reducing the accuracy, even with the 32 camera specific parameters it cannot be solved. In smaller blocks the combination of the 12 standard additional parameters plus the 32 UltraCam-specific parameters may lead to over-parameterisation, reducing the accuracy. With the new merging software from Vexcel Imaging the image geometry got a clear improvement, shown at the block mine site, where the same sub-images have been used with the old and the new software. The UltraCamX images have been merged for the Franklin Mills project with the new software, leading to a better accuracy in relation to the GSD than for the UltraCamD, which was based on the old software. A recalculation of the UltraCamD images by Vexcel Imaging improved the image quality. In addition it became obvious, that with original panchromatic images better results can be achieved. The UltraCam height to base relation of 3.7 for 60% end lap leads to lower vertical accuracy than the wide angle RC30. The lower accuracy of the UltraCam in relation to the RC30 in the case of just 8 control points is also influenced by the larger footprint size of the RC30, causing a smaller distance of the control points in relation to the photo base for the RC30 like for the UltraCam.

With the 3D-line-scanner ADS40 with 2-3cm accuracy for all coordinate components, under the condition of at least 4 control points, clear sub-pixel accuracy has been reached, if the data set is strongly fixed to the control points.

The data acquisition in models should respect the systematic image errors to avoid a not necessary loss of accuracy especially for the UltraCam, but also the traditional aerial photos. Another, but time consuming alternative, is the correction of the images by the systematic image errors.

The information content should be checked by edge analysis, determining the effective GSD, which is the nominal GSD size multiplied with the scale factor of the point spread function. The edge analysis shows, that 12.5µm pixel size for scanning aerial photos is not required and that finally the whole information of a single analogue photo is in the range of the information contents of a single UltraCamD image. An

UltraCamX- or a DMC-image contains more information. The panchromatic UltraCam images have only in the corners a loss of resolution, while the pan-sharpened images showed an overall loss of resolution.

ACKNOWLEDGEMENT

Thanks are going to Leica for the support of the handling of the ADS40-images and to Vexcel Imaging for the new calculation of the UltraCamX-images. The authors also would like to acknowledge the support of Keystone Aerial Survey that carried out the flights with the UltraCamD, the UltraCamX and the RC30. PhotoScience of Lexington Kentucky made flight with the Z/I DMC digital camera. Fugro-EarthData carried out the flight with the ADS40. Mr. Larry Straight, T3GS Inc. and Mr. Frank Lenik of Leica Geosystems supported the determination of the ground control and check points.

REFERENCES

Ebner, H. (1976): Self-calibrating block adjustment, ISP-congress Helsinki 1976, Int. Archive of the ISPRS, Vol 18-3

Grün, A. (1979): Self-Calibration versus Testfield Calibration, ISP WG III/3 Aalborg 1979

Jacobsen, K. (1980): Attempt at Obtaining the Best Possible Accuracy in Bundle Block Adjustment, ISP Hamburg 1980, Int. Archives of Photogrammetry, Vol. 12-3, pp 304 - 313 and Photogrametria 1982, p 219 – 235

Jacobsen, K. (2007a): Comparison of Large Size Digital Airborne Frame Cameras with Analogue Film Cameras, EARSeL symposium Bolzano, 2007

Jacobsen, K., (2007b): Geometric Handling of Large Size Digital Airborne Frame Camera Images, Optical 3D Measurement Techniques VIII, Zürich 2007, pp 164 – 171

Jacobsen, K. (2008): Tells the number of pixels the truth? – Effective Resolution of Large Size Digital Frame Cameras, ASPRS 2008 annual convention, on CD

Oswald, H.C., 2007: Potential digitaler photogramm-metrischer Luftbildkameras, Diploma thesis Leibniz University Hannover

Passini, R., Jacobsen, K., 2008: Geometric Analysis on Digital Photogrammetric Cameras, ASPRS 2008 annual convention, on CD

Spreckels, V., Schlienkamp, A., Jacobsen, K.,2008: Geometric Characteristic of Digital Frame Cameras, EARSel Workshop Remote Sensing - New Challenges of High Resolution, Bochum 2008 + http://www.ipi.uni-hannover.de

Wu, Dun. (2007): Geometric aspects of large size digital frame cameras and their use for photogrammetric data acquisition, diploma thesis, Leibniz University Hannover, http://www.ipi.uni-hannover.de