GEOMETRIC ANALYSIS ON DIGITAL PHOTOGRAMMETRIC CAMERAS

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ABSTRACT

A test field area of approximately 4.9 km² (~1200Acres) was flown with 4 different types of digital cameras, i.e., Microsoft Photogrammetry UltraCamD, UltraCamX, Z/I Imaging DMC and Leica ADS40 with ground sample distances (GSD) of 3.7 to 5.4 cm. The frame cameras were flown with 60% end and 60% lateral overlap. The image stripes taken with the Leica ADS40 have 30 % lateral overlap. The test area, located in the Northern quarter of Philadelphia city, includes mainly a large parking area of the big Franklin Mills shopping mall and surrounding vicinity areas. As such the neighborhood has abundant parking stripes, pavement road signals, painted turning arrows, etc. that has been used as well defined Ground Control Points (GCPs) and Check Points (ChkPts). The control and check points were measured by RTK GPS to standard deviations of the coordinate components of 2 cm or better. Full photograph details were also taken from each point. The objective of the presented part of the test includes bundle block adjustment with accuracy analysis including systematic image errors determined by self calibration with general plus camera specific additional parameters and caused model deformation as well as studies on effective GSD determined by edge analysis versus theoretical GSD that it is reported in a separate paper (See Jacobsen 2008). For analog cameras the photo scale and for digital cameras the ground sampling distance (GSD) is the dominating factor for the specification of photo flights.

An analysis of the residuals of a bundle block adjustment without self calibration shows clear systematic image errors for all cameras. The geometric analysis of the digital cameras has been made with the Hannover program system BLUH which has special additional parameters for the digital cameras, corresponding to the problems of merging sub-images to synthetic images. Within the data sets no significant variation of the systematic image errors can be seen. The accuracy achieved at independent check points is not so much depending upon the chosen additional parameters, nevertheless the number of required additional parameters is quite smaller for the DMC like for the UltraCam. The achieved root mean square errors (RMSE) at ChkPts are ranging for X and Y between 0.3 and 0.9 GSD, while it is between 0.6 and 1.9 GSD for the vertical component. The new software for merging the UltraCamD-images to virtual, homogenous images has improved the image geometry.

INTRODUCTION

Photogrammetric imaging is in the change from analog photos to digital images. The large size digital frame cameras Z/I Imaging DMC and Microsoft Photogrammetry UltraCamD and UltraCamX are based for the panchromatic channel on a combination of 4 sub-cameras. The images of the sub-cameras are merged together using tie points for the optimal fit. For the merge of the sub-images, the calibration of the sub-cameras is respected, so by theory the merged virtual images should be free of any systematic image errors. Systematic image errors can be analyzed by means of the residuals of a bundle block adjustment and determined by self calibration with additional parameters. All digital cameras showed not negligible systematic image errors. General additional parameters are in use for the determination of the image geometry within bundle block adjustment since years, but they may not be able to fit the special geometric problems of the large size digital frame cameras. It was necessary to analyze the optimal improvement by self calibration and the possible accuracy of the determined ground points based on digital cameras.

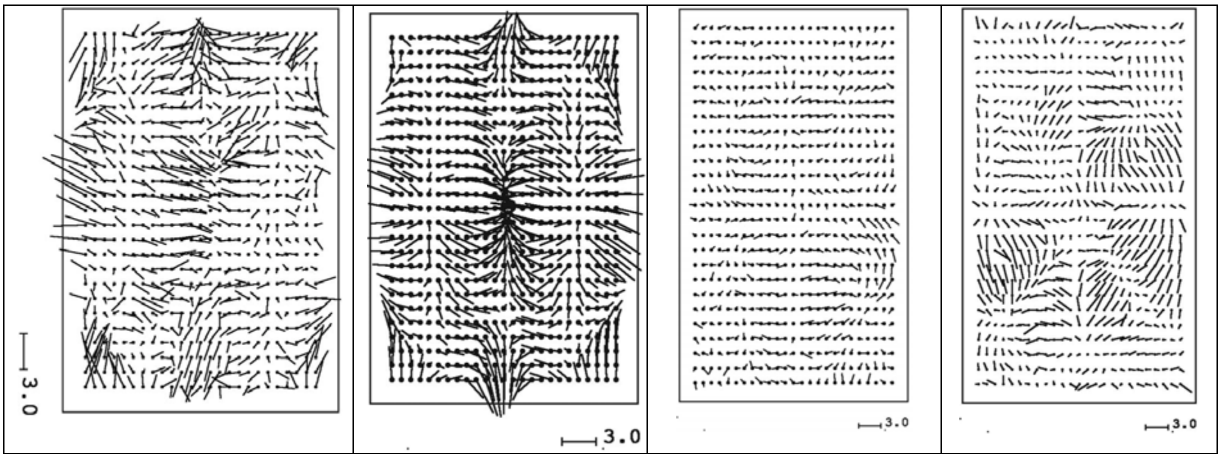
SELF CALIBRATION

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 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 pure mathematical solution or physical justification. 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) used in the Hannover program system BLUH physical justified parameters, supported by some mathematical justified (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 in Hannover program system BLUH



EuroSDR test site Frederiksstad UltraCamD	UltraCamD-block "mine site"	DMC block Rubi ICC Barcelona	DMC-block Ghent, Hansa Luftbild

Figure 1. averaged and overlaid residuals corresponding to their location in the images of block adjustments without self calibration, vector scale 3µm

In a block adjustment without self calibration the systematic image errors are influencing the image coordinate residuals. The residuals are located at the image point position. If all residuals of a bundle block adjustment are overlaid corresponding to their image position, they are indicating the structure of the systematic image errors. The overlaid residuals can be averaged in small image sub-areas to reduce the random error; the systematic error will not be reduced, because it is depending upon the image position (figure 1). Such an analysis can be used for the identification of the shape of the systematic image errors or the remaining systematic image errors of an adjustment with self calibration using the basic set of parameters.

Block adjustments without self calibration and block adjustments just with the standard set of additional parameters (table 1) showed, that the large size digital frame cameras have specific geometric problems which cannot be solved by the standard sets of additional parameters, so camera specific additional parameters have been developed.

The DMC has an offset of the 4 projection centers of the panchromatic sub-cameras, so by theory the sub-images only can be merged together correctly for the specified height level. An error of the specified height level by theory should cause some image deformation. For this the additional parameter 29 has been introduced. In fact, during the handling of the block Rubi of the ICC Barcelona, an error of approximately 200m for the reference height happened. A theoretical computation of the influence to the image coordinates resulted only in negligible systematic errors. Corresponding to this, the additional parameter 29 for respecting the influence of the camera offsets was not significant and in no other block this parameter was justified, showing that the DMC camera offset has no influence.

The parameters 30 – 33 can detect and respect synchronization 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 of several 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 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 together could replace all other DMC specific additional parameters. The deformation corresponding to parameter 79 may be caused by thermal influences – the cone and the ceramic plate of the CCD have different thermal coefficients, while the parameter 80 respects the deformation of the lens system by the thermal gradient within the optics. Both effects may be the same for all sub-cameras.

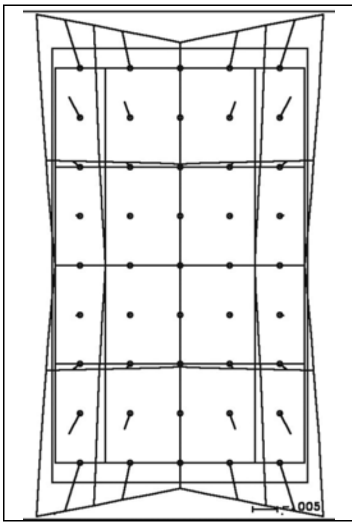


Figure 2a. effect of additional parameter 79 (common change of focal length of the panchromatic sub-cameras; DMC)

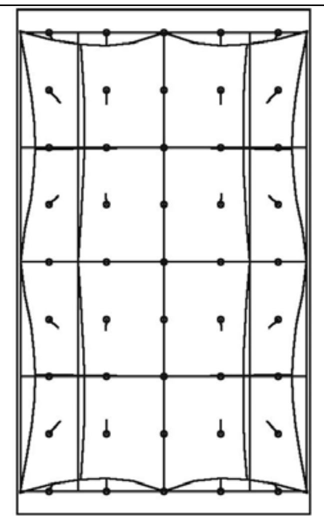


Figure 2b. effect of additional parameter 80 (common radial symmetric distortion of the sub-cameras; DMC)

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-parameterization, requiring only the use of the justified parameters. In program BLUH, based on a T-test, the check of the correlation and the total correlation, the set of chosen additional parameters is reduced by the program to the justified set. That means even if in following tables a larger number of additional parameters are listed, this is only the start set, the final adjustment has been made with a reduced set of parameters.

TEST FIELD FRANKLIN MILLS

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

camera	f	image size x [pixel]	image size y [pixel]	pixel size	field of view x	field of view y
DMC	120.0 mm	7680	13824	12.0 µm	42.0°	69.3°
UltraCamD	105.2 mm	7500	11500	9.0 µm	35.6°	52.4°
UltraCamX	100.5 mm	9420	14430	7.2 µm	37.3°	54.7°
RC30	151.3 mm	18400	18400	12.5 µm	74.5°	75.5°

Table 2. technical data of the frame 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
ADS40, sensor head 52	October 2006	5 lines	53mm x 91mm
RC30	September 2007	35	49mm

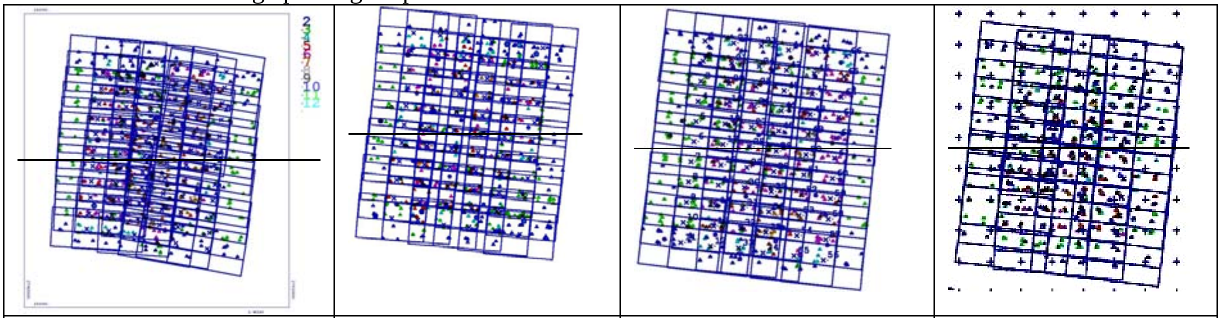
Table 3. photo flights over test area Franklin Mills

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

The ADS40 has a sampling rate of 800 lines per second. A GSD of 91mm in the flight direction corresponds to a flying speed of 262 km/h or 142 knots – this is a standard speed for photo flights. In the across flight direction, the GSD just depends upon the flying height. A square size of the projected pixel size is only possible for GSD exceeding 90mm. The images have been handled over just recently, so no geometric analysis was possible up to now. The radiometric property has been analyzed together with the other cameras in Jacobsen (2008)

BLOCK ADJUSTMENTS

Automatic aero triangulations have been made with LPS. The manual control point measurement was time consuming because of the 60% side lap and 60% end lap. The resulting image coordinates were analyzed with program system BLUH. 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. For a better definition and proper stereoscopic observation of the GCPs and Check Points, field images were used. This help in the precise location of the point since sometimes the center of lines of large parking stripes and sometimes the corners were used.

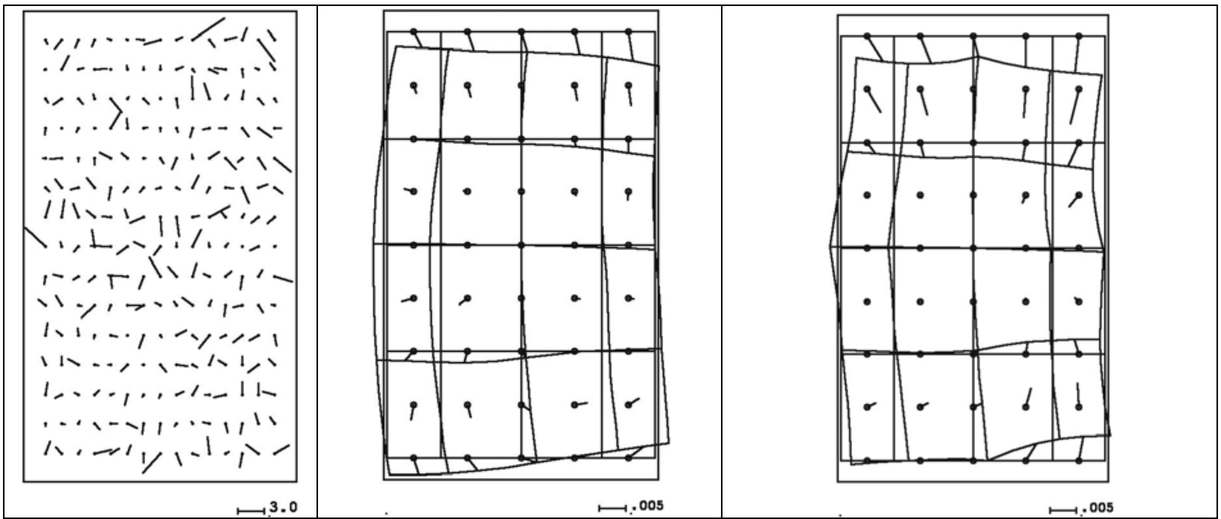


DMC	UltraCamD	UltraCamX	RC30

Figure 3: block configurations test area Franklin Mills with color coded number of images/point

DMC	sigma0	8 control points [cm]			32 check points [cm]		
54mm GSD	12µm pixel	RMSX	RMSY	RMSZ	RMSX	RMSY	RMSZ
without self calibration	3.51µm	1.4	0.7	1.0	2.5	1.8	3.4
add. par. 1 – 12	3.49µm	1.0	0.6	0.7	2.4	1.7	3.4
add. par. 1–12, 79-80	3.48µm	1.1	0.7	0.6	2.4	1.7	3.0
add. par. 1–12, 30-41,74-77	3.48µm	1.1	0.7	0.7	2.4	1.7	3.2

Table 4. block adjustment of DMC-images with 8 control points 2.4cm = 0.44 GSD 1.7cm = 0.31 GSD

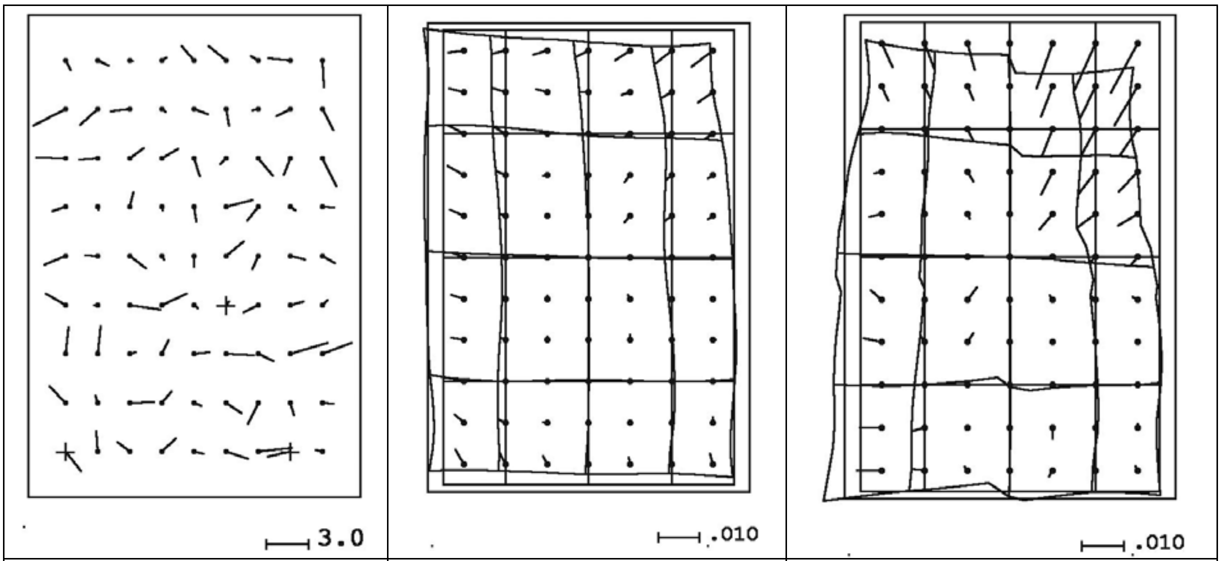


averaged residuals – without self calibration	systematic image errors, adjustment with parameters 1-12	systematic image errors, adjustment with parameters 1 – 12, 79, 80

Figure 4. DMC-block with 42 control points; vector scale of systematic image errors: 5µm

UltraCamD	sigma0	8 control points			33 check points		
42mm GSD	9µm pixel	RMSX	RMSY	RMSZ	RMSX	RMSY	RMSZ
without self calibration	4.32µm	2.9cm	1.3cm	1.9cm	4.3cm	3.0cm	8.3cm
add. par. 1 – 12	4.27µm	1.0cm	0.8cm	1.0cm	3.2cm	2.6cm	7.9cm
add. par. 1–12, 42-73	4.18µm	2.0cm	1.0cm	0.4cm	3.8cm	2.5cm	8.0cm

Table 5. block adjustment of UltraCamD-images with 8 control points 3.2cm = 0.76 GSD 2.5cm = 0.58 GSD

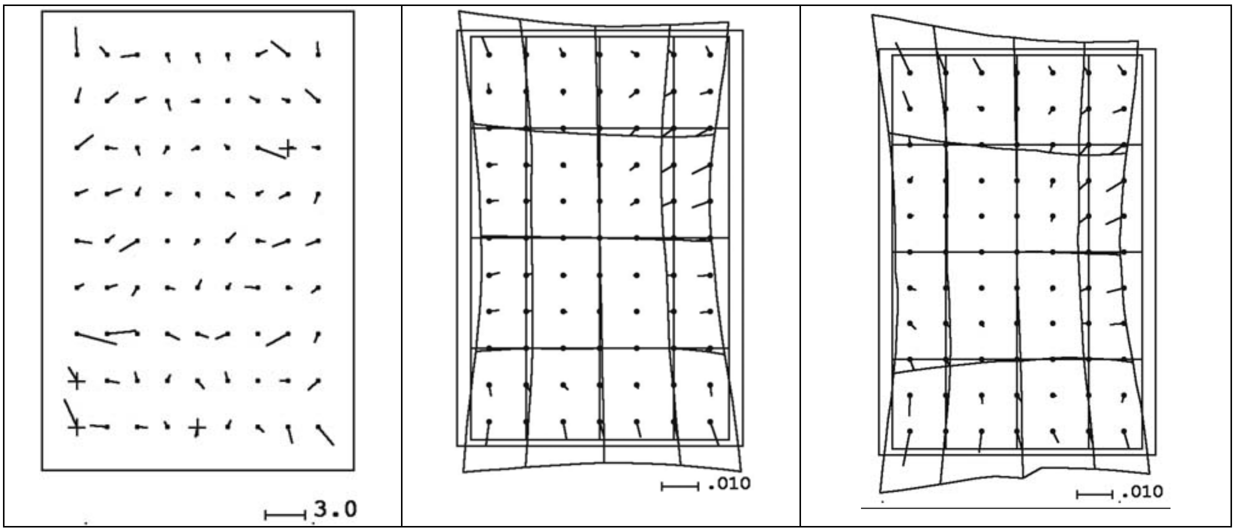


Averaged residuals without self calibration	Systematic image errors, adjustment with parameters 1 - 12	systematic image errors, adjustment with parameters 1 – 12, 42 – 73

Figure 5. UltraCamD: averaged residuals and systematic image errors, adjustment with 42 control points, vector scale 10μm

UltraCamX	sigma0	8 control points			33 check points		
37mm GSD	7.2μm pixel	RMSX	RMSY	RMSZ	RMSX	RMSY	RMSZ
without self calibration	3.06μm	3.3cm	1.4cm	5.5cm	4.3cm	3.0cm	8.3cm
add. par. 1 – 12	2.98μm	1.0cm	1.0cm	2.0cm	2.0cm	1.6cm	3.8cm
add. par. 1–12, 42-73	2.99μm	3.2cm	1.8cm	0.4cm	2.8cm	1.7cm	4.2cm

Table 6. block adjustment of UltraCamX-images with 8 control points 2.0cm = 0.54 GSD 1.6cm = 0.43 GSD



Averaged residuals without self calibration	Systematic image errors, adjustment with parameters 1 - 12	systematic image errors, adjustment with parameters 1 – 12, 42 – 73

Figure 6. UltraCamX: averaged residuals and systematic image errors, adjustment with 41 control points, vector scale 10µm

RC30 f=153mm	Control points			sigma0	Check points		
49mm GSD	RMSX	RMSY	RMSZ		RMSX	RMSY	RMSZ
without self calibration	2.4cm	1.9cm	2.4cm	6.02µm	2.4cm	3.6cm	4.1cm
additional parameters 1 - 12	2.2cm	1.3cm	1.8cm	5.94µm	2.6cm	3.7cm	4.5cm

Table 7. block adjustment of RC30 wide angle images with 8 control points

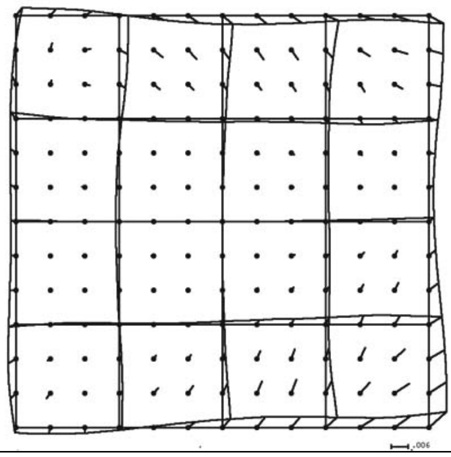


Figure 7. systematic image errors of RC30, adjustment with additional parameters 1 - 12
vector scale = 6µm

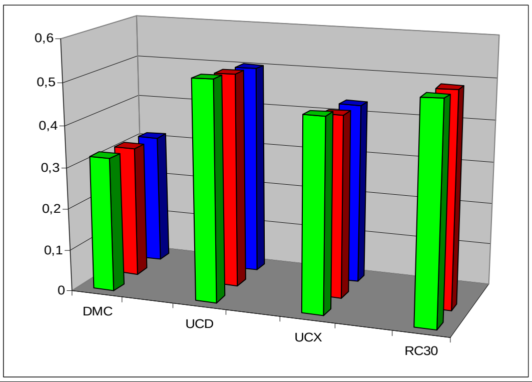


Figure 8. standard deviations of unit weight sigma0 [pixels]

Left to right: DMC, UltraCamD, UltraCamX, RC30

First column (green): without self calibration

Second column (red): self calibration with parameters 1 – 12

Third column (blue): self calibration with parameters 1 – 12 + camera specific parameters

The standard deviation of unit weight sigma0 is only slightly reduced by self calibration. This is a well known fact, but it does not say something about the influence to the ground coordinates. Sigma0 corresponds to the image coordinate accuracy. The largest part of the systematic image errors can be compensated by the orientation unknowns, so only remaining effects finally can be seen at the sigma0-value. There is a clear difference of the sigma0 for the different cameras. This can be explained by the image geometry, but also the image quality. The image quality of the UltraCam images was a little less than for the DMC (Jacobsen 2008). This is caused by the smaller pixel size, the larger field of view of the sub-cameras, the different lens systems, but also by the lower sun elevation of the UltraCam flights. The UltraCamD images have been generated with the old Microsoft Photogrammetry software for merging the images, with the new software the geometric image quality has been improved to the level of the UltraCamX (see below). It is important to point out that the used DMC images were of the panchromatic type were those of the UCD and UCX were pan-sharpened that when it is used some level of noise is added to the original images.

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

The summarized results presented in figure 9 show clear differences of the results achieved with the different cameras. The values of the adjustment with all ground control points (GCP) cannot be compared with the adjustment with a smaller number of GCP, because they are only the root mean square discrepancies at the control points itself and can be manipulated with a high number of additional parameters. This is different for the independent check points shown for the adjustment with 15 and 8 control points. 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 UltraCamX also the X- and Y-component is 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 by 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 Grün-parameters (Grün 1979) were necessary to reach a similar accuracy level like with the BLUH-parameters (Wu 2007).

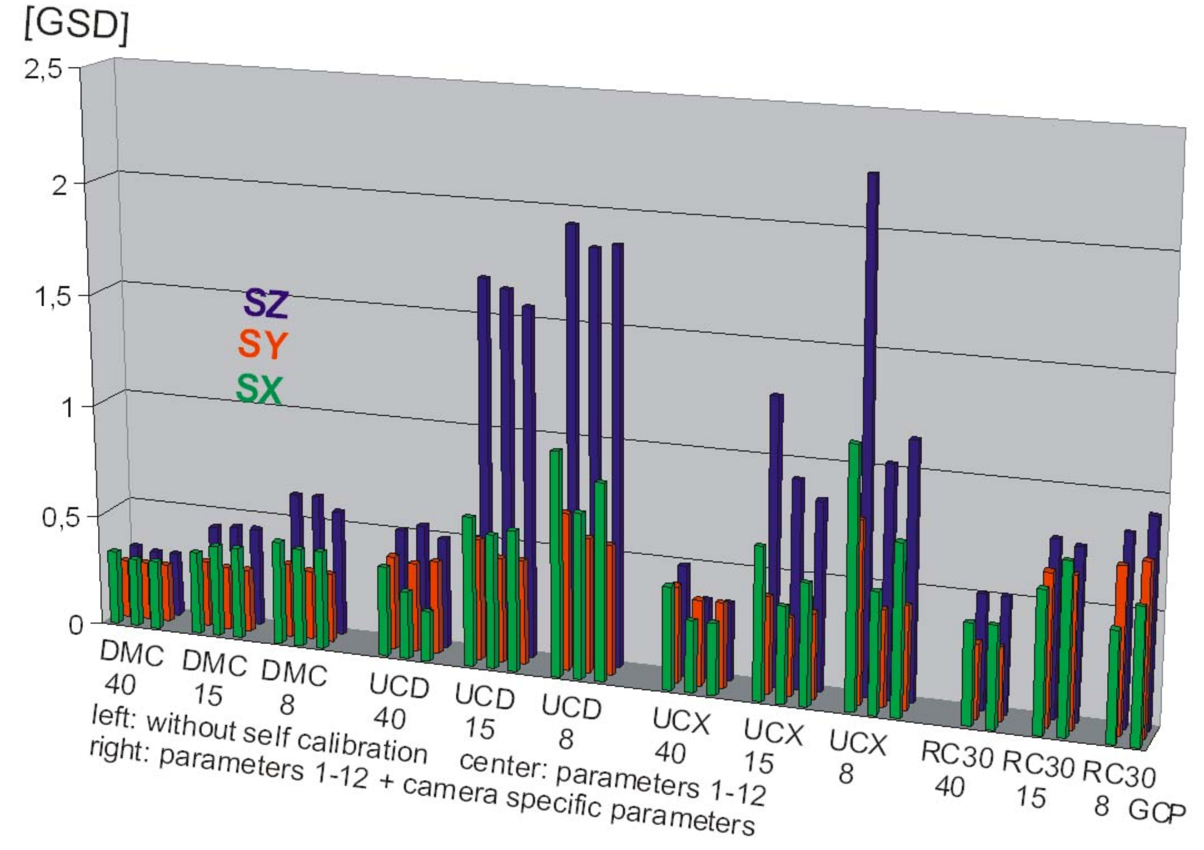
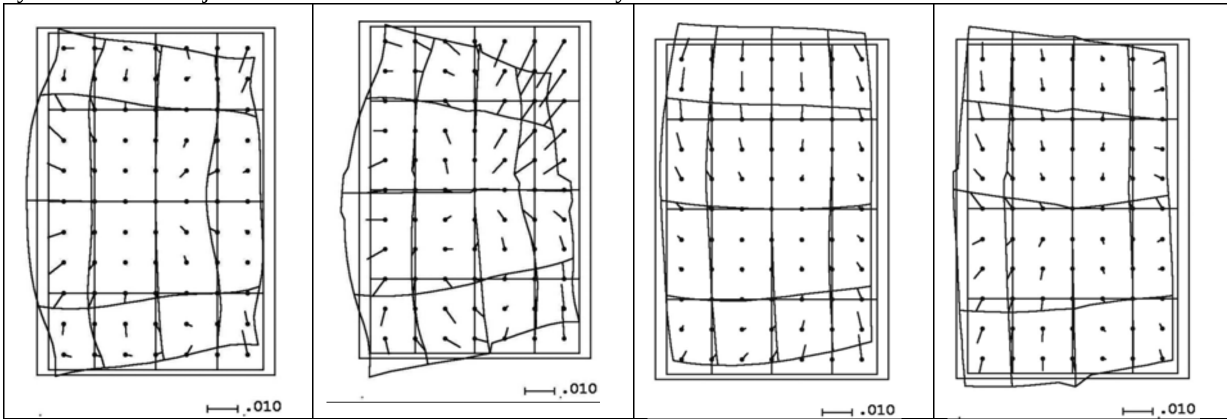


Figure 9. comparison of achieved results in Franklin Mills **[GSD]**
Columns - front to back: RMSX (green), RMSY (red), RMSZ (blue)
In case of all control points – RMS at control points, in case of 15 / 8 control points – RMS at independent check points
From left: groups with all control points / with 15 control points / with 8 control points
Within the groups: from left without self calibration / with parameters 1 – 12 / with parameters 1 – 12 + camera specific parameters

Like mentioned before, the UltraCamD-images are based on the old software for joining the sub-images together, with the improved software from Microsoft Photogrammetry better results are possible, which may be in the range of the results achieved with the UltraCamX, but also this camera is still influenced by systematic image errors as it can be seen at the clear improvement by the self calibration. The UltraCamD-images of a block over a mine site in Germany have been recalculated with the new software and used again for block adjustment (Spreckels et al 2007). This reduced the systematic image errors (figure 10) and made it quite smoother. This is not effecting the block adjustment because in a block with more than 2000 images and close to 50 000 image points, the additional parameters can be calculated precisely, but it is influencing the following model handling.

In all cases where enough images were available, it has been checked if the image geometry is the same for the whole block. In no case and for all used digital cameras the systematic image errors showed a significant change within a block. In addition, all cameras showed the same trend of systematic image errors over longer time, checked by bundle block adjustment of blocks flown at different days.

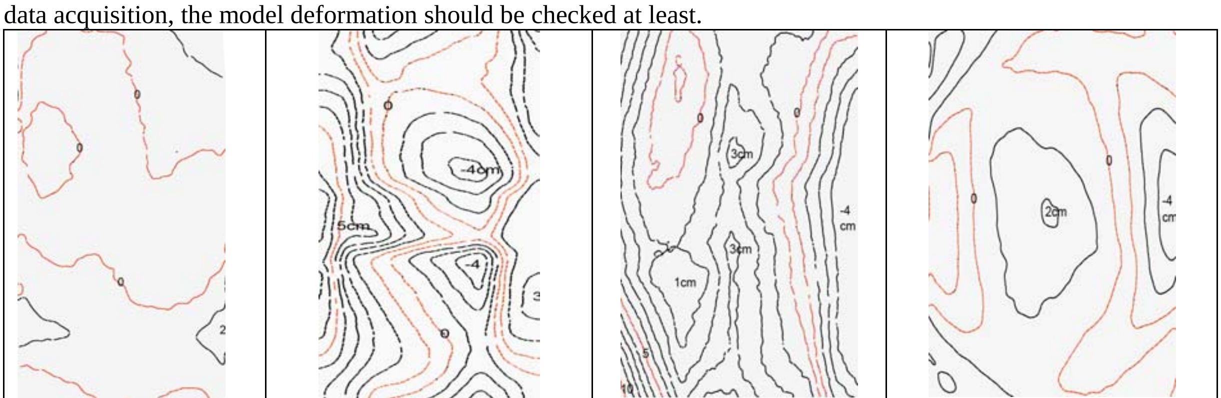


additional parameters 1-12	add. par. 1-12 + 42-73	add. par. 1-12	add. par. 1-12 + 42-73
UltraCamD based on old image generation software		UltraCamD based on new image generation software	

Figure 10. systematic image errors of UltraCamD based on old and new software for generation of virtual images block mine site, Germany (2456 / 108 images) – the same original images have been used

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.



DMC	UltraCamD	UltraCamX	RC30
Min: -1.5cm max:	Min: -5cm max: 8cm	Min : -5cm max : 9cm	Min : -3cm max : 3cm

2cm			

Figure 11: model deformation caused by systematic image errors, based on additional parameters 1 – 12 + camera specific parameters, data set Franklin Mills, contour interval 1cm

Figure 11 shows the model deformation caused by not respected additional parameters for the data set Franklin Mills. 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, 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 the models 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.

CONCLUSION

The high accuracy level of the digital cameras has been confirmed. With the same GSD the DMC enables better accuracy in X, Y and Z than the wide angle RC30 having the same GSD. 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 matching software, have some geometric problems, reducing the accuracy. In smaller blocks the combination of the 12 standard additional parameters plus the 32 UltraCam-specific parameters may lead to over-parameterization, reducing the accuracy. The UltraCamX images have been merged with the new software, leading to a better accuracy in relation to the GSD than for the UltraCamD. In relation to the image coordinates, the UltraCamX shows clearly better results like the UltraCamD. The UltraCam height to base relation of 3.7 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 15 control points the UltraCamX leads to better accuracy in X and Y like the RC30, with 8 control points it is reverse.

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.

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