GEOMETRIC CHARACTERISTICS OF LARGE SIZE AERIAL FRAME CAMERAS

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ABSTRACT:

Analogue photogrammetric aerial cameras are replaced more and more by large size aerial frame cameras like Z/I Imaging DMC and Microsoft Photogrammetry UltraCamD and UltraCamX. Some intensive geometric tests of the DMC and the UltraCamD have been made by the author in the past. In the meantime the higher resolution UltraCamX came to the market and the geometry of the other cameras have been improved mainly by changed software modules for merging the sub-images to the homogenous virtual images. For an inspection of the current cameras, test flights with the 3 mentioned cameras as well as with the analogue RC30 have been made over the same area. Approximately 70 images have been taken by each camera with a ground sampling distance of ~5cm.

The generation of pan-sharpened images may cause slightly different image geometry like the original pan-images. For the DMC beside the pan-images, pan-sharpened colour images and false colour infrared images are available, while the UltraCamX- and the UltraCamD-images are given only as pan-sharpened colour images.

Beside the geometric property, the information content of the images is important. The number of pixels per image is only an indication. As shown in the calibration report, especially for UltraCam-images the modulation transfer function is not optimal in the image corners. By edge analysis the effective resolution of the images has been investigated. The lower image quality in the corners is obvious, but in the case of lower sun angle the image quality of UltraCam scenes is reduced in the whole image up to 30%. Corresponding to the edge analysis of RC30 photos, the information contents of images scanned with 12.5µm pixel size effectively corresponds to approximate 20µm

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 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 individual colour bands of the pan-sharpened UltraCamD may have slightly different geometric deformations.

If the systematic image errors, determined by self-calibration, are not respected in the following data handling of stereo models, especially differences in the object height appears which cannot be accepted in any case. Nevertheless the geometric property of the digital cameras is quite superior to corresponding analogue cameras.

1. INTRODUCTION

Data acquisition by photogrammetry today is based on digital photogrammetric workstations. Scanning analogue photos is causing a loss of information. For example in analytic plotters objects in shadows may be detectible, while this is not the case after scanning. In addition some photo scanners are causing a remarkable loss of accuracy. In addition the large frame digital cameras have better image quality; they are more light sensitive, can generate colour images without additional cost and are not requiring film and film development. The large analogue aerial cameras are not produced any more and the tendency to digital cameras is very clear.

The main technical characteristics for the selection of a camera are the accuracy and the information contents. The information contents can be described by the effective number of pixels. With a smaller pixel size for scanning photos, the number of pixels can be enlarged, but it is usually not improving the information contents if only the noise of the scanned image is enlarged. Also the original digital cameras have to be checked for their imaging quality, because not sharp images with a high number of pixels may not allow the identification of small objects.

2. TEST DATA

In cooperation with BAE SYSTEMS, Network Systems, Mt Laurel, NJ, USA, photo flights with the DMC, the UltraCamD, UltraCamX and a RC30 over the test field Franklin Mills have been analysed. 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.

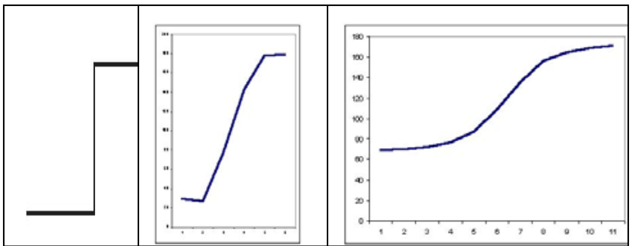
In addition experiences from block adjustments with the DMC in test block Ghent from Hansa Luftbild (7.7cm GSD, 1105 images), Rubi from ICC Barcelona (9.8cm GSD, 426 images) and with UltraCamD images in “Mine Site” from German Coal Mining (9cm GSD, 2282 images) as well as DMC-, UltraCamD- and analogue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

camera	flight	Images	GSD
DMC	July 2007	72	54mm
UltraCamD	February 2006	66	42mm
UltraCamX	April 2007	66	37mm
RC30	September 2007	35	49mm

Table 1: photo flights over test area Franklin Mills

3. INVESTIGATION OF INFORMATION CONTENTS BY EDGE ANALYSIS

An abrupt change of brightness in the object space should cause a corresponding change of grey values in the images, but caused by the modulation transfer, the change of the grey values will be continuous. The function of grey value change at edges is mainly depending upon the optical system including the CCD-array or photo.



object	DMC	RC30

Fig.1: grey values at edge and edge response
same horizontal scale for DMC and RC30
Vertical: grey value horizontal: location (pixels)

Figure 1 show on left hand side the abrupt change of brightness in the object space, in the centre the grey value profile perpendicular to an edge in a DMC image and on the right hand side the same for a RC30-photo, scanned with 12.5µm pixel size. The same edge has been used, with similar ground sampling distance (GSD) of the images. The differentiation of the grey value profiles leads under optimal conditions to a Gaussian function – the point spread function. The width of the Gaussian function can be used as an estimation of the effective pixel size. In the Hannover program EDGE, all grey value profiles across an edge, specified with 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).

In the test area Franklin Mills, close to Philadelphia, DMC, UltraCamD, UltraCamX and RC30 images have been checked for the effective pixel size. The RC30 images are scanned with 12.5µm pixel size.

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
RC30	46°	RGB colour	1.43

Table 2: factor for effective pixel size, Franklin Mills

camera	Factor for effective pixel size	Nominal image size [pixels]	Effective image size [pixels]
DMC	0.92	7680 x 13824	7680 x 13824
UltraCamD	1.16	7500 x 11500	6465 x 9914
UltraCamX	1.23	9420 x 14430	7659 x 11731
RC30	1.43	18400 x 18400	12870 x 12870

Table 3: effective number of pixels per image, Franklin Mills - corresponding to information contents

In the test area Franklin Mills for both UltraCam cameras no variation of the effective pixel size within the images could be seen, while in a photo flight over Istanbul under high sun elevation, but also in the test area Frederikstad under 20° sun elevation, in the centre of UltraCamD images the factor was 1.0, while it was 1.3 in the corners. This corresponds to the modulation transfer function, available in the calibration certificate. Also in the test Frederikstad with less than 20° sun elevation the DMC had with the factor 1.0 no difference between the nominal and the effective pixel size.

A reason for the reduced information contents in the UltraCam images of Franklin Mills may be the use of pan-sharpened images. By pan-sharpening the images sometimes are blurred a little. The factor for the effective pixel size of both UltraCam cameras is a little larger for the red channel than for the other; in table 1 the factors for the back generated panchromatic images are shown which are very close to the green and blue channel. There is no discussion about the lower effective resolution of the scanned RC30 photo, which corresponds to effective 18µm pixel size. Based on experience with mapping in addition a factor 1.5 has to be used to compare the identification of small objects in analogue photos in relation to original digital images or in other words: the same number of objects has been identified in analogue photos scanned with 20µm pixel size having 10cm GSD like with original digital images having 15cm GSD. Corresponding to this, the effective number of pixels for an analogue photo is in the range of 8500 x 8500 compared to the information contents of original digital images.

4. SELF CALIBRATION

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, under optimal conditions for the whole block. In the blocks Rubi, Ghent, Istanbul and Mine Site no change of such so called “systematic image errors” within the blocks could be detected. The systematic image errors are determined and respected by self calibration with additional parameters. The investigations have been made with the Hannover program system BLUH. BLUH has its own set of additional parameters (Jacobsen 2007b). For standard aerial images the self calibration is made with 12 additional parameters; they are a combination between physical parameters e.g. affine deformation and mathematical justified parameters. In BLUH the image coordinate residuals of a bundle adjustment can be stored together with its image position. Based on this, all image residuals can be overlaid and averaged in small sub-areas. By averaging, random errors are reduced and systematic image errors are dominating – this technique allows a check for existing or remaining systematic image errors. The investigation with the blocks Rubi, Ghent, Istanbul and Frederikstad showed also after block adjustment with the standard set of additional parameters significant remaining systematic image errors, requiring camera specific parameters for the UltraCamD and the DMC.

With parameter 29 the not correct handling of the offset of the 4 DMC pan-cameras can be detected and respected. In no case this parameter was significant. 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 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.

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 listed, this is only the start set, the final adjustment has been made with a reduced set.

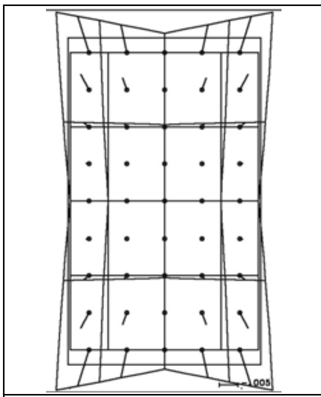


Fig. 2a: effect of additional parameter 79 (common change of focal length; DMC)

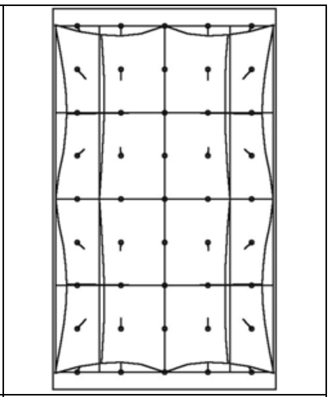


Fig. 2b: effect of additional parameter 80 (common radial symmetric distortion; DMC)

5. BLOCK ADJUSTMENTS

The determination of the tie points of the test area Franklin Mills has been made with LPS. The manual control point measurement was time consuming because of the 60% side lap and 60% end lap. 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. 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.

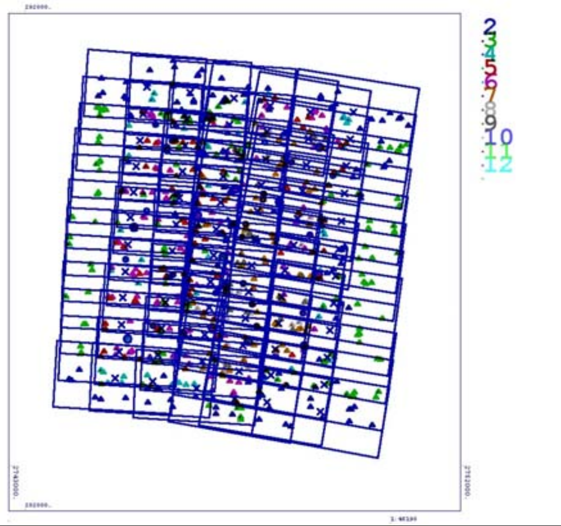
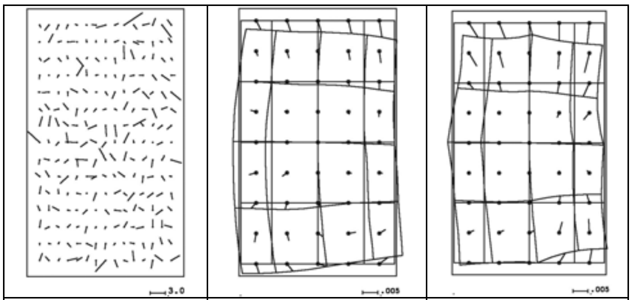


Fig. 3: DMC-block Franklin Mills with colour coded number of images / object points – colour scale see upper right

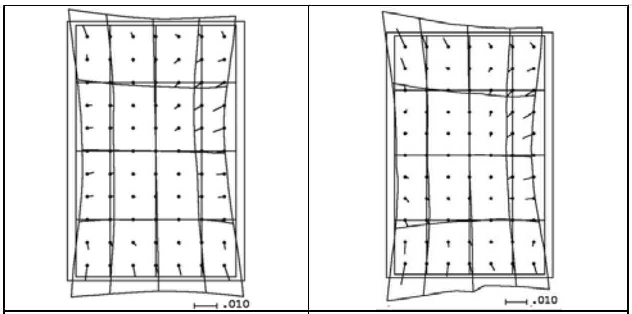
	RMSX	RMSY	RMSZ	sigma0
without self calibration	1.8 cm	1.4 cm	1.6 cm	3.85 µm
parameters 1-12	1.7 cm	1.4 cm	1.5 cm	3.79 µm
parameters 1–12, 79-80	1.7 cm	1.4 cm	1.5 cm	3.77 µm

Table 4: block adjustment of DMC-images with 42 control points; 54mm GSD ; 1.7cm = 0.31 GSD, 1.4cm = 0.26 GSD



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

Fig. 4: DMC-block Franklin Mills with 42 control points; vector length of systematic image errors: 5µm

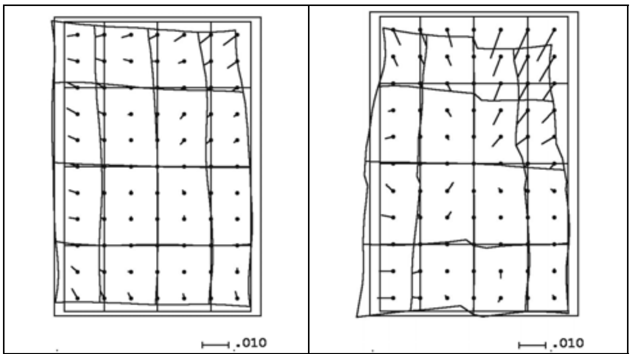


Systematic image errors, adjustment with parameters 1 - 12 | systematic image errors, adjustment with parameters 1 – 12, 42 – 73

Fig. 6: UltraCamX-block Franklin Mills with 42 control points

Also block adjustments with 15 and 8 control points have been made. The not used control points have been handled as independent check points. Only the adjustment with 8 control points showed a small improvement of the Z-component by adjustment with self calibration. Of course the test block has a limited size, so the systematic image errors cannot sum up and deform the block.

The UltraCamD shows larger systematic image errors (fig. 5) than the DMC. The virtual UltraCamD-images have been computed with the old Microsoft Photogrammetry software not improving the image geometry by thermal effects which are indicated by the transformation of the sub-images together. The UltraCamD-images of the block Mine Site have been recomputed with the software improved by Microsoft Photogrammetry. This reduced the systematic image errors and the corresponding model deformation to approximately 50% against the original situation.



Systematic image errors, adjustment with parameters 1 - 12 | systematic image errors, adjustment with parameters 1 – 12, 42 – 73

Fig. 5: UltraCamD-block Franklin Mills based on 42 control points

The adjustment of the UltraCamD-block with self calibration is slightly improving the results at independent check points. Also the UltraCamX-images have not negligible systematic image errors (fig. 6). The size is on the level of the UltraCamD (fig. 5) and approximately twice like for the DMC-images (fig. 4).

Especially the independent check blocks of the adjustment with 8 control points are strongly improved by self calibration, but there is no advantage of the camera specific additional parameters.

The block adjustment with the RC30 results in sigma0-values of approximately 6.4µm – a common result for large scale photos. The block size is too small to show clear advantages of the adjustment with self calibration. For an analogue camera the RC30 has very small systematic image errors (fig. 7).

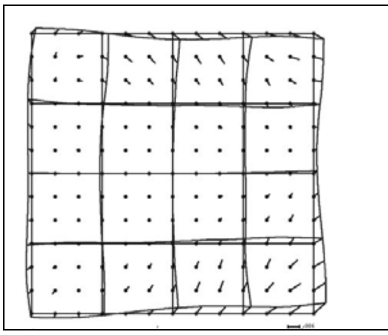


Fig. 7: systematic image errors of the RC30

largest vector = 6µm

The GSD of the images taken with the different cameras and the pixel size is slightly different (table 1). By this reason the comparison of the block adjustment results is shown in fractions of the GSD and the sigma0 in relation to the pixel size.

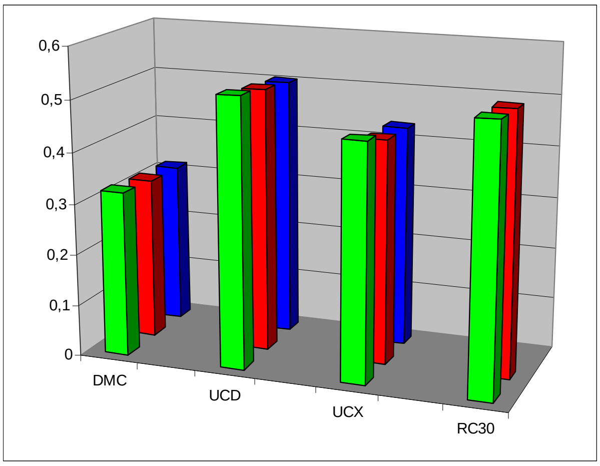


Fig. 8: standard deviations of unit weight sigma0 [pixels]
First column (green): without self calibration
Second column (red): self calibration with parameters 1 – 12
Third column (blue): self calibration with parameters 1 – 12 + camera specific parameters

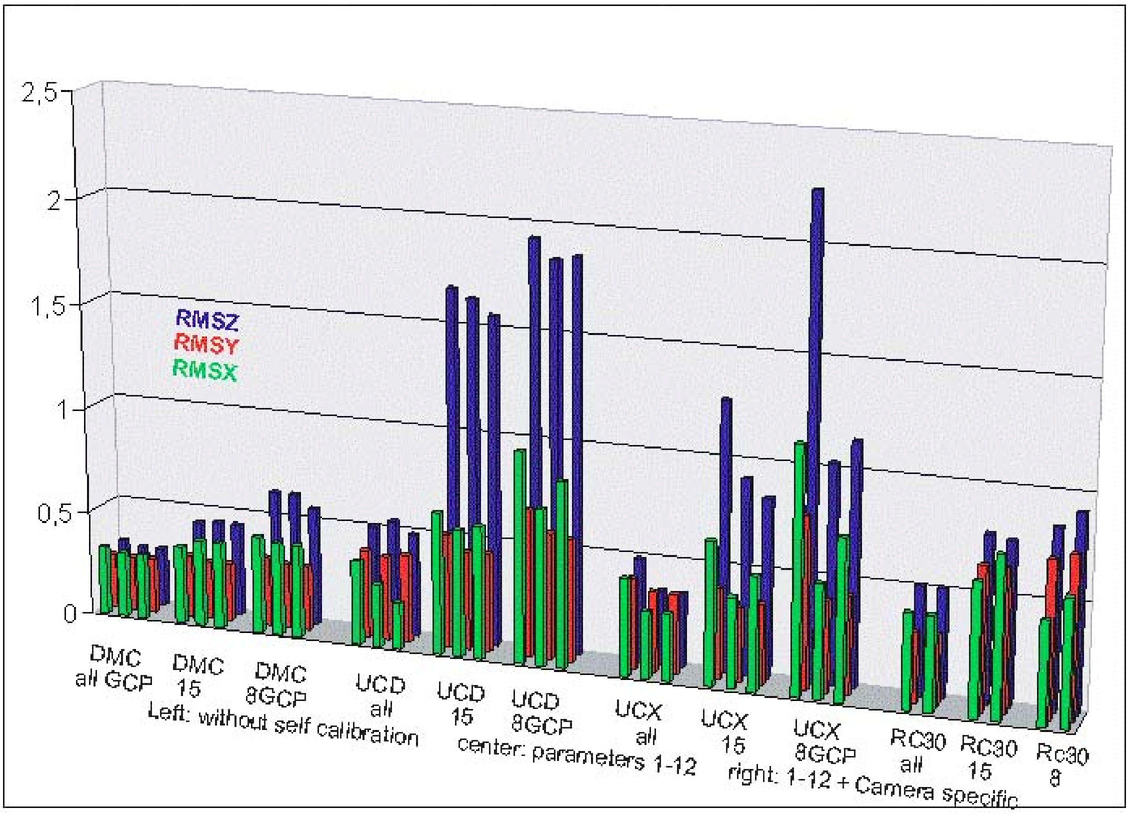


Fig. 9: comparison of achieved results in Franklin Mills **[GSD]**
Columns - front to back: RMSX (green), RMSY (red), RMSZ (blue)
In case of all control points – RMS at control points, in case of 15 / 8 control points – RMS at independent check points
From left: groups with all control points / with 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

All blocks show only a limited improvement of the sigma0 by self calibration. With approximately 0.32 pixels the sigma0 is quite better for the DMC-images like for the other, where sigma0 varies between 0.43 (UltraCamX) and 0.51 pixels for the UltraCamD and the RC30 scanned with 12.5µm pixel size. One of the reasons for the better DMC values may be the better image quality and better contrast in relation to the other cameras, but nevertheless like the image quality, the difference in the sigma0 values as fraction of the pixel size is confirmed by the other mentioned blocks. 3 µm standard deviation of unit weight for the UltraCamX are still a good result in relation to the UltraCamD. In other blocks with DMC images a sigma0 value up to 0.16 pixels has been reached, while it is usually larger for the UltraCamD. Sigma0 values of 5 to 6µm are usual for analogue cameras.

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 point results shown for the adjustment with 15 and 8 control points. Of course the 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.

The UltraCamD is, like mentioned before, based on the old software for joining the sub-images together, with the improved software also better results should be 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 systematic image errors of the RC30 are unusual small, quite larger results are common.

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 model, usually the systematic image errors are not respected, even if the commercial software allows now more often the use of the systematic image errors in the model handling. 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.

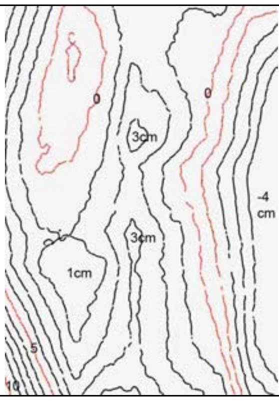
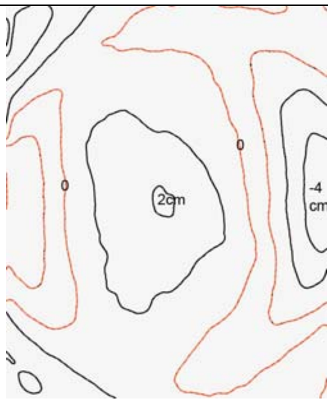
	
DMC Min: -1.5cm max: 2cm	UltraCamX Min: -4.5cm max: 9cm
	
UltraCamD Min : -5.5cm max : 8.2cm	RC30 Min : -3.0cm max : 2.8cm

Fig. 10: model deformation caused by systematic image errors, based on additional parameters 1 – 12 + camera specific parameters, contour interval 1cm

Figure 10 shows the model deformation caused by not respected additional parameters. 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 expected 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 model only 2 images are used and not the large over-determination like in 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.

7. 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. 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. 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 then 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.

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.

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