

# BUNDLE BLOCK ADJUSTMENT WITH ULTRACAM<sub>D</sub> IMAGES

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## ABSTRACT:

Large blocks of UltraCam<sub>D</sub> images have been taken over the area of Istanbul. The high accuracy of the digital images together with crossing flight lines allows a reduction of the number of ground control points against the rules of thumb for analogue photos. By simple theory a calibrated digital camera should not show systematic image errors – we do have no problems with film flattening and film deformation. But the bundle adjustments showed the requirement of a self-calibration. Special additional parameters, able to correct the position of the 9 sub-images of the UltraCam<sub>D</sub>, have been introduced into the used program system BLUH. Block adjustments with different control point configurations and different sets of additional parameters have been investigated. In general there is a clear improvement of the accuracy of independent check points by a block adjustment with self-calibration. Especially with a smaller number of control points the vertical accuracy is quite better with it. Against the standard set of 12 additional parameters the set of 32 special parameters for the UltraCam<sub>D</sub> could not improve the results even if the shape of the systematic image errors is similar for all sets. The dominating effect of the systematic image errors is the radial symmetric component, which must not be caused by the camera geometry. The high accuracy of the digital camera seems to allow a larger control point distance in relation to analogue photos.

## 1. INTRODUCTION

Digital photogrammetric workstations have replaced analytical and also analogue photogrammetric instruments. Now large size digital frame cameras are starting to replace analogue cameras for mapping purposes. It is known, that large size digital photogrammetric frame cameras do have a higher accuracy potential like analogue photogrammetric cameras (Alamus et al 2005, Doerstel et al 2002, Honkavaara et al 2005), but it has not been analysed so often under operational conditions. The optimal handling and required number and distribution of control points for two blocks flown with the Vexcel UltraCam<sub>D</sub> over Istanbul have been investigated.

## 2. BLOCK CONFIGURATION

The city of Istanbul has been flown with the UltraCam<sub>D</sub>. A sub-block with 523 images and another with 485 images have been analyzed. The synthetic UltraCam<sub>D</sub> image has 7500 x 11500 pixels with a pixel size of 9µm\*9µm corresponding to an image format of 67.5mm in the flight direction and 103.5mm across flight direction and a focal length of 101.4mm. This corresponds to a height to base relation of 3.76 for the standard endlap of 60%, that means, the view angle in flight direction with 36.8° is a little smaller than for analogue normal angle cameras having 41.3°. Across flight direction the view angle with 54.1° is between

the normal angle (41.3°) and the wide angle camera (73.8°). The small view angle in flight direction requires more images in the flight lines like for analogue cameras.

Both blocks have been flown in approximately 3500m above ground corresponding to an image scale 1:34000. Each image is covering 2.3km x 3.5km. The block 1 is covering 47km x 25km, the second block 33km x 37km. Crossing strips are stabilizing the configuration. In block 1 (figure 2) the most north located flight line is not supporting the block configuration because especially the eastern part is mainly covered by water. This is also the case for the last images in the neighboured strip and for block 2 on the south east side.

In both blocks the object points have been measured in the average in 4.7 images. In block 1 in the average 23 points are available in each image, in block 2 18 points. The distribution of the points in the images is similar (figure 1).

GPS projection centre coordinates are available, having a standard deviation in Z of approximately 50cm but with significant shift and time depending drift values, different from flight line to flight line – the Z-shift vary in block 1 from -4.2m up to 43.0m, in block 2 from 7.9m up to 19.2m.

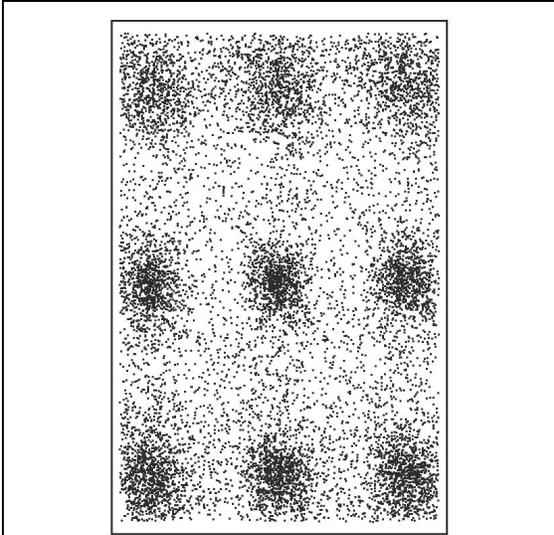


fig. 1: distribution of image points – overlay of all images, block 1

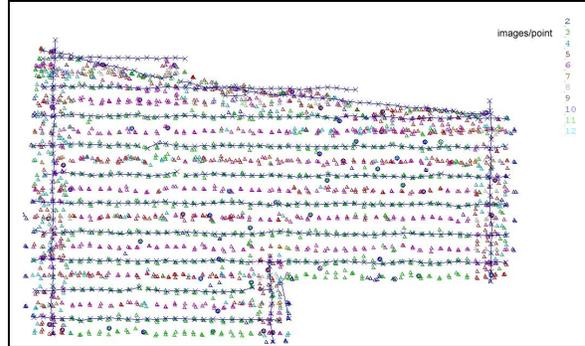


fig. 4: point distribution block 1, colour coded as function of images/point

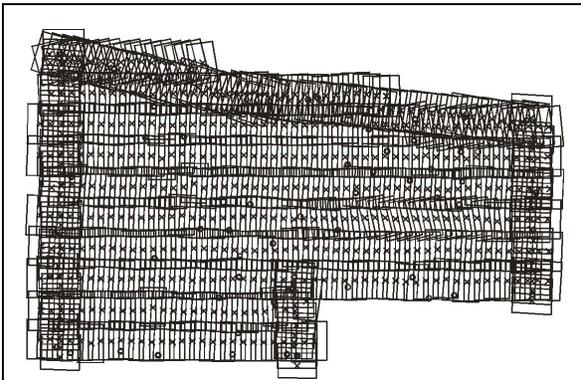


fig. 2: image configuration block 1

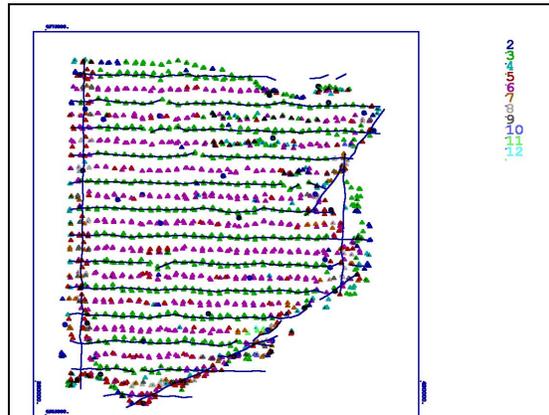


fig. 5: point distribution block 2, colour coded as function of images/point – on right side explanation of colour as number of images / point

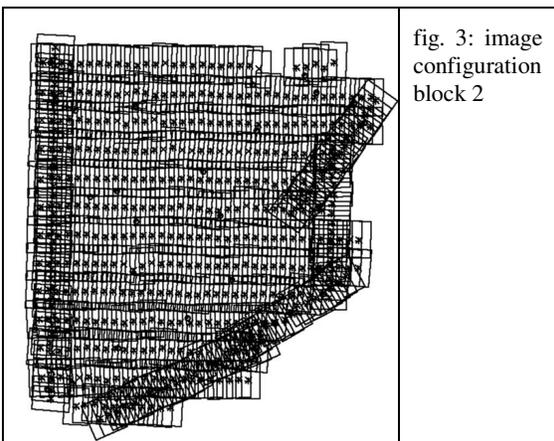


fig. 3: image configuration block 2

The automatic aerotriangulation has been made with the Intergraph workstation, but for the detailed analysis the Hannover program system BLUH has been used.

### 3. IMAGE GEOMETRY

The bundle block adjustment program BLUH can write the residuals at the image coordinates together with the image coordinates itself into an output file for separate analysis. The graphic overview of the averaged residuals shows systematic effects (figure 6).

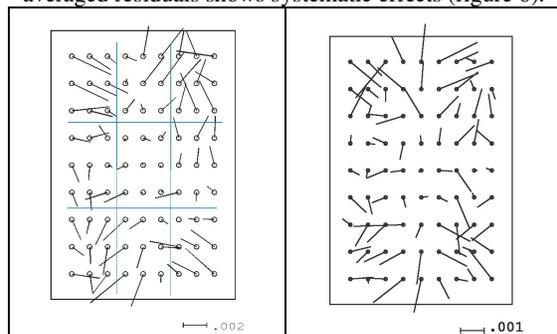


fig. 6: averaged image coordinate residuals, block 1 left, block 2 right

Both blocks show the same tendency of systematic image errors based on block adjustment without GPS-values of the projection centres and without self-calibration by additional parameters.



Fig. 7: configuration of UltraCam<sub>D</sub> lenses

the four centre optics are belonging to the panchromatic cameras, the upper and lower optics are belonging to the multispectral cameras © Vexcel

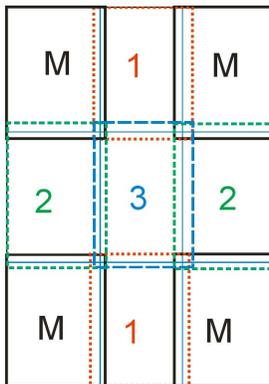


Fig. 8: connection of UltraCam<sub>D</sub> sub-images

M = master image (4 CCD-arrays)

1 = configuration 1 (2 CCD-arrays)

2 = configuration 2 (2 CCD-arrays)

3 = configuration 3 (1 CCD-array)

The UltraCam<sub>D</sub> for the panchromatic band has 4 separate cameras with 1 up to 4 smaller CCD-arrays. The master image includes the 4 CCD arrays located in the corners, 1 camera includes the left centre and right centre CCDs, one the upper centre and lower centre and the last camera has just the centre CCD (figure 6). By means of the overlapping parts, the sub-images of 3 cameras are transformed to the master image with the 4 corner CCDs (Leberl et al 2002). If the calibration of the master image is correct, the systematic image errors should be limited to effects caused by the optics. If the geometric misfits are stable within a block or group of images, the geometric relation can be determined by self-calibration.

Program BLUH handles the self calibration with a standard set of 12 additional parameters. For the UltraCam<sub>D</sub> special additional parameters able to fit the special camera geometry have been introduced. The standard set of parameters 1 – 12 has partially physical meaning, supported with some general parameters to be able to fit general image deformations and avoiding high correlations between the used additional parameters.

Parameter 1 = angular affinity

Parameter 2 = affinity

Parameter 3 – 6 = general deformation

Parameter 7, 8 = tangential distortion

Parameter 9 – 11 = radial symmetric distortion

Parameter 12 = general deformation

Parameters 42 – 49 = UltraCam<sub>D</sub> scale

Parameters 50 – 65 = UltraCam<sub>D</sub> shift values

Parameters 66 – 73 = UltraCam<sub>D</sub> rotations

table 1: additional parameters of program BLUH

The scale variations, shifts and rotations of the sub-images are causing different effects in the virtual image. The parameters are respecting this and avoiding gaps in the virtual image. Similar parameters have been introduced also for the DMC based on the geometric behaviour (Doerstel et al 2002, Alamús et al 2005)

With the parameters 42 up to 73 geometric misfits of 8 sub-images to the centre image are determined.

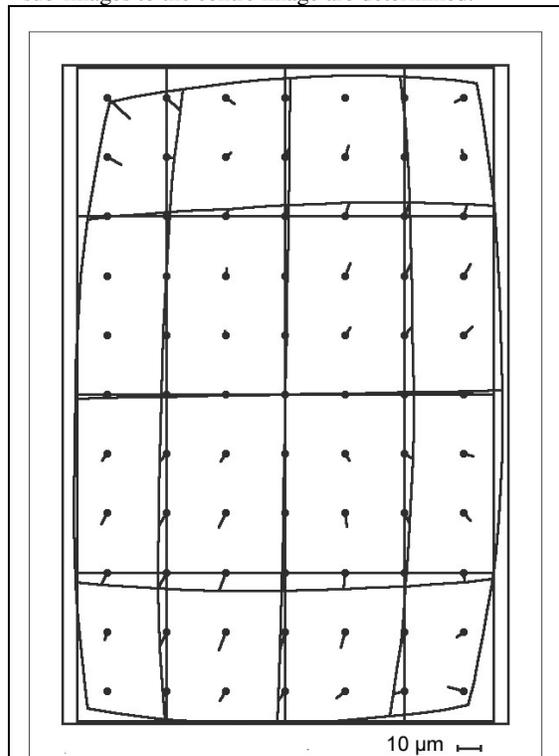


fig. 9: systematic image errors with standard parameters (1-12) of program BLUH, block 1

The averaged residuals are underestimating the “systematic image errors” because they are partially compensated by the standard adjustment. The expression “systematic image errors” is not correct, because we have errors of the mathematical model of simple perspective geometry, but the expression “systematic image errors” is widely used. A block adjustment with the standard 12 additional parameters of program system BLUH is leading to the systematic image errors shown in figure 9, which are approximately 3 times larger like the averaged residuals - this is usual. The mayor effect of the systematic errors shown in figure 6 is compensated by the additional parameters, but not some details.

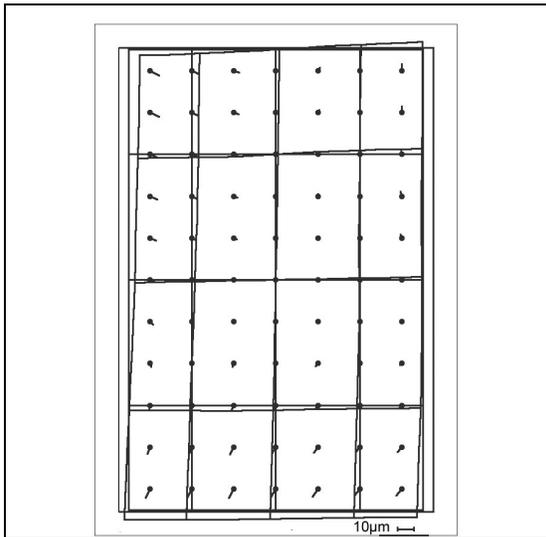


fig. 10: systematic image errors with standard additional parameters (1-12) of program BLUH without radial symmetric components, block 1

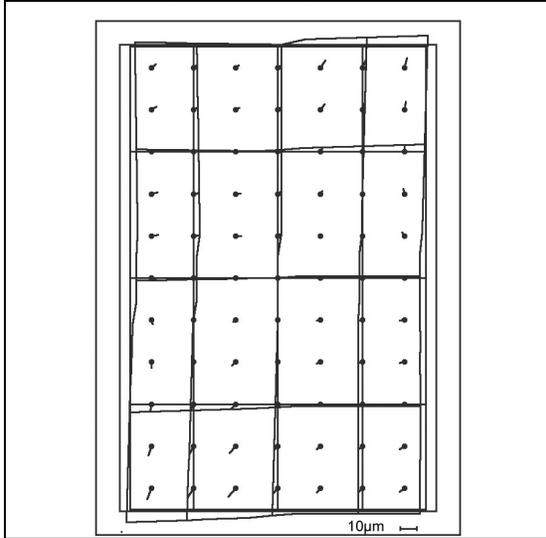


fig. 11: systematic image errors with parameter 9 + special UltraCam<sub>D</sub> parameters, without radial symmetric components, block 1

The block adjustment has been handled in tangential coordinate system to avoid problems with the earth curvature. In addition the image coordinates are improved by standard refraction correction. Nevertheless the radial symmetric component is dominating the systematic image errors. The influence without the radial symmetric component is shown in figure 10.

Even if this cannot be seen at the results of the block adjustment, it seems that the special UltraCam<sub>D</sub> parameters can fit the systematic image errors better than the general additional parameters (compare figure 11 with figure 6).

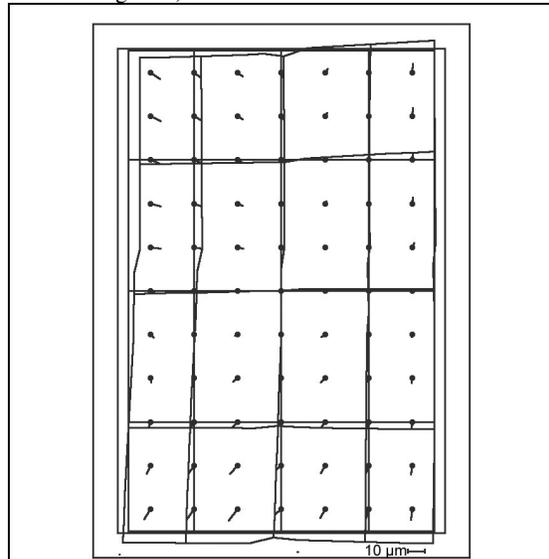


fig. 12: systematic image errors with standard BLUH parameters + special UltraCam<sub>D</sub> parameters, without radial symmetric components, block 1

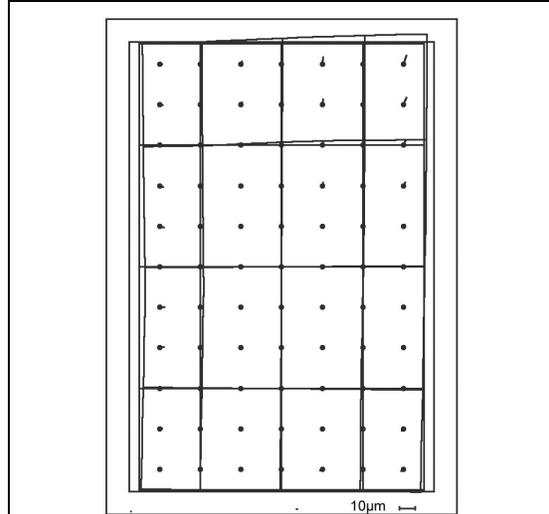


fig. 13: systematic image errors with standard additional parameters (1-12) of program BLUH without radial symmetric components, block 2

Of course the most detailed fit of the systematic image errors can be made with the combination of the 12

standard BLUH parameters and the special UltraCam<sub>D</sub> parameters. From the 44 originally chosen parameters, after reduction of the parameters by BLUH based on correlation, total correlation and Student test, only 22 remained in the last iteration of BLUH. The other additional parameters have been taken out to avoid an over-parameterization.

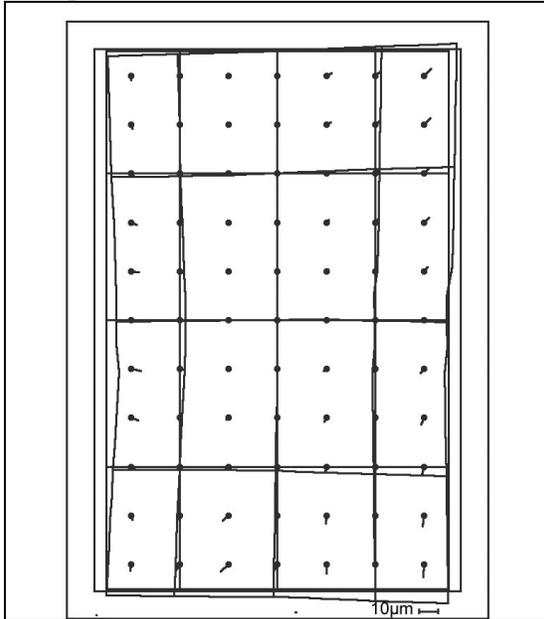


fig. 14: systematic image errors with parameter 9 + special UltraCam<sub>D</sub> parameters, without radial symmetric components, block 2

The second block shows the same trend of the systematic image errors like the first block. Of course the values are not identical because of the influence of random errors.

#### 4. BLOCK ADJUSTMENT

With different control point configurations (figures 15 and 16) and different sets of additional parameters bundle block adjustments have been computed. The discrepancies at control points never should be used for accuracy estimation because there are adjustment programs on the market hiding the real problems and showing always too optimistic results. By this reason only independent check points can be accepted for a real check of the accuracy potential.

The Hannover program system BLUH reduces the number of the additional parameters to the required set by statistical analysis. Of course the parameters can be fixed against a removal, leading to a smaller sigma<sub>0</sub> values and smaller residuals at the control points, but the result at the independent check points usually is better with a reduced number of parameters, this is especially the case for smaller blocks and extrapolations.

The block 1 has some connection problems at the northern, eastern and southern boundary caused by

water areas, so it is not an optimal configuration, but it is an operational test block.

In addition to the control point configurations (CPC) shown in figure 10, an additional configuration CPC3 with 35 horizontal and 38 vertical GCPs was used. The control point configuration is not very homogenous with large distances to be bridged. The original control points not used for the configurations CPC1 up to CPC4 are used as independent check points. So for the configuration CPC4 the number of horizontal check points is 49 and the number of vertical check points is 47.

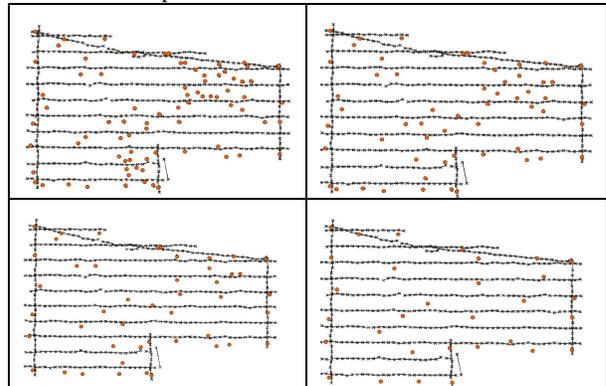


fig. 15: control point configurations (CPC) of block 1  
 upper left: all 78 control points  
 upper right : CPC1: 53 horizontal, 56 vertical  
 lower left: CPC2 41 horizontal 45 vertical  
 lower right: CPC4 29 horizontal, 31 vertical  
 ground control points (GCP)

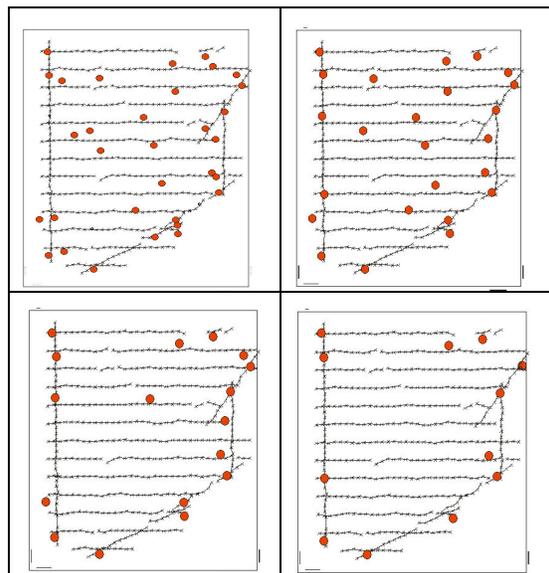


fig. 16: control point configuration block 2  
 all, 24 control points, 18 control points, 12 control points

The standard deviation of unit weight sigma<sub>0</sub> is only slightly changing depending upon the different control point and additional parameter configuration. For

block 1 it is between 4.7 and 4.0 microns, for block 2 it is between 3.9 and 3.5 microns. Also the root mean square discrepancies at the control points of the block adjustments without GPS projection centre coordinates is varying only from 6cm to 11cm for block 1 and from 7cm to 13cm for block 2.  $\sigma_0$  and the root mean square discrepancies at control points cannot be used for real accuracy estimation; this only can be made with independent check points.

The control point distribution is below the limit which can be accepted for analogue photos. So the control point configuration with 12 points in block 2 has to bridge approximately 30 base lengths; but even with 24 control points up to 20 base lengths have to be bridged. This is not quite different for the block 1. The sparse control is sensitive for systematic image errors which can sum up and cause especially a height deformation of the block. By this reason the sparse control is useful for the investigation of remaining systematic effects.

additional parameters	RMSX [m]	RMSY [m]	RMSZ [m]
no	0,36	0,29	0,54
1-12	0,18	0,21	0,36
9, 42-73	0,18	0,21	0,39
1-12, 42-73	0,18	0,20	0,39

table 2: root mean square discrepancies at independent check points, block 1, CPC1

additional parameters	RMSX [m]	RMSY [m]	RMSZ [m]
no	0,35	0,28	0,90
1-12	0,20	0,19	0,59
9, 42-73	0,20	0,19	0,62
1-12, 42-73	0,21	0,19	0,61

table 3: root mean square discrepancies at independent check points, block 1, CPC2

additional parameters	RMSX [m]	RMSY [m]	RMSZ [m]
no	0,37	0,39	0,96
1-12	0,25	0,21	0,56
9, 42-73	0,25	0,21	0,60
1-12, 42-73	0,25	0,21	0,60

table 4: root mean square discrepancies at independent check points, block 1, CPC3

additional parameters	RMSX [m]	RMSY [m]	RMSZ [m]
no	0,50	0,55	1,15
1-12	0,24	0,26	0,76
9, 42-73	0,24	0,25	0,74
1-12, 42-73	0,24	0,25	0,76

table 5: root mean square discrepancies at independent check points, block 1, CPC4

additional parameters	RMSX [m]	RMSY [m]	RMSZ [m]
no	0.22	0.41	2.72
1-12	0.16	0.26	1.00
9, 42-73	0.15	0.26	0.92
1-12, 42-73	0.18	0.25	1.06

table 6: root mean square discrepancies at independent check points, block 2, 24 control points

additional parameters	RMSX [m]	RMSY [m]	RMSZ [m]
no	0.30	0.40	6.11
1-12	0.23	0.34	0.97
9, 42-73	0.21	0.27	1.12
1-12, 42-73	0.21	0.25	1.13

table 7: root mean square discrepancies at independent check points, block 2, 18 control points

additional parameters	RMSX [m]	RMSY [m]	RMSZ [m]
no	0.41	0.47	8.56
1-12	0.35	0.36	2.11
9, 42-73	0.34	0.33	2.36
1-12, 42-73	0.35	0.32	1.99

table 8: root mean square discrepancies at independent check points, block 2, 12 control points

The ground sample distance (GSD) approximately is 30cm, the height to base relation 3.76. With sufficient control point density and distribution the vertical accuracy should be 3.76 times the horizontal accuracy if the points are located only in 2 images. But the control points are located in 2 up to 10 images, in the average in 4.5 images. By this reason in block 1 with higher number of control points, the vertical accuracy is better than two times the horizontal accuracy.

The horizontal accuracy at independent check points corresponds up to 0.6 GSD. For a digital camera this is a limited result. The  $\sigma_0$  is in the range of 0.4 pixels, indicating that the accuracy potential is better. The main reason for the limited result is caused by the limited control point definition and accuracy. By this reason not the absolute accuracy is important in this investigation, the systematic image errors and the strategy for handling and the required control point density is the main result.

The requirement of self-calibration by additional parameters is obvious. As shown above, the systematic image errors are limited in the size, they are smaller than usual for analogue photos, but for sparse control they can cause a deformation of the block. There is no clear advantage of the special UltraCam<sub>D</sub> parameters 42 – 73 against the standard 12 additional parameters of the program BLUH. The radial symmetric distortion by  $r^3$  (additional parameter 9) is important even for the handling in a tangential coordinate system and pre-correction by refraction correction. By this reason this parameter has been used in any case and with a student test value of approximately 25 there is

no doubt for the requirement. With the combination of parameter 9 together with the special UltraCam<sub>D</sub> parameters 42 – 73 in the average not a better accuracy has been reached like with the standard BLUH parameters 1 – 12.

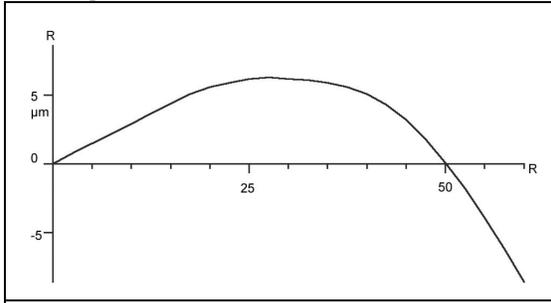


fig. 17: radial symmetric distortion block 2

The systematic image errors of block 1 and block 2 are similar. This is guaranteeing that the influence of the control points is negligible for this. If the camera geometry is stable, the systematic image errors determined in one block could be used as a camera calibration. By this reason in a second step, the image coordinates of block 2 have been corrected by the systematic image errors of block 1.

pre-correction by additional parameters from block 1	RMSX [m]	RMSY [m]	RMSZ [m]
no	0.22	0.41	2.72
no, add. par. 9	0.20	0.36	1.09
1-12	0.16	0.27	0.94
1-12, 42-73	0.38	0.49	0.99

table 9: root mean square discrepancies at independent check points, block 2, 24 control points, no self calibration

pre-correction by additional parameters from block 1	RMSX [m]	RMSY [m]	RMSZ [m]
no	0.30	0.40	6.11
no, add. par. 9	0.30	0.36	1.53
1-12	0.37	0.57	0.90
1-12, 42-73	0.37	0.52	0.96

table 10: root mean square discrepancies at independent check points, block 2, 18 control points, no self calibration

pre-correction by additional parameters from block 1	RMSX [m]	RMSY [m]	RMSZ [m]
no	0.41	0.47	8.56
no, add. par. 9	0.42	0.48	1.82
1-12	0.57	0.47	2.70
1-12, 42-73	0.55	0.47	2.58

table 11: root mean square discrepancies at independent check points, block 2, 12 control points, no self calibration

In comparison to the adjustment without self-calibration, the adjustment with pre-corrected image coordinates leads to better results for the height, but in the average not to better results in X and Y. Especially the height of the adjustment with just 12 control points located at the periphery, with root mean square Z-discrepancies of 2.70m and 2.58m is quite better like the adjustment without pre-corrected image coordinates leading to 8.56m.

There is no clear difference in the results if the pre-correction is made with the systematic image errors of block 1 based on the standard additional parameters 1 up to 12 or the combination between the standard parameters and the special UltraCam<sub>D</sub> parameters. But in general the results based on self-calibration (tables 6 – 8) are better like the results based on a pre-correction (tables 9 – 11). That means, only the trend of the systematic image errors is stable, but there are small deviations. Without pre-correction and just the radial symmetric additional parameter 9 ( $r^3$ ), nearly the same result has been reached like with the pre-correction. This also demonstrates that a self-calibration is required.

As described, GPS coordinates of the projection centres with a limited accuracy of approximately 50cm are available. Shift values quite different from flight line to flight line and also a not neglect able time depending drift requires a correction separately for every flight line with 6 unknowns. Only the sparse control CPC4 of block 1 is improved by the combined adjustment to a vertical accuracy of 39cm. The quite more poor control point density of block 2 is improved in the height for all 3 configurations to RMSZ = 64cm (24 control points) up to 82cm (12 control points). The horizontal accuracy is more or less not improved by the combined adjustment with GPS coordinates of the projection centres. The reason for the missing influence of the combined adjustment to the horizontal coordinates is the strong correlation of the image rotations phi and omega to the projection centre coordinates  $X_0$  and  $Y_0$  - it is listed as 0.99 up to 1.00 that means it is very close to 1.0. By this reason the GPS-coordinates for the projection centres  $X_0$  and  $Y_0$  have nearly no influence to the adjustment for the small view angle of the UltraCam<sub>D</sub>. But this is not a problem for the block adjustment because the problem of the block adjustment with sparse control is mainly the height and this is supported by the GPS coordinates.

## CONCLUSION

The bundle block adjustment of two sub-blocks in the area of Istanbul imaged with the digital camera Vexcel UltraCam<sub>D</sub> resulted in a satisfying accuracy. The stabilisation of the blocks with crossing flight lines allowed a handling with a smaller number of control points. Systematic image errors based on the image coordinate residuals indicate geometric problems of the merge of the UltraCam<sub>D</sub> sub-images to synthetic scenes. Special additional parameters for the

identification and respecting of the sub-image merge have been introduced into program BLUH. Empirical bundle block adjustments with different control point configurations and different sets of additional parameters have not confirmed an improvement of the block adjustment with the special UltraCam<sub>D</sub> additional parameters. With the standard set of 12 additional parameters of program BLUH the same accuracy at independent check points has been reached like with the high number of the special parameters. The self-calibration with additional parameters is required. The radial symmetric errors are dominating. The systematic image errors determined in block 1 have been used as calibration for block 2. This caused a strong improvement of the height values, but it has not reached the accuracy of block adjustments with self-calibration.

The analysis was limited by the accuracy of the available control points, so the full accuracy potential could not be tested. But in general a high accuracy level could be reached with the digital images. A block with analogue photos having such a poor control point distribution like tested would not reach the same quality. It seems that the control point distance can be extended for digital cameras in relation to analogue photos.

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