BUNDLE BLOCK ADJUSTMENT WITH HIGH RESOLUTION ULTRACAMD IMAGES

I. Baz*, G. Buyuksalih*, K. Jacobsen**

* BIMTAS, Tophanelioglu Cad. ISKI Hizmet Binasi No:62 K.3-4
34460 Altunizade-Istanbul, Turkey
gb@bimtas.com.tr
**Institute of Photogrammetry and Geoinformation
Leibniz University Hannover
jacobsen@ipi.uni-hannover.de

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ABSTRACT:

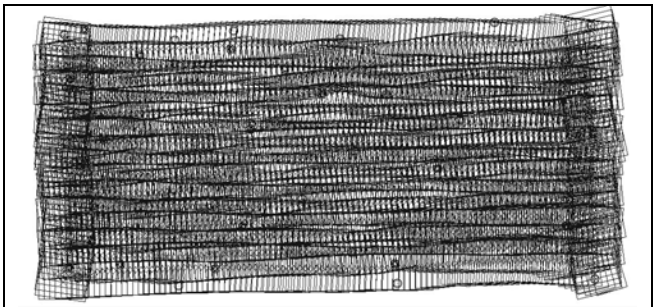
A high resolution photo flight with the UltraCamD has been made by the Bosporus Engineering Consultancy Services Inc (BIMTAS) over the city area of Istanbul for the generation of maps with the scale 1 : 1000. The used 9cm ground sampling distance (GSD) can be compared with the information contents of a photo scale 1 : 2700 taken by analogue cameras. The resolution satisfies any requirement for mapping in the scale 1 : 1000. The narrow angle of the UltraCam is optimal in the city area with high buildings and narrow streets.
The mapping requires an accuracy of 0.25mm in the mapping scale or 25cm, corresponding to 3 GSD. This is a low demand for the block adjustment. Nevertheless quite better accuracy is possible with the digital images. The optimal results only can be achieved with self calibration by additional parameters. The block adjustment is investigated in detail and the influence of the systematic image errors to the mapping is analysed.

1. INTRODUCTION

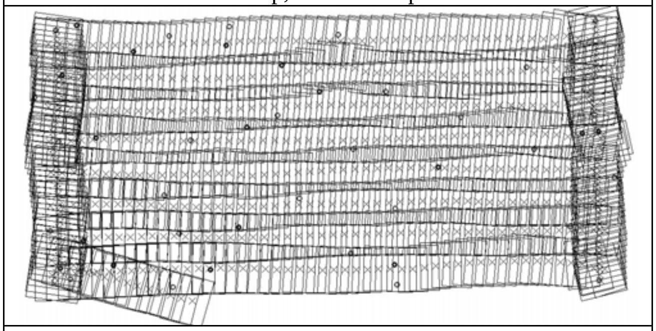
Photogrammetric evaluation today is made with digital photogrammetric workstations, requiring digital images. Analogue photos can be scanned, but this is causing additional effort and a loss of geometric and radiometric quality. This is one of the reason for a continuing replacement of analogue by digital cameras. In addition the radiometric image quality and light sensitivity of digital cameras is quite better like for analogue cameras. An intensive investigation (Oswald 2006) showed also similar or even better information contents of one large digital frame image taken with Vexcel UltraCamD or Intergraph DMC than one analogue aerial image. The good image quality leads to improved automatic aero triangulation. The geometric potential is shown.

2. ANALYZED DATA

A sub-area of the large scale photo flight taken by a Vexcel UltraCamD over the city area of Istanbul has been investigated. The average flying height of 1076m together with the average ground elevation of 110m leads to a photo scale 1:9532 or more important to 86mm GSD. For original digital images the GSD is the important figure and not the photo scale because for the geometry the pixel size in the CCD is not important – it may be compensated by the focal length.
The photo flight has been made with 60% side lap and 80% end lap (block 80/60). The influence of this strong overlap has been investigated in relation to a sub-set of images with 20% side lap and 60% end lap (block 60/20).



block 80/60 80% end lap, 60% side lap



block 60/20 60% end lap, 20% side lap

Figure 1: overlap of investigated block configurations

The blocks are stabilized by crossing flight lines at both ends, allowing a reduction of the number of control points. The partially varying side lap is caused by aircraft roll and not a deviation from the planned flight lines.

	block 60/20	block 80/60
photos	507	1 608
object points	2 302	2 475
photo points	10 183	29 840
maximal photos/point	13	29

Table 1: technical data of analyzed block configurations

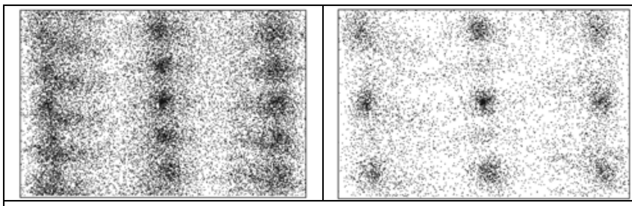


Figure 2: distribution of image points (overlay of all images)
block 80/60 block 60/20

3. VEXCEL ULTRACAMD

The geometry of the UltraCamD images is determined by the combination of the 9 sub-images to one homogenous virtual image. For the panchromatic band the Vexcel UltraCamD has 4 separate cameras, parallel to each other, with 1 up to 4 smaller CCD-arrays (figure 3). The master image includes 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. 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).

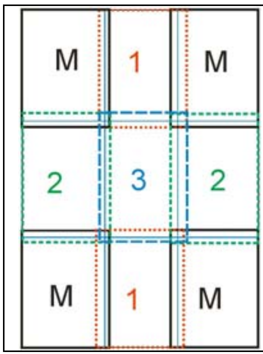


Figure 3: connection of UltraCamD sub-images

M = master image (4 CCD-arrays)

1 = configuration 1 (2 CCD-arrays)

2 = configuration 2 (2 CCD-arrays)

3 = configuration 3 (1 CCD-array)

If the calibration of the master image is correct, the systematic image errors should be limited to effects caused by the flight conditions to the optics. The optics are calibrated in the laboratory and this result is respected for the generation of the homogenous virtual image, so by simple theory, the virtual image should be free of any distortion. The reality shows systematic image errors as known from analogue photos. By this reason special additional parameters for the UltraCamD have been introduced into the Hannover bundle block adjustment program BLUH. For the sub-images, with the exception of the centre image, a scale, two shifts and a rotation parameter have been introduced – that means 8*4 = 32 parameters corresponding to a similarity transformation of the 8 outside located sub-images in relation to the centre image. The special additional parameters respect the fact that the sub-images are merged based on the overlapping image areas, so no gaps between the sub-images can appear. In addition to the special additional parameters the self-calibration may be based on the 12 standard additional parameters used also for standard analogue images. Program BLUH checks the additional parameters for significance, individual and total correlation and removes the not usable parameters automatically from the adjustment. So the final iteration of the bundle block adjustment will be made with a reduced set of additional parameters, guaranteeing the use of only the parameters which can be determined and which are not too strong correlated to each other.

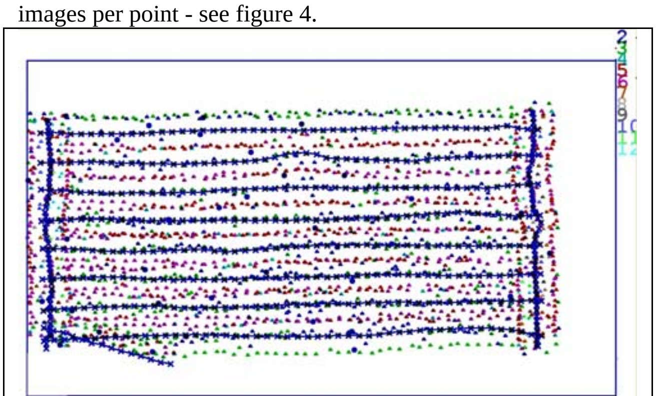
1. $x' = x - y \cdot P1$ $\quad y' = y - x \cdot P1$
2. $x' = x - x \cdot P2$ $\quad y' = y + y \cdot P2$
3. $x' = x - x \cdot \cos 2b \cdot P3$ $\quad y' = y - y \cdot \cos 2b \cdot P3$
4. $x' = x - x \cdot \sin 2b \cdot P4$ $\quad y' = y - y \cdot \sin 2b \cdot P4$
5. $x' = x - x \cdot \cos b \cdot P5$ $\quad y' = y - y \cdot \cos b \cdot P5$
6. $x' = x - x \cdot \sin b \cdot P6$ $\quad y' = y - y \cdot \sin b \cdot P6$
7. $x' = x + y \cdot r \cdot \cos b \cdot P7$ $\quad y' = y - x \cdot r \cdot \cos b \cdot P7$
8. $x' = x + y \cdot r \cdot \sin b \cdot P8$ $\quad y' = y - x \cdot r \cdot \sin b \cdot P8$
9. $x' = x - x \cdot (r^2 - 16384) \cdot P9$ $\quad y' = y - y \cdot (r2 - 16384) \cdot P9$
10. $x' = x - x \cdot \sin(r \cdot 0.049087) \cdot P10$ $\quad y' = y - y \cdot \sin(r \cdot 0.049087) \cdot P10$
11. $x' = x - x \cdot \sin(r \cdot 0.098174) \cdot P11$ $\quad y' = y - y * \sin(r \cdot 0\ 0.098174) \cdot P11$
12. $x' = x - x \cdot \sin 4b \cdot P12$ $\quad y' = y - y \cdot \sin 4b \cdot P12$

1 = angular affinity 2 = affinity 7,8 = tangential distortion
9 = radial symmetric distortion (r^3) with zero crossing
10, 11 = radial symmetric, higher degree
the constants are scaled by the largest radial distance / 162.3

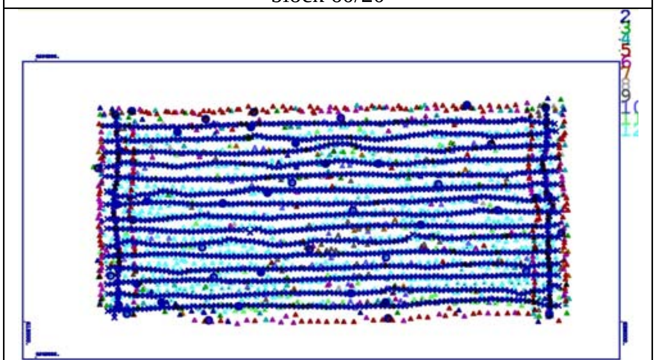
Table 2: standard set of additional parameters of Hannover program BLUH

4. BLOCK ADJUSTMENT

The quality of the block adjustment is depending upon the tie points, connecting the images. Gaps in the connection may cause local geometric problems. The tie of the block can be seen at the tie points, colour coded depending upon number of images per point - see figure 4.



block 60/20

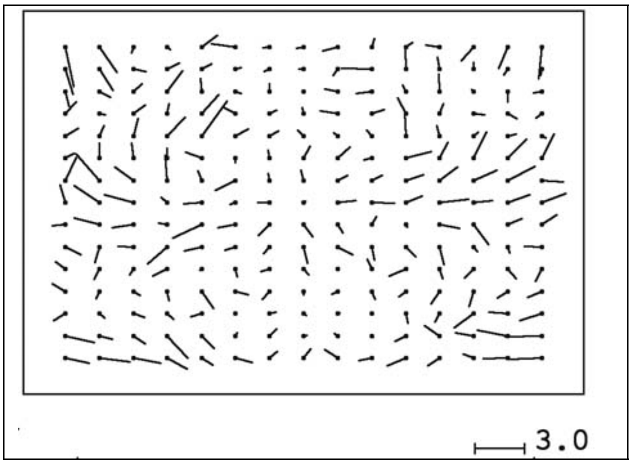


block 80/60

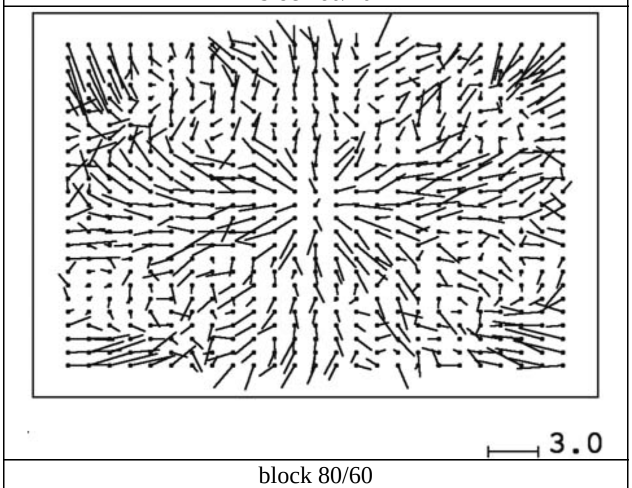
Figure 4: colour coded number of images per point (colour scale – see upper right)

In both blocks few image have a missing connection to the over-next image within the flight line. These are areas where the images have only a limited number of tie points, showing problems of the automatic aerial triangulation. This is not a too large problem because these parts have a satisfying connection to the neighboured flight lines. Figure 4 shows by the colour of the tie points to neighboured flight lines a generally satisfying connection.

The residuals – the remaining discrepancies at the photo coordinates after bundle block adjustment – are influenced by random, but also systematic image errors. An indication of systematic errors can be achieved by overlay of all residuals corresponding to their location within the images. Such a high amount of residuals is confusing and dominated by the random error, so it has an advantage to calculate the average value in small image sub-areas. This is reducing the random part and indicates very well the systematic component. Such an overview (figure 5) is only indicating the systematic image errors because parts are compensated by the exterior orientation and the over-determination of the individual object points.



block 60/20

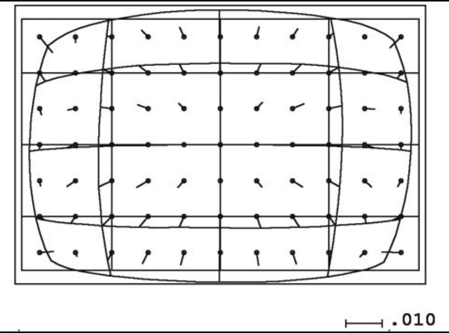


block 80/60

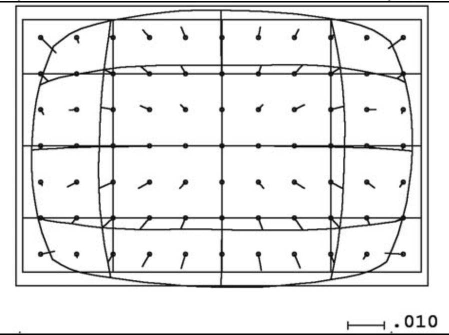
Figure 5: averaged residuals of bundle block adjustments without self-calibration

On the first view the averaged image residuals of the bundle block adjustments without self-calibration of both blocks seems to be different even if it is based on the same images. The dominating radial symmetric deformation of the block 80/60 cannot be seen so clear in the block 60/20. In block 80/60 the object points are measured in the average in 12.0 images while for block 60/20 we have only 4.4 images/point. That means in block 60/20 larger parts of the systematic errors can be compensated by the exterior orientation and the over-determination of the object points. But the general trend of systematic image errors agrees.

The Bundle block adjustments with self-calibration by additional parameters with the standard set of additional parameters of Hannover program BLUH (table 2), used also for analogue photos, leads to systematic image errors shown in figure 6. It shows the systematic deviation between the mathematical model of perspective and the real image geometry without compensation by the exterior orientation. Now for both blocks the systematic errors are nearly identical – the root mean square difference is just 0.3µm.



block 60/20



block 80/60

Figure 6: "systematic image errors" of bundle block adjustment with the standard set of additional parameters of BLUH (parameters 1-12)

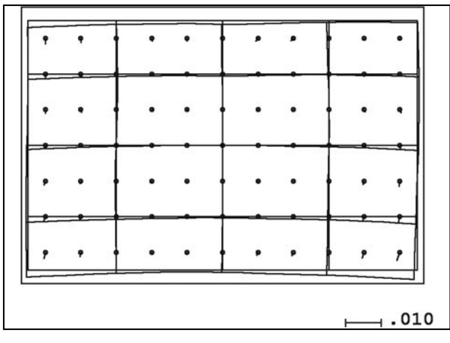
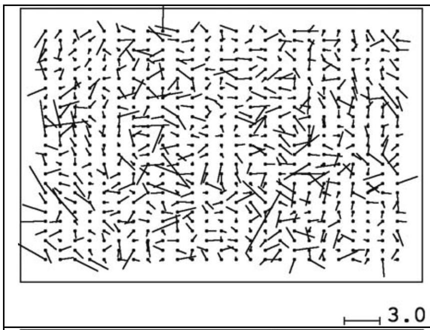


Figure 7: systematic image errors like figure 6 but without radial symmetric component

block 80/60

The radial symmetric parameter 9 (see table 2) dominates with T-test values of 75.4 for block 80/60 and because of the smaller number of observations 23.0 for block 60/20. The second larges T-test value is shown for tangential distortion parameter 7 with values of 13.4 and 9.4 (figure 7). Both can be explained by the optical system but at least partially also by the special UltraCam-geometry. The averaged residuals are strongly reduced by the bundle block adjustment with the additional parameters 1 – 12 (figure 8). Nevertheless some remaining systematic patches can be seen.



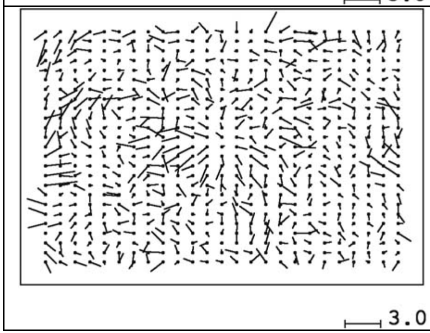
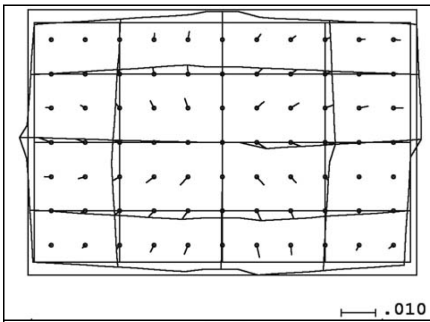


Figure 8: averaged residuals of block adjustment with additional parameters 1 – 12

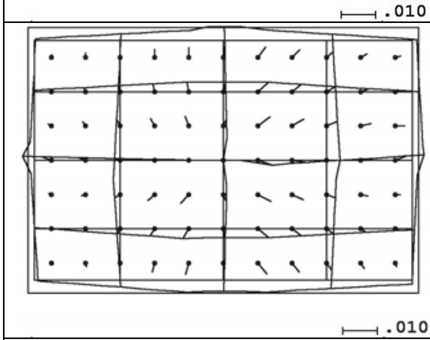
upper part: block 60/20

lower part: block 80/60

If the geometric problems are only based on the merge of correct sub-images, the systematic image errors could be handled just with the special UltraCamD-parameters (BLUH-parameters 42 – 73).



block 60/20



block 80/60

Figure 9: "systematic image errors" of bundle block adjustment with the special UltraCamD-parameters (parameters 42-73)

The general character of the systematic image errors determined with the special UltraCamD-parameters is very similar to the systematic image errors determined by the standard parameters 1 – 12 (figure 6) – the root mean square difference for x is 1.4µm and for y 2.2µm. But also here the averaged residuals (figure 10) show some remaining systematic patches. From the 32 special UltraCamD-parameters only 4 have been automatically removed because of missing significance.

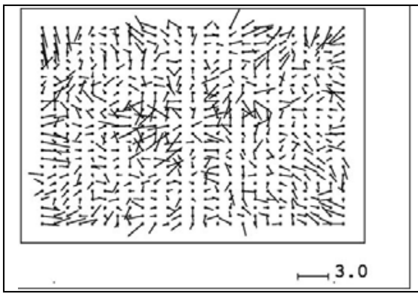


Figure 10: averaged residuals of block adjustment with special UltraCamD-parameters

block 80/60

A self calibration with the standard BLUH-parameters together with the special UltraCamD-parameters that means with 12 + 32 = 44 additional parameters should be able to determine all geometric problems.

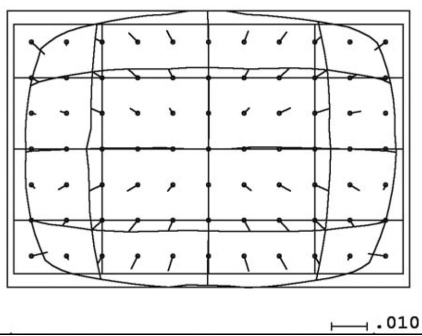


Figure 11a: "systematic image errors" of bundle block adjustment with general + special UltraCamD-parameters (parameters 1-12 +42-73)

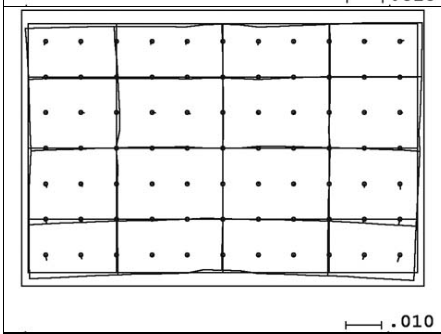
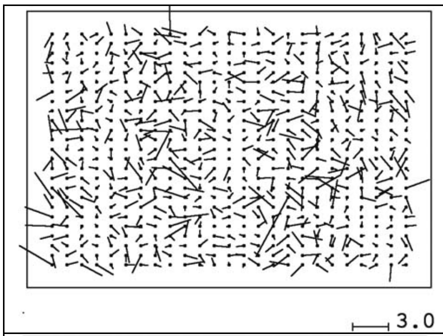


Figure 11b: systematic image errors like figure 11a, but without influence of the radial symmetric component



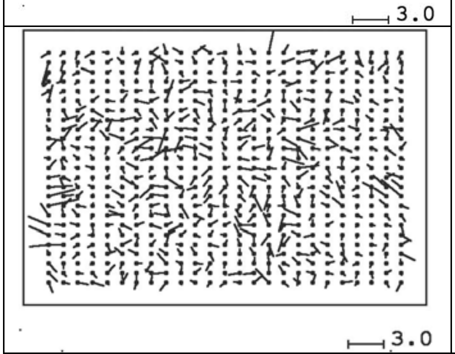


Figure 12: averaged residuals of block adjustment with additional parameters 1 – 12 + 42 - 73

upper part: block 60/20

lower part: block 80/60

The systematic image errors (figure 11) of such an adjustment is very close to the to the systematic image errors of the adjustment just with the standard set of additional parameters (figures 6 and 7), the root mean square difference is just 0.5µm. The averaged residuals (figure 12) are nearly random – neighboured vectors of the block 60/20 are just correlated with r=0.02, for block 80/60 with r=0.11. Over a distance of 8mm in the image in both blocks there is no more correlation.

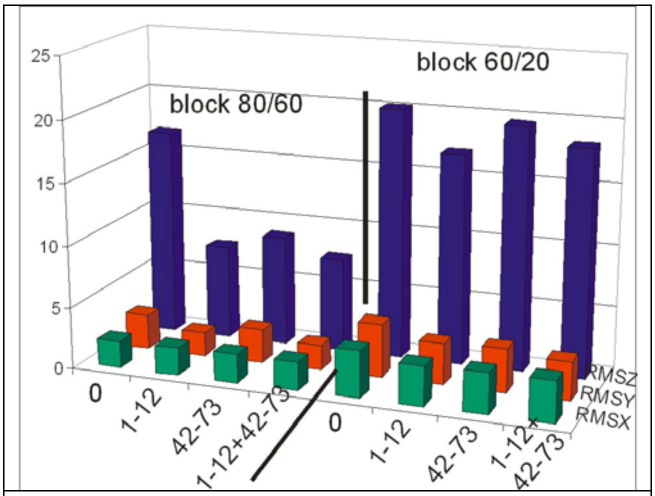


Figure 13: root mean square differences at check points

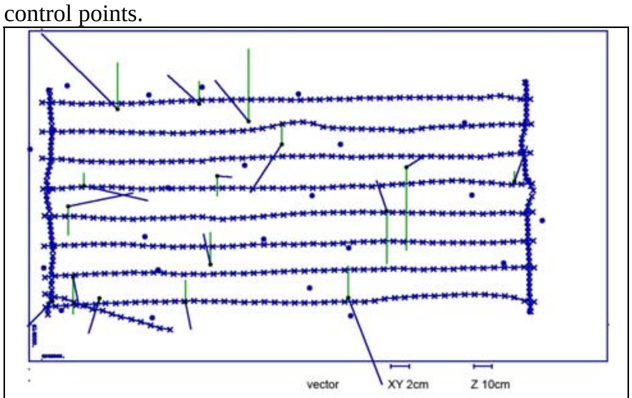
additional parameters	0	1-12	42-73	1-12 + 42-73
GCP SX	0.8cm	0.8cm	0.8cm	0.8cm
GCP SY	2.1cm	0.8cm	1.0cm	0.8cm
GCP SZ	23.4cm	6.5cm	10.5cm	5.1cm
sigma0	3.01µm	2.76µm	2.85µm	2.75µm
check SX	2.2cm	2.2cm	2.3cm	2.3cm
check SY	2.8cm	1.9cm	2.7cm	2.0cm
check SZ	16.8cm	7.6cm	8.9cm	7.5cm

Table 3: results of bundle block adjustment block 80/60

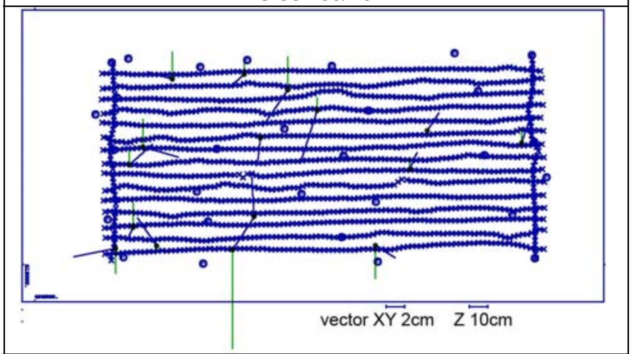
additional parameters	0	1-12	42-73	1-12 + 42-73
GCP SX	0.7cm	0.5cm	0.5cm	0.7cm
GCP SY	0.5cm	0.5cm	0.7cm	0.8cm
GCP SZ	3.6cm	2.7cm	2.2cm	3.3cm
sigma0	3.06µm	2.87µm	2.92µm	2.83µm
check SX	3.8cm	3.2cm	3.3cm	3.3cm
check SY	4.3cm	3.3cm	3.5cm	3.1cm
check SZ	20.2cm	17.0cm	19.6cm	18.3cm

Table 4: results of bundle block adjustment block 60/20

The distance of the control points is in the range of 10 base length related to 60% end lap (figures 13 and 14). Without support of projection centres determined by relative kinematic GPS-positioning for analogue photos this is an unusual low number of control points. Some control points have not been used for the block adjustment, so they could be used as independent check points. As it can be seen in figure 13 and tables 3 and 4, the horizontal accuracy is not so much influenced by the self-calibration, for block 80/60 it is between 0.33 GSD and 0.22 GSD; for block 60/20 it is between 0.50 and 0.37 GSD. The check points of block 80/60 are located in the average in 13.5 images; in block 60/20 in 4.5 images. The high number of images per point of course is improving the result – for the horizontal location this should be depending upon the square root of the number of points – explaining the difference in accuracy between both block configurations. For the height the situation is more complex. Here a clear dependency upon the systematic image errors exists. The height of blocks not strongly supported by control points shows a bending caused by systematic image errors, so a bundle block adjustment with self calibration is required. As it can be seen also at the averaged residuals, the systematic image errors are respected with the major part by the standard set of additional parameters (1-12) used also for analogue photos, even better like with the special UltraCamD-parameters (42-73) alone, but the best result has been achieved with a combination of both sets (1-12 + 42-73). From this set of 44 additional parameters in the final iteration only 23 are used for block 80/60 and 19 for block 60/20. Mainly the radial symmetric parameters and the parameters for tangential distortion of the general set of parameters and some of the special UltraCamD-parameters finally have been used. In the case of the block 60/20 the height has been not so much improved by the self calibration – in this case the large distance of the control points are dominating. The UltraCam has a height to base relation of 3.8, that means if the standard deviation of the x-parallax corresponds to the sigma0-value, the standard deviation of the height should be 3.8 times as much as the standard deviation for X and Y. The standard deviation for the check point height (SZ) for the block adjustment with all additional parameters for block 80/60 is 7.5cm, while for X and Y 2.15cm has been reached – this corresponds to the relation of 3.5, which is close to the height to base relation. For block 60/20 the relation is 5.7, this means, it is more than the height to base relation. This can be explained by a too poor support by control points.

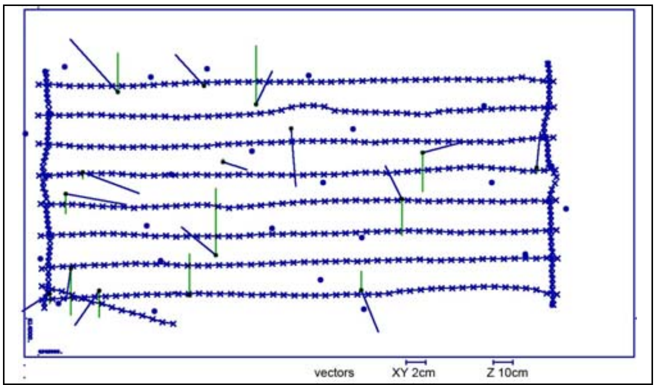


block 60/20

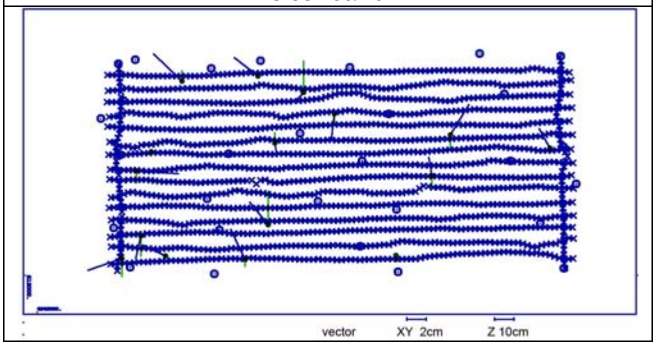


block 80/60

Figure 14: discrepancies at check points of block adjustment without self calibration
green (vertical vector) = Z-discrepancies



block 60/20



block 80/60

Figure 15: discrepancies at check points of block adjustment with standard parameters 1 - 12
green (vertical vector) = Z-discrepancies

The block 80/60 with the strong overlap of the images is quite more stable like the block with the minimal overlap. Also from block adjustment with analogue photos the experience exists that with 60% side lap the distance of the control points can be extended.

A comparison of the systematic image errors determined with this data set (8.6cm GSD) with a data set taken with the UltraCamD also over Istanbul a year before and with 30cm GSD (Baz et al 2006) shows some, but still limited similarities. A year before also an angular affinity could be seen in addition to radial symmetric effects. Also that block showed similar accuracy behaviour, the major part of the systematic image errors could be respected with the standard set of the BLUH-parameters, but the complete removal required the special UltraCamD-parameters in addition.

5. CONCLUSION

The bundle block adjustment with the UltraCamD-images leads to sigma0-values of approximately 3µm, corresponding to 0.3 GSD. This is quite better like with analogue photos. In spite of the expectations at the introduction of the digital cameras, also the UltraCamD-images show systematic image errors like known from analogue photos. The bundle block adjustment with the basic set of the BLUH-parameters can eliminate the largest amount of the systematic image errors, but for a complete determination the special UltraCamD-parameters are required in addition. The systematic image errors can be determined with 20% side lap and 60% end lap as well as with higher image overlap. Only the averaged residuals from a bundle block adjustment without self-calibration are clearer in the case of a block with higher overlap.

At check points the standard deviation for X and Y for block 80/60 is between 0.33 GSD and 0.22 GSD; for block 60/20 it is between 0.50 and 0.37 GSD. The vertical accuracy at the check points corresponds for block 80/60 to a standard deviation of the x-parallax of 0.23 GSD, for block 60/20 to 0.53 GSD. Even without self-calibration sub-pixel accuracy has been reached. The original requirement of a horizontal accuracy of 25cm for mapping has been exceeded by nearly a 10 times higher accuracy. So for further photo flights for mapping in scale 1 : 1000 also a larger GSD can be used if this is possible from the side of the object identification.

The used spare control point distribution is quite sufficient for horizontal accuracy and also for the block with 60% side lap for the vertical accuracy. With just 20% side lap not the full possible vertical accuracy has been reached, this requires a more dense distribution of vertical control points in the block centre.

REFERENCES

Baz, I., Jacobsen, K., Büyüksalih, G., 2006: Analysis of a bundle block adjustment with UltraCam$_D$ images over Istanbul, Turkish-German Geodetic Days, Berlin 2006

Leberl, F., Perko, M., Gruber, M., Ponticelli, M., 2002: Novel Concepts for Aerial Digital cameras, ISPRS Com I, Denver 2002, ISPRS Archive Vol. 34 Part 1

Oswald, H.C., 2006: Potential digitaler photogramm-metrischer Luftbildkameras, Diploma thesis Leibniz University Hannover 2006