ANALYSIS OF A BUNDLE BLOCK ADJUSTMENT WITH ULTRACAM$_D$ IMAGES OVER ISTANBUL

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ABSTRACT:

Organized by The Bosporus Engineering Consultancy Services Inc (Bimtas), a photo flight with the Vexcel UltraCam$_D$ has been made for the Istanbul city. A sub-block over the Historic Peninsula has been analysed in cooperation of Bimtas with the Zonguldak Karaelmas University and the University of Hannover.

The high accuracy of the digital images together with crossing flight lines allows a reduction of the number of ground control points. Different configurations have been checked.
By simple theory the digital camera should have fewer problems with systematic image errors – this cannot be confirmed. The influence of the self calibration with additional parameters, also with some special parameters fitted to the geometry of the UltraCam$_D$, has been analysed.

1. INTRODUCTION

Digital photogrammetric workstations always 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 a block flown with the Vexcel UltraCam$_D$ over Istanbul have been investigated.

2. BLOCK CONFIGURATION

The city of Istanbul has been flown with the UltraCam$_D$. A sub-block with 523 images has been investigated. The synthetic UltraCam$_D$ 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 is in flight direction with 36.8° a little smaller than for analogue normal angle cameras having 41.3°. Across flight direction the view angle is with 54.1° 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.

The sub-block has been flown 3420m above ground corresponding to the image scale 1:33474. Each image is covering 2.2km x 3.5km. The whole sub-block has a size of 47km x 25km. As it can be seen in figure 1 and 2, the most north located flight line is not supporting the block configuration because especially the east part is mainly covered by water. This is also the case for the last images in the neighboured strip.

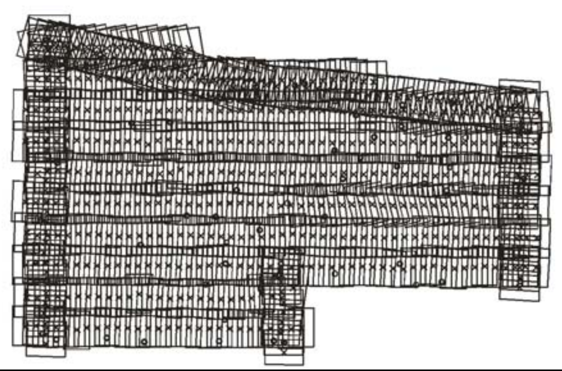

fig. 1: image configuration of the sub-block Historic Peninsula of Istanbul

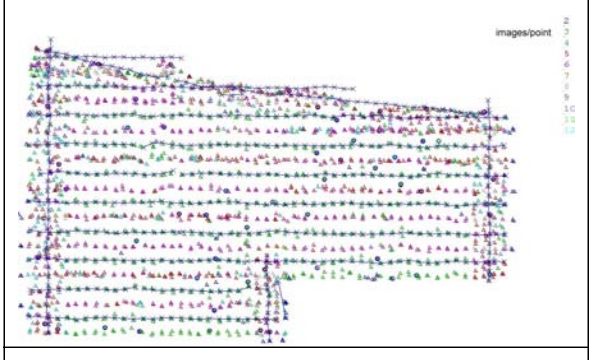

fig. 2: point distribution of the sub-block

The automatic aerotriangulation has been made with the Intergraph workstation, but for the detailed analysis the Hannover program system BLUH has been used. By automatic aerotriangulation 2529 object points were identified; in the average the object points are located in 4.7 images. Between 7 and 59 points are in the images with in average 23 points. One image with just 5 image points, having an unfavourable distribution, was removed from the block.

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 some systematic effects (figure 3).

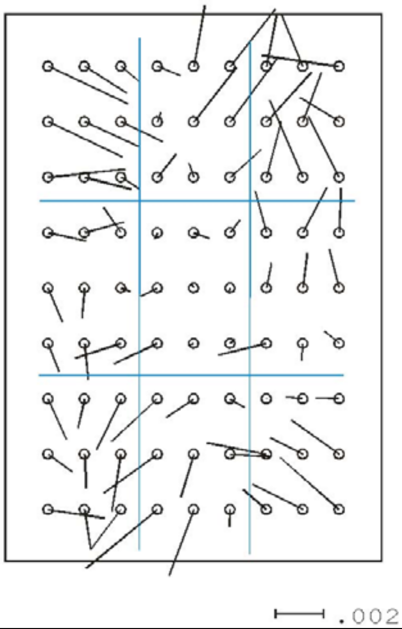

fig. 3: averaged image coordinate residuals

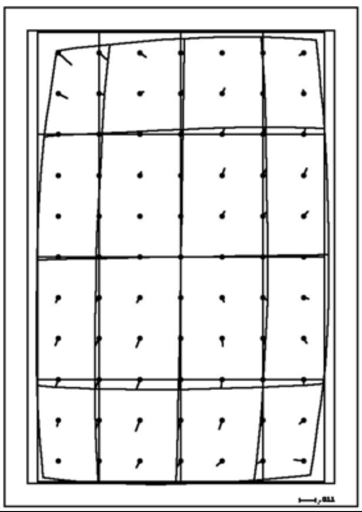

fig. 4: systematic image errors with standard additional parameters of program BLUH

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 4, which are approximately 3 times larger like the averaged residuals - this is usual. The mayor effect of the systematic errors shown in figure 3 is compensated by the additional parameters, but not some details.

The UltraCamD 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. The dominating influence of the self-calibration with the standard additional parameters is affinity, angular affinity and radial symmetric distortion. The radial symmetric distortion can be caused by the lens system including thermal influences and also a not respected earth curvature and refraction correction. The affinity and angular affinity should not be present for digital cameras based on CCD arrays.

Fig. 5: configuration of UltraCam$_D$ lenses

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

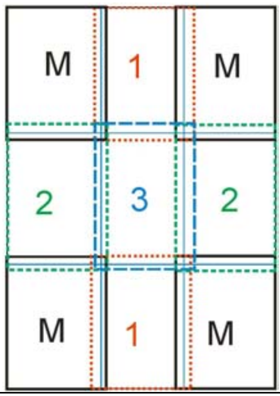

Fig. 6: connection of UltraCam$_D$ sub-images
M = master image (4 CCD-arrays)
1 = configuration 1 (2 CCD-arrays)
2 = configuration 2 (2 CCD-arrays)
3 = configuration 3 (1 CCD-array)

Figure 3 indicates errors of the connection of the 9 sub-images; by this reason corresponding additional parameters have been introduced into program BLUH. For each of the 8 sub-images outside of the centre a scale, two shifts and a rotation parameter have been introduced – that means 8*4 = 32 parameters corresponding to a similarity transformation.

The dominating influence of the systematic image errors can be compensated with the radial symmetric distortion and the UltraCam$_D$ scale parameters (figure 7). With the radial symmetric distortion and all 32 UltraCam$_D$ parameters, reduced to the required set of 23 additional parameters from originally 33, a very similar shape and size of the systematic image errors like with the standard 12 BLUH-parameters has been achieved (figure 8).

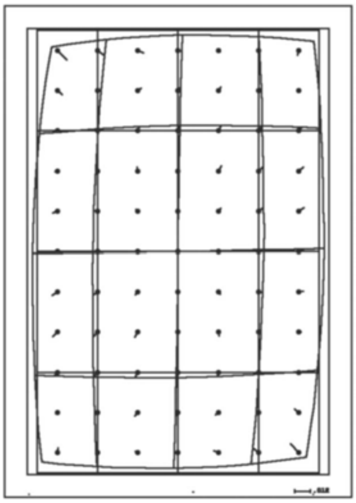

fig. 7: systematic image errors determined by the scale parameters of the UltraCam$_D$ additional parameters + radial symmetric distortion

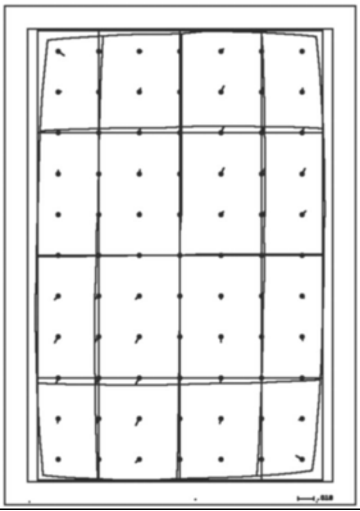

fig. 8: systematic image errors determined by all UltraCam$_D$ additional parameters + radial symmetric distortion

The distribution of the image points (figure 9) is not equal, but a sufficient number of points are located in all image sub-areas to allow a determination of all UltraCam$_D$ parameters.

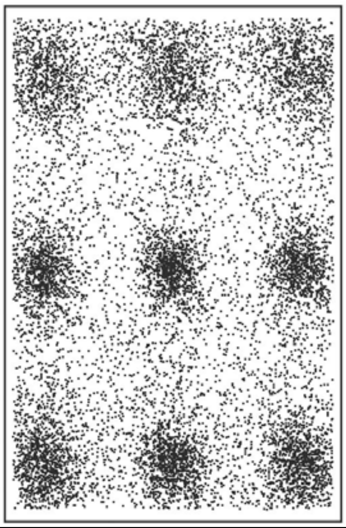

fig. 9: distribution of image points – overlay of all images

4. BLOCK ADJUSTMENT

With different control point configurations (figure 10) and different sets of additional parameters (table 1) bundle block adjustments have been computed with the Hannover program system BLUH. 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 – the correlation, total correlation and a Student test (T-test) are used. So a set of the 12 standard additional parameters of BLUH and the 32 special UltraCam$_D$ parameters – in total 44 additional parameters - are reduced to 24 additional parameters used in the final adjustment. Of course the parameters can be fixed against a removal, leading to a smaller sigma0 and smaller residuals at the control points, but the results at the independent check points usually are better with a reduced number of parameters, this is especially the case for smaller blocks.

The Historic Peninsula block has some connection problems at the northern, eastern and southern boundary caused by water surfaces, so it is not in any case an optimal, by 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 areas 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.

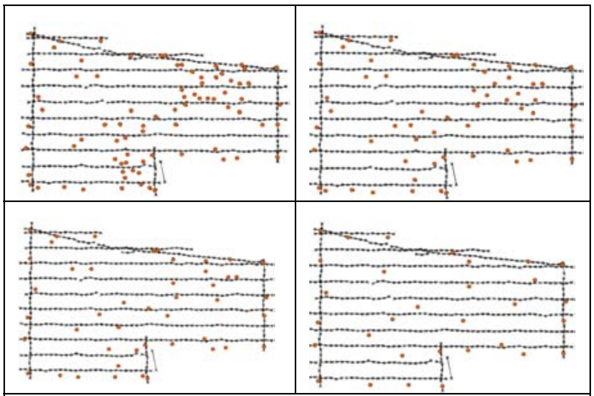

fig. 10: control point configurations (CPC) of Istanbul Historic Peninsula block
above: all 78 control points
above: CPC1: 53 horizontal, 56 vertical
below: CPC2 41 horizontal 45 vertical
below: CPC4 29 horizontal, 31 vertical

ground control points (GCP)

AP1: no additional parameter
AP2: only radial symmetric parameter r³
AP3: radial symmetric parameter r³ + affinity and angular affinity for whole image
AP4: standard set of 12 BLUH parameters
AP5: radial symmetric parameter r³ + 8 $UltraCam_D$ scale parameters
AP6: radial symmetric parameter r³ + 32 $UltraCam_D$ parameters
AP7: standard set of 12 BLUH parameters + 32 $UltraCam_D$ parameters
Table 1: used sets of additional parameters

With the exception of additional parameter configuration AP1, that means without additional parameters, in any case the radial symmetric parameter r³ (minus a constant value for a zero crossing) has been used because it requirement is obvious.

The standard deviation of unit weight sigma0 – the accuracy of the image coordinates – is between 4.5µm without additional parameters and 3.95µm for a sufficient determination of the systematic image errors.

The sigma0 is in the range of 0.44 up to 0.5 pixels. With the scale number of 33474 this corresponds to 0.15m on the ground – this is an estimation of the standard deviation of the ground coordinates X and Y without influence of a block deformation. With the height to base relation of 3.76 for points located only in neighboured images of a flight line, the estimation of the vertical ground accuracy is 0.55m without an influence of a block deformation.

There is a clear dependency of the object point accuracy upon the number and configuration of control points – it goes for the adjustment with the standard set of BLUH-parameters (AP4) from RMSX=0.178m, RMSY=0.211m and RMSZ=0.359m for CPC1 up to RMSX=0.237m, RMSY=0.259m and RMSZ=0.758m for CPC4. This is an expected result

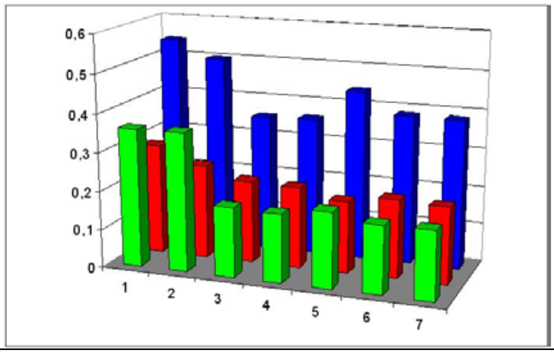

fig. 11: root mean square errors at independent check points [m] CPC1 53 horizontal, 56 vertical GCP

1 – 7 are corresponding to parameter configuration AP1 – AP7
sequence of columns: RMSX in front, RMSY, RMSZ behind

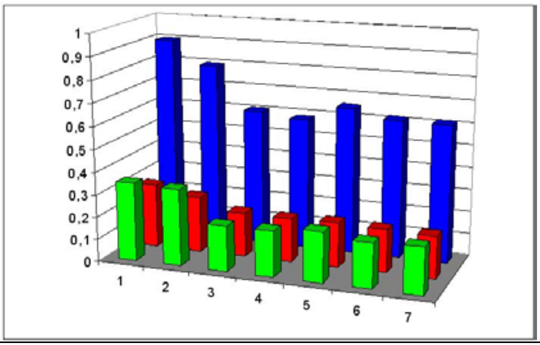

fig. 12: root mean square errors at independent check points [m] CPC2 41 horizontal, 45 vertical GCP

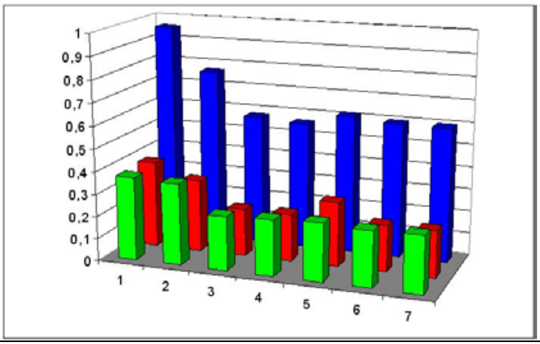

fig. 13: root mean square errors at independent check points [m] CPC3 35 horizontal, 38 vertical GCP

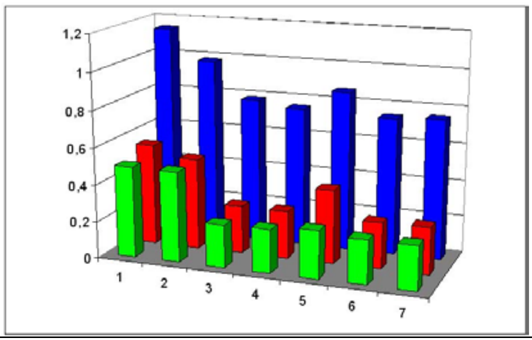

fig. 14: root mean square errors at independent check points [m] CPC4 29 horizontal, 31 vertical GCP

Of course without self-calibration with additional parameters (AP1) the results are not so good, but for the large distance of control points the loss of accuracy against the adjustment with additional parameters is limited. With the 12 standard BLUH parameters (AP4) with just 1% difference a negligible smaller standard deviation has been reached like with the combination of the 12 standard parameters with the 32 special $UltraCam_D$ parameters (AP7); that means 44 additional parameters. It was not expected from the beginning, that with just 3 additional parameters (AP3) nearly the same accuracy has been reached like with 44 additional parameters (AP7) fitted to special problems of the $UltraCam_D$. That means, for this data set the special $UltraCam_D$ additional parameters are not justified by the controlled results.

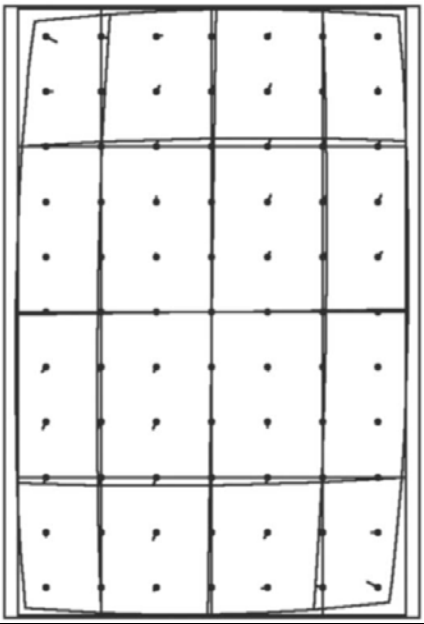

fig. 15: systematic image errors AP3

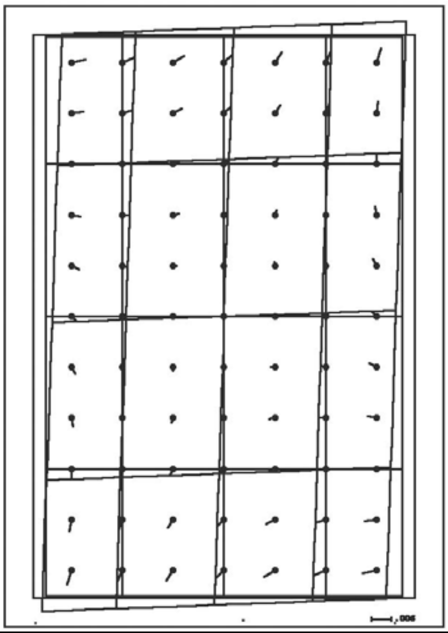

fig 16: systematic image errors AP3 without influence of r^3

The systematic image errors computed with the set AP3 (just affinity, angular affinity, r^3) shown in figure 15 is very similar to the effects shown in figures 4, 7 and 8. That means the dominating effects can be reduced to just a limited correction with 3 additional parameters. In figure 16 systematic image errors without the influence of r^3 are shown. The radial distortion described with r^3 can be caused by the lens, but also refraction and earth curvature. The affine deformation shown in figure 16 has a size of 6µm at the corners. Such a deformation is unusual for a digital camera and can only be explained with a not precise calibration of the $UltraCam_D$ master cone.

On the first view, with a sufficient number of control points (CPC1) with RMSZ=0.359m a better vertical accuracy has been reached than estimated above with 0.55m; but the control points have been measured in the average in 4.2 images. Based on this, the base is larger than for 2 images and the number of rays are improving the results.

CONCLUSION

The bundle block adjustment of the Historic Island of Istanbul with Vexcel $UltraCam_D$ images resulted in a satisfying accuracy. The stabilisation of the block with crossing flight lines allowed a handling also with a smaller number of control points. The systematic image errors based on the image coordinate residuals indicate geometric problems of the merge of the $UltraCam_D$ sub-images to synthetic scenes. Special additional parameters for the identification and respecting 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 $UltraCam_D$ additional parameters. With the standard set of 12 additional parameters of program BLUH the same or a better accuracy at independent check points has been reached, like with the high number of the special parameters. With just 3 additional parameters, nearly the full accuracy potential could be reached. This is not justifying the special $UltraCam_D$ parameters, or reverse, there is finally no proof of problems of the $UltraCam_D$ sub-image merge with the handled data set.
In general a high accuracy level could be reached with the digital images even with a smaller number of control points like usual.

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