ACCURACY AND RADIOMETRIC STUDY ON LATEST GENERATION LARGE FORMAT DIGITAL FRAME CAMERAS

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Keystone Aerial Surveys, Inc.  Corporate Summary

• Acquisition based company supporting customers in the US, Canada and Mexico
• Fully permitted for quick response in Mexico and Canada
• ABGPS\IMU processing, AT services and more available
• Extensive historical imagery library
• Digital Globe Precision Aerial Imagery reseller

• 17 Survey Aircraft
• 12 Leica RC 30/20 Cameras
• 4 Microsoft UltraCam Digital Cameras
• 1 Optech Gemini LiDAR scanner
Motivation for the Study:

1. To find out through different block configurations, treatment of information, etc. the possible limits in terms geometrical accuracy for the two most popular and latest digital frame cameras existing in the market, i.e. the 3 versions of the Z/I DMC II and the UltraCam Eagle.

2. Given the geometric characteristics of the Test Field Area where the UltraCam Eagle took place and many other related parameters, it was possible to try a system calibration (i.e., camera inner orientation parameters and their relationship to the IMU-ABGPS of the camera system).

3. Radiometrically speaking, the aim concentrated on finding out the real vs. theoretical/nominal resolution of the camera and in such a way to see if there is any possible lost of information on the acquired images.

Experimental Tests:

1. Areas chosen for the different experiments carried out with the different cameras

2. Flight parameters and number/distribution of Ground/Check control points used on each experimental test

3. Data acquisition, data reduction, without/with self-calibration approach in the adjustment phases. Analysis of the statistical results on Each case
This was not a comparison study between the two types of cameras.

- Flights in different places and times of the year, different latitude of the places, hence different illumination of the terrain.
- Geometric parameters of the flights, number, distribution and characteristics of the GCPs different.
- GSD different for each camera/project.

In view of all above, the authors have summarized the obtained results of each test only.
<table>
<thead>
<tr>
<th>Camera</th>
<th>Number of Pixels</th>
<th>Pixel-Size [µm]</th>
<th>Focal length [mm]</th>
<th>Δt [sec]</th>
<th>Image Size [mm]</th>
<th>b/h for p=60%</th>
<th>Mega-pixel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>x y</td>
<td></td>
<td></td>
<td>x y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DMC</td>
<td>7680 13824</td>
<td>12.0</td>
<td>120</td>
<td>2</td>
<td>49.15 86.02</td>
<td>1:6.1</td>
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<td>DMCII 140</td>
<td>11200 12096</td>
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<td>2</td>
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<td>DMCII 230</td>
<td>14144 15556</td>
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<tr>
<td>DMCII 250</td>
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<td>82.41 96.41</td>
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<tr>
<td>UC D</td>
<td>7500 11500</td>
<td>9.0</td>
<td>101.4</td>
<td>1</td>
<td>67.50 105.5</td>
<td>1:3.8</td>
<td>86</td>
</tr>
<tr>
<td>UC X</td>
<td>9420 14430</td>
<td>7.2</td>
<td>100.5</td>
<td>1.4</td>
<td>67.82 103.9</td>
<td>1:3.7</td>
<td>136</td>
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<tr>
<td>UC Xp</td>
<td>11310 17310</td>
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<td>100</td>
<td>2</td>
<td>67.86 103.9</td>
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<tr>
<td>UC Eagle</td>
<td>13080 20010</td>
<td>5.2</td>
<td>80 / 210</td>
<td>1.8</td>
<td>68.02 104.1</td>
<td>1:2.9</td>
<td>261</td>
</tr>
</tbody>
</table>

Red=New Generation  Black=Old Generation
UltraCam Eagle – Test Field Area
~ 38.6 sq. Km.

Area Description:
• NE Philadelphia
• Relatively Open/Flat Area
• Large Shopping Mall with Large Parking Lots With Lines
• Wide Roads and Streets With Painted Traffic Lines
UltraCam Eagle – Test Field Area
~ 38.6 sq. miles

84 signalized GCPs.
~1.5 cm standard deviation

East-West 5 cm GSD, North-South 15cm → 60% end and 60% lat. overlap

Typical Targeted GCP. Intersection of Parking Stripes

Typical signal/signalized GCP/CHK points
1. **BUNDLE BLOCK ADJUSTMENT**

2. **BLUH (Bundle block adjustment Leibniz University Hannover)** Author: Karsten Jacobsen

3. **Self-calibration Models**

   x, y = image coordinates normalized to maximal radial distance 162.6mm (scale factor: 162.6 / maximal radial distance)  
   
   \[ r^2 = x^2 + y^2 \]  
   \[ b = \arctan \left( \frac{y}{x} \right) \]

   1. \( x' = x - y \cdot P_1 \)
   2. \( x' = x - x \cdot P_2 \)
   3. \( x' = x - x \cdot \cos 2b \cdot P_3 \)
   4. \( x' = x - x \cdot \sin 2b \cdot P_4 \)
   5. \( x' = x - x \cdot \cos b \cdot P_5 \)
   6. \( x' = x - x \cdot \sin b \cdot P_6 \)
   7. \( x' = x + y \cdot r \cdot \cos b \cdot P_7 \)
   8. \( x' = x + y \cdot r \cdot \sin b \cdot P_8 \)
   9. \( x' = x - x \cdot (r^2 - 16384) \cdot P_9 \)
   10. \( x' = x - x \cdot \sin(r \cdot 0.049087) \cdot P_{10} \)
   11. \( x' = x - x \cdot \sin(r \cdot 0.098174) \cdot P_{11} \)
   12. \( x' = x - x \cdot \sin 4b \cdot P_{12} \)

Angular affinity

Tangential distortion 1

Tangential distortion 2

Radial symmetric \( r^3 \)

Radial symmetric
Special additional parameters in Hannover program system BLUH
BLUH includes additional parameters specifically for the Z/I DMC (1st version) and UltraCam cameras as well as for cameras having problems with the flatness of their CCD (parameters 81 to 88)

- 29 – 33 special parameters for the internal transformation of DMC sub-images
- 34. \(x' = x - x*y*P34\) \(y' = y\) for upper right quarter DMC Y 1
- 35. \(x' = x\) \(y' = y - x*y*P35\) for upper right quarter DMC X 1
- 36. \(x' = x - x*y*P36\) \(y' = y\) for lower right quarter DMC Y 2
- 37. \(x' = x\) \(y' = y - x*y*P37\) for lower right quarter DMC X 2
- 38. \(x' = x - x*y*P38\) \(y' = y\) for lower left quarter DMC Y 3
- 39. \(x' = x\) \(y' = y - x*y*P39\) for lower left quarter DMC X 3
- 40. \(x' = x - x*y*P40\) \(y' = y\) for upper left quarter DMC Y 4
- 41. \(x' = x\) \(y' = y - x*y*P41\) for upper left quarter DMC X 4

- 42 – 49 scale parameters for UltraCam
- 50 – 57 shift X parameters for UltraCam
- 58 – 65 shift Y parameters for UltraCam
- 66 – 73 UltraCam master images perspective
- 79 common perspective deformation of DMC version 1 sub-images
- 80 common radial symmetric parameter for DMC version 1 sub-images
- 81-88 parameters for geometry at the corners of the image (problem of CCD flatness)
**UltraCam Eagle results:**

**Double coverage Block. All GCPs**

<table>
<thead>
<tr>
<th>Block: Low + High Altitude Flight (GSD= 5cm respectively 15cm)</th>
<th>additional parameters</th>
<th>(\sigma_o) [\mu m]</th>
<th>RMSE 84 GCPs [cm]</th>
<th>MAX Errors 84 GCPs [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>RMX</td>
<td>RMY</td>
</tr>
<tr>
<td>no selfcalibr.</td>
<td>1.28</td>
<td>2.3</td>
<td>2.8</td>
<td>3.0</td>
</tr>
<tr>
<td>12 St</td>
<td>1.23</td>
<td>2.3</td>
<td>2.7</td>
<td>2.8</td>
</tr>
<tr>
<td>12 ST+C.S.</td>
<td>1.18</td>
<td>2.2</td>
<td>2.6</td>
<td>2.7</td>
</tr>
<tr>
<td>C. Spec</td>
<td>1.18</td>
<td>2.3</td>
<td>2.6</td>
<td>2.7</td>
</tr>
<tr>
<td>C. Spec+C</td>
<td>1.18</td>
<td>2.3</td>
<td>2.6</td>
<td>2.6</td>
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</table>

<table>
<thead>
<tr>
<th>Block: Low Altitude Flight (GSD=5cm)</th>
<th>additional parameters</th>
<th>(\sigma_o) [\mu m]</th>
<th>RMSE 84 GCPs [cm]</th>
<th>Maximal Errors 84 GCPs [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>RMX</td>
<td>RMY</td>
</tr>
<tr>
<td>no self calibr</td>
<td>1.15</td>
<td>2.2</td>
<td>2.5</td>
<td>2.8</td>
</tr>
<tr>
<td>12 St</td>
<td>1.10</td>
<td>2.5</td>
<td>2.3</td>
<td>2.5</td>
</tr>
<tr>
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<td>2.0</td>
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<td>2.4</td>
</tr>
<tr>
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<td>2.0</td>
<td>2.3</td>
<td>2.4</td>
</tr>
<tr>
<td>C. Spec+C</td>
<td>1.07</td>
<td>2.0</td>
<td>2.4</td>
<td>2.4</td>
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</table>

<table>
<thead>
<tr>
<th>Block: High Altitude Flight (GSD=15cm)</th>
<th>additional parameters</th>
<th>(\sigma_o) [\mu m]</th>
<th>RMSE 84 GCPs [cm]</th>
<th>Maximal Errors 84 GCPs [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>RMX</td>
<td>RMY</td>
</tr>
<tr>
<td>no self calibr</td>
<td>1.16</td>
<td>6.2</td>
<td>6.7</td>
<td>7.5</td>
</tr>
<tr>
<td>12 St</td>
<td>1.14</td>
<td>5.9</td>
<td>6.4</td>
<td>7.0</td>
</tr>
<tr>
<td>12 St +C. S</td>
<td>1.10</td>
<td>6.0</td>
<td>6.3</td>
<td>7.2</td>
</tr>
<tr>
<td>C. Spec</td>
<td>1.09</td>
<td>6.0</td>
<td>6.3</td>
<td>7.2</td>
</tr>
<tr>
<td>C. Spec+C</td>
<td>1.09</td>
<td>6.0</td>
<td>6.3</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Overall accuracy (\(\sigma_o\)) improved approx 10% by self-calibration. Horizontal accuracy not improved by self-calibration. Only vertical accuracy improved by self calibration.

Only East-West 5cm GSD - same effect as above. Although up to 4 mm in Z again negligible. UC Eagle height-to-base ratio 2.93 - smaller than in other UltraCam models

Only North-South 15 cm GSD - same tendency.
UltraCam Eagle results: Double coverage Block. All GCPs

Low + High Altitude Flight. All GCPs

Accuracy is clearly influenced by the points of the low altitude flight
Best fit with camera specific add. Parameters
No additional gain with add. Parameters for corner distortions

Low Altitude Flight. All GCPs. 5 cm

No apparent gain in accuracy between 12 St + Cam. Spec and Cam Specific Add. Param. alone
No additional gain with add. Parameters for corner distortions
As expected RMSZ is the lowest accuracy (H/B ≈1:2.9)
1. In terms of GSD there is no significant difference between no self-Calib and the different self-calibration approaches.
2. In all cases accuracy in terms of RMS is between 0.4 and 0.5 GSD.
3. Best fit is when Camera specific Add. Param are used.
4. Lowest accuracy (in terms of RMS) is for the Z-component (remember H/B for the Eagle is still 1:2.9 for focal length 80 mm).
5. Advisable to use all combination of add. Parameters. Program decides based on stochastical model eliminating the possibility of over parameterization.
Although very small - with 12 standard parameters remaining systematic image errors (b). Becomes small with camera specific Add Param (c). cleaning of the corner effect by (d) – even if only negligible effect to ground coordinates

**Systematic image errors by self-calibration**

advisable to use all additional parameters (automatically reduced by program to required parameters)
Accuracy versus number and distribution of GCPs and ChK Pts.

<table>
<thead>
<tr>
<th>GCPs/CHKs</th>
<th>ADJ. TYPE</th>
<th>Root mean square differences at check points [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\sigma_{0\mu m}$</td>
<td>RMX</td>
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<tr>
<td>44/40</td>
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<td>1.22</td>
</tr>
<tr>
<td></td>
<td>12 St.</td>
<td>1.18</td>
</tr>
<tr>
<td></td>
<td>12 St. + C S</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>C Spec+81-88</td>
<td>1.13</td>
</tr>
<tr>
<td>28/56</td>
<td>no self calibr.</td>
<td>1.18</td>
</tr>
<tr>
<td></td>
<td>12 St.</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td>12 St. + C S</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td>C Spec</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>C Spec+81-88</td>
<td>1.09</td>
</tr>
<tr>
<td>10/74</td>
<td>no self calibr.</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>12 St.</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>12 St. + C S</td>
<td>1.02</td>
</tr>
<tr>
<td></td>
<td>C Spec</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>C Spec+81-88</td>
<td>1.06</td>
</tr>
<tr>
<td>5/79</td>
<td>no self calibr.</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>12 St.</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
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<td>1.03</td>
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<tr>
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<td>C Spec</td>
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<tr>
<td></td>
<td>C Spec+81-88</td>
<td>1.04</td>
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</table>

Accuracy for fewer number of GCPs along with different sets of additional parameters.

In general:
Smaller Standard Deviation for less number of GCPs.
1. Absolute Accuracy in terms of RMS/GSD falls (although not that much) for lower numbers of GCPs. Systematic errors start exercising some influence.
2. Nevertheless in all cases remains bellow the smallest GSD for all cases.
3. Once again one can notice the dominating effect of the low altitude flight in terms of accuracy of their pass/tie points, but not for the extreme case of only 5 GCPs.
4. Additional Parameters for corner distortions are not significant and may add slight deformation in the area.

**Absolute Accuracy on Check Points**

5 GCPs and 79 Check Points
### Standar Deviation and Num. of GCPs

1. Fewer numbers of GCPs result in better accuracy in terms of St. Deviation. Systematic errors are more free to exercise their influence because there are less constraints.

2. In all cases best accuracy in terms of St. Deviation occurs for 12 St. Add. Param + Camera Specific Additional Parameters

3. Almost no difference in accuracy between Camera Specific Add. Param only and these plus Add. Param. for corner Deformation. Conclusion: no geometric distortion on the corners of the synthetic image of the Eagle
ULTRACAM EAGLE. CAMERA SYSTEM CALIBRATION
CAMERA SYSTEM CALIBRATION

For “DIRECT SENSOR ORIENTATION or INTEGRATED SENSOR ORIENTATION”, meaning Orientation with no use of control points, or in other words to use readings from exterior sensors of the camera, we need to know or to assure the following:

1. Location of camera principal point. ABGPS and PPC are highly correlated → any ABGPS shift affects this and consequently the image coordinates

2. If the angular EOs are to be obtained from IMU (Roll, Pitch, roll) → (Omega, Phi, Kappa) angular misalignment required

3. IMU – ABGPS usually includes a Kalman filter, “LEVER ARM” important = distance between IMU and camera projection center

4. calibrated distance focal length of the camera may change with flying height

<table>
<thead>
<tr>
<th>Pressurized cabin, cover glass</th>
<th>Lens in free atmosphere t = 7 ° C</th>
<th>Lens in free atmosphere t like air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flying Altitude</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Km</td>
<td>14 km</td>
<td>6 Km</td>
</tr>
<tr>
<td>Wide Angle f=153 mm</td>
<td>-20μm</td>
<td>-36μm</td>
</tr>
<tr>
<td>Normal Angle f= 305 mm</td>
<td>+12μm</td>
<td>-33μm</td>
</tr>
</tbody>
</table>

Change of focal length with altitude of Platform, according to Mayer 1978
EEFECT OF CHANGE OF FOCAL LENGTH
DOES NOT INFLUENCE X and Y. IT ONLY PRODUCES AN AFFINE DEFORMATION
OF ALTITUDE

Suppose df = 15 μm, in case of traditional orientation with control points – for
image scale 1:6,500 and a Δh = 100 m against leveled control points is

6,500 = H + dh/(f + df);  or dh = 6,500 (f + df) – H; replacing dh ~ 1 cm

As above in the case for Direct Sensor Orientation it can be proved that dh ~ 10
cm.

“HENCE, FOR DIRECT SENSOR ORIENTATION,
LABORATORY CALIBRATION IS NOT SUFFICIENT”
SYSTEM CALIBRATION PARAMETERS:

1. Location of camera principal point
2. Operational focal length of the camera
3. Misalignment angles between the IMU axis and Camera axis
4. Calibrated distance between the IMU origin and camera projection center (also known as the Lever Arm)

The tests were conducted using the same UC Eagle, same block GSDs, IMU and Airborne GPS, same GCPs as before, but with strip line flown in a forward and reverse direction. This allows independent determination of airborne GPS shift and principal point.

<table>
<thead>
<tr>
<th>Correction for focal length</th>
<th>-.008 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shift of principal point in x</td>
<td>.004 mm</td>
</tr>
<tr>
<td>Shift of the principal point in y</td>
<td>-.006 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CPITCH</th>
<th>CROLL</th>
<th>CYAW</th>
<th>CX</th>
<th>CY</th>
<th>CZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>.00326</td>
<td>.00520</td>
<td>.00065</td>
<td>-.262</td>
<td>.123</td>
<td>.286</td>
</tr>
</tbody>
</table>

These parameters are used to correct the IMU-GPS.
SQUARE MEAN OF DIFFERENCES
RMSX = +/- 3cm  RMSY = +/- 3cm  RMSZ = +/- 6cm
root mean square differences at 84 GCPs used as check points

MAXIMAL DIFFERENCES
MAX DX = 7cm  MAX DY = 10cm  MAX DZ = 14cm

Using the calibrated focal length and the calibrated/corrected image coordinates → RELATIVE ORIENTATION
MAXIMUM – Y-PARALLAX = 8.7 Microns

<table>
<thead>
<tr>
<th>Calibration</th>
<th>GCPS</th>
<th>Add. Params</th>
<th>RMX</th>
<th>RMY</th>
<th>RMZ</th>
<th>max X</th>
<th>max Y</th>
<th>max Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factory</td>
<td>5 GCPS</td>
<td>12 St. + C S</td>
<td>3.6</td>
<td>4.4</td>
<td>5.8</td>
<td>11.3</td>
<td>12.4</td>
<td>23.5</td>
</tr>
<tr>
<td>System Cal.</td>
<td>None</td>
<td>None</td>
<td>3.0</td>
<td>3.0</td>
<td>6.0</td>
<td>7.0</td>
<td>10.0</td>
<td>14.0</td>
</tr>
</tbody>
</table>
Geometric Analysis of DMC II 230

Monolithic CCD

Image footprints – 54mm GSD and 9 used GCPs, footprint: 752m x 827m image base = 215m → 71% end lap, 47% side lap + 2 crossing flight lines

color coded number of images / object point
Geometric Analysis of DMC II 230

Averaged residuals, block adjustment without self calibration. \( \text{RMS}_x = 0.41 \mu m \)
\( \text{RMS}_y = 0.40 \mu m \)

Block adjustment without self calibration – discrepancies at independent check points, circles = GCPs
Geometric Analysis of DMC II 230

Systematic image errors – left: with additional parameters 1 – 12, right: with additional parameters 1 – 12, 80 - 88

Block adjustment with self calibration – discrepancies at independent check points, left: additional parameters 1 – 12, right: additional parameters 1 – 12 + 81 - 88
Geometric Analysis of DMC II 230

Averaged residuals – block adjustment with additional parameters 1 – 12, 81 – 88

<table>
<thead>
<tr>
<th></th>
<th>at (8) GCPs</th>
<th>σo microns</th>
<th>at (36) check points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RMSX</td>
<td>RMSY</td>
<td>RMSZ</td>
</tr>
<tr>
<td>0 parameters</td>
<td>1.7cm</td>
<td>1.1cm</td>
<td>1.9cm</td>
</tr>
<tr>
<td>1 - 12</td>
<td>1.6cm</td>
<td>1.1cm</td>
<td>1.9cm</td>
</tr>
<tr>
<td>1 – 12, 80 - 88</td>
<td>1.7cm</td>
<td>1.1cm</td>
<td>2.2cm</td>
</tr>
</tbody>
</table>
Geometric Analysis of DMC II 250

**CASE A.** Image scale 1 : 9658 or 5.4cm GSD
Endlap 60%; Sidelap 40%
Footprint size: 758m x 906m

**CASE B.** Image scale 1 : 16 813 or 9.4cm GSD.
Endlap 60%; Sidelap 60%
+ crossing with same overlap
Footprint size: 1320m x 1579m

**CASE C.** Image scale 1 : 27 824 or 15.6cm GSD
Endlap 60%; Sidelap 60%
+ crossing flight
Footprint size: 2184m x 2613m
Geometric Analysis of DMC II 250

CASE A. GSD=5 cm

Root mean square differences at check points [GSD].
1/5 = without self calibration  2/6= additional parameters 1-12.
3/7 = additional parameters 1-12, 81-88. Whole Block stronger due to cross strips.
CASE B. GSD=9 cm

Root mean square differences at check points [in GSDs]
1/5/9 = without self calibration, 2/6/10= additional parameters 1-12.
3/7/11 = additional parameters 1-12, 81-88
Whole block better in dz (due to cross strips) with self-calib 1-12.
(See column 2 )
CASE C. GSD=15 cm

root mean square differences at check points [in GSDs]
1/5/9 = without self calibration, 2/6/10= additional parameters 1-12,
3/7/11 = additional parameters 1-12, 81-88.
Geometric Analysis of DMC II 250

JUST ONE FLIGHT LINE

Root mean square differences at check points [in GSDs] of block adjustments with self calibration by additional parameters 1-12 of blocks with images of just one flight line – the average of the results of East-West- and North-South-flight lines is shown
ZI IMAGING DMCII TEST

| DMCII 250 block, 5cm GSD | DMCII 250 block, above 9cm GSD below 15cm GSD | DMCII 230 block, 7cm GSD (Operational Block) |

DMCII-versions based on a monolithic large size CCD, so no camera specific additional parameters required. Only the standard parameters 1 – 12 and the special parameters for the image corners 81 – 88 are justified. All 8 DMCII-blocks did not require the special additional parameters 81 – 88, so for optimal results only the standard parameter 1 – 12 had to be used.
Image points of operational block not equally distributed, so gaps in remaining systematic image errors, vectors above and below gaps are larger because of limited number of points in these sub-areas. In general, systematic image errors and remaining systematic image errors very small. Over all blocks and images average of the systematic image errors are 0.32μm or 0.06 pixels.
Radiometric image quality (edge analysis)

- **Object**
- **Image**
  - Edge in image
  - Gray value profile
  - Point spread function

<table>
<thead>
<tr>
<th>Camera</th>
<th>Blue, pan-sharpened</th>
<th>Green, pan-sharpened</th>
<th>Red, pan-sharpened</th>
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<td>UltraCam Eagle</td>
<td>1.01</td>
<td>1.02</td>
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</tr>
</tbody>
</table>

Factors for effective resolution - multiplication with GSD or pixel size

→ The figure is important for identification of objects
CONCLUSIONS

UltraCam Eagle

1. Reduction of GCP number does not aggressively affect the overall accuracy of the block. The rate of change of the $\sigma_0$ is practically negligible.

2. The vertical accuracy component is greatly influenced by using fewer GCPs, while the changes to the horizontal components is insignificant.

3. The use of corner additional parameters does not improve ground coordinates. Surprisingly, nearly identical results were achieved with self-calibration using the 12 standard parameters plus the camera specific add parameters as compared with camera specific alone. Nevertheless, it is advisable to use all parameters.

4. A boresight calibration field area was flown with all appropriate requirements. Results of the calibration of the camera parameters and other data acquisition systems were totally acceptable. Direct Sensor Orientation was carried out with discrepancies on 84 GCPs with RMS in the range of 4 to 6 cm for plan and height with maximum discrepancies of 9 cm and 14 cm - largest computed y-parallax $= 8.6\mu$m

5. Factor for effective resolution only slightly greater than 1.0, meaning that the apparent (real) GSD is practically equal to the nominal GSD.
Z/I DMCII

1. Very small systematic errors. They can be ignored for data acquisition in model.
2. For block configurations $p=60\%$ and $q=40\%$ RMSE at the critical height component clearly below 1 GSD.
3. Factor for effective resolution only slightly lower than 1, meaning the apparent (real) GSD is practically equal to nominal GSD.
Thank you very much for your kind attention

QUESTIONS..?

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David Day
Karsten Jacobsen