GPS and IMU supported Bundle Block Adjustment as Base of Homogenous GIS Data Acquisition

Dr. Karsten Jacobsen
Leibniz University Hannover, Germany
Institute of Photogrammetry and Geoinformation

jacobsen@ipi.uni-hannover.de
Introduction

Aerial images
sensor orientation, required for geo-referencing of photogrammetric data acquisition

- Orientation of single model – several ground control points (GCP) required
- Bundle block adjustment – reduced number of GCP
- Bundle block with crossing flight lines – further reduction of GCP
- Projection center coordinates as observation in bundle block adjustment – also without GCP (combined bundle block adjustment)
- Projection center coordinates + attitudes by inertial measuring unit (IMU) → direct sensor orientation
Components of direct sensor orientation

Global Navigation Satellite System (GNSS)
GPS, GLONASS, Galileo, GAGAN, BeiDou, QZSS
relative kinematic positioning
position of antenna → projection center

Inertial Measurement Unit (IMU) (INS)

camera
Large size digital aerial frame cameras

Development dominated by development of CCDs

<table>
<thead>
<tr>
<th>Camera</th>
<th>Pixels (camera)</th>
<th>Pixel size [µm]</th>
<th>f [mm]</th>
<th>Mega-pixel</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMC</td>
<td>7680 x 13824</td>
<td>12.0</td>
<td>120</td>
<td>106</td>
</tr>
<tr>
<td>DMCII 140</td>
<td>11200 x 12096</td>
<td>7.2</td>
<td>92</td>
<td>135</td>
</tr>
<tr>
<td>DMCII 230</td>
<td>14144 x 15556</td>
<td>5.6</td>
<td>92</td>
<td>220</td>
</tr>
<tr>
<td>DMCII 250</td>
<td>14656 x 17216</td>
<td>5.6</td>
<td>112</td>
<td>249</td>
</tr>
<tr>
<td>UC D</td>
<td>7500 x 11500</td>
<td>9.0</td>
<td>101.4</td>
<td>86</td>
</tr>
<tr>
<td>UC X</td>
<td>9420 x 14430</td>
<td>7.2</td>
<td>100.5</td>
<td>136</td>
</tr>
<tr>
<td>UC Xp</td>
<td>11310 x 17310</td>
<td>6.0</td>
<td>100</td>
<td>196</td>
</tr>
<tr>
<td>UC Eagle</td>
<td>13080 x 20010</td>
<td>5.2</td>
<td>80 / 210</td>
<td>261</td>
</tr>
</tbody>
</table>

Today only digital cameras should be used

- more accurate, higher information content, IMU-system fixed in cameras

- Large size digital frame cameras or line scan cameras (Leica ADS80) – similar accuracy, only model handling of line scan images more complex
Electronic components of GNSS became small – integration of GNSS with IMU to GNSS-Inertial system

Relative positioning required for precise positioning – CORS-station -distance ~ 50km or network solution with net of CORS-stations or worldwide reference system as Omni Star → positioning with standard deviation of ~ 0.1m up to 0.5m

Transformation of position from antenna phase center to projection center (entrance nodal point)
In case of gyro stabilized platform reading of platform attitude
System calibration

1. Camera calibration: laboratory calibration only for focal length + principal point, details by self calibration in bundle block adjustment

2. Offset antenna phase center – camera entrance nodal point: can be determined at aircraft – problem: camera orientation in aircraft not fixed (crab angle compensation, gyro controlled platform) – crab angle no influence if antenna directly above camera

3. Misalignment of IMU against camera complete calibration by reference adjustment with few GCP including antenna offset, inner orientation of camera based on flight lines flown in opposite direction

if calibration shall be used in different areas – take care about coordinate system
Influence of object coordinate system

**local scale of transverse Mercator system**

\[ S_0 = \text{scale factor for meridian} \]

\( (0.9996 \text{ for UTM}) \)

\[ R = \text{earth radius} \]

\[ X = \text{distance from meridian} \]

\[ \text{scale} = S_0 \cdot \left( 1 + \frac{X^2}{2R^2} \right) \]

For 10 km flying height

- at meridian: -4 m
- 333 km from meridian: +13.7 m

Caused by the flattening of the earth to the mapping coordinate system, local scale correction not to Z-coordinates, causing height differences between projection center and ground depending upon location in the national coordinate system.

→ Handling in tangential coordinate system or height corrections or calibration within the project area.
### Inertial Measurement Unit

<table>
<thead>
<tr>
<th>System</th>
<th>Position</th>
<th>Roll/Pitch</th>
<th>Yaw (Heading)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trimble AP 20 (Applanixs)</strong></td>
<td>0.05 – 0.30m</td>
<td>0.015°</td>
<td>0.035°</td>
</tr>
<tr>
<td><strong>Trimble AP 40</strong></td>
<td>0.05 – 0.30m</td>
<td>0.008°</td>
<td>0.025°</td>
</tr>
<tr>
<td><strong>Trimble AP 50</strong></td>
<td>0.05 – 0.30m</td>
<td>0.005°</td>
<td>0.008°</td>
</tr>
<tr>
<td><strong>Trimble AP 60</strong></td>
<td>0.05 – 0.30m</td>
<td>0.0025°</td>
<td>0.005°</td>
</tr>
<tr>
<td><strong>Leica IPAS20 NUS4</strong></td>
<td>0.05 – 0.30m</td>
<td>0.008°</td>
<td>0.015°</td>
</tr>
<tr>
<td><strong>Leica IPAS20 DUSS</strong></td>
<td>0.05 – 0.30m</td>
<td>0.005°</td>
<td>0.008°</td>
</tr>
<tr>
<td><strong>Leica IPAS20 NUS5</strong></td>
<td>0.05 – 0.30m</td>
<td>0.005°</td>
<td>0.008°</td>
</tr>
<tr>
<td><strong>Leica IPAS20 CU56</strong></td>
<td>0.05 – 0.30m</td>
<td>0.0025°</td>
<td>0.005°</td>
</tr>
<tr>
<td><strong>IGI AEROcontrol (SMU)-m</strong></td>
<td>0.05m</td>
<td>0.010°</td>
<td>0.020°</td>
</tr>
<tr>
<td><strong>IGI AEROcontrol (SMU)-I</strong></td>
<td>0.05m</td>
<td>0.008°</td>
<td>0.015°</td>
</tr>
<tr>
<td><strong>IGI AEROcontrol (SMU)-II</strong></td>
<td>0.05m</td>
<td>0.004°</td>
<td>0.010°</td>
</tr>
<tr>
<td><strong>IGI AEROcontrol (SMU)-III</strong></td>
<td>0.05m</td>
<td>0.003°</td>
<td>0.007°</td>
</tr>
</tbody>
</table>

**Relative accuracy** = absolute accuracy if GNSS-data combined with IMU-data

IMU positions and attitudes have drift problems → combination with GNSS-positions by Kalman filtering – GNSS-data support IMU-data and reverse – also GNSS-positions supported by IMU improved – no more problems with cycle slips.
## Required attitude accuracy

influence of 1µm and 1 pixel in image to roll, pitch and yaw for nadir view

### roll / pitch $\rightarrow$ image  
yaw $\rightarrow$ image

<table>
<thead>
<tr>
<th>Model</th>
<th>1µm to roll/pitch</th>
<th>0.5 pixel to roll/pitch</th>
<th>1µm to yaw</th>
<th>0.5 pixel to yaw</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMC (1\textsuperscript{st} version)</td>
<td>0.000 5°</td>
<td>0.002 8°</td>
<td>0.001 1°</td>
<td>0.006 9°</td>
</tr>
<tr>
<td>DMCII 230</td>
<td>0.000 6°</td>
<td>0.001 8°</td>
<td>0.001 0°</td>
<td>0.002 7°</td>
</tr>
<tr>
<td>DMCII 250</td>
<td>0.000 5°</td>
<td>0.001 4°</td>
<td>0.000 9°</td>
<td>0.002 6°</td>
</tr>
<tr>
<td>UC XP</td>
<td>0.000 6°</td>
<td>0.001 8°</td>
<td>0.000 9°</td>
<td>0.002 7°</td>
</tr>
<tr>
<td>UC Eagle f=80mm</td>
<td>0.000 7°</td>
<td>0.001 8°</td>
<td>0.000 9°</td>
<td>0.002 4°</td>
</tr>
<tr>
<td>UC Eagle f=210mm</td>
<td>0.000 3°</td>
<td>0.000 7°</td>
<td>0.000 9°</td>
<td>0.002 4°</td>
</tr>
</tbody>
</table>

By automatic block adjustment $\sigma_0 = 1\mu$m operational  
Object point accuracy $SX, SY = 0.5 \text{ GSD}$ and $SZ = 0.7 – 1.2 \text{ GSD}$ possible  
best standard deviation of IMU: roll/pitch 0.0025° yaw 0.007°
Available / required attitude accuracy

Standard deviation roll/pitch

Trimble | Leica | IGI

~ required for 0.5 pixel

Standard deviation yaw

Trimble | Leica | IGI

~ required for 0.5 pixel

→ Even with most expensive IMU highest object point accuracy cannot be reached by direct sensor orientation, operational acceptable results not far away, but problems with disturbing y-parallaxes in model handling cannot be avoided.
Direct sensor orientation, integrated and combined block adjustment

**Integrated bundle block adjustment**: use of orientation from GNSS/IMU + tie points (+ GCP) – by adjustment improvement of direct sensor orientation + improved reliability -advantage against standard automatic aero triangulation: no problems if gaps of tie points because of poor object contrast or other problems – always orientation values GCP for reliability check

**Combined block adjustment**: use of GNSS-projection center coordinates + tie points (+ GCP) – in case of block of images attitude values not required as input, can be computed, also GCP not absolutely required – for reliability at least one GCP GCP required for single flight line

If no problems with tie points, operationally most often combined bundle block adjustment – nevertheless IMU improves GNSS-positions, direct sensor orientation helpful as approximations for automatic tie point generation
Integrated bundle block adjustment

Image scale 1 : 4000

At independent check points:
SX: 5.1cm  SY: 5.2cm  (13µm)
SZ: 7.4cm   (11µm for Spx)
Combined bundle block adjustment

Block configuration
~ 30 images in flight line
12 (red) or 18 (red+ green GCPs)
Image scale 1:3500

Results of reference adjustment (no GNSS)
Case 1 and 3: no self calibration
Case 2 and 4 self calibration

Results of combined block adjustment
Case 1 and 3: no self calibration
Case 2 and 4 self calibration
SZ = 0.1‰ hg
Combined bundle block adjustment

5501 images, ~ 70 flight lines
Image scale 1:19 200
Scanned with 15 μm pixel size → 30cm GSD
end lap 60%, side lap 30%

With 175 GCP – at check points:
RMSX/Y = 30cm       RMSZ = 23cm
1.0 GSD              0.77 GSD

With 22 GCP – at check points:
RMSX/Y = 30cm       RMSZ = 24cm
1.0 GSD              0.80 GSD
Conclusion

GNSS-inertial systems reached high accuracy and reliability level

Hardware components continuously improved (GNSS-inertial + cameras)

use of relative kinematic GNSS-positioning + inertial measurements became standard

GNSS-electronics and IMU today in most cases integrated in a GNSS-inertial system

attitude information from IMU not reaching today high level of digital cameras

→ **Integrated bundle block adjustment** with direct sensor orientation also because of reliability, attitude data helpful in areas with no object contrast and as start information of tie point generation

Attitude information not required for block → **combined block adjustment** with GNSS-data nevertheless also for this GNSS-data improved by IMU-information,