

- when it has to be right



Leica Geosystems Leica TerrainMapper-2 Calibration Certificate

| | |
|----------------------|-----------------------|
| Product | Leica TerrainMapper-2 |
| Serial Number | 92523 |
| Date | 20 July 2021 |
| Inspector | Xu Wang |



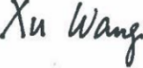

1. System Components

| Components | Type | Serial Number |
|-------------------------|-----------------------|---------------|
| Pod | TerrainMapper-2 Pod | 92523 |
| GNSS/IMU | Litef LCI-100C 500 Hz | 1429 |
| LiDAR Unit | Hyperion2+ LiDAR Unit | 6638 |
| Nadir RGB Camera | | |
| Camera Head | CH150S-RGB | S150088 |
| Lens system | D69.70/4.0 71 mm | RE70023 |
| Nadir NIR Camera | | |
| Camera Head | CH150S-NIR | NS150044 |
| Lens system | D69.70/4.0-NIR 71 mm | N70062 |

2. Estimation Process

| | | Passed | Date | Inspector |
|--------------------------------|-----------|---------------|-------------|------------------------|
| Image Flight | completed | ok | 09.07.2021 | Deniz Arslan |
| Image Quality Check | checked | ok | 13.07.2021 | Fatih Kaya |
| Image Calibration | completed | ok | 20.07.2021 | Xu Wang / Ivan Belchev |
| Image Misalignment Update | completed | | | |
| LiDAR Flight | completed | ok | 09.07.2021 | Deniz Arslan |
| LiDAR Quality Check | checked | ok | 13.07.2021 | Rene Heierli |
| LiDAR Calibration and Accuracy | completed | ok | 13.07.2021 | Ivan Belchev |
| LiDAR Misalignment Update | completed | | | |

3. Inspectors

| | | | |
|-----------------|--------------------|------------|--|
| Name | Bernhard Riedl | 20.07.2021 |  |
| Position | Production Manager | | |
| Name | Xu Wang | 20.07.2021 |  |
| Position | Support Engineer | | |
| Name | Michael Vetter | 20.07.2021 |  |
| Position | Support Engineer | | |

4. Remarks

5. LiDAR Calibration Results

The calibration results for the LiDAR Unit are only valid for:

- IMU and Pod as listed in the System Components section

5.1 LiDAR Geometric Calibration Results

| IMU Misalignment | | Value | Unit |
|---------------------|-----------------|-----------|-------------------------|
| | ω | 0.008115 | degree |
| | Φ | 0.010577 | degree |
| | κ | 0.027989 | degree |
| Boresight | | Value | Unit |
| | Θ | 0.006101 | degree |
| | Φ | 0.002199 | degree |
| Receiver 1 | | Value | Unit |
| Range | Δ Offset | 0.000000 | meters |
| Wedge 0 | | Value | Unit |
| Wedge | Δ Alpha | 0.009505 | degree |
| Wedge Position | Δ Offset | 0.010496 | degree |
| Position Correction | X | -0.022505 | degree |
| | Y | 0.023536 | degree |
| Mount | Roll | 0.309882 | degree |
| | Pitch | 0.302227 | degree |
| Rotation Axis | Roll | 0.157381 | degree |
| | Pitch | 0.154673 | degree |
| Wedge 1 | | Value | Unit |
| Wedge | Δ Alpha | 0.017498 | degree |
| Wedge Position | Δ Offset | -0.049177 | degree |
| Position Correction | X | 0.013040 | degree |
| | Y | -0.006611 | degree |
| Mount | Roll | -0.010509 | degree |
| | Pitch | 0.011679 | degree |
| | Speed Pitch | 8.55E-07 | degree/rps ² |
| Rotation Axis | Roll | 0.034928 | degree |
| | Pitch | -0.017613 | degree |

LiDAR Geometric Calibration File

HYPERION_GEOMETRY_LIDARUNIT-6638-D-916900-DATETIME-20210713-124345.XML

| | | |
|--|------|------------|
| | Date | 13.07.2021 |
| LiDAR Misalignment Flight | Date | - |
| LiDAR Misalignment Update Completed | Date | - |

5.2 LiDAR Unit Accuracy Check

Accuracy checks:

- Deviation of two perpendicular lines to GCP's
- Difference of two perpendicular lines
- Difference of forward and backward scan of one line

5.2.1 Multi-line accuracy of two perpendicular lines to ground control points

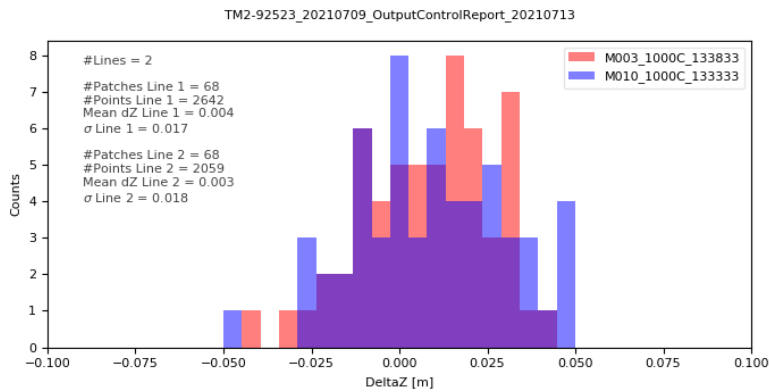


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

M010_1000C_133333

161947 valid patches with size of 2 m found. Only patches with standard deviation < 0.05 m and minimum of 5 points are included.

| Color | Limits [m] | Number of patches | Proportion of total number of patches [%] |
|--------------|------------|-------------------|---|
| Dark Green | <=0.04 | 161346 | 99.63 |
| Bright Green | 0.04-0.07 | 506 | 0.31 |
| Yellow | 0.07-0.1 | 67 | 0.04 |
| Red | >0.1 | 28 | 0.02 |

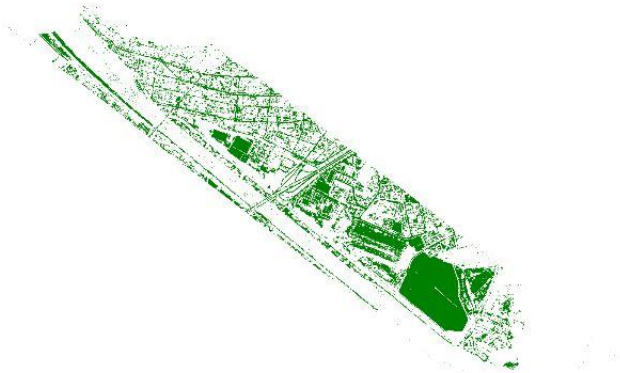


Figure 2 Vertical difference between forward and backward scan at 1000 m AGL.

5.2.3 Multi-line accuracy between two perpendicular lines

M003_1000C_133833_vs_M010_1000C_133333

43434 valid patches with size of 2 m found. Only patches with standard deviation < 0.05 m and minimum of 5 points are included.

| Color | Limits [m] | Number of patches | Proportion of total number of patches [%] |
|--------------|------------|-------------------|---|
| Dark Green | <=0.04 | 43250 | 99.58 |
| Bright Green | 0.04-0.07 | 163 | 0.38 |
| Yellow | 0.07-0.1 | 17 | 0.04 |
| Red | >0.1 | 4 | 0.01 |



Vertical difference

Figure 3 Vertical difference between two perpendicular lines at 1000 m AGL.

6. Imaging Sensors Estimation Results

The estimation results for the camera head and lens combination are only valid for:

- IMU and Pod as listed in the System Components section.
- Camera Head, lens and specified position as listed in the Estimation Results sections.

6.1 Camera Model of distortion free images

All factory calibration results contain fixed nominal focal lengths and zero principal point offsets. Leica HxMap applies the grid to create distortion-free images of nominal focal length and pixel size.

6.2 Results of Geometric Calibration

6.2.1 Calibration method for Green Reference Band

Estimation of additional parameters (focal length, principal point, radial symmetric distortion, correction grid) and IMU misalignment in simultaneous bundle adjustment

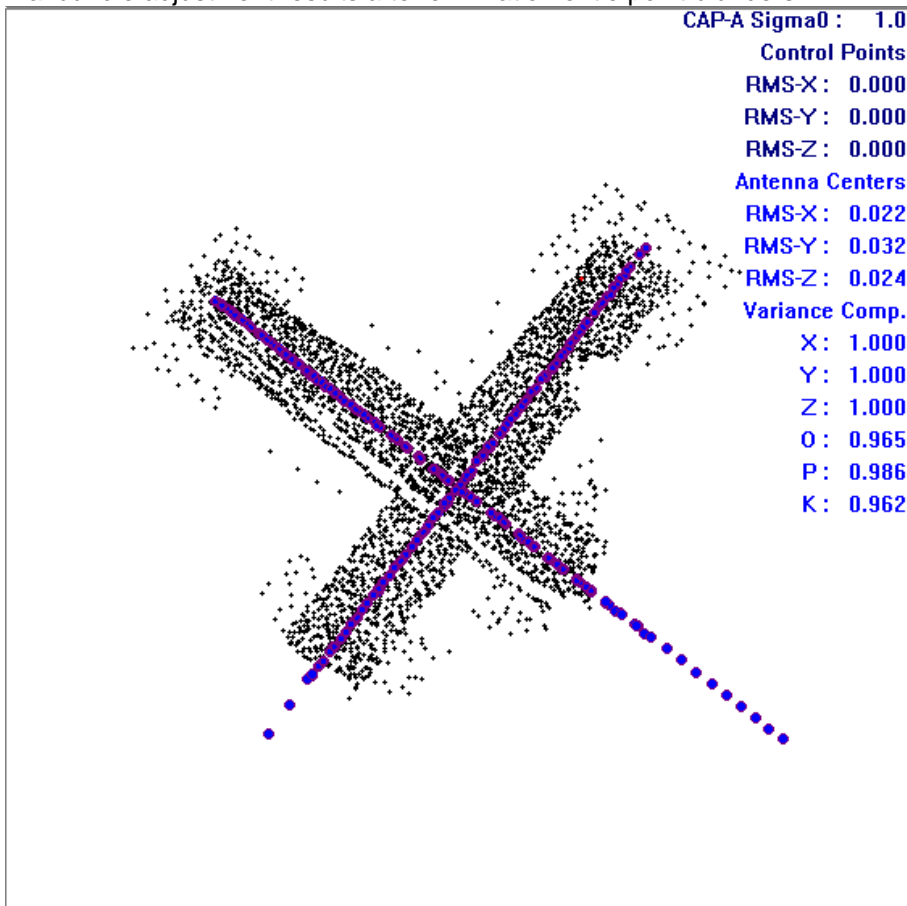
Reference band (green)

Distance [mm]

Resulting sigma naught of bundle adjustment:

0.0010

Final bundle adjustment results after elimination of tie point blunders:



6.2.2 Calibration method for NIR Band

Estimation of additional parameters (focal length, principal point, radial symmetric distortion, correction grid) and IMU misalignment in simultaneous bundle adjustment

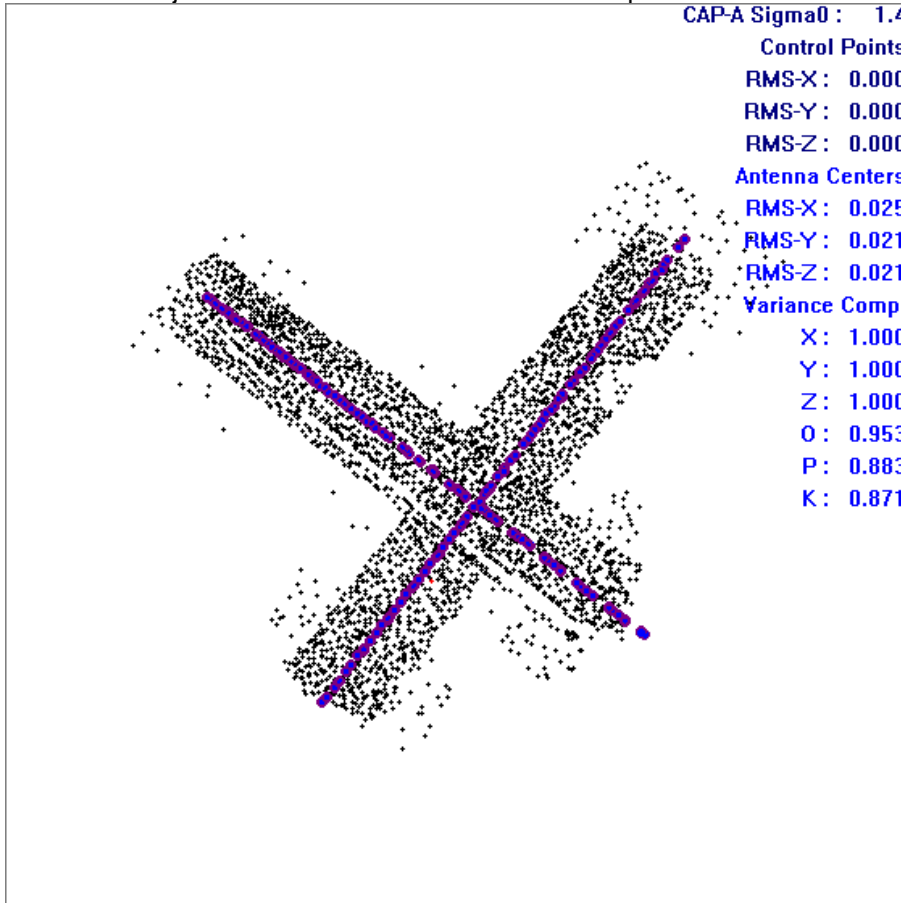
NIR band

Distance [mm]

Resulting sigma naught of bundle adjustment:

0.0014

Final bundle adjustment results after elimination of tie point blunders:



6.3 Estimation Results for Nadir RGB Camera

| | Component | Serial Number |
|-------------------------------------|--|----------------------|
| Camera Head | CH150S-RGB | S150088 |
| Lens system | D69.70/4.0 71 mm | RE70023 |
| View Direction | Nadir | |
| Radiometric Calibration Date | | 28.06.2021 |
| Geometric Calibration Date | | 16.07.2021 |
| Geometric Calibration File | MFC150_GEO_CH-S150088-A-891059_LENS-RE70023-A-949034_20210716-163200.xml | |

IMU Misalignment [degree]

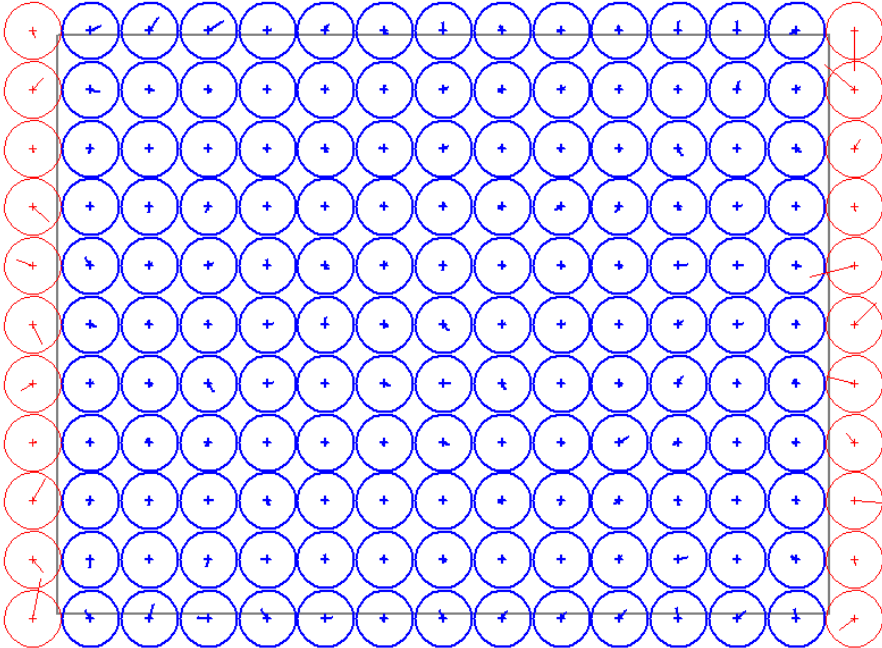
| | | | | |
|---|----------|---------------|---------------|---------------|
| | ω | | | 0.01945 |
| | Φ | | | -0.07882 |
| | κ | | | 0.01788 |
| | | Red | Green | Blue |
| Calibrated Focal Length [mm] | c | 69.908 | 69.908 | 69.908 |
| Principal Point [mm] | x | -0.00602 | -0.00602 | -0.00602 |
| | y | -0.01207 | -0.01207 | -0.01207 |
| Radial Symmetric Distorsion [mm] | a0 | -3.022692E-06 | -3.022692E-06 | -3.022692E-06 |
| | a1 | -7.069604E-09 | -7.069604E-09 | -7.069604E-09 |
| | a2 | 2.274631E-12 | 2.274631E-12 | 2.274631E-12 |

6.3.1 Specifications for output image

| | Value |
|---------------------------------------|--------------|
| Nominal Focal Length [mm] | 71.000 |
| Pixel size [mm] | 0.00376 |
| Rows [pixels] | 10640 |
| Columns [pixels] | 14192 |
| Nominal Principal Point x [mm] | 0.00000 |
| Nominal Principal Point y [mm] | 0.00000 |

6.3.2 Distorsion grid

RMS-X: 0.27
RMS-Y: 0.27



Radius of circles is 0.0010 mm

6.4 Estimation Results for Nadir NIR Camera

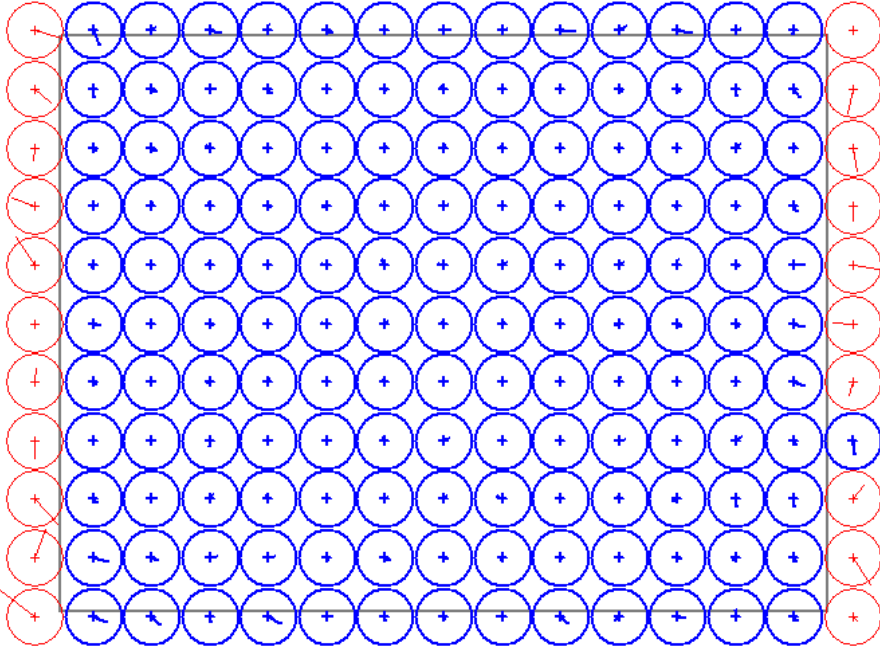
| | Component | Serial Number |
|---|--|----------------------|
| Camera Head | CH150S-NIR | NS150044 |
| Lens system | D69.70/4.0-NIR 71 mm | N70062 |
| View Direction | Nadir | |
| Radiometric Calibration Date | | 15.06.2021 |
| Geometric Calibration Date | | 20.07.2021 |
| Geometric Calibration File | MFC150_GEO_CH-NS150044-A-914609_LENS-N70062-D-918065_20210720-134020.xml | |
| IMU Misalignment [degree] | | |
| | ω | 0.08417 |
| | Φ | -0.04197 |
| | κ | 0.25919 |
| | | NIR |
| Calibrated Focal Length [mm] | c | 70.218 |
| Principal Point [mm] | x | 0.04172 |
| | y | -0.00612 |
| Radial Symmetric Distorsion [mm] | a_0 | -3.278004E-06 |
| | a_1 | -6.826067E-09 |
| | a_2 | 2.042780E-12 |

6.4.1 Specifications for output image

| | Value |
|---------------------------------------|--------------|
| Nominal Focal Length [mm] | 71.000 |
| Pixel size [mm] | 0.00376 |
| Rows [pixels] | 10640 |
| Columns [pixels] | 14192 |
| Nominal Principal Point x [mm] | 0.00000 |
| Nominal Principal Point y [mm] | 0.00000 |

6.4.2 Distorsion grid

RMS-X: 0.27
RMS-Y: 0.26



Radius of circles is 0.0010 mm