

- when it has to be **right**

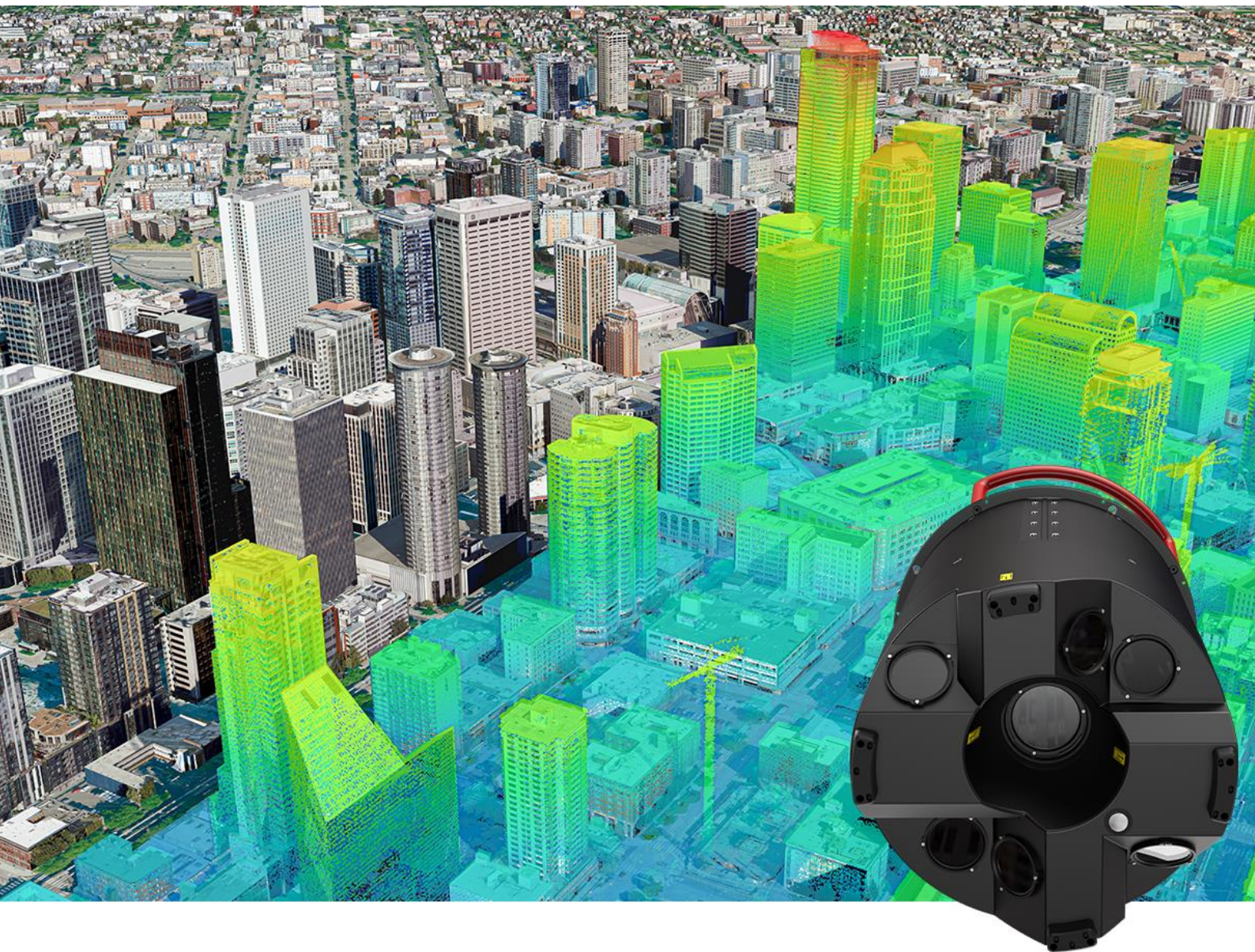


Leica Geosystems

Leica CityMapper-2

Calibration Certificate

| | |
|----------------------|--------------------|
| Product | Leica CityMapper-2 |
| Serial Number | 96774 |
| Date | 27 October 2023 |
| Inspector | Ivan Belchev |



1. System Components

| Components | Type | Serial Number |
|----------------------------|-----------------------|---------------|
| Pod | CityMapper-2 Pod | 96774 |
| GNSS/IMU | Litef LCI-100C 500 Hz | 1500-001 |
| LiDAR Unit | Hyperion2+ LiDAR Unit | 6512 |
| Nadir RGB Camera | | |
| Camera Head | CH150S-RGB | S150169 |
| Lens system | D69.70/4.0 71 mm | RE70042 |
| Nadir NIR Camera | | |
| Camera Head | CH150S-NIR | NS150092 |
| Lens system | D69.70/4.0-NIR 71 mm | N70094 |
| Forward RGB Camera | | |
| Camera Head | CH150S-RGB | S150174 |
| Lens system | D69.112/4.0 112 mm | 112112 |
| Backward RGB Camera | | |
| Camera Head | CH150S-RGB | S150170 |
| Lens system | D69.112/4.0 112 mm | 112108 |
| Left RGB Head | | |
| Camera Head | CH150L-RGB | L150096 |
| Lens system | D69.112/4.0 112 mm | 112099 |
| Right RGB Camera | | |
| Camera Head | CH150L-RGB | L150097 |
| Lens system | D69.112/4.0 112 mm | 112110 |

2. Estimation Process

| | | Passed | Date | Inspector |
|--------------------------------|-----------|--------|------------|------------------------|
| Image Flight | completed | ok | 24.02.2023 | Deniz Arslan |
| Image Quality Check | checked | ok | 27.02.2023 | Fatih Kaya |
| Image Calibration | completed | ok | 16.03.2023 | Ivan Belchev \ Xu Wang |
| Image Misalignment Update | completed | | | |
| LiDAR Flight | completed | ok | 09.06.2023 | Deniz Arslan |
| LiDAR Quality Check | checked | ok | 12.06.2023 | Rene Heierli |
| LiDAR Calibration and Accuracy | completed | ok | 16.06.2023 | Ivan Belchev |
| LiDAR Misalignment Update | completed | ok | 27.10.2023 | Ivan Belchev |

3. Inspectors

| | | | |
|-----------------|---------------------|------------|---|
| Name | Bernhard Riedl | 27.10.2023 |  |
| Position | Production Manager | | |
| Name | Xu Wang | 27.10.2023 |  |
| Position | Support Engineer | | |
| Name | Ivan Belchev | 27.10.2023 |  |
| Position | Workflow Specialist | | |

4. Remarks

LiDAR misalignment update based on a customer's calibration flight from 20230907

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 | 0.000387 | degree |
| | Φ | 0.078294 | degree |
| | κ | 0.065539 | degree |
| Boresight | | Value | Unit |
| | Θ | 0.010173 | degree |
| | Φ | -0.001081 | degree |
| Receiver 1 | | Value | Unit |
| Range | Δ Offset | 0.000000 | meters |
| Wedge 0 | | Value | Unit |
| Wedge | Δ Alpha | -0.044441 | degree |
| Wedge Position | Δ Offset | 0.296137 | degree |
| Position Correction | X | -0.015765 | degree |
| | Y | 0.006784 | degree |
| Mount | Roll | 0.186157 | degree |
| | Pitch | 0.457657 | degree |
| Rotation Axis | Roll | 0.151732 | degree |
| | Pitch | 0.078835 | degree |
| Wedge 1 | | Value | Unit |
| Wedge | Δ Alpha | 0.007098 | degree |
| Wedge Position | Δ Offset | 0.350935 | degree |
| Position Correction | X | 0.025284 | degree |
| | Y | -0.010150 | degree |
| Mount | Roll | -0.002189 | degree |
| | Pitch | 0.013165 | degree |
| Rotation Axis | Speed Pitch | 1.65E-06 | degree/rps ² |
| | Roll | 0.020492 | degree |
| | Pitch | -0.053490 | degree |

LiDAR Geometric Calibration File

HYPERION_GEOMETRY_LIDARUNIT-6512-F-916900-DATETIME-20231027-081612.XML

| | | |
|-------------------------------------|------|------------|
| | Date | 27.10.2023 |
| LiDAR Misalignment Flight | Date | 07.09.2023 |
| LiDAR Misalignment Update Completed | Date | 27.10.2023 |

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

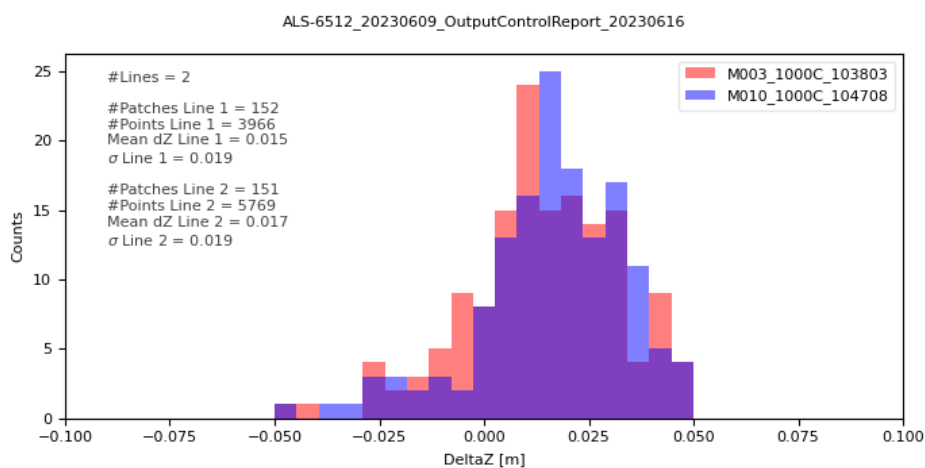


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

M010_1000C_104708

255222 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 | 250091 | 97.99 |
| Light Green | 0.04-0.07 | 4938 | 1.93 |
| Yellow | 0.07-0.1 | 179 | 0.07 |
| Red | > 0.1 | 14 | 0.01 |

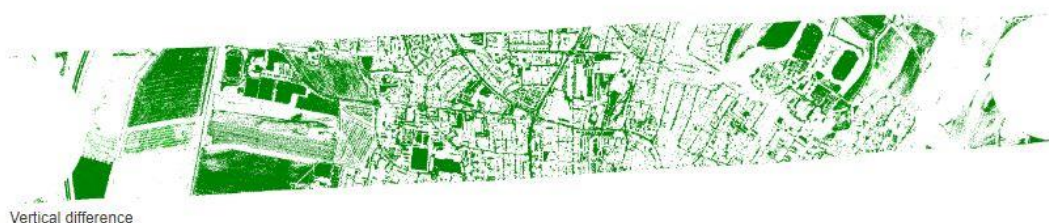


Figure 2 Vertical difference between forward and backward scan at 1000 m AGL.

5.2.3 Multi-line accuracy between two perpendicular lines

M003_1000C_103803_vs_M010_1000C_104708

40496 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 | 40298 | 99.51 |
| Light Green | 0.04-0.07 | 190 | 0.47 |
| Yellow | 0.07-0.1 | 3 | 0.01 |
| Red | >0.1 | 5 | 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)

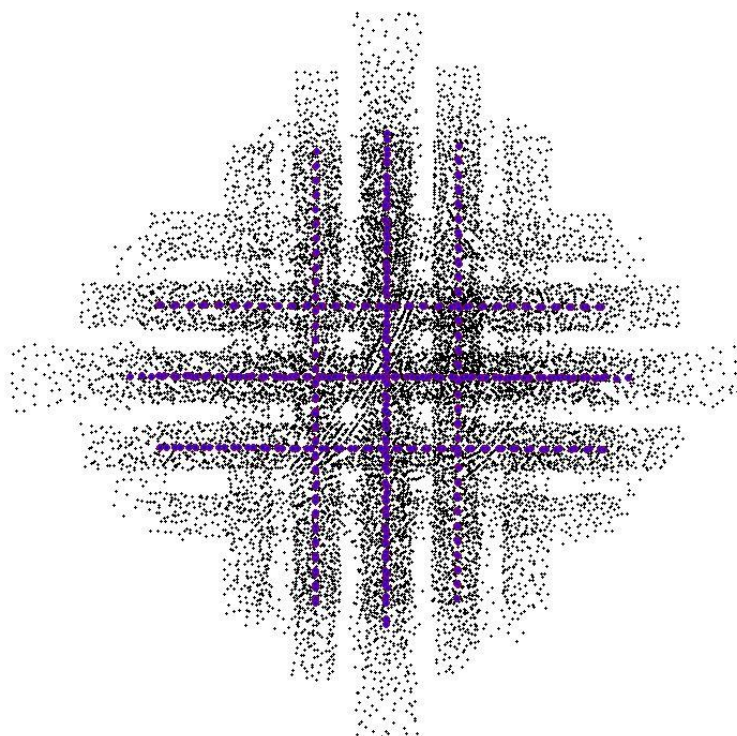
Distance [mm]

Resulting sigma naught of bundle adjustment:

0.0011

Final bundle adjustment results after elimination of tie point blunders:

CAP-A Sigma0 : 1.1
Control Points
RMS-X: 0.000
RMS-Y: 0.000
RMS-Z: 0.000
Antenna Centers
RMS-X: 0.018
RMS-Y: 0.020
RMS-Z: 0.023
Variance Comp.
X: 1.000
Y: 1.000
Z: 1.000
O: 0.945
P: 0.981
K: 0.951



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:

0.0011

Final bundle adjustment results after elimination of tie point blunders:

CAP-A Sigma0 : 1.1

Control Points

RMS-X : 0.000

RMS-Y : 0.000

RMS-Z : 0.000

Antenna Centers

RMS-X : 0.018

RMS-Y : 0.020

RMS-Z : 0.015

Variance Comp.

X : 1.000

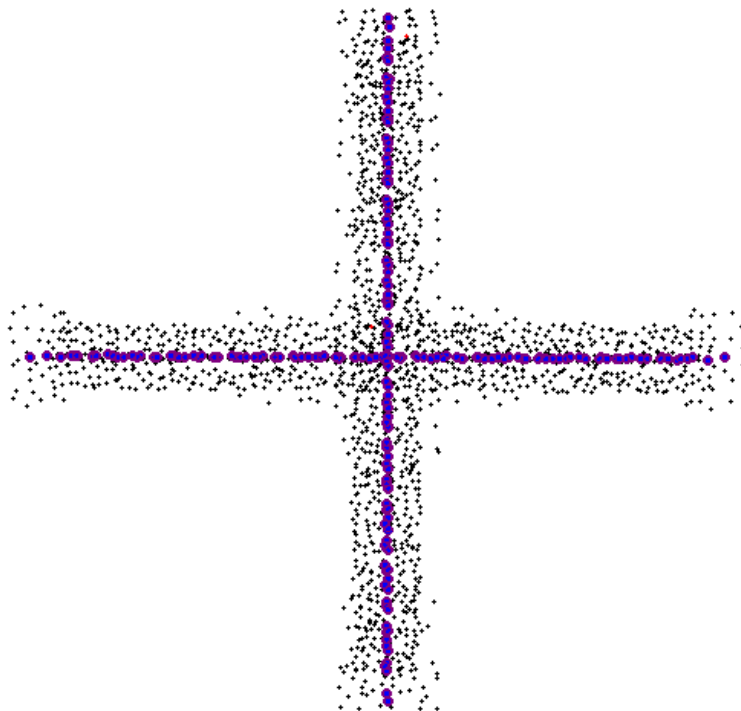
Y : 1.000

Z : 1.000

O : 0.976

P : 0.979

K : 1.000



6.3 Estimation Results for Nadir RGB Camera

| | Component | Serial Number |
|------------------------------|--|---------------|
| Camera Head | CH150S-RGB | S150169 |
| Lens system | D69.70/4.0 71 mm | RE70042 |
| View Direction | Nadir | |
| Radiometric Calibration Date | | 18.11.2022 |
| Geometric Calibration Date | | 16.03.2023 |
| Geometric Calibration File | MFC150_GEO_CH-S150169-C-891059_LENS-RE70042-C-949034_20230316-121010.xml | |

IMU Misalignment [degree]

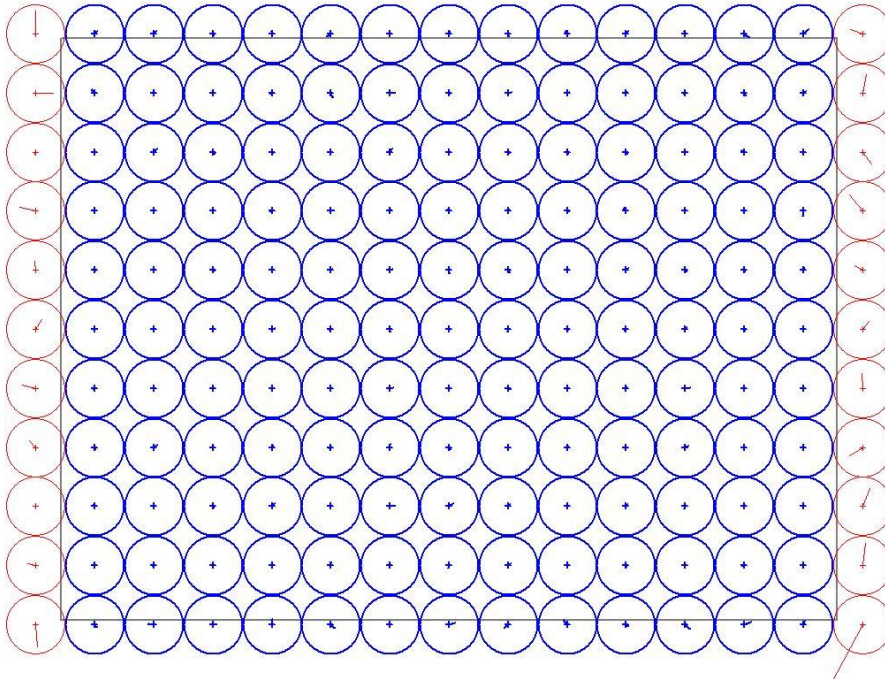
| | | | | |
|------------------------------|----------|---------------|---------------|---------------|
| | ω | -0.06529 | | |
| | ϕ | -0.06203 | | |
| | κ | -0.00128 | | |
| | | Red | Green | Blue |
| Calibrated Focal Length [mm] | c | 69.858 | 69.858 | 69.858 |
| Principal Point [mm] | x | 0.06564 | 0.06564 | 0.06564 |
| | y | -0.00964 | -0.00964 | -0.00964 |
| Radial Symmetric Distortion | a0 | -2.840759E-06 | -2.840759E-06 | -2.840759E-06 |
| | a1 | -7.404329E-09 | -7.404329E-09 | -7.404329E-09 |
| | a2 | 2.446907E-12 | 2.446907E-12 | 2.446907E-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 Distortion grid

RMS-X: 0.16
RMS-Y: 0.25



Radius of circles is 0.0010 mm

6.4 Estimation Results for Nadir NIR Camera

| | Component | Serial Number |
|------------------------------|----------------|--|
| Camera Head | CH150S-NIR | NS150092 |
| Lens system | D69.70/4.0-NIR | N70094 |
| | 71 mm | |
| View Direction | Nadir | |
| Radiometric Calibration Date | | 22.02.2023 |
| Geometric Calibration Date | | 03.10.2023 |
| Geometric Calibration File | | MFC150_GEO_CH-NS150092-C-914609_LENS-N70094-E-918065_20230310-165530.xml |

IMU Misalignment [degree]

| | |
|----------|----------|
| ω | 0.09294 |
| Φ | -0.07358 |
| κ | -0.11578 |

NIR

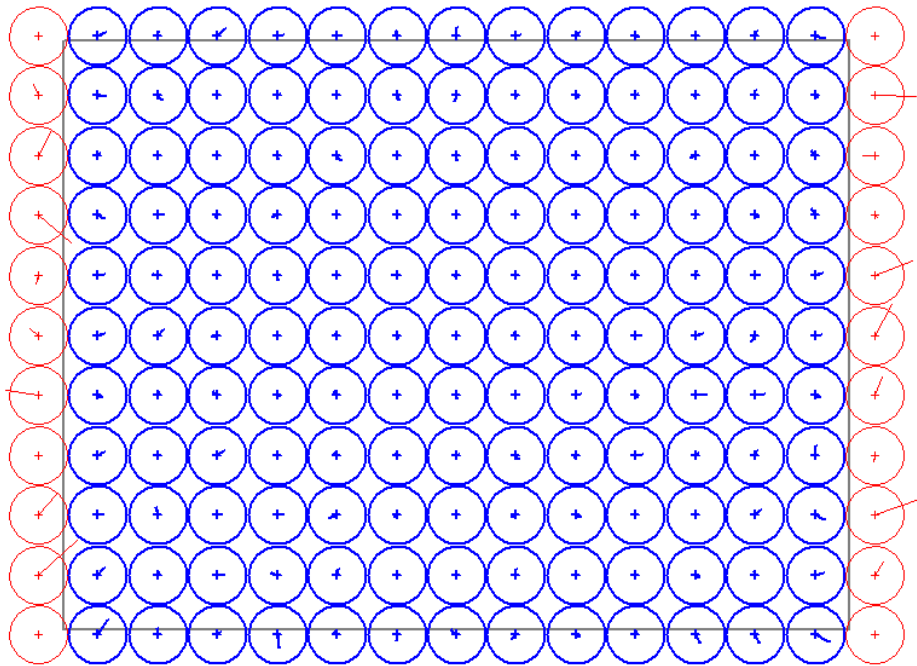
| | | |
|------------------------------|----|---------------|
| Calibrated Focal Length [mm] | c | 70.098 |
| Principal Point [mm] | x | 0.08045 |
| | y | -0.03515 |
| Radial Symmetric Distortion | a0 | -2.650262E-06 |
| | a1 | -7.538142E-09 |
| | a2 | 2.315359E-12 |

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 Distortion grid

RMS-X: 0.32
RMS-Y: 0.24



Radius of circles is 0.0010 mm

6.5 Estimation Results for Forward Camera

| | Component | Serial Number |
|------------------------------|---|---------------|
| Camera Head | CH150S-RGB | S150174 |
| Lens system | D69.112/4.0 112 mm | 112112 |
| View Direction | Forward | |
| Radiometric Calibration Date | | 01.04.2023 |
| Geometric Calibration Date | | 16.03.2023 |
| Geometric Calibration File | MFC150_GEO_CH-S150174-C-891059_LENS-112112-D-918062_20230316-121043.xml | |

IMU Misalignment [degree]

| | |
|----------|----------|
| ω | 0.15688 |
| ϕ | -0.10092 |
| κ | -0.04647 |

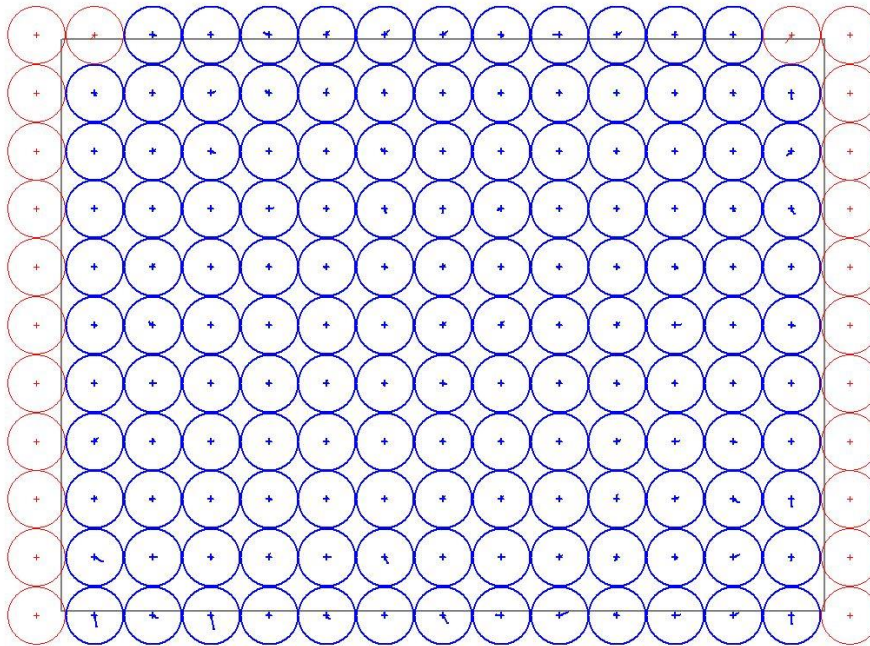
| | | Red | Green | Blue |
|------------------------------|----|---------------|---------------|---------------|
| Calibrated Focal Length [mm] | c | 108.554 | 108.554 | 108.554 |
| Principal Point [mm] | x | -0.05834 | -0.05834 | -0.05834 |
| | y | 0.02286 | 0.02286 | 0.02286 |
| Radial Symmetric Distortion | a0 | 2.522779E-05 | 2.522779E-05 | 2.522779E-05 |
| | a1 | 2.262578E-10 | 2.262578E-10 | 2.262578E-10 |
| | a2 | -8.433287E-14 | -8.433287E-14 | -8.433287E-14 |

6.5.1 Specifications for output image

| | Value |
|--------------------------------|---------|
| Nominal Focal Length [mm] | 112.000 |
| 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 |

6.5.2 Distortion grid

RMS-X: 0.09
RMS-Y: 0.10



Radius of circles is 0.0010 mm

6.6 Estimation Results for Backward Camera

| | Component | Serial Number |
|------------------------------|---|---------------|
| Camera Head | CH150S-RGB | S150170 |
| Lens system | D69.112/4.0 112 mm | 112108 |
| View Direction | Backward | |
| Radiometric Calibration Date | | 23.11.2022 |
| Geometric Calibration Date | | 16.03.2023 |
| Geometric Calibration File | MFC150_GEO_CH-S150170-C-891059_LENS-112108-D-918062_20230316-121018.xml | |

IMU Misalignment [degree]

| | |
|----------|----------|
| ω | -0.17262 |
| ϕ | 0.07116 |
| κ | -0.19846 |

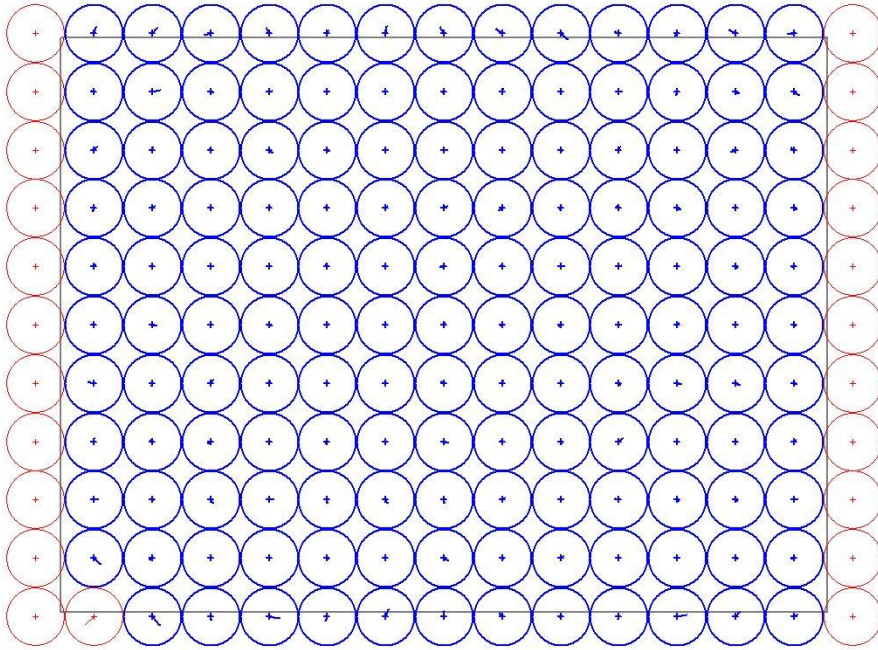
| | | Red | Green | Blue |
|------------------------------|----|--------------|--------------|--------------|
| Calibrated Focal Length [mm] | c | 108.273 | 108.273 | 108.273 |
| Principal Point [mm] | x | -0.05303 | -0.05303 | -0.05303 |
| | y | 0.02076 | 0.02076 | 0.02076 |
| Radial Symmetric Distortion | a0 | 2.509003E-05 | 2.509003E-05 | 2.509003E-05 |
| | a1 | 8.449100E-11 | 8.449100E-11 | 8.449100E-11 |
| | a2 | 8.448247E-14 | 8.448247E-14 | 8.448247E-14 |

6.6.1 Specifications for output image

| | Value |
|--------------------------------|---------|
| Nominal Focal Length [mm] | 112.000 |
| 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 |

6.6.2 Distortion grid

RMS-X: 0.10
RMS-Y: 0.09



Radius of circles is 0.0010 mm

6.7 Estimation Results for Left Camera

| | Component | Serial Number |
|------------------------------|---|---------------|
| Camera Head | CH150L-RGB | L150096 |
| Lens system | D69.112/4.0 112 mm | 112099 |
| View Direction | Left | |
| Radiometric Calibration Date | | 12.09.2022 |
| Geometric Calibration Date | | 16.03.2023 |
| Geometric Calibration File | MFC150_GEO_CH-L150096-C-914608_LENS-112099-D-918062_20230316-120945.xml | |

IMU Misalignment [degree]

| | |
|----------|----------|
| ω | -0.06139 |
| ϕ | 0.18683 |
| κ | -0.07684 |

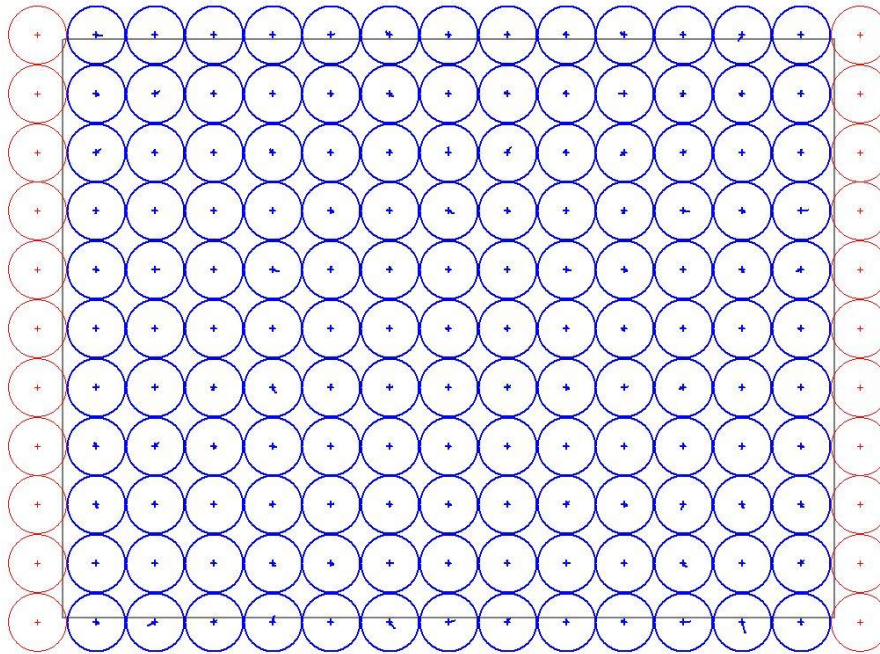
| | | Red | Green | Blue |
|------------------------------|----|---------------|---------------|---------------|
| Calibrated Focal Length [mm] | c | 108.308 | 108.308 | 108.308 |
| Principal Point [mm] | x | -0.03315 | -0.03315 | -0.03315 |
| | y | 0.02385 | 0.02385 | 0.02385 |
| Radial Symmetric Distortion | a0 | 2.495084E-05 | 2.495084E-05 | 2.495084E-05 |
| | a1 | 2.098834E-10 | 2.098834E-10 | 2.098834E-10 |
| | a2 | -6.334149E-14 | -6.334149E-14 | -6.334149E-14 |

6.7.1 Specifications for output image

| | Value |
|--------------------------------|---------|
| Nominal Focal Length [mm] | 112.000 |
| 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 |

6.7.2 Distortion grid

RMS-X: 0.09
RMS-Y: 0.08



Radius of circles is 0.0010 mm

6.8 Estimation Results for Right Camera

| | Component | Serial Number |
|------------------------------|---|---------------|
| Camera Head | CH150L-RGB | L150097 |
| Lens system | D69.112/4.0 112 mm | 112110 |
| View Direction | Right | |
| Radiometric Calibration Date | | 12.09.2022 |
| Geometric Calibration Date | | 16.03.2023 |
| Geometric Calibration File | MFC150_GEO_CH-L150097-C-914608_LENS-112110-D-918062_20230316-120959.xml | |

IMU Misalignment [degree]

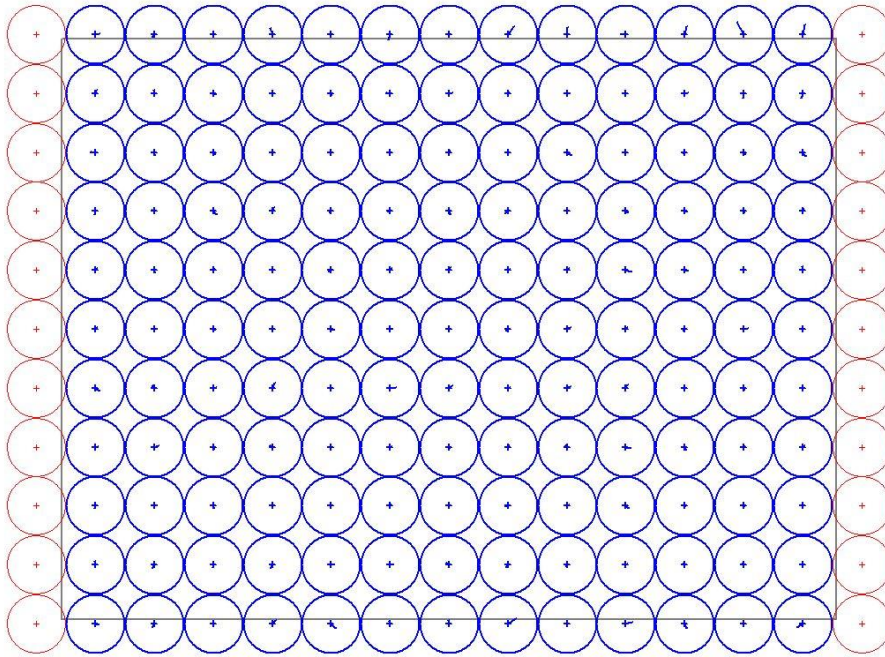
| | | | | |
|------------------------------|----------|---------------|---------------|---------------|
| | ω | -0.51527 | | |
| | Φ | 0.01510 | | |
| | κ | -0.03782 | | |
| | | Red | Green | Blue |
| Calibrated Focal Length [mm] | c | 108.143 | 108.143 | 108.143 |
| Principal Point [mm] | x | -0.01507 | -0.01507 | -0.01507 |
| | y | -0.01603 | -0.01603 | -0.01603 |
| Radial Symmetric Distortion | a0 | 2.499715E-05 | 2.499715E-05 | 2.499715E-05 |
| | a1 | 1.726925E-10 | 1.726925E-10 | 1.726925E-10 |
| | a2 | -1.723494E-14 | -1.723494E-14 | -1.723494E-14 |

6.8.1 Specifications for output image

| | Value |
|--------------------------------|---------|
| Nominal Focal Length [mm] | 112.000 |
| 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 |

6.8.2 Distortion grid

RMS-X: 0.08
RMS-Y: 0.09



Radius of circles is 0.0010 mm