

Leica Geosystems Leica CityMapper Calibration Certificate

Product	Leica CityMapper
Serial Number	95538
Date	11 November 2020
Inspector	Roberto Clerigo



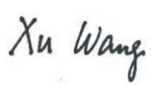
1. System Components

Component	Type	Serial Number
Pod	CityMapper Pod	95538
GNSS/IMU	Litef LCI-100C 500 Hz	1153
LiDAR Unit	Hyperion II	5537
Camera Head	CH82	82612
Lens	NAT-D 2.8/80	80220
Camera Head	CH81m	81828
Lens	SAT-D 4.0/150	150236
Camera Head	CH81m	81829
Lens	SAT-D 4.0/150	150237
Camera Head	CH81m	81830
Lens	SAT-D 4.0/150	150238
Camera Head	CH81m	81831
Lens	SAT-D 4.0/150	150239

2. Estimation Process

		Passed	Date	Inspector
Image Flight	completed	ok	01.05.2019	Kevin Bless
Image Quality Check	checked	ok	03.05.2019	Rene Heierli
Image Calibration	completed	ok	05.05.2019	Muzaffer Adigüzel
Image Misalignment Update	completed			
LiDAR Flight	completed	ok	01.05.2019	Kevin Bless
LiDAR Quality Check	checked	ok	03.05.2019	Philip Kurt Benz
LiDAR Calibration and Accuracy	completed	ok	07.05.2019	Xu Wang
LiDAR Misalignment Update	completed	ok	11.11.2020	Roberto Clerigo

3. Inspectors

Name	Bernhard Riedl	11.11.2020	
Position	Production Manager		
Name	Xu Wang	11.11.2020	
Position	Support Engineer		
Name	Michael Vetter	11.11.2020	
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	-0.015653	degree
	Φ	0.001272	degree
	κ	-0.019151	degree
Boresight		Value	Unit
	Θ	-0.000871	degree
	Φ	-0.002450	degree
Receiver 1		Value	Unit
Range	Δ Offset	0.000000	meters
Wedge 0		Value	Unit
Wedge	Δ Alpha	0.028332	degree
Wedge Position	Δ Offset	0.140803	degree
Position Correction	X	-0.020381	degree
	Y	0.006169	degree
Mount	Roll	0.248296	degree
	Pitch	0.576408	degree
Rotation Axis	Roll	0.077505	degree
	Pitch	0.243510	degree
Wedge 1		Value	Unit
Wedge	Δ Alpha	-0.022392	degree
Wedge Position	Δ Offset	0.292223	degree
Position Correction	X	0.014140	degree
	Y	0.008778	degree
Mount	Roll	-0.024847	degree
	Pitch	-0.036991	degree
Rotation Axis	Speed Pitch	1.50E-06	degree/rps ²
	Roll	-0.020874	degree
	Pitch	-0.017270	degree
LiDAR Geometric Calibration File			
HYPERION_GEOMETRY_LIDARUNIT-5537-C-855570-DATETIME-20201111-030118.XML			
	Date	11.11.2020	
LiDAR Misalignment Flight	Date	30.10.2020	
LiDAR Misalignment Update Completed	Date	11.11.2020	

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

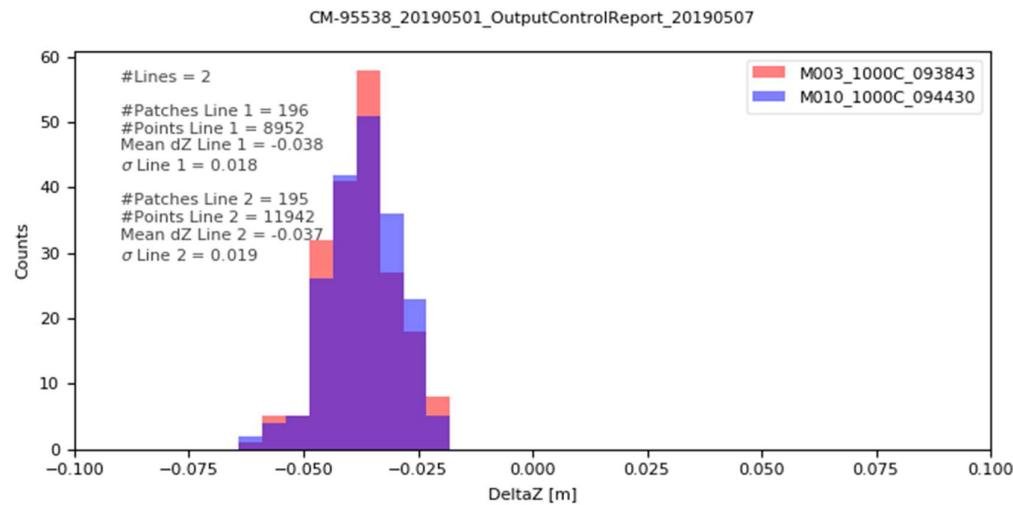


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

M010_1000C_094430

344190 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	343418	99.78
Light Green	0.04-0.07	722	0.21
Yellow	0.07-0.1	45	0.01
Red	>0.1	5	0.00



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_093843_vs_M010_1000C_094430

44531 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	44482	99.89
Light Green	0.04-0.07	40	0.09
Yellow	0.07-0.1	5	0.01
Red	>0.1	4	0.01



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.

6.1.1 CH8x Model

		Component	
Camera Head		CH82	
Lens		NAT-D 2.8/80	
Camera Model			
Focal Length		Distance [mm]	
	c	83.00	
Radial Symmetric Distorsion		Distance [mm]	
	k ₀	0.0000	
	k ₁	0.0000	
	k ₂	0.0000	
Decentering Distortion		Distance [mm]	
	p ₁	0.0000	
	p ₂	0.0000	
Non-Orthogonality Distortion		Distance [mm]	
	b ₁	0.0000	
	b ₂	0.0000	
Pixel Size (Height and Width)		Distance [mm]	
	RGB	0.0052	
	NIR	0.0120	
Rows and Columns		Rows	Columns
	Active RGB	7752	10320
	Raw RGB	7788	10336
	Active NIR	3654	4478
	Raw NIR	3366	4500

6.1.2 CH81m Model

		Component	
Camera Head		CH81m	
Lens		SAT-D 4.0/150	
Camera Model			
Focal Length		Distance [mm]	
	c	156.00	
Radial Symmetric Distorsion		Distance [mm]	
	k ₀	0.0000	
	k ₁	0.0000	
	k ₂	0.0000	
Decentering Distortion		Distance [mm]	
	p ₁	0.0000	
	p ₂	0.0000	
Non-Orthogonality Distortion		Distance [mm]	
	b ₁	0.0000	
	b ₂	0.0000	
Pixel Size (Height and Width)		Distance [mm]	
	RGB	0.0052	
Rows and Columns		Rows	Columns
	Active RGB	7752	10320
	Raw RGB	7788	10336

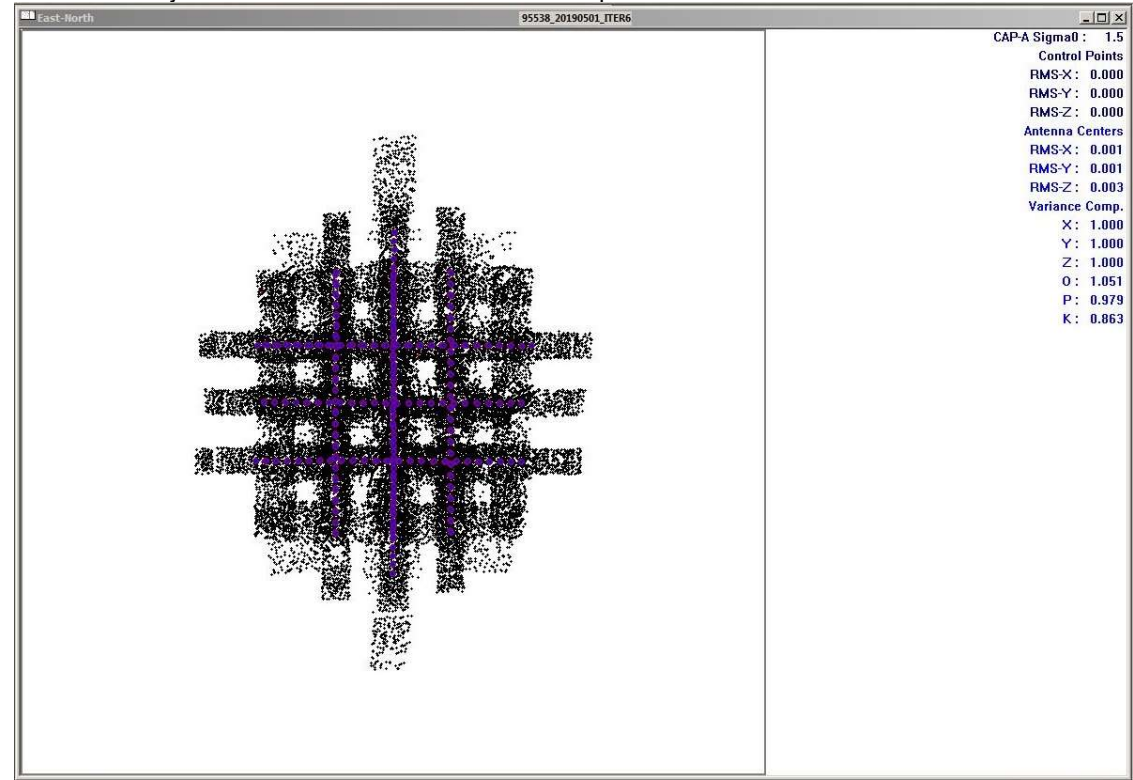
6.2 Results of Geometric Calibration

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:	0.0015

Final bundle adjustment results after elimination of tie point blunders:



6.2.2 Calibration method for Other Spectral Bands

Estimation of additional parameters (correction grid), based on the result for green in simultaneous bundle adjustment

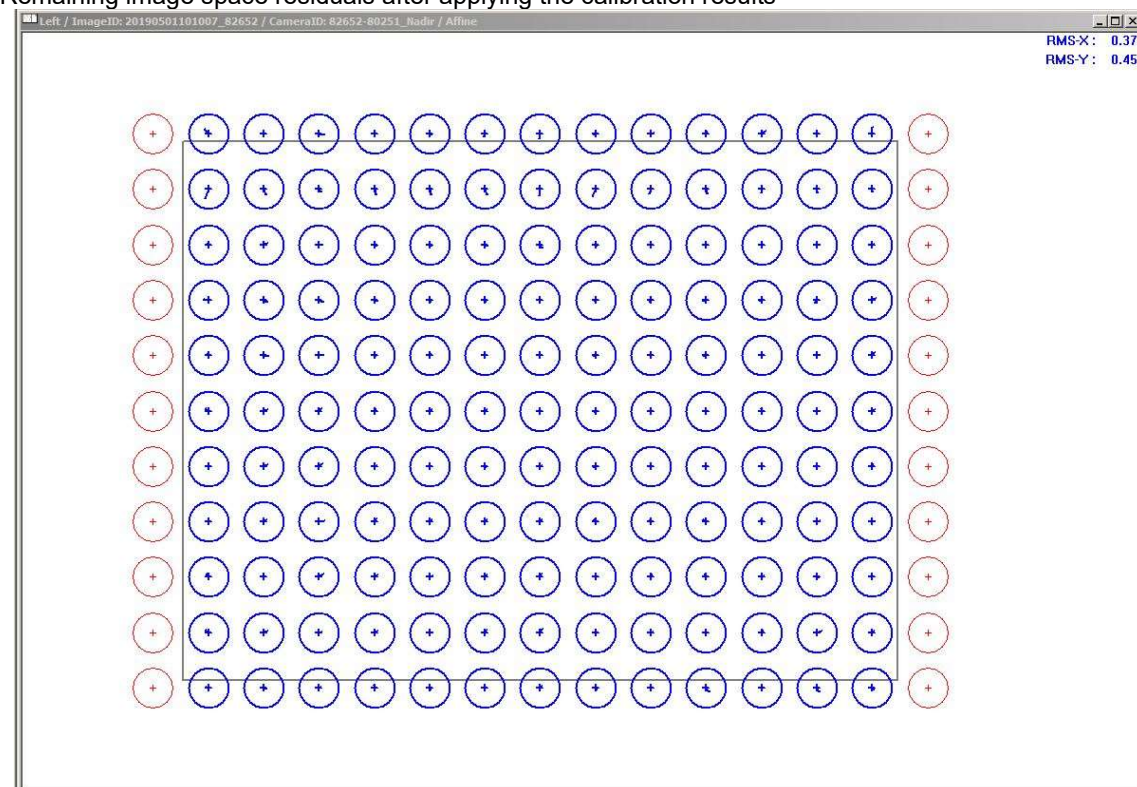
Other Spectral Bands	Distance [mm]
Co-registration to green better than:	0.002

Leica HxMap applies the grid to create distortion-free images of nominal focal length and fixed pixel size of 0.0052 mm.

6.3 Estimation Results for Nadir Camera Head and Lens

	Component	Serial Number
Camera Head	CH82	82612
Lens	NAT-D 2.8/80	80220
View Direction in Pod Position	Nadir	
IMU Misalignment	Angle [degree]	
	ω	0.096155
	ϕ	-0.012830
	κ	-0.311447
Principal Point	Distance [mm]	
	x	0.0000
	y	0.0000
Focal Length	Distance [mm]	
	c	83.00
Geometric Calibration File		
RCD30_GEOMETRY_CAMERAHEAD-82612-E-798528_LENSSYSTEM-80220-B-785423_DATETIME-20201111-190019.xml		
Geometric Calibration	Date	04.05.2019
Radiometric Calibration	Date	26.03.2019
Misalignment Flight	Date	30.10.2020
Misalignment Update Completed	Date	11.11.2020

Remaining image space residuals after applying the calibration results

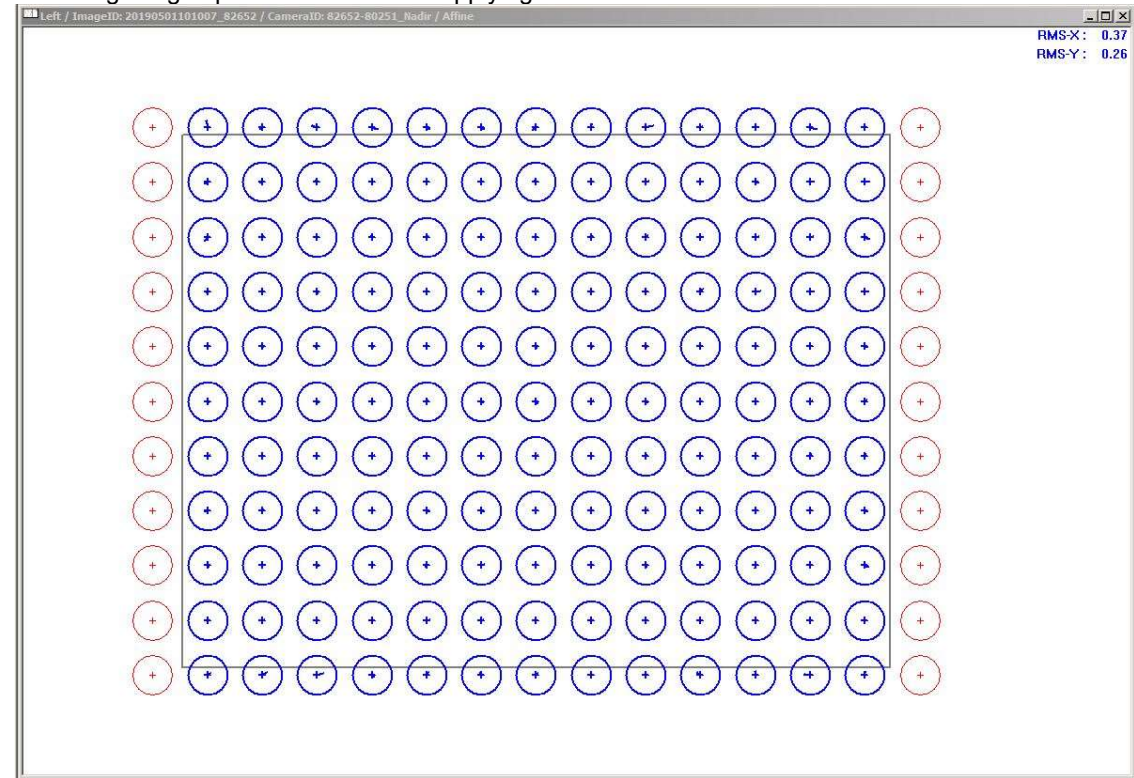


Radius of circles is 0.0015 mm

6.4 Estimation Results for Forward Camera Head and Lens

		Component	Serial Number
Camera Head		CH81m	81828
Lens		SAT-D 4.0/150	150236
View Direction in Pod Position		Forward	
IMU Misalignment		Angle [degree]	
	ω	-0.15056	
	Φ	0.08262	
	κ	-0.07931	
Principal Point		Distance [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		Distance [mm]	
		156.00	
Geometric Calibration File			
RCD30_Geometry_CameraHead-81828-D-842157_LensSystem-150236-B-819435_DateTime-20190505-215558.xml			
Geometric Calibration	Date	05.05.2019	
Radiometric Calibration	Date	28.03.2019	
Misalignment Flight	Date	-	
Misalignment Update Completed	Date	-	

Remaining image space residuals after applying the calibration results

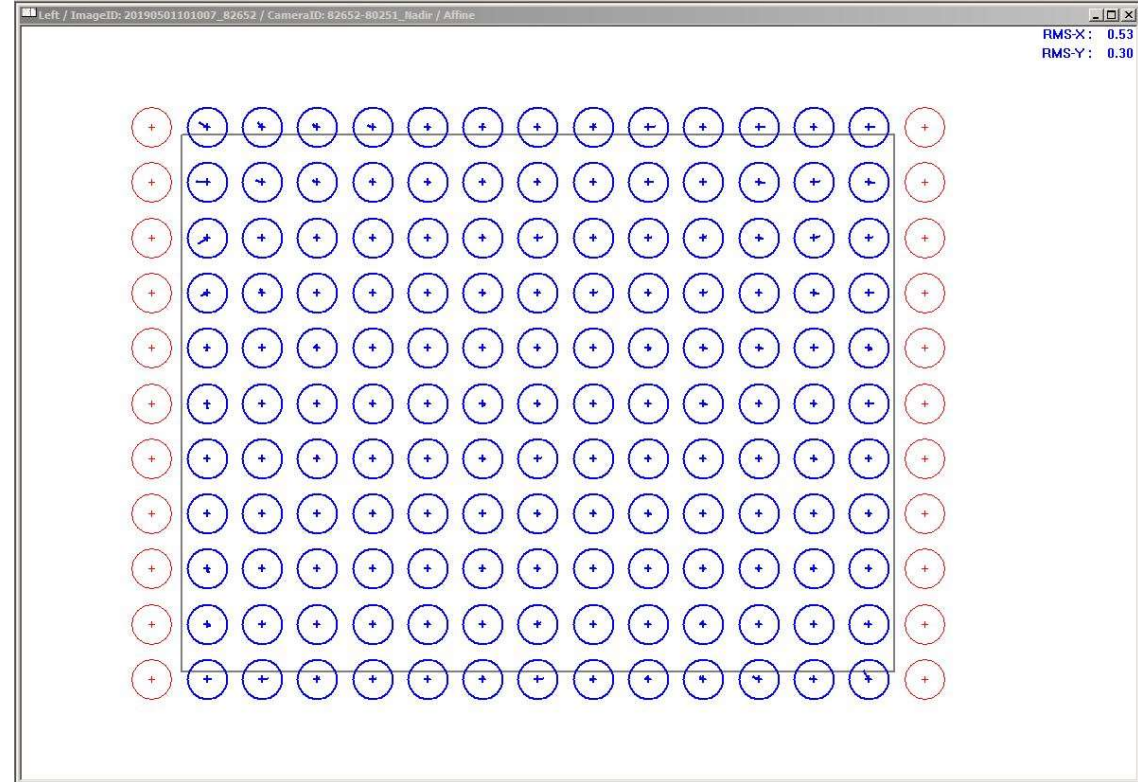


Radius of circles is 0.0015 mm

6.5 Estimation Results for Backward Camera Head and Lens

	Component	Serial Number
Camera Head	CH81m	81829
Lens	SAT-D 4.0/150	150237
View Direction in Pod Position	Backward	
IMU Misalignment	Angle [degree]	
	ω	0.05575
	ϕ	0.04064
	κ	-0.07323
Principal Point	Distance [mm]	
	x	0.0000
	y	0.0000
Focal Length	Distance [mm]	
		156.00
Geometric Calibration File		
RCD30_Geometry_CameraHead-81829-D-842157_LensSystem-150237-B-819435_DateTime-20190505-215628.xml		
Geometric Calibration	Date	05.05.2019
Radiometric Calibration	Date	29.03.2019
Misalignment Flight	Date	-
Misalignment Update Completed	Date	-

Remaining image space residuals after applying the calibration results

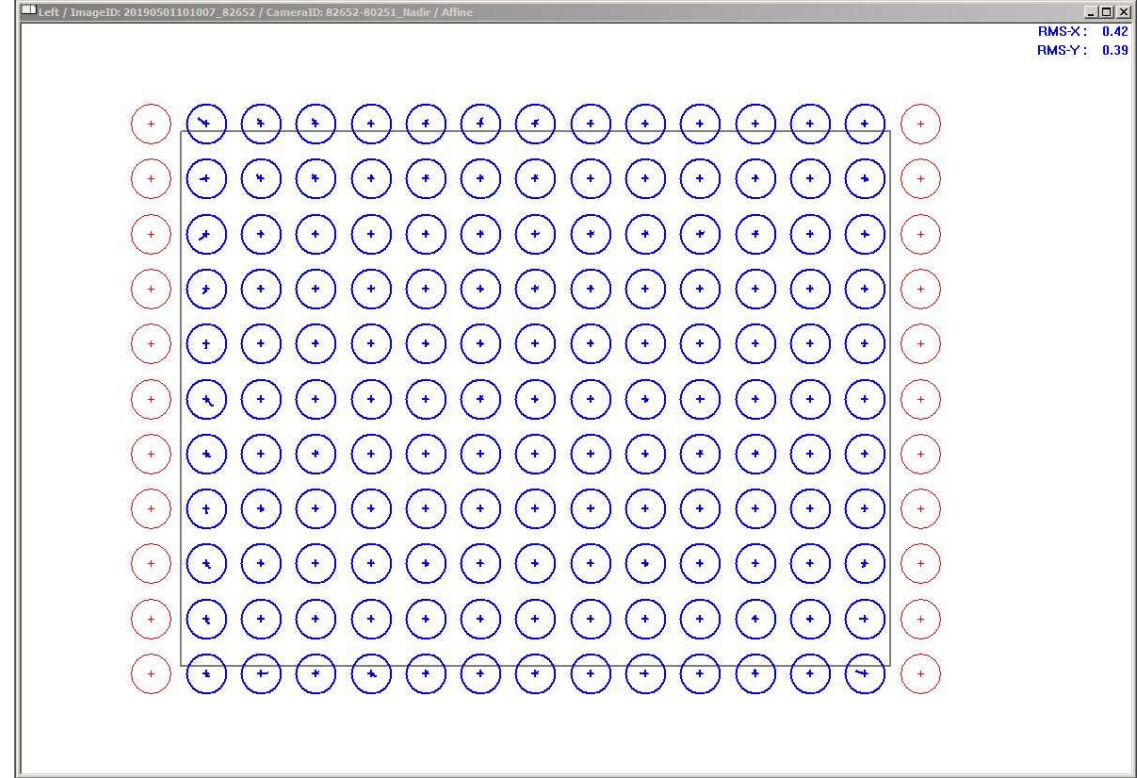


Radius of circles is 0.0015 mm

6.6 Estimation Results for Left Camera Head and Lens

		Component	Serial Number
Camera Head		CH81m	81830
Lens		SAT-D 4.0/150	150238
View Direction in Pod Position		Left	
IMU Misalignment		Angle [degree]	
	ω	-0.10267	
	Φ	0.01911	
	K	-0.08819	
Principal Point		Distance [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		Distance [mm]	
		156.00	
Geometric Calibration File			
RCD30_Geometry_CameraHead-81830-D-842157_LensSystem-150238-B-819435_DateTime-20190505-215703.xml			
Geometric Calibration	Date	05.05.2019	
Radiometric Calibration	Date	01.04.2019	
Misalignment Flight	Date	-	
Misalignment Update Completed	Date	-	

Remaining image space residuals after applying the calibration results

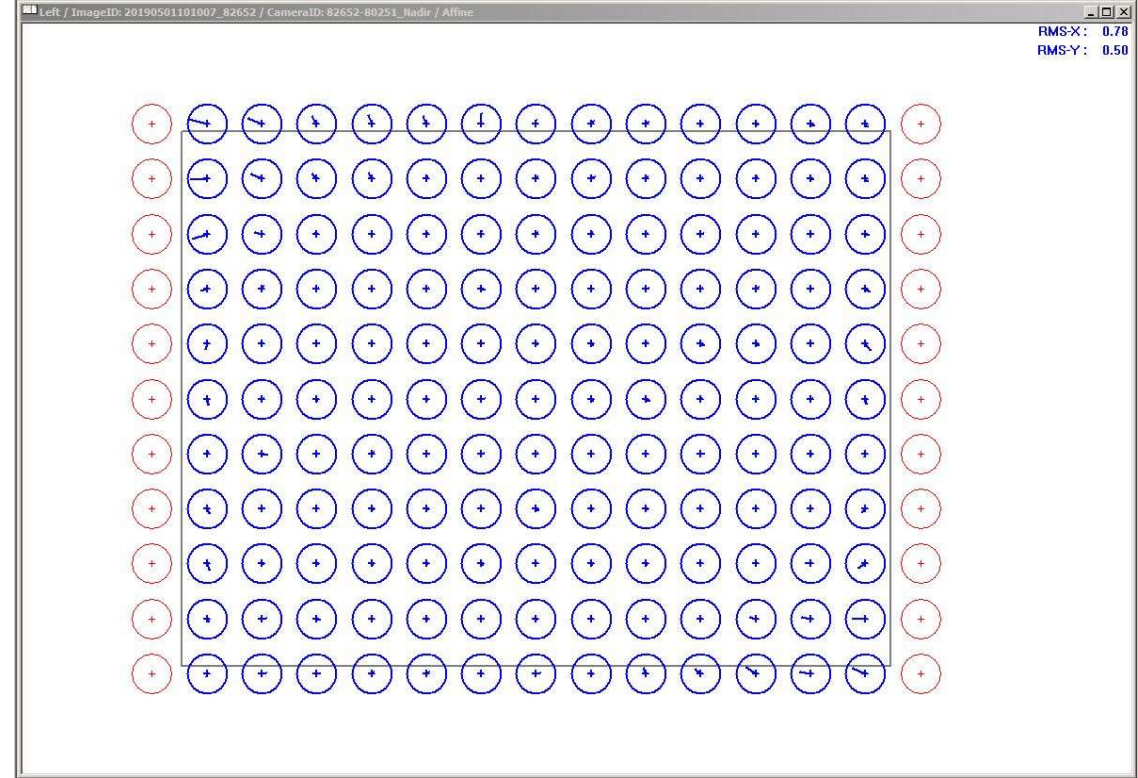


Radius of circles is 0.0015 mm

6.7 Estimation Results for Right Camera Head and Lens

		Component	Serial Number
Camera Head		CH81m	81831
Lens		SAT-D 4.0/150	150239
View Direction in Pod Position		Right	
IMU Misalignment		Angle [degree]	
	ω	0.13175	
	ϕ	-0.01092	
	κ	-0.17540	
Principal Point		Distance [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		Distance [mm]	
		156.00	
Geometric Calibration File			
RCD30_Geometry_CameraHead-81831-D-842157_LensSystem-150239-B-819435_DateTime-20190505-215716.xml			
Geometric Calibration Date	Date	05.05.2019	
Radiometric Calibration Date	Date	01.04.2019	
Misalignment Flight	Date	-	
Misalignment Update Completed	Date	-	

Remaining image space residuals after applying the calibration results



Radius of circles is 0.0015 mm