- when it has to be right

Leica Geosystems
Leica CityMapper
Calibration Certificate

Product	Leica CityMapper
Serial Number	95523
Date	30 June 2021
Inspector	Xu Wang

Leica Geosystems AG
Heinrich-Wild-Strasse
CH-9435 Heerbrugg
Schweiz
www.leica-geosystems.com

Document Code: 855923

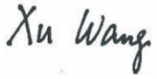
1. System Components

Component	Type	Serial Number
Pod	CityMapper Pod	95523
GNSS/IMU	Litef LCI-100C 500 Hz	1248
LiDAR Unit	Hyperion2+ LiDAR Unit	6525
Camera Head	CH82	82638
Lens	NAT-D 2.8/80	80241
Camera Head	CH81m	81796
Lens	SAT-D 4.0/150	150204
Camera Head	CH81m	81797
Lens	SAT-D 4.0/150	150205
Camera Head	CH81m	81798
Lens	SAT-D 4.0/150	150206
Camera Head	CH81m	81838
Lens	SAT-D 4.0/150	150246

2. Estimation Process

		Passed	Date	Inspector
Image Flight	completed	ok	26.06.2021	Philip Benz Kurt
Image Quality Check	checked	ok	30.06.2021	Fatih Kaya
Image Calibration	completed	ok	30.06.2021	Xu Wang
Image Misalingment Update	completed			
LiDAR Flight	completed	ok	18.06.2021	Philip Benz Kurt
LiDAR Quality Check	checked	ok	22.06.2021	Rene Heierli
LiDAR Calibration and Accuracy	completed	ok	22.06.2021	Ivan Belchev
LiDAR Misalingment Update	completed			

3. Inspectors

Name	Bernhard Riedl	30.06.2021	
Position	Production Manager		
Name	Xu Wang	30.06.2021	
Position	Support Engineer		
Name	Michael Vetter	30.06.2021	
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	-0.037726	degree
	Φ	-0.022427	degree
	κ	-0.056967	degree
Boresight		**Value**	**Unit**
	Θ	0.005814	degree
	Φ	0.007781	degree
Receiver 1		**Value**	**Unit**
Range	Δ Offset	0.000000	meters
Wedge 0		**Value**	**Unit**
Wedge	Δ Alpha	0.034359	degree
Wedge Position	Δ Offset	0.455143	degree
Position Correction	X	-0.073692	degree
	Y	0.049961	degree
Mount	Roll	0.491251	degree
	Pitch	0.818338	degree
Rotation Axis	Roll	0.509018	degree
	Pitch	0.812147	degree
Wedge 1		**Value**	**Unit**
Wedge	Δ Alpha	-0.020102	degree
Wedge Position	Δ Offset	0.406624	degree
Position Correction	X	0.042391	degree
	Y	-0.005671	degree
Mount	Roll	0.161821	degree
	Pitch	0.003689	degree
	Speed Pitch	1.50E-06	degree/rps^2
Rotation Axis	Roll	0.029669	degree
	Pitch	0.014039	degree

LiDAR Geometric Calibration File

HYPERION_GEOMETRY_LIDARUNIT-6525-D-916900-DATETIME-20210622-084015.XML

	Date	22.06.2021
LiDAR Misalingment Flight	Date	**-**
LiDAR Misalingment 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

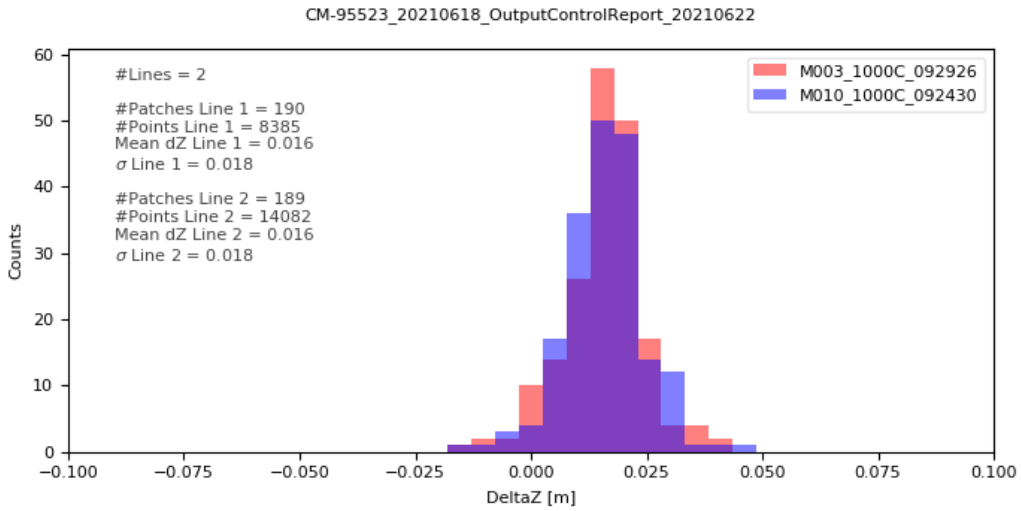


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

M010_1000C_092430

309307 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 [%]
	<=0.04	308752	99.82
	0.04-0.07	498	0.16
	0.07-0.1	33	0.01
	>0.1	24	0.01

Vertical difference

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

5.2.3 Multi-line accuracy between two perpendicular lines

M010_1000C_092430_vs_M003_1000C_092926

41917 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 [%]
	<=0.04	41886	99.93
	0.04-0.07	22	0.05
	0.07-0.1	2	0.00
	>0.1	7	0.02

Vertical difference

Figure 3 Vertical difference betweeen 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

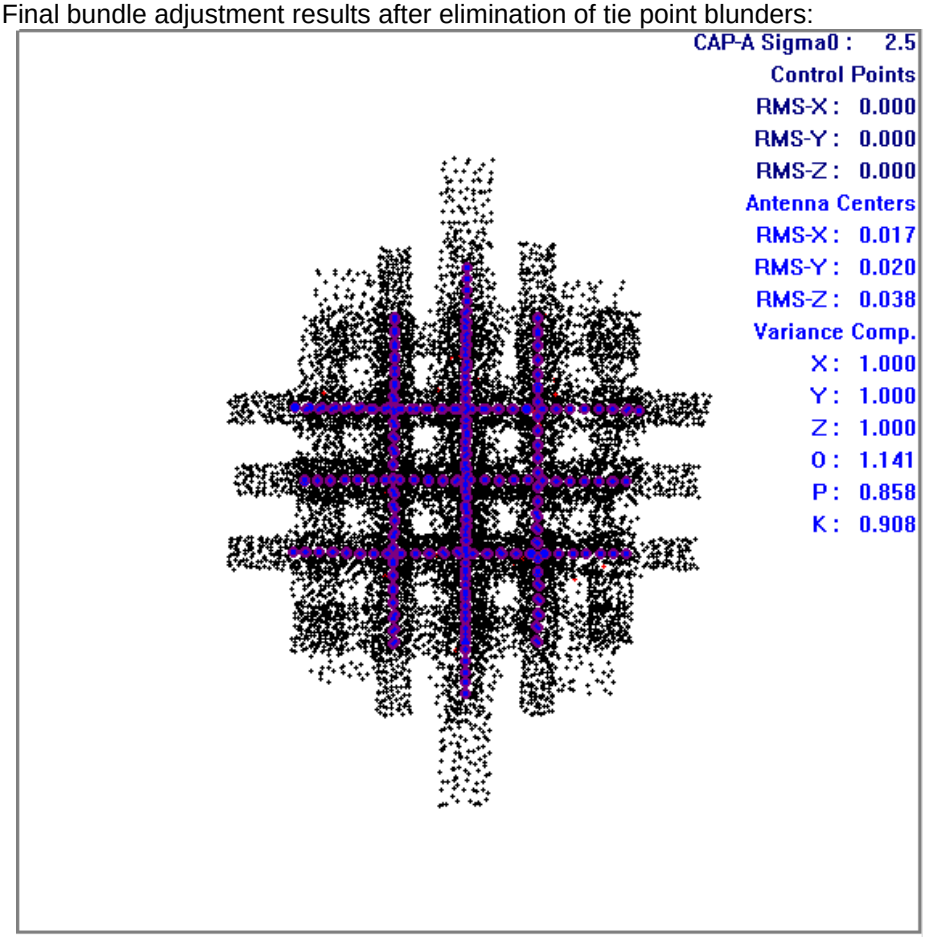
6.2 Results of Geometric Calibration

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:	0.0025

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

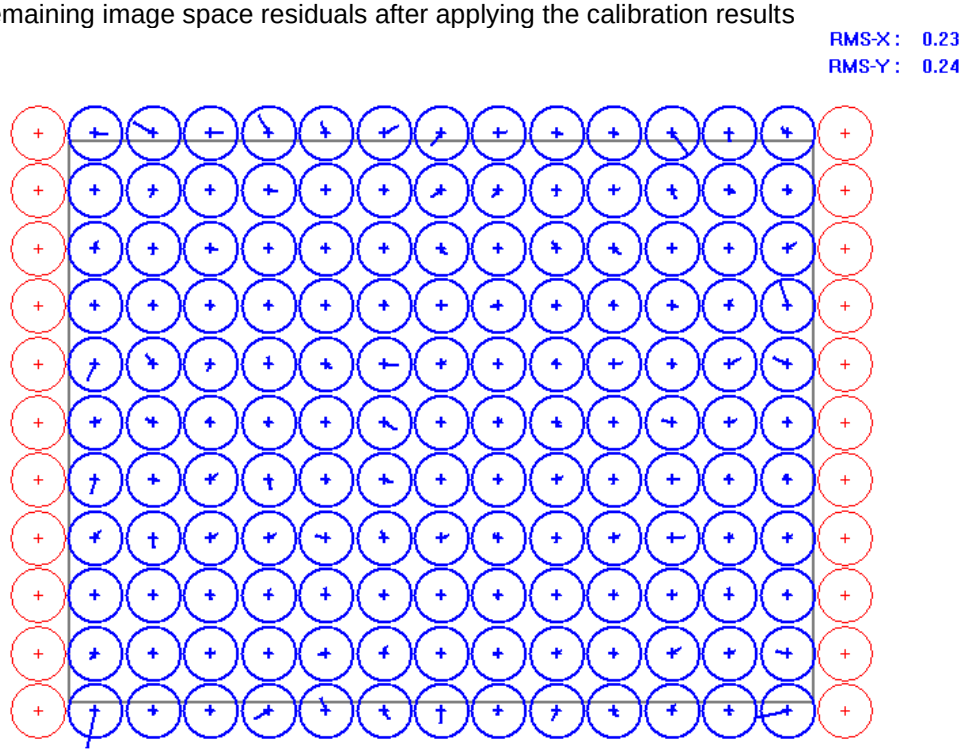
		Component	Serial Number
Camera Head		CH82	82638
Lens		NAT-D 2.8/80	80241
View Direction in Pod Position		Nadir	
IMU Misalignment		**Angle** [degree]	
	ω	-0.06806	
	Φ	-0.05036	
	κ	0.07988	
Principal Point		**Distance** [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		**Distance** [mm]	
	c	83.00	

Geometric Calibration File

RCD30_Geometry_CameraHead-82638-E-798528_LensSystem-80241-B-785423_DateTime-20210630-075004.xml

Geometric Calibration	Date	30.06.2021
Radiometric Calibration	Date	15.11.2018
Misalingment Flight	Date	-
Misalingment Update Completed	Date	-

Remaining image space residuals after applying the calibration results



Radius of circles is 0.0010 mm

6.4 Estimation Results for Forward Camera Head and Lens

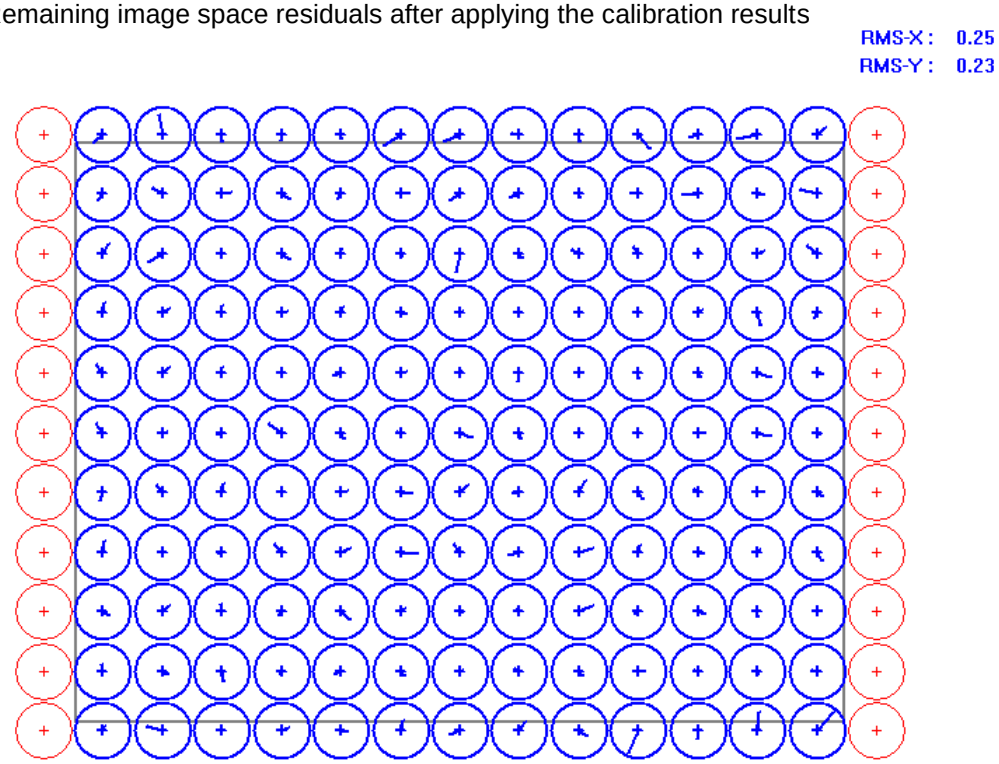
		Component	Serial Number
Camera Head		CH81m	81796
Lens		SAT-D 4.0/150	150204
View Direction in Pod Position		Forward	
IMU Misalignment		**Angle** [degree]	
	ω	0.06514	
	Φ	-0.01602	
	κ	0.11963	
Principal Point		**Distance** [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		**Distance** [mm]	
		156.00	

Geometric Calibration File

RCD30_Geometry_CameraHead-81796-D-842157_LensSystem-150204-B-819435_DateTime-20210630-074841.xml

Geometric Calibration	Date	30.06.2021
Radiometric Calibration	Date	20.11.2018
Misalingment Flight	Date	-
Misalingment Update Completed	Date	-

Remaining image space residuals after applying the calibration results



Radius of circles is 0.0010 mm

6.5 Estimation Results for Backward Camera Head and Lens

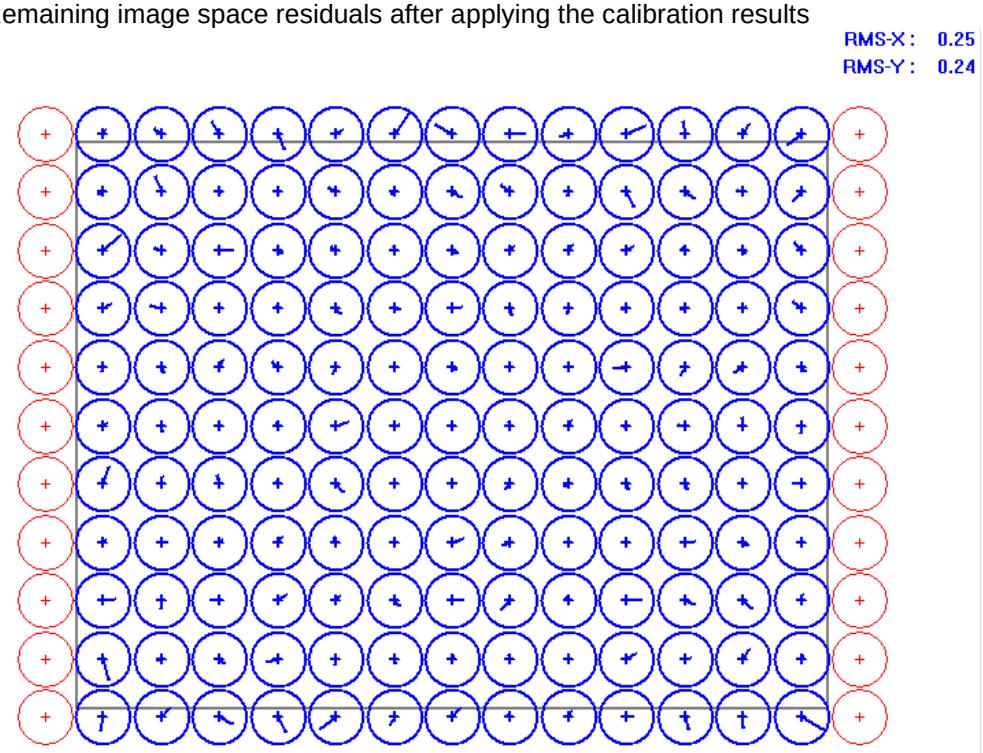
		Component	Serial Number
Camera Head		CH81m	81797
Lens		SAT-D 4.0/150	150205
View Direction in Pod Position		Backward	
IMU Misalignment		**Angle** [degree]	
	ω	0.09115	
	Φ	0.02955	
	κ	0.11899	
Principal Point		**Distance** [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		**Distance** [mm]	
		156.00	

Geometric Calibration File

RCD30_Geometry_CameraHead-81797-D-842157_LensSystem-150205-B-819435_DateTime-20210630-074857.xml

Geometric Calibration	Date	30.06.2021
Radiometric Calibration	Date	21.11.2018
Misalingment Flight	Date	-
Misalingment Update Completed	Date	-

Remaining image space residuals after applying the calibration results



Radius of circles is 0.0010 mm

6.6 Estimation Results for Left Camera Head and Lens

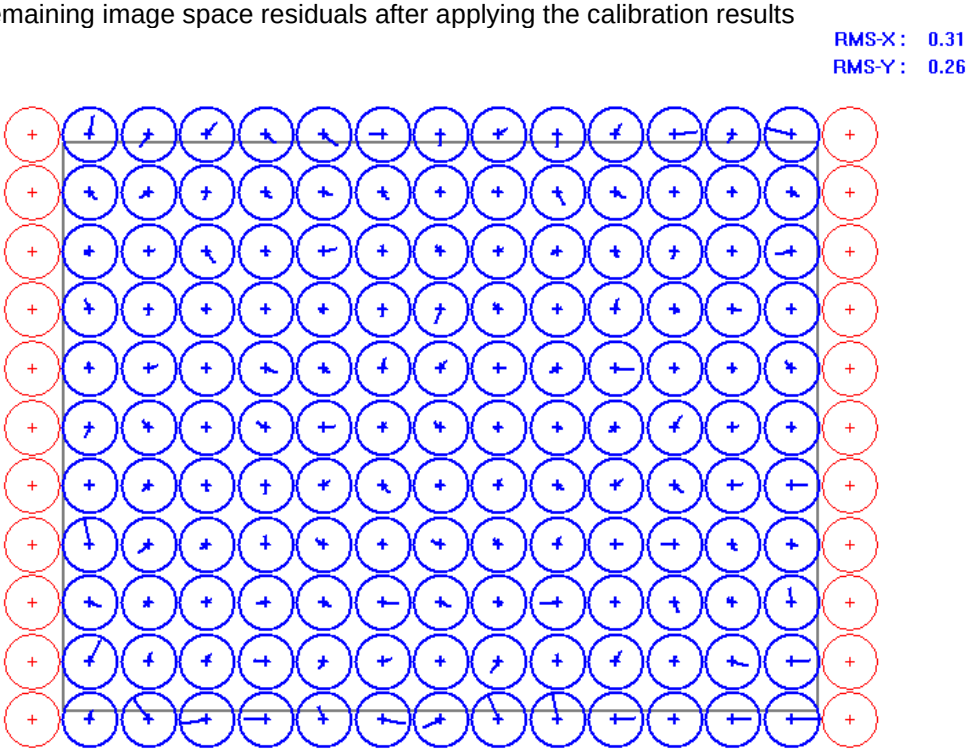
		Component	Serial Number
Camera Head		CH81m	81798
Lens		SAT-D 4.0/150	150206
View Direction in Pod Position		Left	
IMU Misalignment		**Angle** [degree]	
	ω	-0.00513	
	Φ	0.01409	
	κ	-0.18762	
Principal Point		**Distance** [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		**Distance** [mm]	
		156.00	

Geometric Calibration File

RCD30_Geometry_CameraHead-81798-D-842157_LensSystem-150206-B-819435_DateTime-20210630-074922.xml

Geometric Calibration	Date	30.06.2021
Radiometric Calibration	Date	21.11.2018
Misalingment Flight	Date	-
Misalingment Update Completed	Date	-

Remaining image space residuals after applying the calibration results



Radius of circles is 0.0010 mm

6.7 Estimation Results for Right Camera Head and Lens

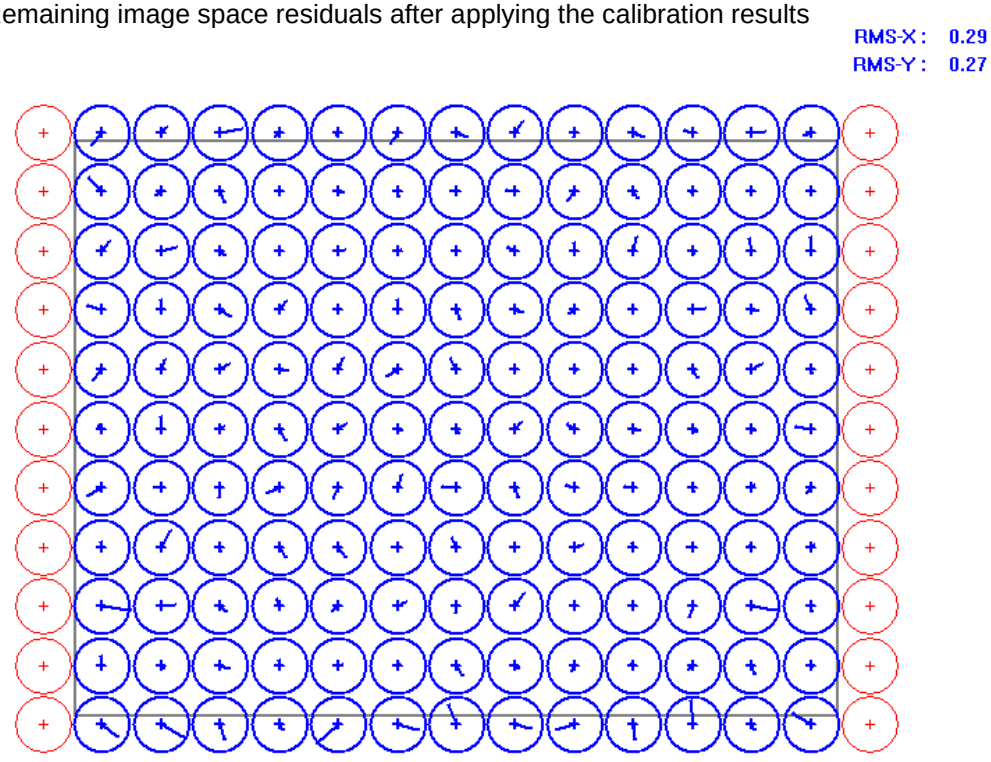
		Component	Serial Number
Camera Head		CH81m	81838
Lens		SAT-D 4.0/150	150246
View Direction in Pod Position		Right	
IMU Misalignment		**Angle** [degree]	
	ω	-0.04840	
	Φ	-0.06464	
	κ	0.03350	
Principal Point		**Distance** [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		**Distance** [mm]	
		156.00	

Geometric Calibration File

RCD30_Geometry_CameraHead-81838-D-842157_LensSystem-150246-B-819435_DateTime-20210630-074943.xml

Geometric Calibration Date	Date	30.06.2021
Radiometric Calibration Date	Date	23.05.2019
Misalingment Flight	Date	-
Misalingment Update Completed	Date	-

Remaining image space residuals after applying the calibration results



Radius of circles is 0.0010 mm