

- when it has to be **right**



# Leica Geosystems Leica CityMapper Calibration Certificate

<b>Product</b>	Leica CityMapper
<b>Serial Number</b>	95535
<b>Date</b>	02 August 2019
<b>Inspector</b>	Kevin Spruill






# 1. System Components

Component	Type	Serial Number
Pod	CityMapper Pod	95535
GNSS/IMU	Litef LCI-100C 500 Hz	1275
LiDAR Unit	Hyperion II	5534
Camera Head	CH82	82649
Lens	NAT-D 2.8/80	80250
Camera Head	CH81m	81824
Lens	SAT-D 4.0/150	150232
Camera Head	CH81m	81825
Lens	SAT-D 4.0/150	150233
Camera Head	CH81m	81826
Lens	SAT-D 4.0/150	150234
Camera Head	CH81m	81827
Lens	SAT-D 4.0/150	150235

# 2. Estimation Process

		Passed	Date	Inspector
Image Flight	completed	ok	03.15.2019	Deniz Arslan
Image Quality Check	checked	ok	03.20.2019	Bernhard Riedl
Image Calibration	completed	ok	03.22.2019	Zoltan Poth
Image Misalignment Update	completed			
LiDAR Flight	completed	ok	03.14.2019	Deniz Arslan
LiDAR Quality Check	checked	ok	03.14.2019	Rene Heierli
LiDAR Calibration and Accuracy	completed	ok	03.25.2019	Michael Vetter
LiDAR Misalignment Update	completed	ok	08.02.2019	Kevin Spruill

# 3. Inspectors

<b>Name</b>	Bernhard Riedl	03.28.2019	
<b>Position</b>	Production Manager		
<b>Name</b>	Zoltan Poth	03.28.2019	
<b>Position</b>	Support Engineer		
<b>Name</b>	Michael Vetter	03.28.2019	
<b>Position</b>	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

<b>IMU Misalignment</b>		<b>Value</b>	<b>Unit</b>
	$\omega$	-0.050163	degree
	$\Phi$	0.005493	degree
	$\kappa$	-0.068460	degree
<b>Boresight</b>		<b>Value</b>	<b>Unit</b>
	$\Theta$	-0.000681	degree
	$\Phi$	-0.005860	degree
<b>Receiver 1</b>		<b>Value</b>	<b>Unit</b>
Range	$\Delta$ Offset	0.000000	meters
<b>Wedge 0</b>		<b>Value</b>	<b>Unit</b>
Wedge	$\Delta$ Alpha	0.008473	degree
Wedge Position	$\Delta$ Offset	0.110584	degree
Position Correction	X	-0.051508	degree
	Y	0.024478	degree
Mount	Roll	0.476298	degree
	Pitch	0.506757	degree
Rotation Axis	Roll	0.262871	degree
	Pitch	0.466442	degree
<b>Wedge 1</b>		<b>Value</b>	<b>Unit</b>
Wedge	$\Delta$ Alpha	-0.008660	degree
Wedge Position	$\Delta$ Offset	0.303113	degree
Position Correction	X	0.003147	degree
	Y	-0.007534	degree
Mount	Roll	0.058776	degree
	Pitch	0.025819	degree
	Speed Pitch	1.50E-06	degree/rps <sup>2</sup>
Rotation Axis	Roll	0.035198	degree
	Pitch	-0.044551	degree

#### LiDAR Geometric Calibration File

HYPERION\_GEOMETRY\_LIDARUNIT-5534-C-855570-DATETIME-20190731-142746.XML

	Date	31.07.2019
<b>LiDAR Misalignment Flight</b>	Date	13.07.2019
<b>LiDAR Misalignment Update Completed</b>	Date	02.08.2019

## 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

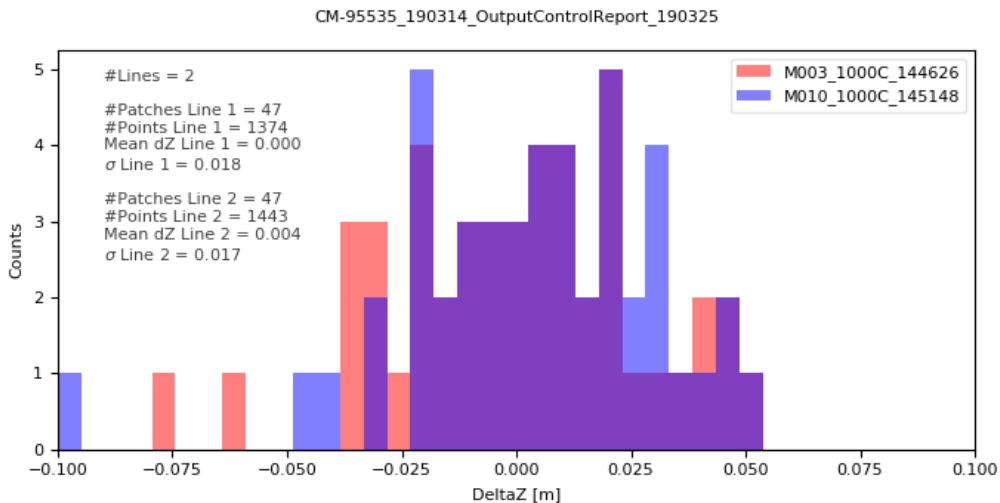


Figure 1 Vertical distance to ground control points at 1000 m AGL.

### 5.2.2 Difference of forward and backward scan of one line

#### M010\_1000C\_145148

319484 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 [%]
Green	$\leq 0.04$	319065	99.87
Yellow	0.04-0.07	367	0.11
Orange	0.07-0.1	17	0.01
Red	$> 0.1$	35	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\_144626\_vs\_M010\_1000C\_145148

30536 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	30505	99.90
Bright Green	0.04-0.07	26	0.09
Yellow	0.07-0.1	2	0.01
Red	>0.1	3	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

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

### 6.1.2 CH81m Model

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

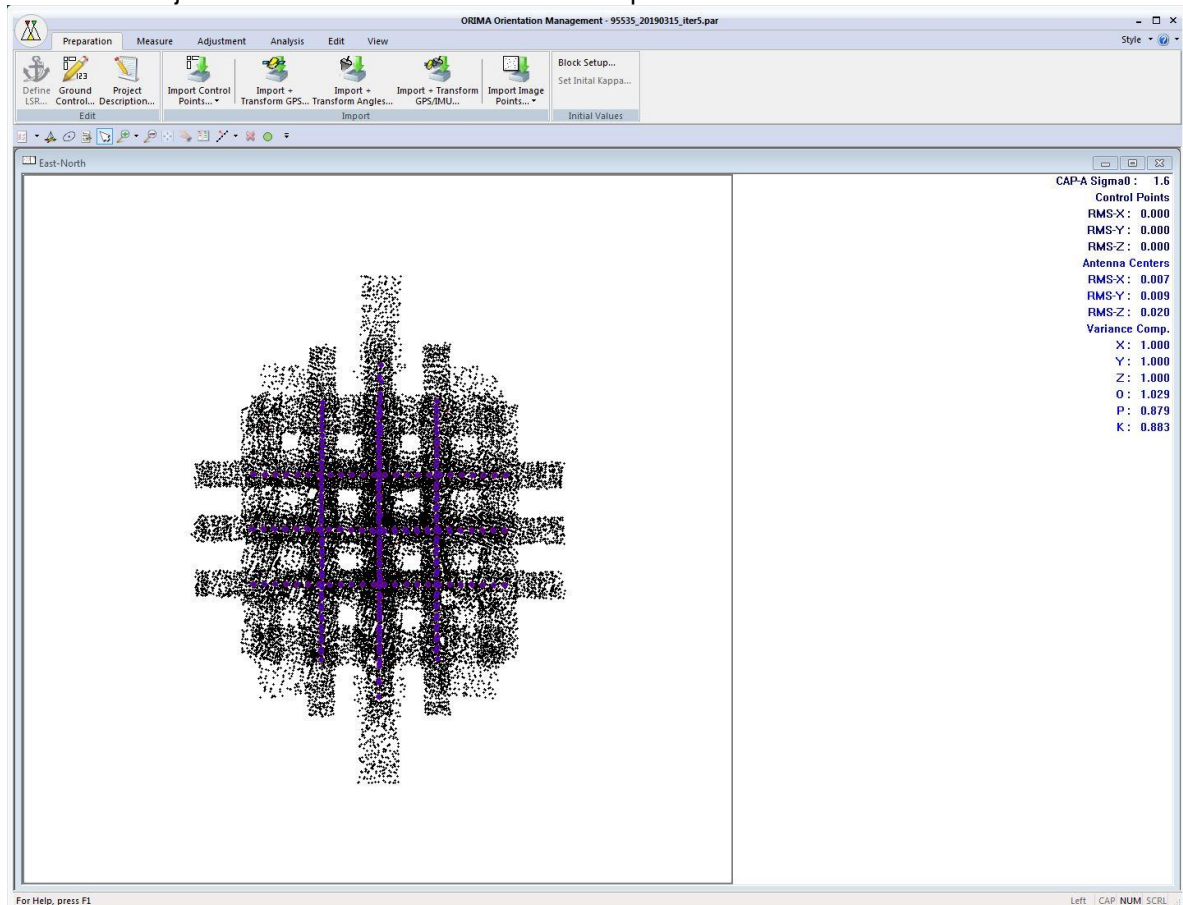
**Reference band (green)**

**Distance [mm]**

Resulting sigma naught of bundle adjustment:

0.0016

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

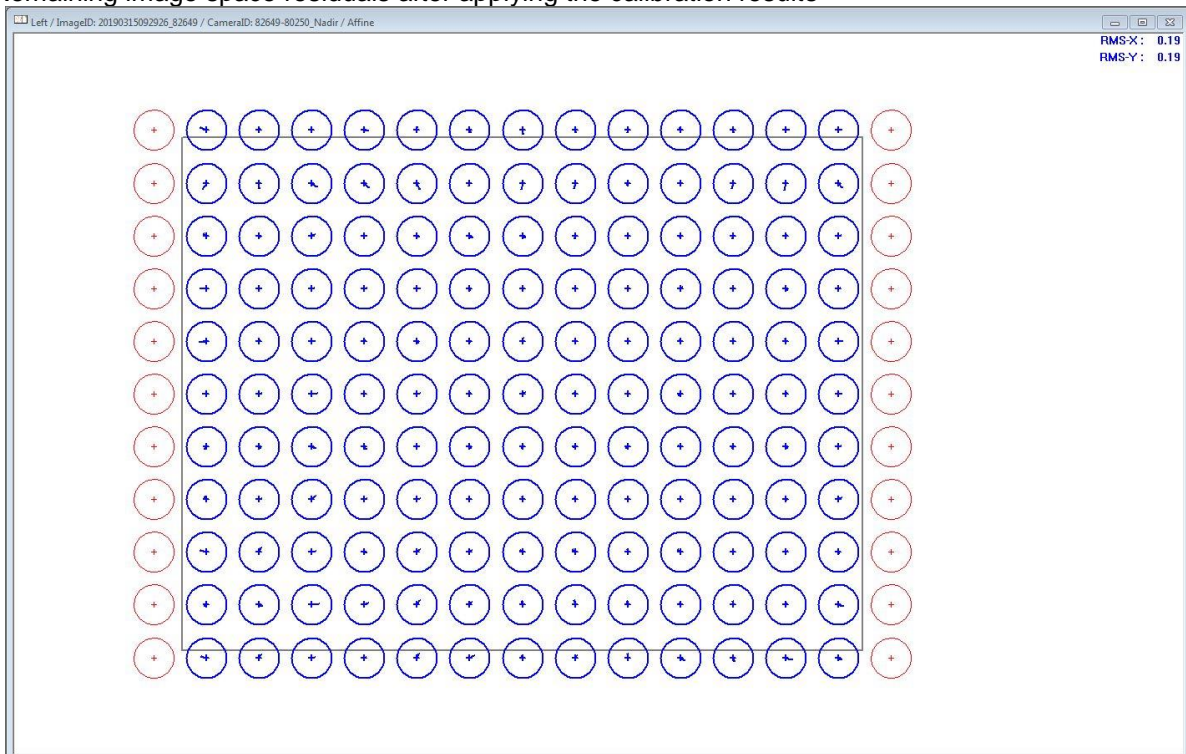
Leica HxMap applies the grid to create distortion-free images of nominal focal length and fixed pixel size of 0.0052 mm.



### 6.3 Estimation Results for Nadir Camera Head and Lens

	<b>Component</b>	<b>Serial Number</b>
<b>Camera Head</b>	CH82	82649
<b>Lens</b>	NAT-D 2.8/80	80250
<b>View Direction in Pod Position</b>	Nadir	
<b>IMU Misalignment</b>	<b>Angle [degree]</b>	
	$\omega$	0.03143
	$\Phi$	0.04911
	$\kappa$	-0.23324
<b>Principal Point</b>	<b>Distance [mm]</b>	
	x	0.0000
	y	0.0000
<b>Focal Length</b>	<b>Distance [mm]</b>	
	c	83.00
<b>Geometric Calibration File</b>		
RCD30_Geometry_CameraHead-82649-E-798528_LensSystem-80250-B-785423_DateTime-20190319-112500.xml		
<b>Geometric Calibration</b>	Date	19.03.2019
<b>Radiometric Calibration</b>	Date	22.02.2019
<b>Misalignment Flight</b>	Date	-
<b>Misalignment Update Completed</b>	Date	-

Remaining image space residuals after applying the calibration results

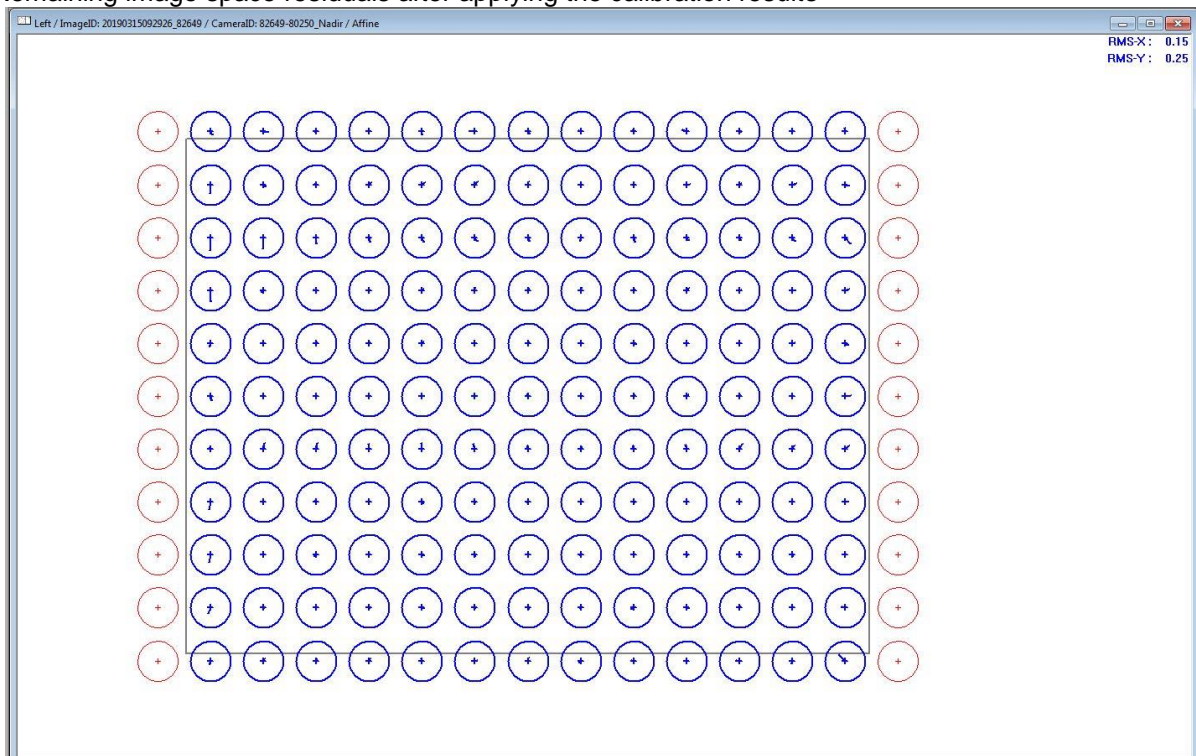


Radius of circles is 0.0010 mm

## 6.4 Estimation Results for Forward Camera Head and Lens

	<b>Component</b>	<b>Serial Number</b>
<b>Camera Head</b>	CH81m	81824
<b>Lens</b>	SAT-D 4.0/150	150232
<b>View Direction in Pod Position</b>	Forward	
<b>IMU Misalignment</b>	<b>Angle [degree]</b>	
	$\omega$	-0.32525
	$\Phi$	0.09697
	$\kappa$	0.03724
<b>Principal Point</b>	<b>Distance [mm]</b>	
	x	0.0000
	y	0.0000
<b>Focal Length</b>	<b>Distance [mm]</b>	
		156.00
<b>Geometric Calibration File</b>		
RCD30_Geometry_CameraHead-81824-D-842157_LensSystem-150232-B-819435_DateTime-20190322-142414.xml		
<b>Geometric Calibration</b>	Date	22.03.2019
<b>Radiometric Calibration</b>	Date	28.02.2019
<b>Misalignment Flight</b>	Date	-
<b>Misalignment Update Completed</b>	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

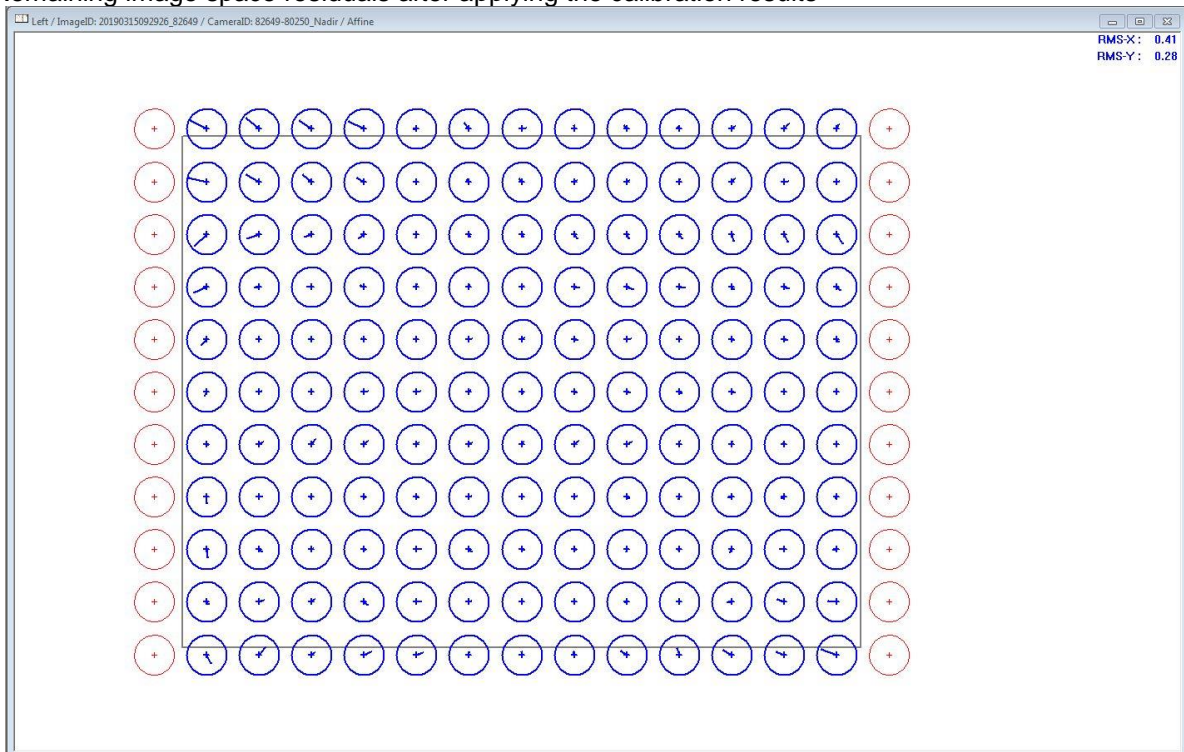
	Component	Serial Number
Camera Head	CH81m	81825
Lens	SAT-D 4.0/150	150233
View Direction in Pod Position	Backward	
IMU Misalignment	<b>Angle [degree]</b>	
	$\omega$	0.05496
	$\Phi$	-0.02916
	$\kappa$	-0.04058
Principal Point	<b>Distance [mm]</b>	
	x	0.0000
	y	0.0000
Focal Length	<b>Distance [mm]</b>	
		156.00

### Geometric Calibration File

RCD30\_Geometry\_CameraHead-81825-D-842157\_LensSystem-150233-B-819435\_DateTime-20190322-142429.xml

Geometric Calibration	Date	22.03.2019
Radiometric Calibration	Date	28.02.2019
Misalignment Flight	Date	-
Misalignment Update Completed	Date	-

Remaining image space residuals after applying the calibration results

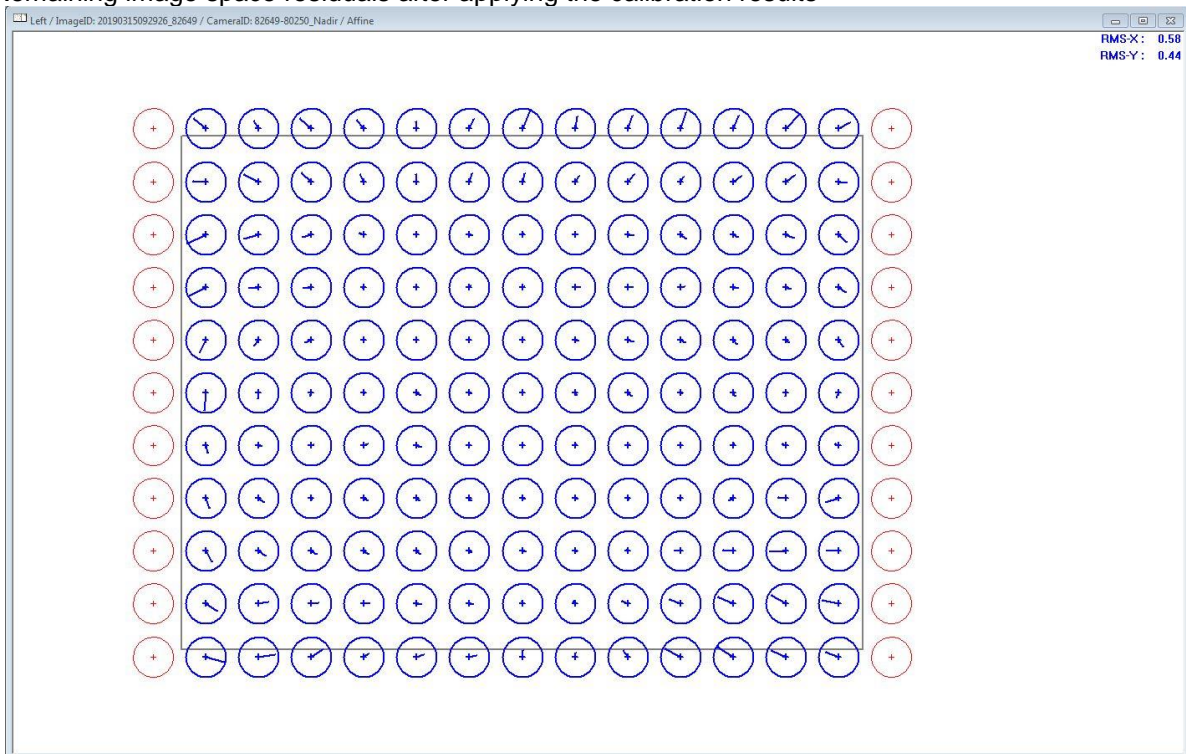


Radius of circles is 0.0010 mm

## 6.6 Estimation Results for Left Camera Head and Lens

	<b>Component</b>	<b>Serial Number</b>
<b>Camera Head</b>	CH81m	81826
<b>Lens</b>	SAT-D 4.0/150	150234
<b>View Direction in Pod Position</b>	Left	
<b>IMU Misalignment</b>	<b>Angle [degree]</b>	
	$\omega$	-0.15712
	$\phi$	-0.05764
	$\kappa$	-0.12157
<b>Principal Point</b>	<b>Distance [mm]</b>	
	x	0.0000
	y	0.0000
<b>Focal Length</b>	<b>Distance [mm]</b>	
		156.00
<b>Geometric Calibration File</b>		
RCD30_Geometry_CameraHead-81826-D-842157_LensSystem-150234-B-819435_DateTime-20190322-142442.xml		
<b>Geometric Calibration</b>	Date	22.03.2019
<b>Radiometric Calibration</b>	Date	28.02.2019
<b>Misalignment Flight</b>	Date	-
<b>Misalignment Update Completed</b>	Date	-

Remaining image space residuals after applying the calibration results

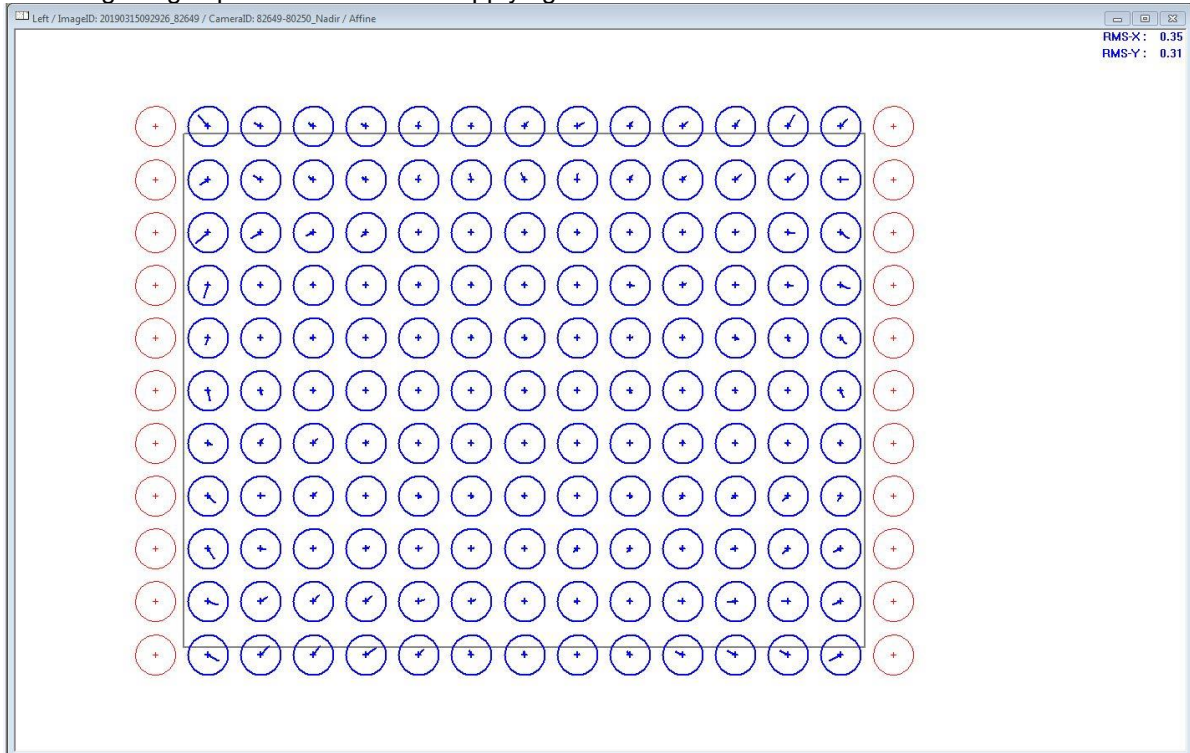


Radius of circles is 0.0010 mm

## 6.7 Estimation Results for Right Camera Head and Lens

	<b>Component</b>	<b>Serial Number</b>
<b>Camera Head</b>	CH81m	81827
<b>Lens</b>	SAT-D 4.0/150	150235
<b>View Direction in Pod Position</b>	Right	
<b>IMU Misalignment</b>	<b>Angle [degree]</b>	
	$\omega$	0.06415
	$\phi$	-0.04580
	$\kappa$	-0.14238
<b>Principal Point</b>	<b>Distance [mm]</b>	
	x	0.0000
	y	0.0000
<b>Focal Length</b>	<b>Distance [mm]</b>	
		156.00
<b>Geometric Calibration File</b>		
RCD30_Geometry_CameraHead-81827-D-842157_LensSystem-150235-B-819435_DateTime-20190322-142513.xml		
<b>Geometric Calibration Date</b>	Date	22.03.2019
<b>Radiometric Calibration Date</b>	Date	01.03.2019
<b>Misalignment Flight</b>	Date	-
<b>Misalignment Update Completed</b>	Date	-

Remaining image space residuals after applying the calibration results



Radius of circles is 0.0010 mm