

- when it has to be **right**



Leica Geosystems Leica TerrainMapper-LN Calibration Certificate

Product	Leica TerrainMapper-LN
Serial Number	91511
Date	03 July 2019
Inspector	Mark O'Neal






1. System Components

Component	Type	Serial Number
Pod	TerrainMapper Pod	91511
GNSS/IMU	Litef LCI-100C 500 Hz	1139
LiDAR Unit	Hyperion2 LiDAR Unit	5511
Camera Head	CH82	82659
Lens	NAT-D 2.8/80	80254

2. Estimation Process

		Passed	Date	Inspector
Image Flight	completed	ok	10.05.2019	Philip Benz
Image Quality Check	checked	ok	16.05.2019	Philip Benz
Image Calibration	completed	ok	18.05.2019	Xu Wang
Image Misalignment Update	completed	ok	02.07.2019	Mark O'Neal
LiDAR Flight	completed	ok	10.17.2018	Deniz Arslan
LiDAR Quality Check	checked	ok	23.10.2018	Rene Heirli
LiDAR Calibration and Accuracy	completed	ok	24.10.2018	Robert Bosch
LiDAR Misalignment Update	completed			

3. Inspectors

Name	Bernhard Riedl	15.11.2018	
Position	Production Manager		
Name	Robert Bosch	23.05.2019	
Position	Support Engineer		
Name	Michael Vetter	03.07.2019	
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	-0.138877	degree
	Φ	0.130994	degree
	κ	-0.006412	degree
Boresight		Value	Unit
	Θ	0.001052	degree
	Φ	-0.001885	degree
Receiver 1		Value	Unit
Range	Δ Offset	0.000000	meters
Wedge 0		Value	Unit
Wedge	Δ Alpha	0.001241	degree
Wedge Position	Δ Offset	-0.426898	degree
Position Correction	X	-0.019523	degree
	Y	0.007883	degree
Mount	Roll	-0.020901	degree
	Pitch	0.107683	degree
Rotation Axis	Roll	0.103712	degree
	Pitch	0.124140	degree
Wedge 1		Value	Unit
Wedge	Δ Alpha	-0.009545	degree
Wedge Position	Δ Offset	0.412993	degree
Position Correction	X	0.004000	degree
	Y	0.011085	degree
Mount	Roll	0.102859	degree
	Pitch	0.025756	degree
	Speed Pitch	1.50E-06	degree/rps ²
Rotation Axis	Roll	0.114811	degree
	Pitch	-0.080531	degree

LiDAR Geometric Calibration File

HYPERION_GEOMETRY_LIDARUNIT-5511-C-855570-DATETIME-20181023-153458.XML

Date 23.10.2018

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

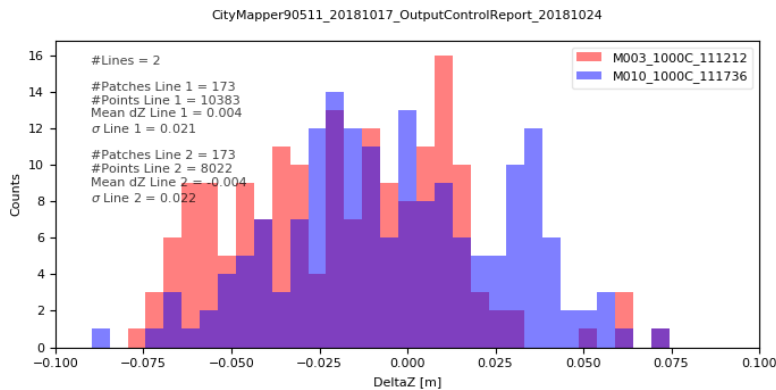


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

M010_1000C_111736

314314 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	≤ 0.04	293823	93.48
Yellow	0.04-0.07	20386	6.49
Orange	0.07-0.1	89	0.03
Red	> 0.1	16	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_111212_vs_M010_1000C_111736

39940 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	32066	80.29
Light Green	0.04-0.07	7841	19.63
Yellow	0.07-0.1	21	0.05
Red	>0.1	12	0.03



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.

6.1.1 CH8x Model

Camera Head		Component	
Lens		CH82	
		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

6.2 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

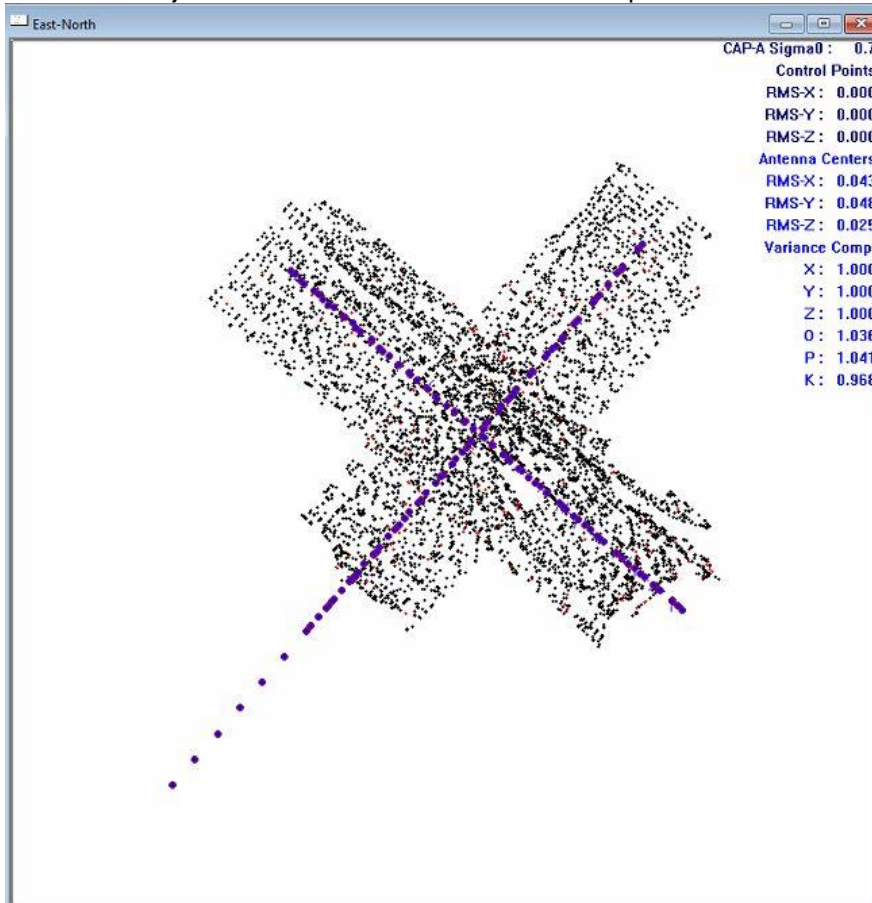
Reference band (green)

Distance [mm]

Resulting sigma naught of bundle adjustment:

0.0007

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:

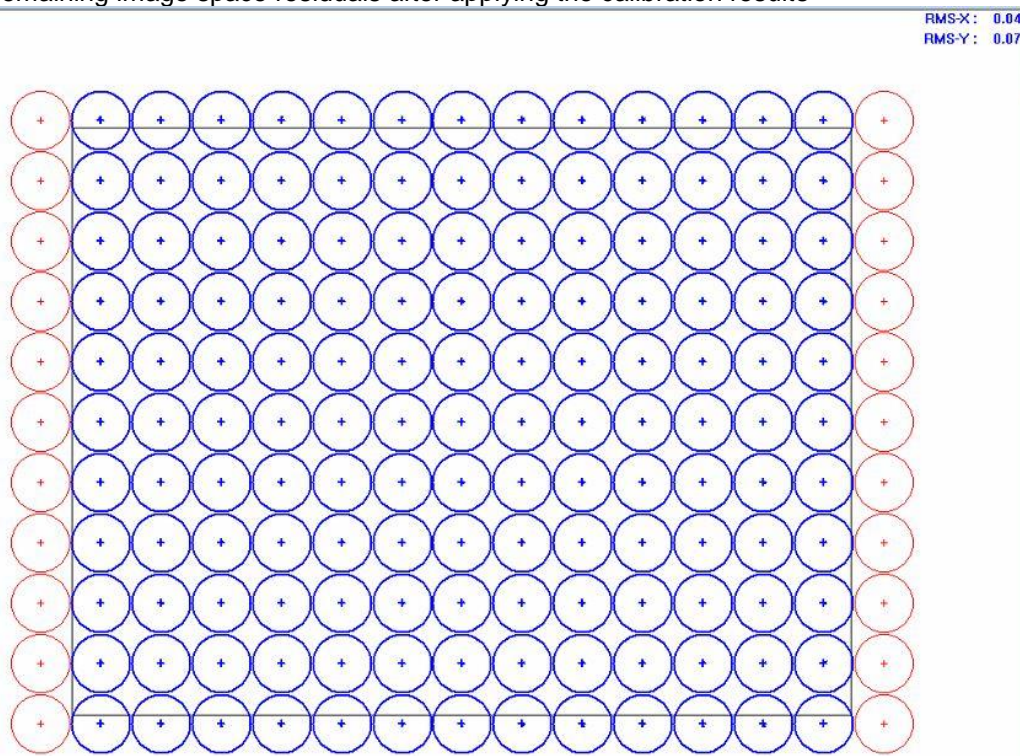
0.002

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	82659
Lens	NAT-D 2.8/80	80254
View Direction in Pod Position	Nadir	
IMU Misalignment	Angle [degree]	
	ω	-0.00815
	ϕ	0.00028
	κ	-0.26654
Principal Point	Distance [mm]	
	x	0.0000
	y	0.0000
Focal Length	Distance [mm]	
	c	83.00
Geometric Calibration File		
RCD30_Geometry_CameraHead-82659-E-798528_LensSystem-80254-B-785423_DateTime-20190518-214751.xml		
Geometric Calibration Date	Date	18.05.2019
Radiometric Calibration Date	Date	05.02.2019
Misalignment Flight	Date	23.06.2019
Misalignment Update Completed	Date	02.07.2019

Remaining image space residuals after applying the calibration results



Radius of circles is 0.0007 mm

- when it has to be **right**



Leica Geosystems Leica TerrainMapper-LN Calibration Certificate

Product	Leica TerrainMapper-LN
Serial Number	91513
Date	25 February 2019
Inspector	Xu Wang






1. System Components

Component	Type	Serial Number
TerrainMapper Pod	TerrainMapper Pod	91513
GNSS/IMU	Litef LCI-100C 500 Hz	1205
LiDAR Unit	Hyperion2 LiDAR Unit	5513
Camera Head	CH82	82644
Lens	NAT-D 2.8/80	80245

2. Estimation Process

		Passed	Date	Inspector
Image Flight	completed	ok	14.02.2019	Deniz Arslan
Image Quality Check	checked	ok	24.02.2019	Bernhard Riedl
Image Calibration	completed	ok	25.02.2019	Xu Wang
Image Misalignment Update	completed			
LiDAR Flight	completed	ok	04.02.2019	Deniz Arslan
LiDAR Quality Check	checked	ok	04.02.2019	René Heierli
LiDAR Calibration and Accuracy	completed	ok	07.02.2019	Xu Wang
LiDAR Misalignment Update	completed			

3. Inspectors

Name	Bernhard Riedl	25.02.2019	
Position	Production Manager		
Name	Robert Bosch	25.02.2019	
Position	Support Engineer		
Name	Michael Vetter	25.02.2019	
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	-0.006841	degree
	Φ	0.032871	degree
	κ	-0.061655	degree
Boresight		Value	Unit
	Θ	0.004111	degree
	Φ	0.002086	degree
Receiver 1		Value	Unit
Range	Δ Offset	0.000000	meters
Wedge 0		Value	Unit
Wedge	Δ Alpha	-0.039072	degree
Wedge Position	Δ Offset	0.993387	degree
Position Correction	X	-0.023366	degree
	Y	0.002286	degree
Mount	Roll	0.192519	degree
	Pitch	0.679010	degree
Rotation Axis	Roll	0.027303	degree
	Pitch	0.110180	degree
Wedge 1		Value	Unit
Wedge	Δ Alpha	-0.006531	degree
Wedge Position	Δ Offset	0.521209	degree
Position Correction	X	0.002034	degree
	Y	-0.002471	degree
Mount	Roll	-0.015741	degree
	Pitch	-0.056400	degree
	Speed Pitch	1.50E-06	degree/rps ²
Rotation Axis	Roll	-0.029805	degree
	Pitch	-0.043904	degree

LiDAR Geometric Calibration File

HYPERION_GEOMETRY_LIDARUNIT-5513-C-855570-DATETIME-20190207-172145.XML

	Date	07.02.2019
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

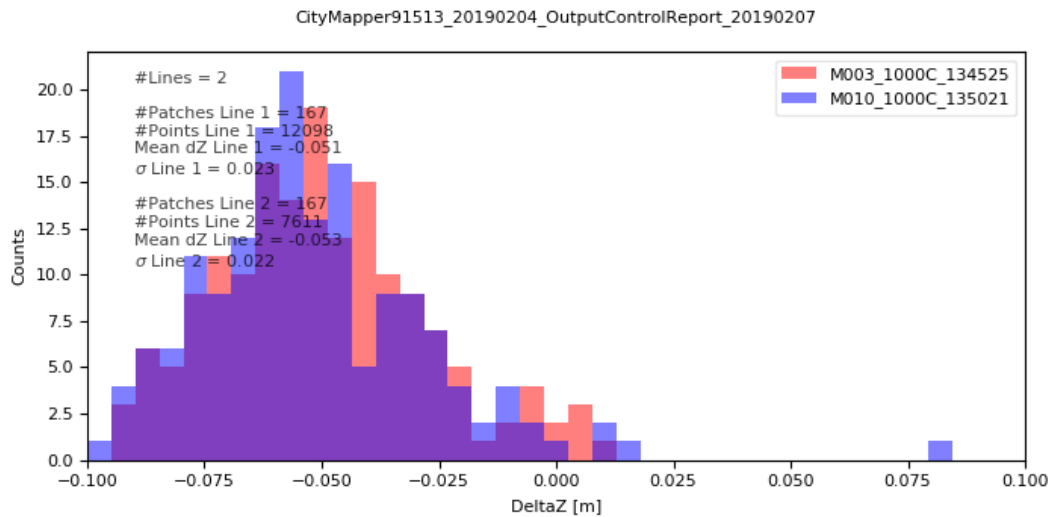


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

M010_1000C_135021

373128 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	372822	99.92
Bright Green	0.04-0.07	233	0.06
Yellow	0.07-0.1	23	0.01
Red	>0.1	50	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_134525_vs_M010_1000C_135021

41041 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	41014	99.93
Bright Green	0.04-0.07	20	0.05
Yellow	0.07-0.1	4	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

Camera Head		Component	
Lens		CH82	
		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

6.2 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

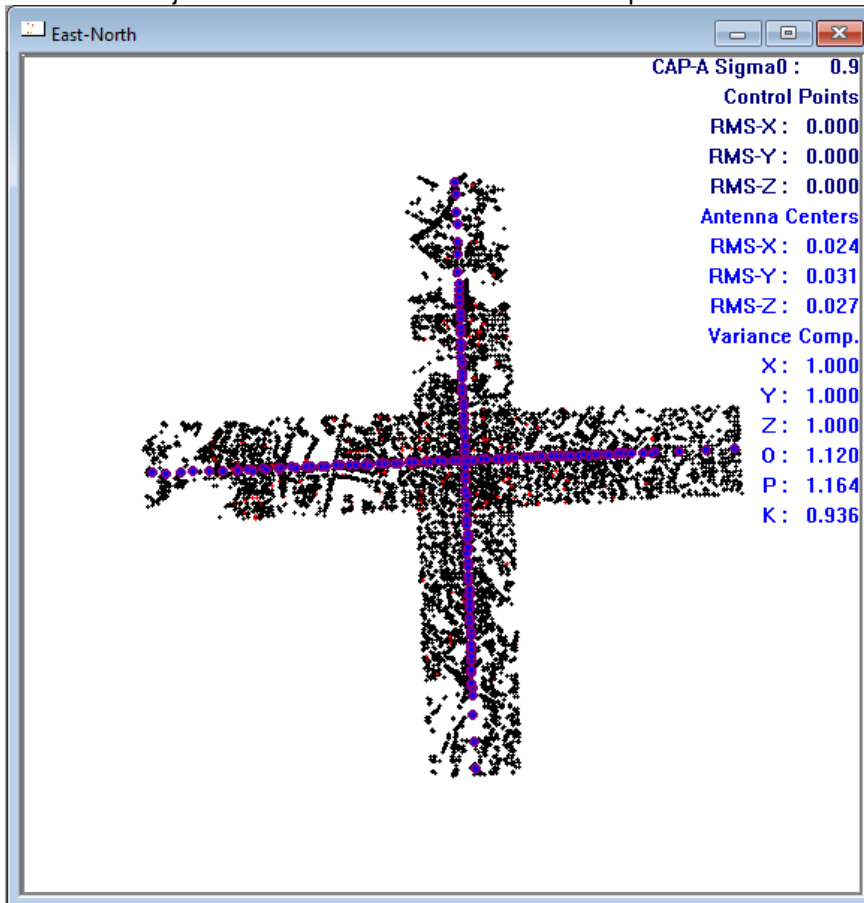
Reference band (green)

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 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:

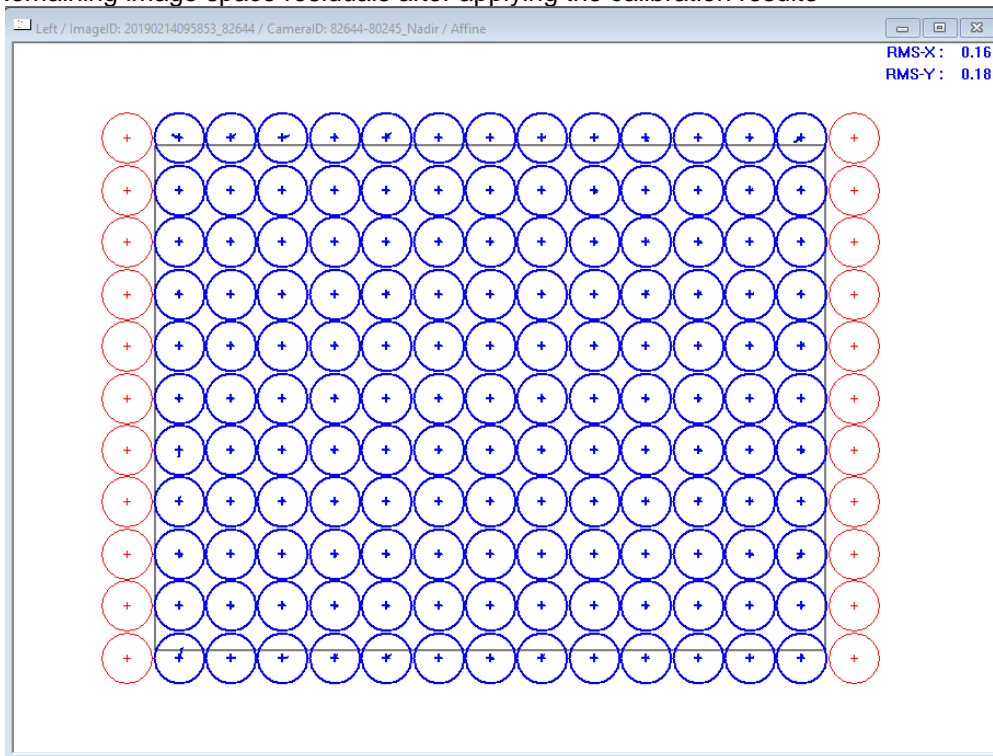
0.002

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	82644
Lens		NAT-D 2.8/80	80245
View Direction in Pod Position		Nadir	
IMU Misalignment		Angle [degree]	
Valid for this calibration flight only	ω	-0.009454	
	ϕ	-0.048891	
	κ	-0.023235	
Principal Point		Distance [mm]	
	x	0.0000	
	y	0.0000	
Focal Length		Distance [mm]	
	c	83.00	
Geometric Calibration File			
RCD30_Geometry_CameraHead-82644-E-798528_LensSystem-80245-B-785423_DateTime-20190225-115639.xml			
Geometric Calibration Date	Date	25.02.2019	
Radiometric Calibration Date	Date	11.01.2019	
Misalignment Flight	Date	-	
Misalignment Update Completed	Date	-	

Remaining image space residuals after applying the calibration results



Radius of circles is 0.0010 mm

- when it has to be **right**



Leica Geosystems Leica TerrainMapper-LN Calibration Certificate

Product	Leica TerrainMapper-LN
Serial Number	91515
Date	27 June 2019
Inspector	Mark O'Neal




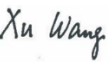

1. System Components

Component	Type	Serial Number
Pod	TerrainMapper Pod	91515
GNSS/IMU	Litef LCI-100C 500 Hz	1226
LiDAR Unit	Hyperion2 LiDAR Unit	5516
Camera Head	CH82	82658
Lens	NAT-D 2.8/80	80253

2. Estimation Process

		Passed	Date	Inspector
Image Flight	completed	ok	10.05.2019	Philip Benz
Image Quality Check	checked	ok	16.05.2019	Bernhard Riedl
Image Calibration	completed	ok	23.05.2019	Xu Wang
Image Misalignment Update	completed	ok	25.06.2019	Mark O'Neal
LiDAR Flight	completed	ok	29.11.2018	Philip Benz
LiDAR Quality Check	checked	ok	06.12.2018	Rene Heierli
LiDAR Calibration and Accuracy	completed	ok	12.12.2018	Robert Bosch
LiDAR Misalignment Update	completed	ok	27.06.2019	Mark O'Neal

3. Inspectors

Name	Bernhard Riedl	27.06.2019	
Position	Production Manager		
Name	Xu Wang	27.06.2019	
Position	Support Engineer		
Name	Robert Bosch	12.12.2018	
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	-0.017122	degree
	Φ	0.048251	degree
	κ	0.000135	degree
Boresight		Value	Unit
	Θ	0.015419	degree
	Φ	-0.001923	degree
Receiver 1		Value	Unit
Range	Δ Offset	0.000000	meters
Wedge 0		Value	Unit
Wedge	Δ Alpha	-0.043014	degree
Wedge Position	Δ Offset	0.442789	degree
Position Correction	X	-0.012826	degree
	Y	0.000012	degree
Mount	Roll	0.045379	degree
	Pitch	0.210132	degree
Rotation Axis	Roll	0.031087	degree
	Pitch	0.076675	degree
Wedge 1		Value	Unit
Wedge	Δ Alpha	-0.005517	degree
Wedge Position	Δ Offset	0.559649	degree
Position Correction	X	0.030760	degree
	Y	-0.001169	degree
Mount	Roll	0.012366	degree
	Pitch	0.054254	degree
	Speed Pitch	1.50E-06	degree/rps ²
Rotation Axis	Roll	0.032485	degree
	Pitch	-0.029191	degree

LiDAR Geometric Calibration File

HYPERION_GEOMETRY_LIDARUNIT-5516-C-855570-DATETIME-20181204-161828.XML

	Date	12.04.2018
LiDAR Misalignment Flight	Date	06.14.2019
LiDAR Misalignment Update Completed	Date	06.27.2019

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

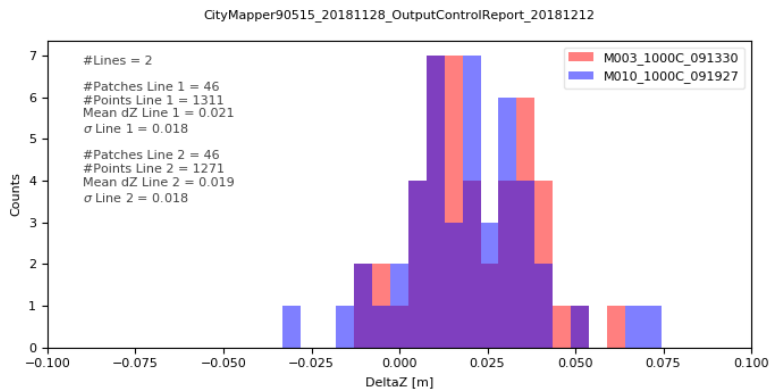


Figure 1 Vertical distance to ground control points at 1000 m AGL.

5.2.2 Difference of forward and backward scan of one line

M010_1000C_091927

303355 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	≤ 0.04	302593	99.75
Yellow	0.04-0.07	716	0.24
Orange	0.07-0.1	17	0.01
Red	> 0.1	29	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_091330_vs_M010_1000C_091927

29588 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	29546	99.86
Bright Green	0.04-0.07	38	0.13
Yellow	0.07-0.1	1	0.00
Red	>0.1	3	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.

6.1.1 CH8x Model

Camera Head		Component	
Lens		CH82	
		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

6.2 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

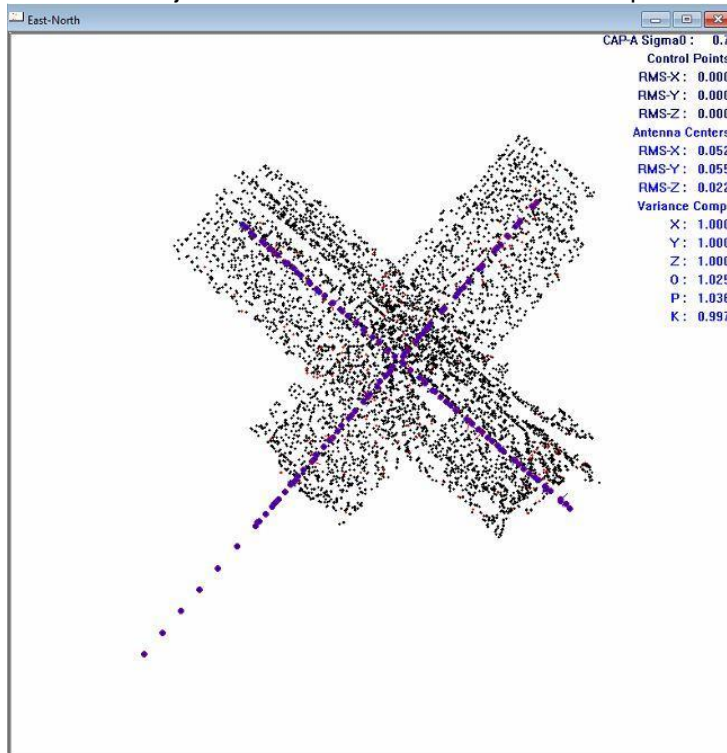
Reference band (green)

Distance [mm]

Resulting sigma naught of bundle adjustment:

0.0007

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

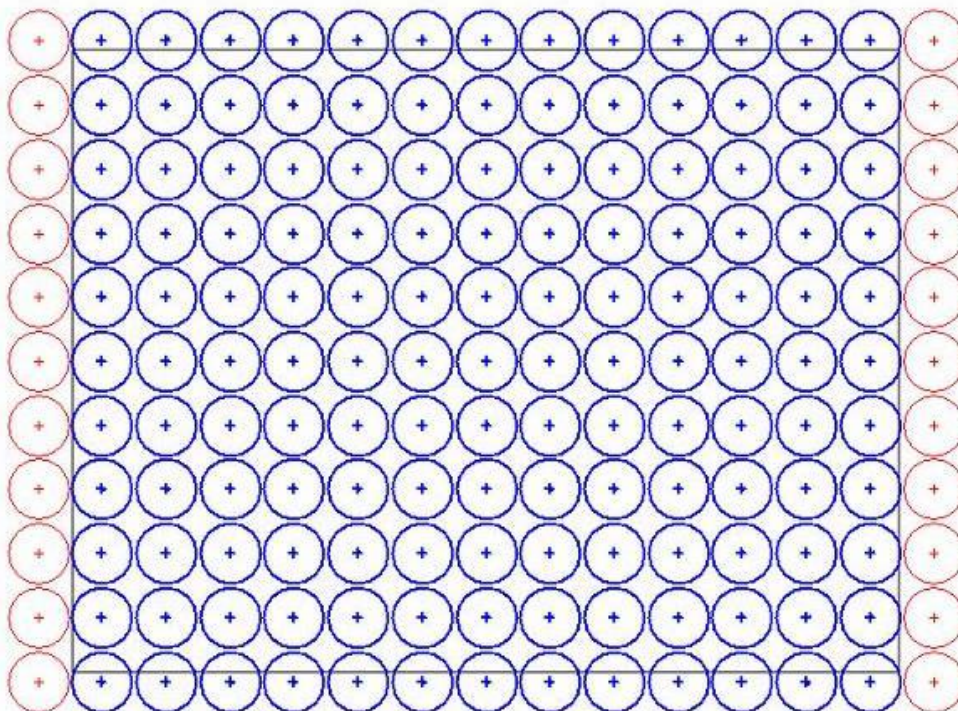
Leica HxMap applies the grid to create distortion-free images of nominal focal length and fixed pixel size of 0.0052 mm.

6.3 Estimation Results for Nadir Camera Head and Lens

	Component	Serial Number
Camera Head	CH82	82658
Lens	NAT-D 2.8/80	80253
View Direction in Pod Position	Nadir	
IMU Misalignment	Angle [degree]	
	ω	0.07949
	ϕ	-0.00801
	κ	-0.22593
Principal Point	Distance [mm]	
	x	0.0000
	y	0.0000
Focal Length	Distance [mm]	
	c	83.00
Geometric Calibration File		
RCD30_Geometry_CameraHead-82658-E-798528_LensSystem-80253-B-785423_DateTime-20190521-110247.xml		
Geometric Calibration Date	Date	21.05.2019
Radiometric Calibration Date	Date	05.06.2019
Misalignment Flight	Date	14.06.2019
Misalignment Update Completed	Date	25.06.2019

Remaining image space residuals after applying the calibration results

RMS-X: 0.06
RMS-Y: 0.06



Radius of circles is 0.0007 mm