



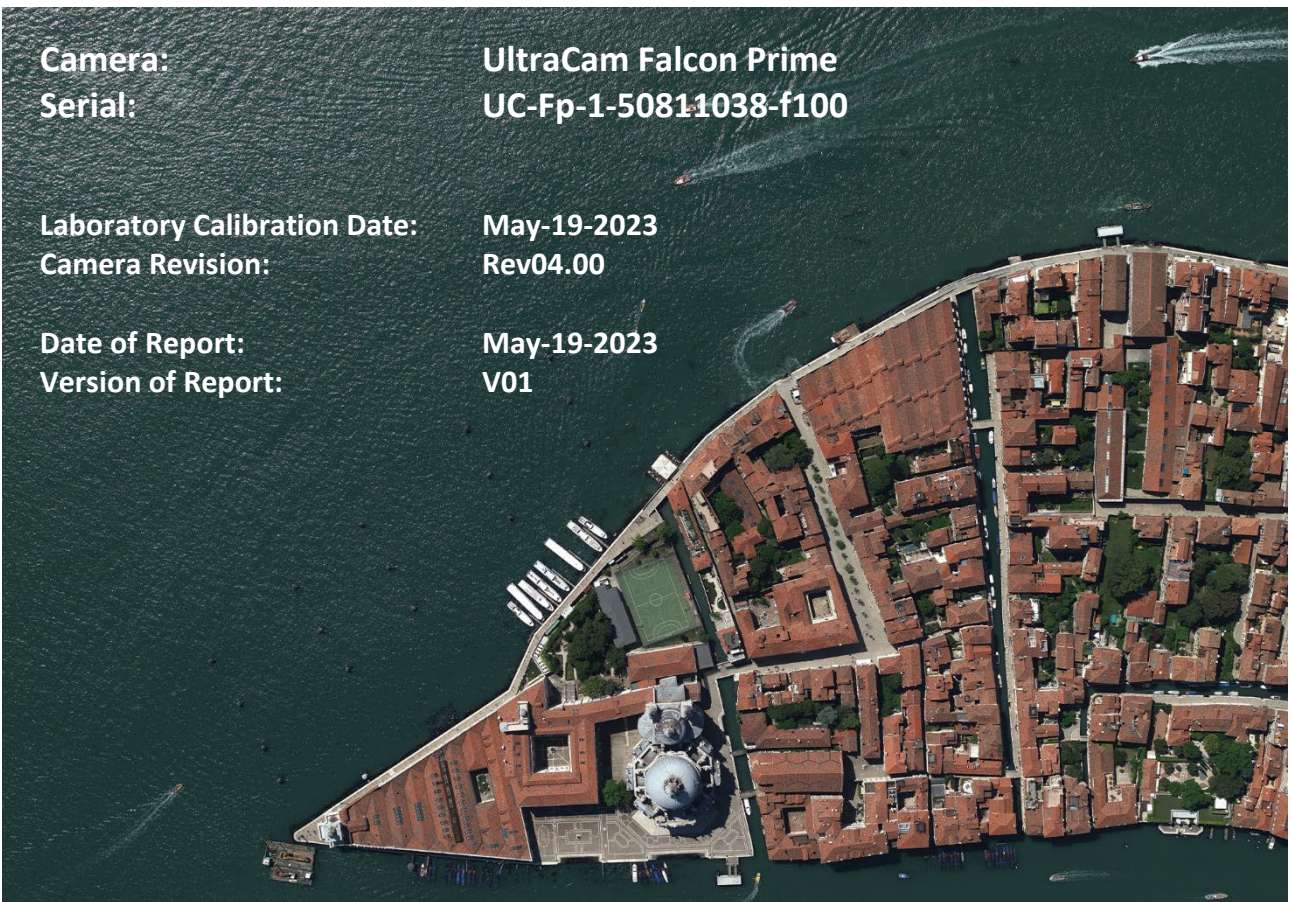
ULTRACAM

Calibration Report

Camera: UltraCam Falcon Prime
Serial: UC-Fp-1-50811038-f100

Laboratory Calibration Date: May-19-2023
Camera Revision: Rev04.00

Date of Report: May-19-2023
Version of Report: V01



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Venice, Italy

Photo on page 1 courtesy of Vexcel Imaging GmbH



ULTRACAM

Geometric Calibration

Camera: UltraCam Falcon Prime
Serial: UC-Fp-1-50811038-f100

Panchromatic Camera: ck = 100.500 mm
Multispectral Camera: ck = 100.500 mm

PPA Information: X: 0.000mm
Y: -0.120mm



Panchromatic Camera

Large Format Panchromatic Output Image

Image Format	long track cross track	67.860mm 103.860mm	11310pixel 17310pixel
Image Extent		(-33.930, -51.930)mm	(33.930, 51.930)mm
Pixel Size		6.000µm*6.000µm	
Focal Length	ck	100.500mm	± 0.002mm
Principal Point (Level 2)	X_ppa	0.000mm	± 0.002mm
	Y_ppa	-0.120mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

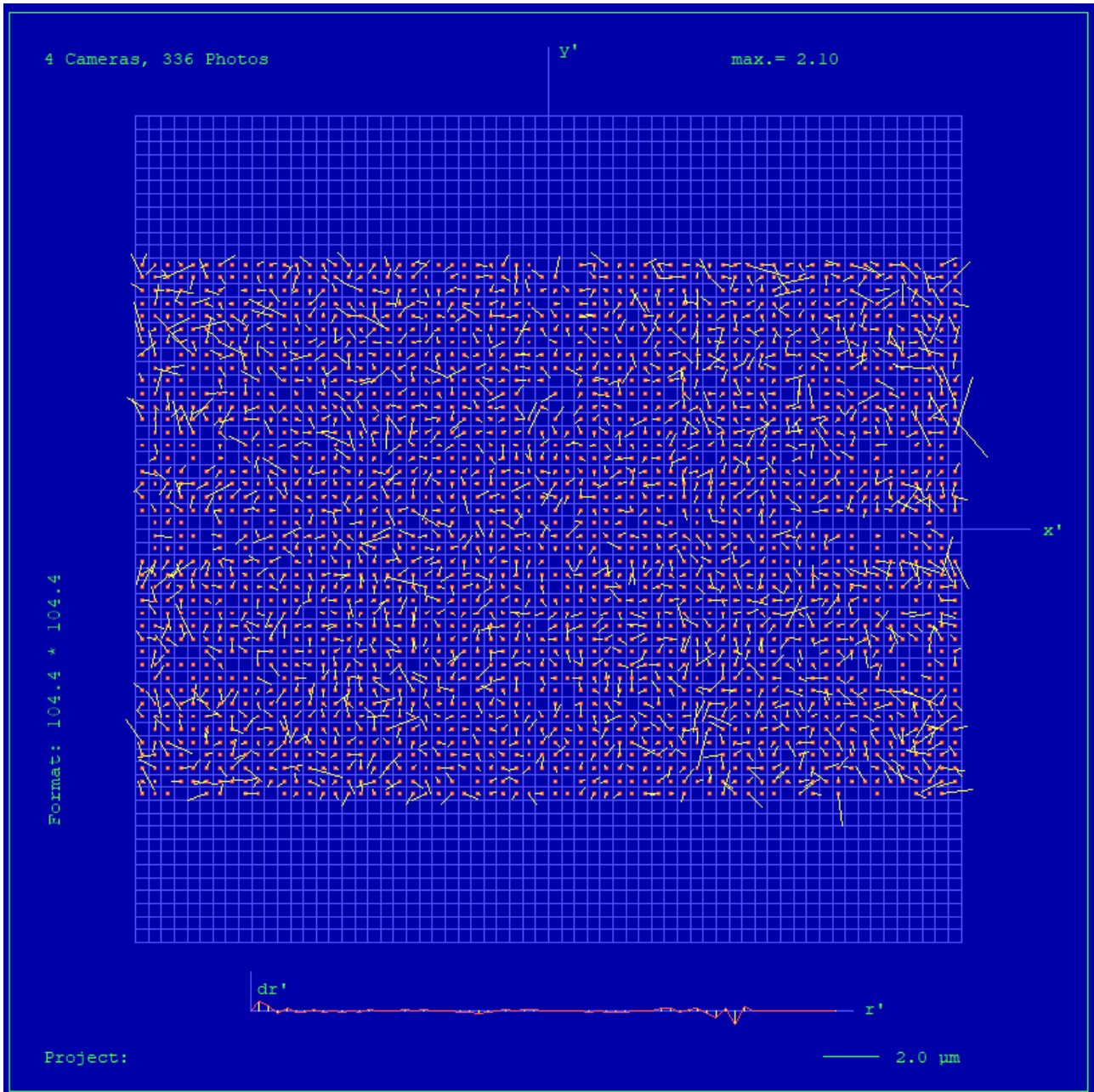
Multispectral Camera

Medium Format Multispectral Output Image (Upscaled to panchromatic image format)

Image Format	long track cross track	67.860mm 103.860mm	3770pixel 5770pixel
Image Extent		(-33.930, -51.930)mm	(33.930, 51.930)mm
Pixel Size		18.000µm*18.000µm	
Focal Length	ck	100.500mm	± 0.002mm
Principal Point (Level 2)	X_ppa	0.000mm	± 0.002mm
	Y_ppa	-0.120mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		



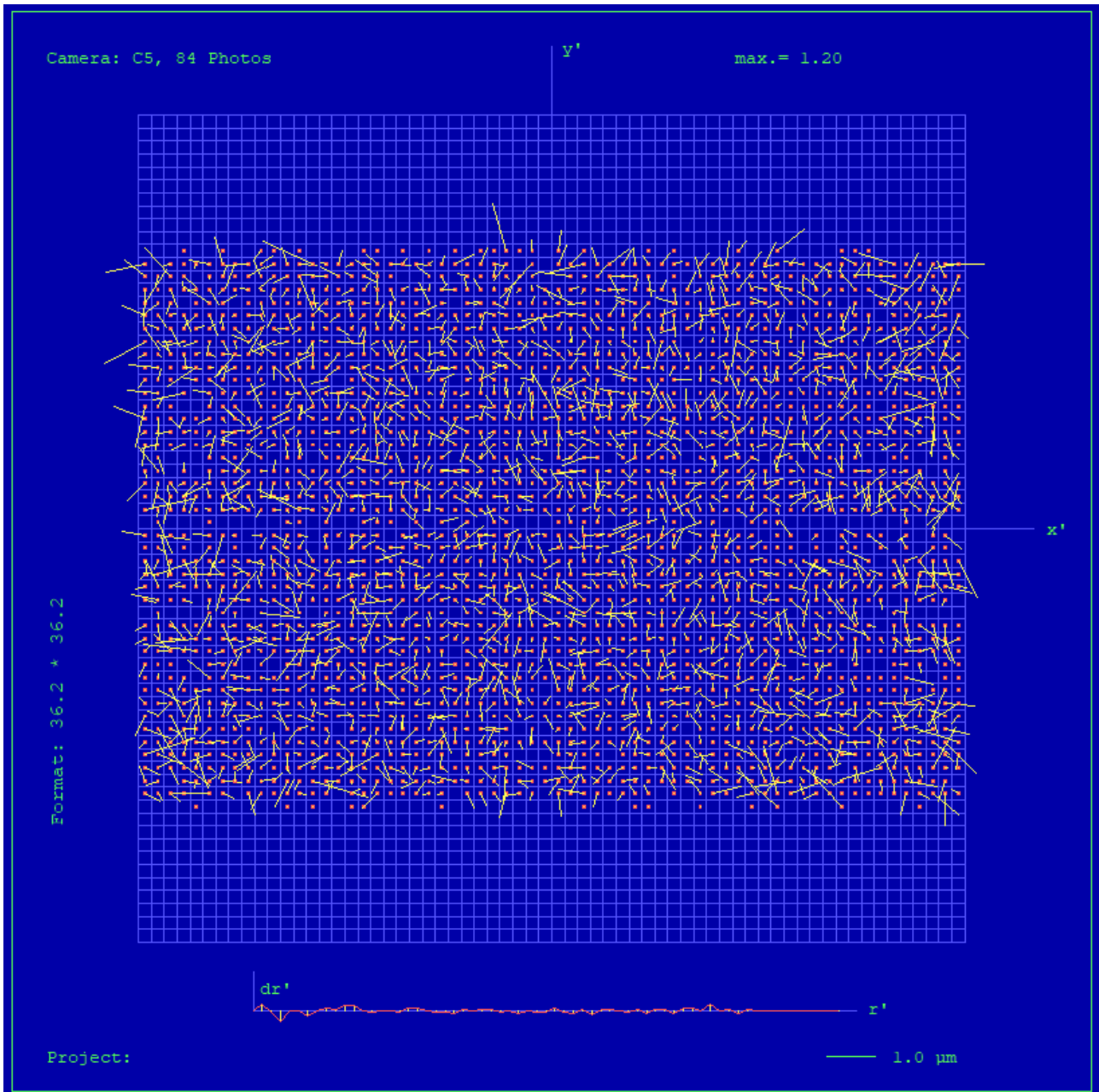
Full Panchromatic Image, Residual Error Diagram



Residual Error (RMS): **0.81 μm**



Green Cone (Cone 5), Residual Error Diagram



Residual Error (RMS): **0.59 μm**



Explanations

Calibration Method:

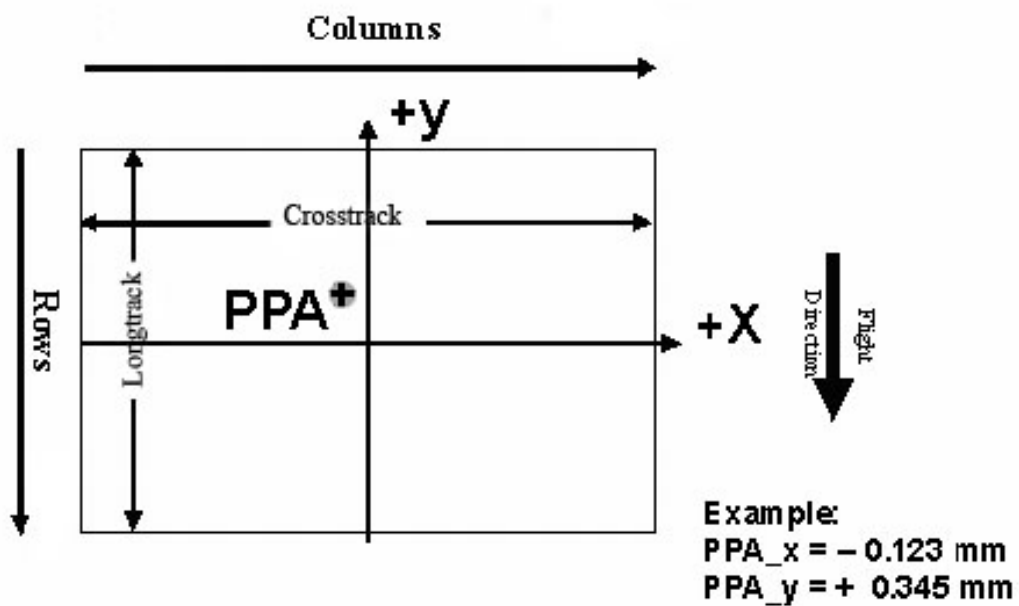
The geometric calibration is based on a set of 84 images of a defined geometry target with 394 GCPs.

Number of point measurements for the panchromatic camera : >16000
Number of point measurements for the multispectral camera : >60000

Determination of the image parameters by Least Squares Adjustment.
Software used for the adjustment: BINGO (GIP Eng. Aalen, Germany)

Level 2 Image Coordinate System:

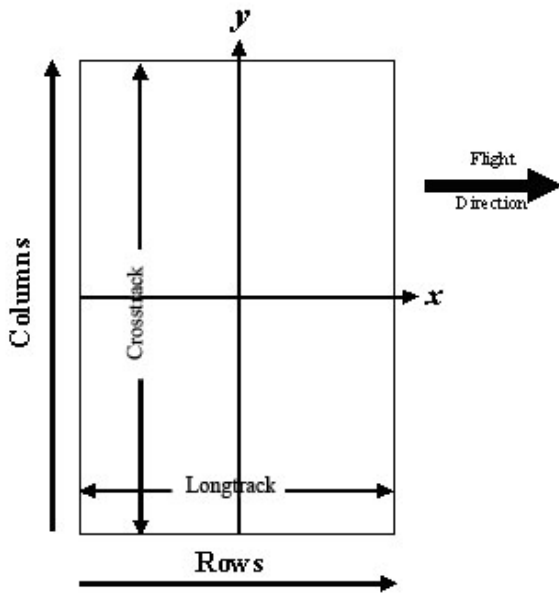
Lvl2, Camera prop. Orientation



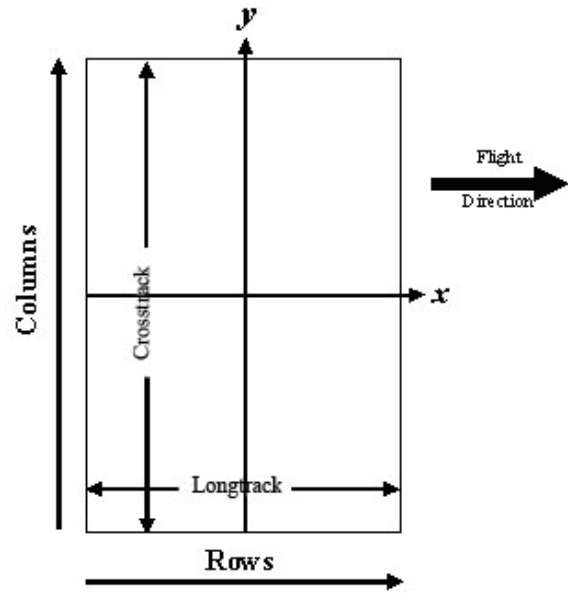
The image coordinate system of the Level 2 images is shown in the above figure. The basic image format and coordinate of the principal point in the level 2 image is given on page 4 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).



Level 3 Image Coordinate System:
(after rotation of 270° CW)



Panchromatic Image Format



Multispectral Image Format

Position of Principal Point in Level 3 Image

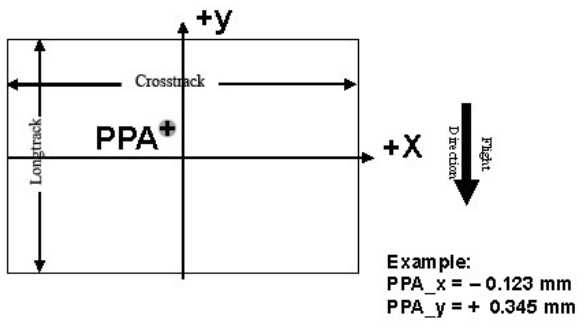
The position of the principal point in the level 3 image depends on the “rotation” setting used in UltraMap during the pan-sharpening step. The exact position relative to the image center is given in the table below as a function of the rotation setting used in UltraMap. The coordinates are specified for clockwise (CW) rotation in steps of 90 degrees, according to the principal point coordinate given on page 4 for high- and low resolution images.

Image Format	Clockwise Rotation (Degree)	PPA	
		X	Y
Level 2	-	0.000	-0.120
Level 3	0	0.000	-0.120
Level 3	90	-0.120	0.000
Level 3	180	0.000	0.120
Level 3	270	0.120	0.000

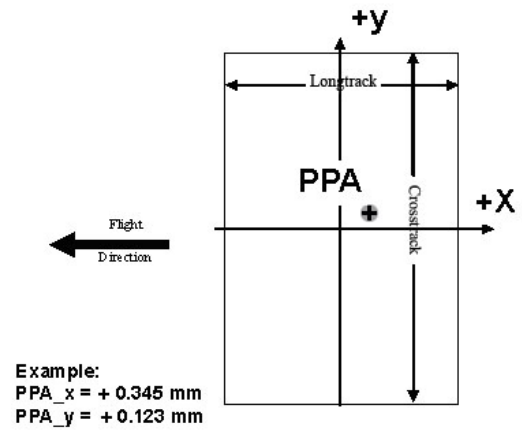


The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

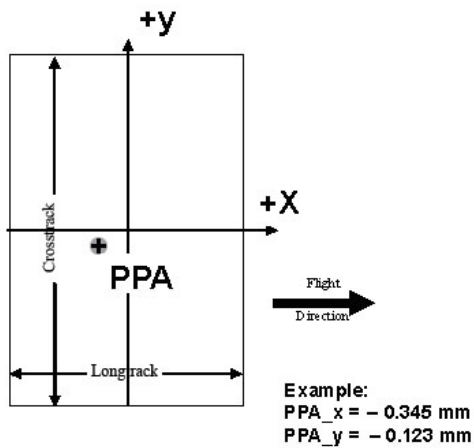
Lvl3, Rotation 0 deg clockwise



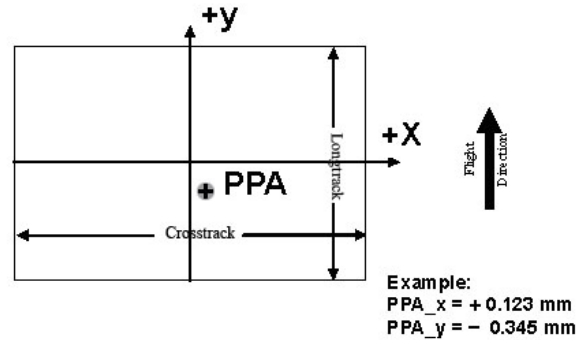
Lvl3, Rotation 90 deg clockwise



Lvl3, Rotation 270 deg clockwise



Lvl3, Rotation 180 deg clockwise





Lens Resolving Power

The following curves show the development of the modulation transfer function across different image heights of the panchromatic cones.

Please note that these values have been calculated and can vary up to 10% with optics from production (especially at high LP's).

The curves are given for the meridional (tangential) and sagittal (radial) component of signals at frequencies of 12.5, 25, 50 and 100 line pairs per millimeter.

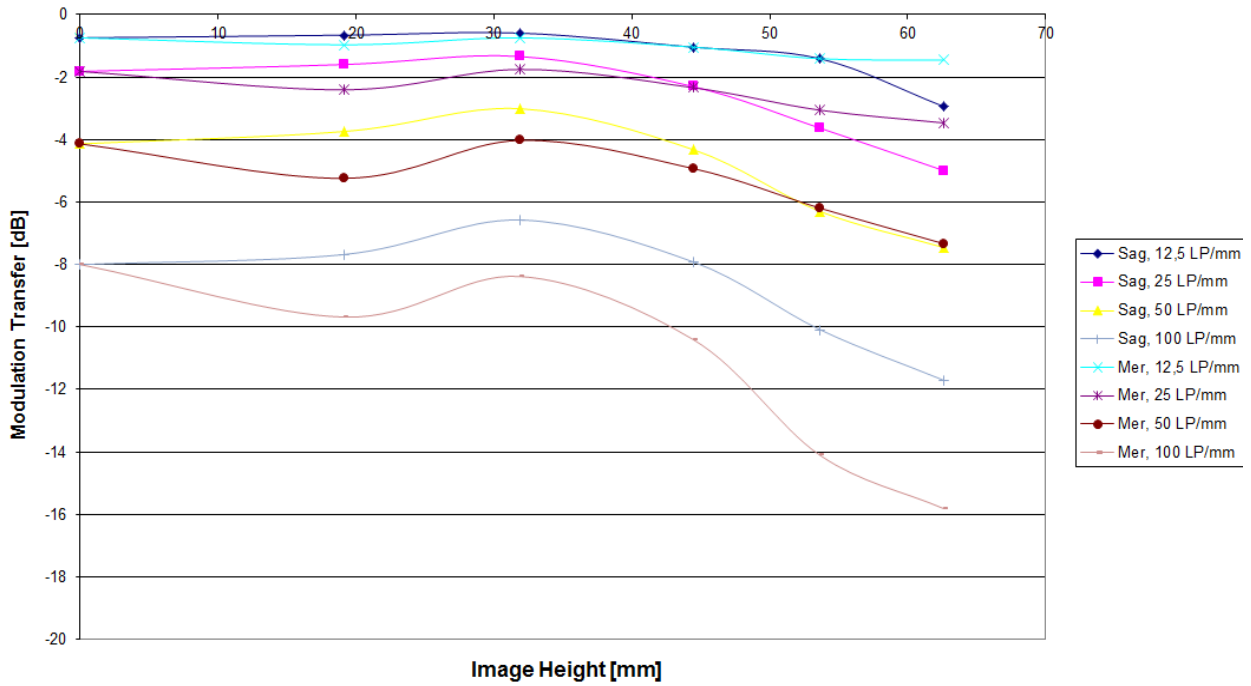
As the MTF is a function of the specific aperture size used, one set of curves is given for each aperture size.

Lens types

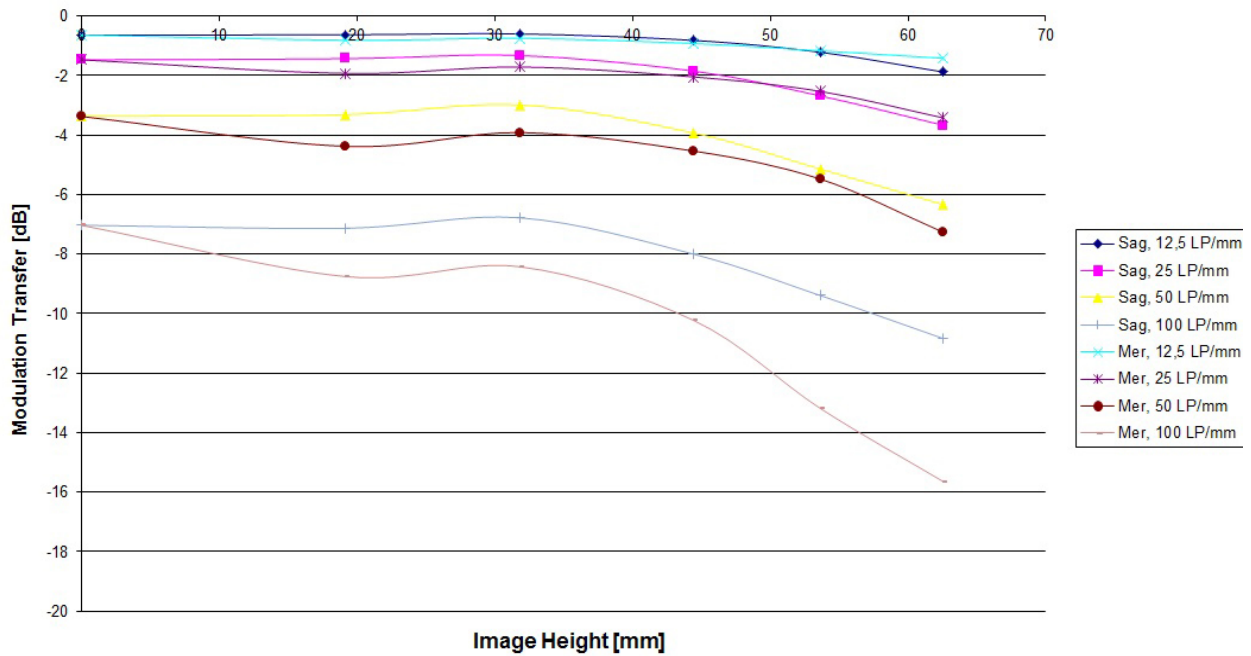
Cone	Lens
C0	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C1	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C2	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C3	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C4 (RED)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany
C5 (GREEN)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany
C6 (BLUE)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany
C7 (NIR)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany



Modulation versus Image Height - Aperture f/ 5.6

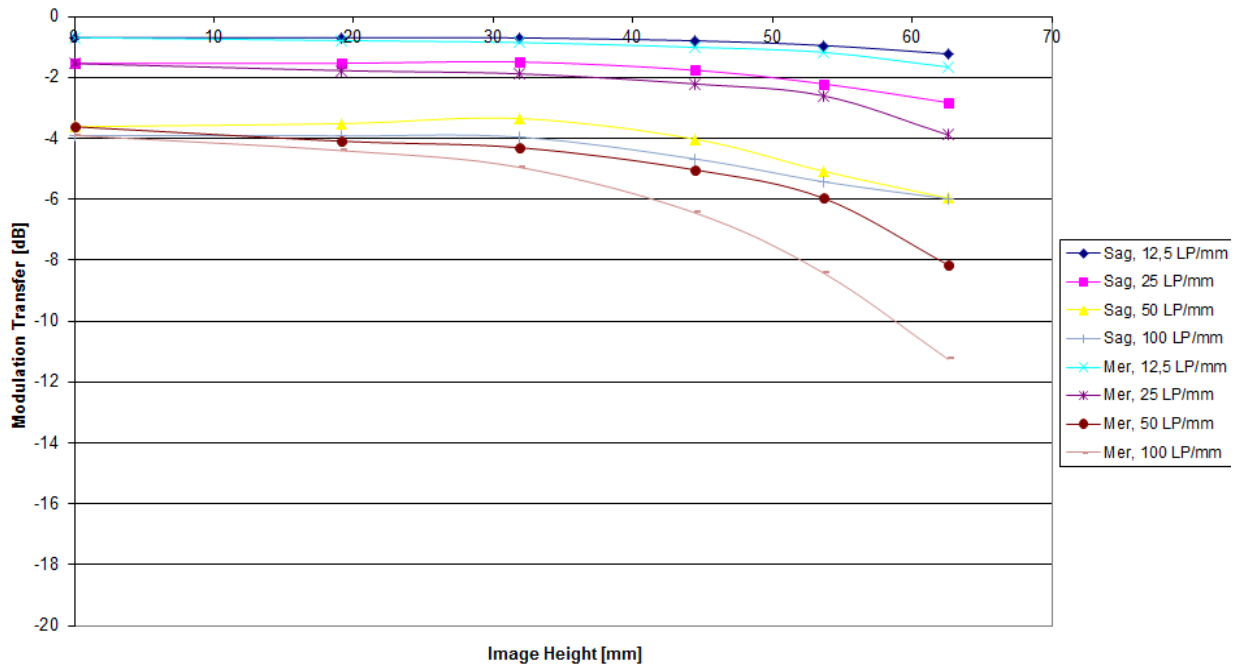


Modulation versus Image Height - Aperture f/ 6.7

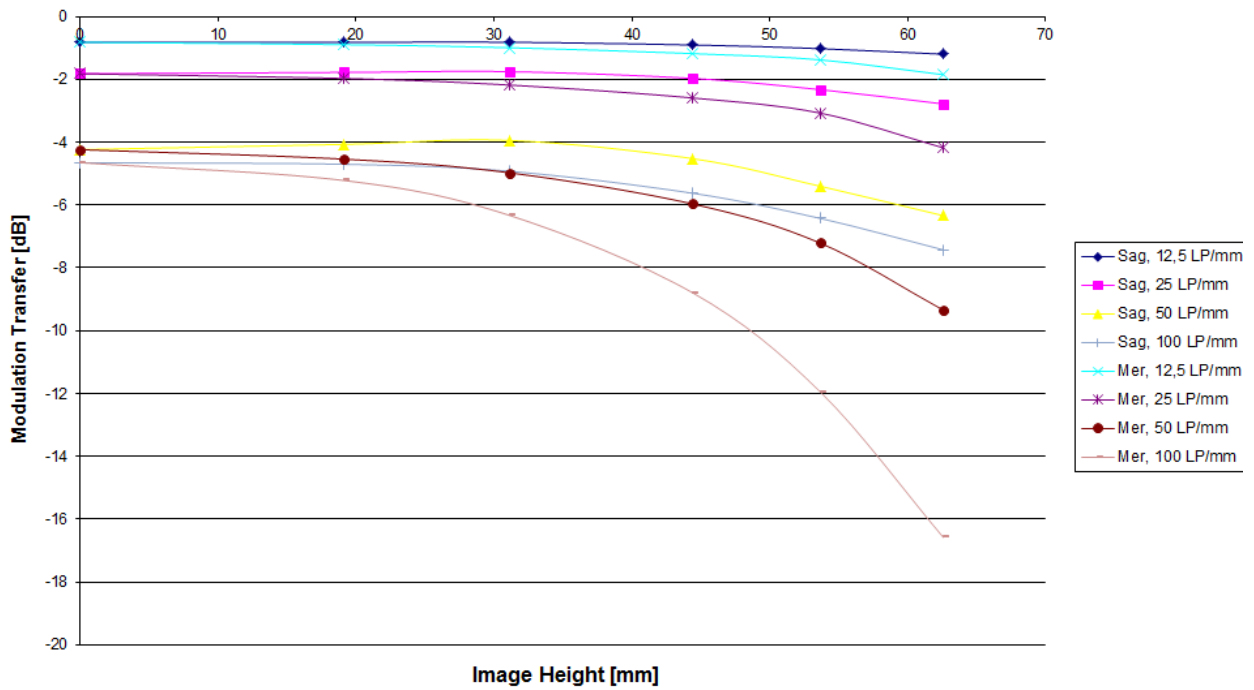




Modulation versus Image Height - Aperture f / 8



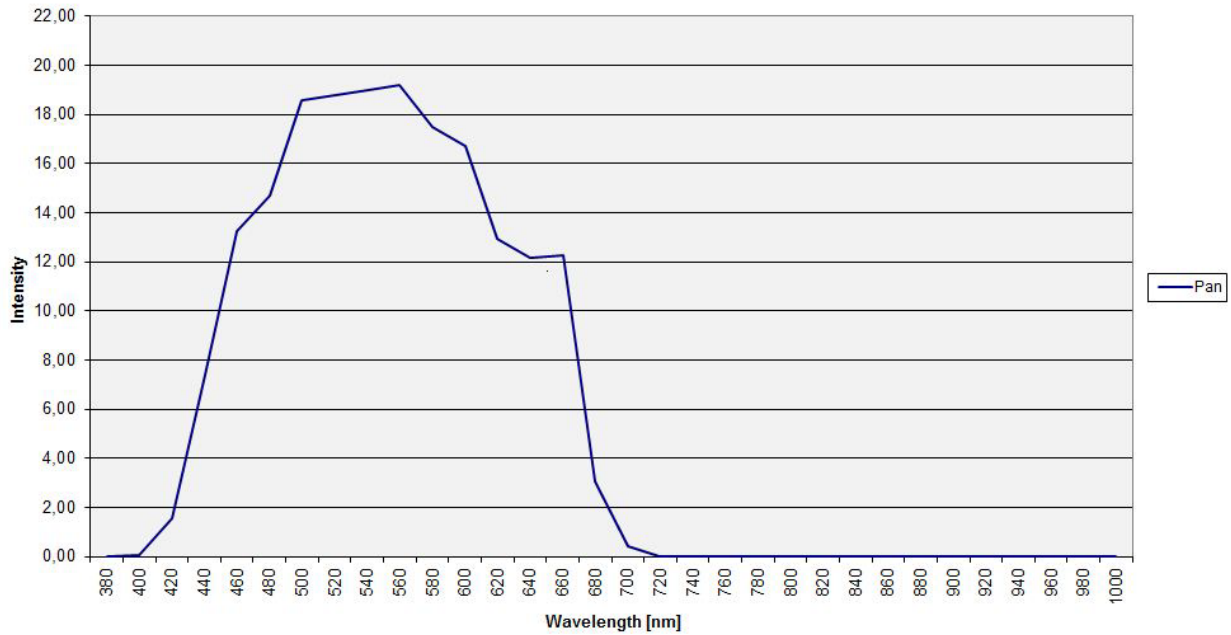
Modulation versus Image Height - Aperture f / 9.5



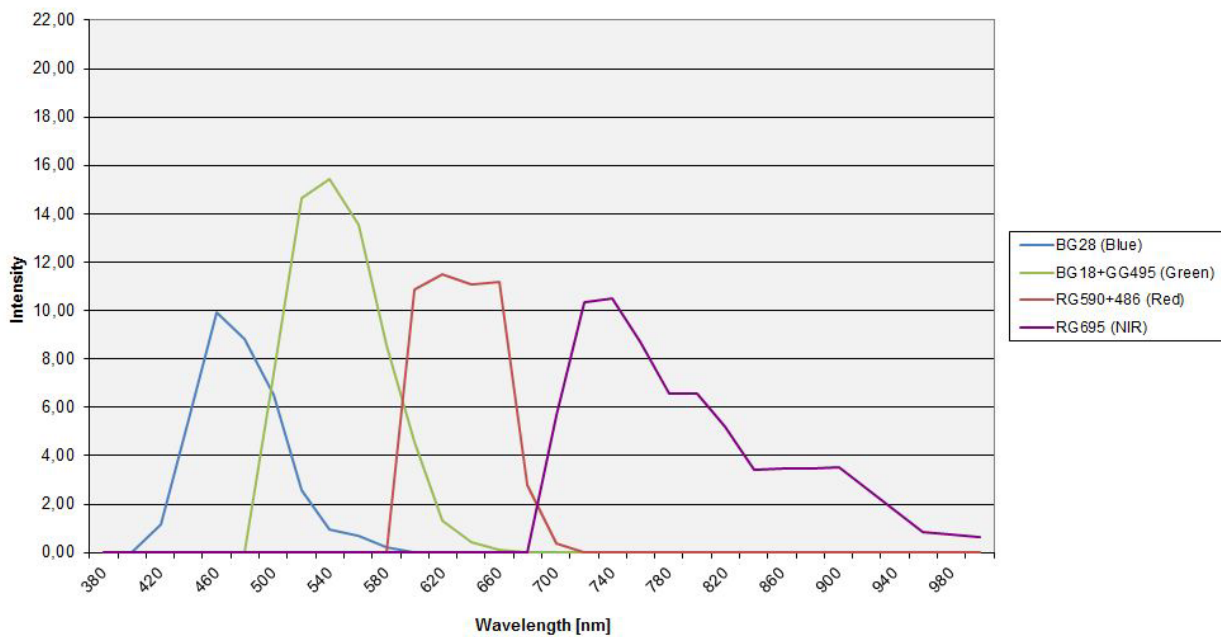


Spectral Sensitivity

Spectral Sensitivity Vexcel UCX - Panchromatic with AR-106 Coating



Spektral Sensitivity Vexcel UCX - Multispectral with AR-106 Coating





ULTRACAM

Radiometric Calibration

Camera: UltraCam Falcon Prime
Serial: UC-Fp-1-50811038-f100

	PAN	R, G, NIR	B
Used Apertures	F5.6	F4.8	F4.8
	F6.7	F5.6	F4.8
	F8	F6.7	F4.8
	F9.5	F8	F5.6
	F11	F9.5	F6.7
	F13	F11	F8
	F16	F13	F9.5
	F22	F19	F13

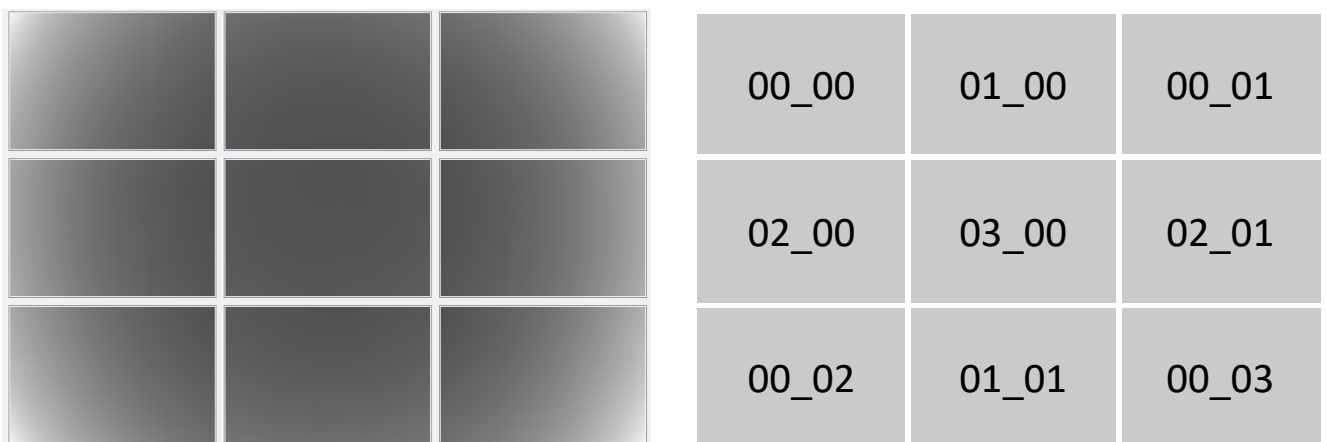
Dead Pixel Report: see Appendix I



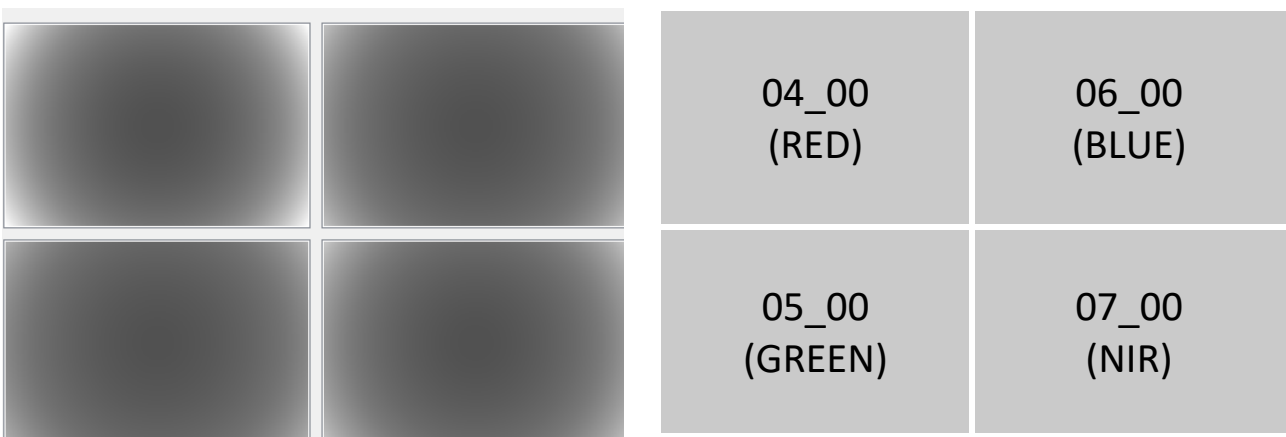
Calibration of Vignetting for working Aperture F6.7

	PAN	R, G, NIR	B
Aperture	F6.7	F5.6	F4.8

Graphical Overview of Pan Sensors:



Graphical Overview of Multispectral Sensors:





Explanations

Calibration Method:

The radiometric calibration is based on a series of 50 flat field images for each aperture size and sensor. The flat field is illuminated by eight normal light lamps with known spectral illumination curves.

These images are used to calculate the specific sensitivity of each pixel to compensate local as well as global variations in sensitivity. Sensitivity tables are calculated for each sensor and aperture setting, and applied during post processing from level 0 to level 1.

Outlier Pixels that do not have a linear behavior as described in the CCD specifications are marked as defective during the calibration procedure. These pixels are not used or only partially used during post processing and the information is restored by interpolation between the neighborhood pixels surrounding the defective pixels.

Certain pixels that are named Qmax pixels due to the fact that they can only store and transfer charge up to a certain maximum amount are detected in an additional calibration step. These pixels are treated differently during post processing, since their behavior can affect not only single pixel values but whole columns.



ULTRACAM

Shutter Calibration

Camera: UltraCam Falcon Prime
Serial: UC-Fp-1-50811038-f100

Panchromatic Camera: 4 * Prontor Magnetic 0
Prontor-Werk Alfred Gauthier GmbH, Germany

Multispectral Camera: 4 * Prontor Magnetic 0
Prontor-Werk Alfred Gauthier GmbH, Germany



Calibration of Shutter Release Times:

The shutter release times measured during the calibration describe the time from the moment when the electrical current through the shutter is turned off by the electronics, until the shutter is mechanically closed.

This time is relevant for the exposure control and needs to be known before image recording can take place.

Currently used SRT values (operation values):

Cone Number	Lens Serial Number	SRT F5.6 [ms]	SRT F6.7 [ms]	SRT F8 [ms]	SRT F9.5 [ms]	SRT F11 [ms]	SRT F13 [ms]	SRT F16 [ms]	SRT F22 [ms]	Measurement Tolerance [ms]
C0 (Pan)	12 13 49 59	10.6 2	10.8 1	11.2 3	11.7 8	12.0 7	12.4 3	12.7 5	13.0 6	+/- 0.2
C1 (Pan)	12 13 49 55	10.6 5	10.8 7	11.1 9	11.6 3	12.0 0	12.3 7	12.6 0	12.9 2	+/- 0.2
C2 (Pan)	12 13 49 38	10.1 7	10.4 3	10.7 7	11.1 7	11.4 8	11.8 1	12.1 1	12.4 4	+/- 0.2
C3 (Pan)	12 13 49 39	10.3 1	10.4 9	10.9 5	11.3 6	11.6 6	11.9 7	12.2 1	12.5 1	+/- 0.2
C4 (Red)	12 13 49 39	11.5 2	11.6 9	12.0 3	12.3 1	12.5 4	12.7 7	12.8 9	13.0 7	+/- 0.2
C5 (Green)	12 13 62 31	10.4 7	10.6 0	10.9 1	11.2 1	11.3 7	11.5 6	11.6 9	11.7 6	+/- 0.2
C6 (Blue)	12 13 62 33	10.5 3	10.5 6	10.6 4	11.0 4	11.3 4	11.5 6	11.8 6	12.0 0	+/- 0.2
C7 (NIR)	12 13 62 36	11.9 2	12.2 0	12.3 4	12.6 2	12.7 3	12.7 8	12.9 9	13.0 8	+/- 0.2



ULTRACAM

Electronics and Sensor Calibration

Camera: UltraCam Falcon Prime
Serial: UC-Fp-1-50811038-f100

Panchromatic Camera: 9 * FTF6040-M Area CCD Sensor by DALSA
Multispectral Camera: 4 * FTF6040-M Area CCD Sensor by DALSA



Calibration of Negative Substrate Voltage (VNS):

For optimum performance of the DALSA CCD sensors, the negative substrate voltage is adjusted to a value specified by DALSA.

This voltage value is measured to achieve the best anti-blooming performance possible for each particular sensor.

Currently used VNS and VOG values (operation values):

Cone_Sensor	Sensor Type	Sensor Serial Number	VNS Voltage [V]
00_00	FTF6040-M	14 4982/073	22.50
00_01	FTF6040-M	14 4985/063	22.30
00_02	FTF6040-M	14 4982/079	21.80
00_03	FTF6040-M	14 3859/100	22.60
01_00	FTF6040-M	14 3859/106	22.50
01_01	FTF6040-M	14 3859/081	22.50
02_00	FTF6040-M	14 4982/057	22.10
02_01	FTF6040-M	14 4982/059	22.50
03_00	FTF6040-M	14 4982/075	22.10
04_00 (red)	FTF6040-M	14 3859/091	22.50
05_00 (green)	FTF6040-M	14 4982/077	22.30
06_00 (blue)	FTF6040-M	14 4982/052	22.10
07_00 (NIR)	FTF6040-M	14 3859/131	22.50



Calibration of Intensity Threshold for Exposure Control:

Each CCD sensor and electronics module varies slightly in global sensitivity and intensity scale.

Therefore the maximum possible intensity of each sensor needs to be measured to evaluate the sensitivity behavior of the CCD and electronics.

This value is used as a threshold for the exposure control dialogue shown in the in-flight user interface of the Eagle.

Currently used Threshold values (operation values):

Cone_Sensor	Sensor Type	Sensor Serial Number	Intensity Threshold [DN]
00_00	FTF6040-M	14 4982/073	13180
00_01	FTF6040-M	14 4985/063	12390
00_02	FTF6040-M	14 4982/079	13240
00_03	FTF6040-M	14 3859/100	13570
01_00	FTF6040-M	14 3859/106	13590
01_01	FTF6040-M	14 3859/081	13610
02_00	FTF6040-M	14 4982/057	12340
02_01	FTF6040-M	14 4982/059	12870
03_00	FTF6040-M	14 4982/075	13270
04_00 (red)	FTF6040-M	14 3859/091	12680
05_00 (green)	FTF6040-M	14 4982/077	11830
06_00 (blue)	FTF6040-M	14 4982/052	12820
07_00 (NIR)	FTF6040-M	14 3859/131	13540



ULTRACAM

Summary

Camera:	UltraCam Falcon Prime
Serial:	UC-Fp-1-50811038-f100
Laboratory Calibration Date:	May-19-2023
Camera Revision:	Rev04.00
Date of Report:	May-19-2023
Version of Report:	V01

The following calibrations have been performed for the above mentioned digital aerial mapping camera:

- Geometric Calibration
- Radiometric Calibration
- Shutter Calibration
- Sensor and Electronics Calibration

This equipment is operating fully within specification as defined by Vexcel Imaging GmbH.

Dr. Michael Gruber
Chief Scientist, Photogrammetry
Vexcel Imaging GmbH

Dipl. Ing. (FH) Helmut Jauk
Senior Project Engineer R&D
Vexcel Imaging GmbH



Appendix I

Dead Pixel Report:

Sensor number	Anomaly type	X-Coordinate	Y-Coordinate
C00-00			
	PIXEL:	2616/ 110	PIXEL: 4425/ 878
	PIXEL:	3730/1103	PIXEL: 2366/1242
	PIXEL:	4423/1292	PIXEL: 2649/1399
	PIXEL:	2757/2874	PIXEL: 222/2879
	PIXEL:	1772/3805	PIXEL: 2823/3950
	PIXEL:	1863/3695	PIXEL: 1864/3695
	PIXEL:	4011/3907	PIXEL: 2073/1028
			PIXEL: 4632/1244
			PIXEL: 3768/1859
			PIXEL: 3074/3541
			PIXEL: 3906/1180
			PIXEL: 2342/3845
			PIXEL: 530/1292
			PIXEL: 5851/2490
			PIXEL: 3822/3637
			PIXEL: 2189/3688
			PIXEL: 3361/3882
C00-01			
	PIXEL:	5236/ 498	PIXEL: 422/1295
	PIXEL:	2260/1016	PIXEL: 1504/1885
	PIXEL:	1473/1793	PIXEL: 667/2591
	PIXEL:	1081/2428	PIXEL: 3590/3500
	PIXEL:	1202/3088	PIXEL: 2771/1128
	PIXEL:	2970/3732	PIXEL: 2539/3028
	PIXEL:	3384/2520	PIXEL: 3728/3923
	PIXEL:	3728/3924	PIXEL: 6017/3907
	PIXEL:	4834/3934	PIXEL: 839/1358
	PIXEL:	2378/ 48	PIXEL: 2686/2210
			PIXEL: 1558/2623
			PIXEL: 1010/3521
			PIXEL: 2346/2254
			PIXEL: 3249/3059
			PIXEL: 3729/3923
			PIXEL: 2675/ 24
			PIXEL: 1987/1704
			PIXEL: 5353/2344
			PIXEL: 5588/3077
			PIXEL: 5716/3669
			PIXEL: 2347/2254
			PIXEL: 2926/3182
			PIXEL: 3729/3924
			PIXEL: 2674/ 24
C00-02			
	PIXEL:	1788/ 398	PIXEL: 5823/ 547
	PIXEL:	3827/ 429	PIXEL: 365/1009
	PIXEL:	3496/ 882	PIXEL: 3059/2362
	PIXEL:	545/2228	PIXEL: 5162/2660
	PIXEL:	2642/2657	PIXEL: 1445/3089
	PIXEL:	3751/2908	PIXEL: 5443/ 696
	PIXEL:	62/3797	PIXEL: 5514/3950
	PIXEL:	5346/2973	PIXEL: 5513/3951
	PIXEL:	1551/ 40	PIXEL: 2632/ 617
			PIXEL: 4430/1308
			PIXEL: 1551/2431
			PIXEL: 3012/2843
			PIXEL: 1722/3313
			PIXEL: 5813/1074
			PIXEL: 5514/3951
			PIXEL: 702/ 638
			PIXEL: 2648/1823
			PIXEL: 5811/2570
			PIXEL: 5795/2846
			PIXEL: 3486/3482
			PIXEL: 5949/1732
			PIXEL: 3120/ 16
C00-03			
	PIXEL:	1693/ 403	PIXEL: 5150/ 446
	PIXEL:	867/ 660	PIXEL: 1272/ 755
	PIXEL:	4668/1411	PIXEL: 2750/1638
			PIXEL: 1542/ 500
			PIXEL: 2276/1046
			PIXEL: 4476/1638
			PIXEL: 1289/ 535
			PIXEL: 4505/1145
			PIXEL: 3851/1686



PIXEL: 3092/1725	PIXEL: 2177/1790	PIXEL: 2188/1915	PIXEL: 1322/2014
PIXEL: 5867/2118	PIXEL: 5230/2198	PIXEL: 388/2215	PIXEL: 3800/2522
PIXEL: 2502/2529	PIXEL: 3641/2596	PIXEL: 5279/2638	PIXEL: 4969/2838
PIXEL: 1374/3388	PIXEL: 3621/3508	PIXEL: 3931/3664	PIXEL: 5146/3847
PIXEL: 1203/2464	PIXEL: 2224/2742	PIXEL: 2225/2742	PIXEL: 2223/2743
PIXEL: 2224/2743	PIXEL: 5733/3982	PIXEL: 5733/3983	

C01-00

PIXEL: 1450/ 140	PIXEL: 6020/ 597	PIXEL: 1610/ 783	
PIXEL: 5687/ 990	PIXEL: 4599/1239	PIXEL: 3975/1510	PIXEL: 5238/1570
PIXEL: 4069/1671	PIXEL: 3164/2257	PIXEL: 4842/2282	PIXEL: 4472/2485
PIXEL: 5158/2645	PIXEL: 5456/2696	PIXEL: 1774/3334	PIXEL: 1774/3335
PIXEL: 1925/3339	PIXEL: 3777/3342	PIXEL: 3156/3537	PIXEL: 3132/3696
PIXEL: 690/ 476	PIXEL: 4778/3004	PIXEL: 4778/3005	PIXEL: 689/ 476

C01-01

PIXEL: 1806/ 272	PIXEL: 4606/ 465		
PIXEL: 248/1114	PIXEL: 4065/1408	PIXEL: 2611/1431	PIXEL: 1721/1464
PIXEL: 2577/1620	PIXEL: 5205/1756	PIXEL: 713/1796	PIXEL: 2629/2035
PIXEL: 5084/2076	PIXEL: 358/2218	PIXEL: 1270/2928	PIXEL: 4969/3243
PIXEL: 3785/3339	PIXEL: 4050/3342	PIXEL: 525/3466	PIXEL: 5911/3751
PIXEL: 5925/3886			

C02-00

PIXEL: 3613/ 92			
PIXEL: 2798/ 200	PIXEL: 2219/ 445	PIXEL: 4008/ 611	PIXEL: 288/ 824
PIXEL: 149/ 865	PIXEL: 628/1000	PIXEL: 118/1230	PIXEL: 762/1411
PIXEL: 31/1566	PIXEL: 3272/2305	PIXEL: 3727/2693	PIXEL: 2471/3305
PIXEL: 5938/3467	PIXEL: 4597/3527	PIXEL: 2927/3670	PIXEL: 3217/3913
PIXEL: 2652/1743	PIXEL: 4323/2738	PIXEL: 2917/2777	PIXEL: 2918/2777
PIXEL: 2918/2778	PIXEL: 637/3622	PIXEL: 638/3622	PIXEL: 639/3622
PIXEL: 27/3904	PIXEL: 1763/ 16		

C02-01

PIXEL: 3415/ 109	PIXEL: 4907/ 363	PIXEL: 3182/1046	PIXEL: 2015/1059
PIXEL: 5892/1472	PIXEL: 53/1563	PIXEL: 1532/1841	PIXEL: 3998/2447
PIXEL: 3697/2518	PIXEL: 2066/2837	PIXEL: 1639/3154	PIXEL: 59/3663
PIXEL: 1280/3777	PIXEL: 2759/3792	PIXEL: 126/3976	

C03-00

PIXEL: 4938/ 157	PIXEL: 838/ 254	PIXEL: 2256/ 290	
PIXEL: 2045/ 521	PIXEL: 5481/1387	PIXEL: 3324/1521	PIXEL: 1745/1581
PIXEL: 2477/1893	PIXEL: 5259/2013	PIXEL: 475/2490	PIXEL: 5293/2568
PIXEL: 1765/3763	PIXEL: 2599/3836	PIXEL: 5452/ 403	PIXEL: 1311/ 447
PIXEL: 3640/1044	PIXEL: 2670/1867		

C04-00

PIXEL: 967/1576	PIXEL: 2229/1656	PIXEL: 942/1775	PIXEL: 3000/2437
PIXEL: 1840/2715	PIXEL: 1648/2959	PIXEL: 3006/3045	PIXEL: 3006/3046
PIXEL: 5920/3819	PIXEL: 630/ 846	PIXEL: 3664/2830	PIXEL: 395/3531



PIXEL: 225/ 31	PIXEL: 976/ 32	PIXEL: 977/ 32	PIXEL: 976/ 33
PIXEL: 975/ 33			

C05-00

PIXEL: 617/ 172			
PIXEL: 2388/ 284	PIXEL: 1326/ 429	PIXEL: 206/ 613	PIXEL: 4754/1413
PIXEL: 4558/1622	PIXEL: 5308/1852	PIXEL: 5023/2110	PIXEL: 5001/2195
PIXEL: 5524/2522	PIXEL: 286/2610	PIXEL: 5800/2680	PIXEL: 4189/2717
PIXEL: 2392/2726	PIXEL: 2872/3000	PIXEL: 129/3288	PIXEL: 4179/3323
PIXEL: 3888/3332	PIXEL: 417/3390	PIXEL: 2580/3396	PIXEL: 2554/3491
PIXEL: 799/3504	PIXEL: 5049/3571	PIXEL: 272/3580	PIXEL: 5267/3814
PIXEL: 1350/3994	PIXEL: 2205/3993	PIXEL: 2206/3993	PIXEL: 2205/3994
PIXEL: 5472/ 55	PIXEL: 154/3938	PIXEL: 1120/3942	PIXEL: 1120/3941
PIXEL: 1120/3940	PIXEL: 2206/3993	PIXEL: 2205/3994	PIXEL: 5807/3972

C06-00

PIXEL: 5963/ 242	PIXEL: 3855/1382		
PIXEL: 1630/2272	PIXEL: 630/2717	PIXEL: 1043/2782	PIXEL: 2614/3619
PIXEL: 269/3711	PIXEL: 574/3756	PIXEL: 477/2857	PIXEL: 4458/ 71
PIXEL: 2598/ 53			

C07-00

PIXEL: 261/ 625			
PIXEL: 315/1021	PIXEL: 3075/3223	PIXEL: 2149/3647	PIXEL: 3141/3727
PIXEL: 5020/3745	PIXEL: 5787/3648	PIXEL: 5788/3648	PIXEL: 5787/3649
PIXEL: 5788/3649	PIXEL: 955/ 57		

Notes

COLUMN anomaly: all pixels below the Qmax detector at location (X,Y) may be affected.
 PIXEL anomaly: single detector at location (X,Y) is not functioning within normal range

The Level0 coordinates exclude the two leftmost pixels containing the line index: the corresponding pixel can therefore be located at column (X+2,Y).



Appendix II

Calibration and Modification Dates

Type of Calibration	Laboratory Calibration Date	Modification Date	Modification Reason
Geometric Calibration	19.May.2023	N/A	
Radiometric Calibration	19.May.2023	N/A	
Shutter Calibration	19.May.2023	N/A	
Electronics and Sensor Calibration	19.May.2023	N/A	

Note: The above-mentioned Laboratory Calibration Dates represent the dates the camera was calibrated in one of our calibration labs for a full Laboratory Calibration. The Modification date represents a date on which the calibration has been modified due to a calibration enhancement or part exchange. It is an additional information and does not replace the Laboratory Calibration date in any way. With the Modification Reason, always the last modification to the calibration is highlighted.