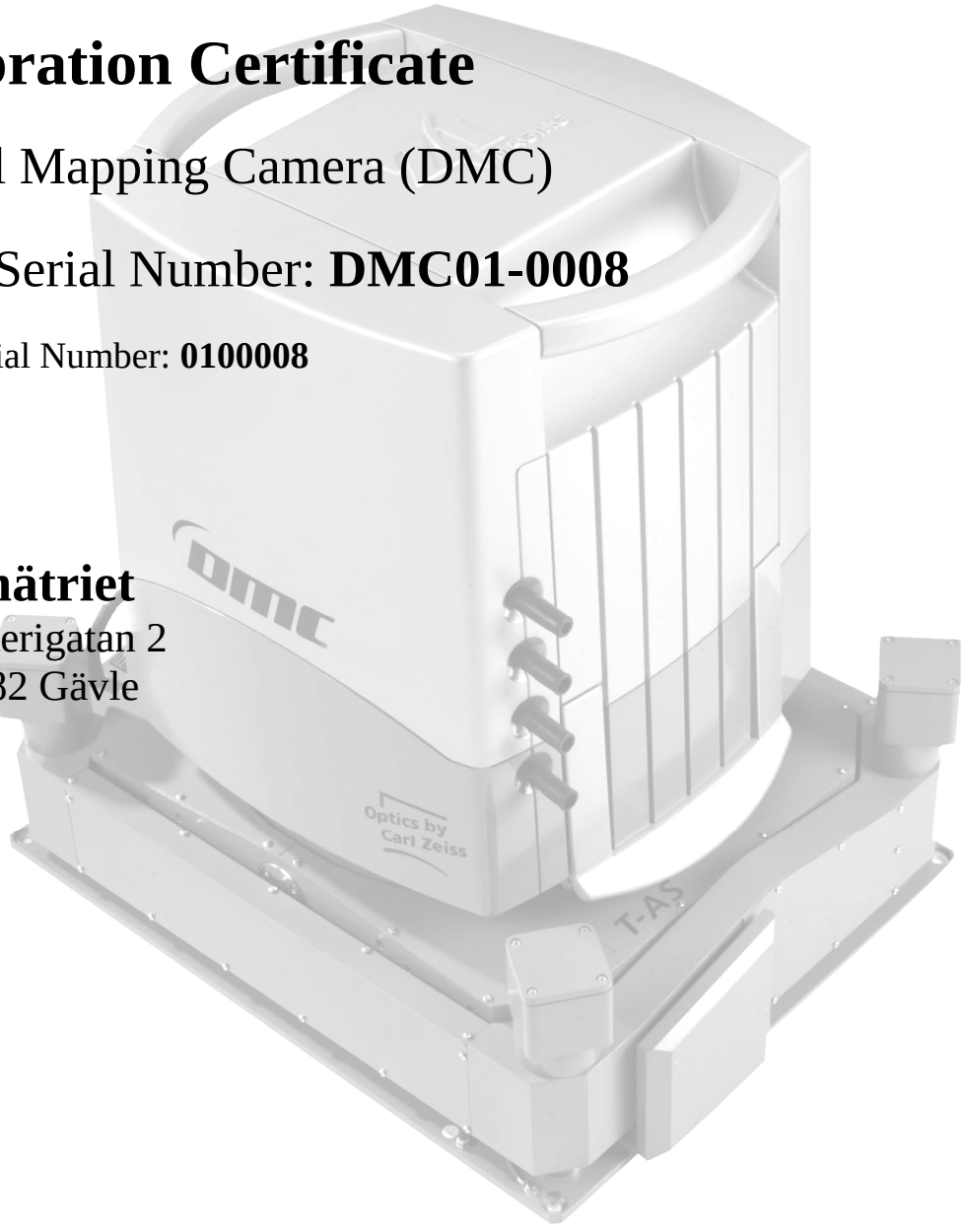
Calibration Certificate

Digital Mapping Camera (DMC)

DMC Serial Number: **DMC01-0008**

CBU Serial Number: **0100008**



For

Lantmätriet
Lantmäterigatan 2
SE-80182 Gävle

Sweden

System Overview

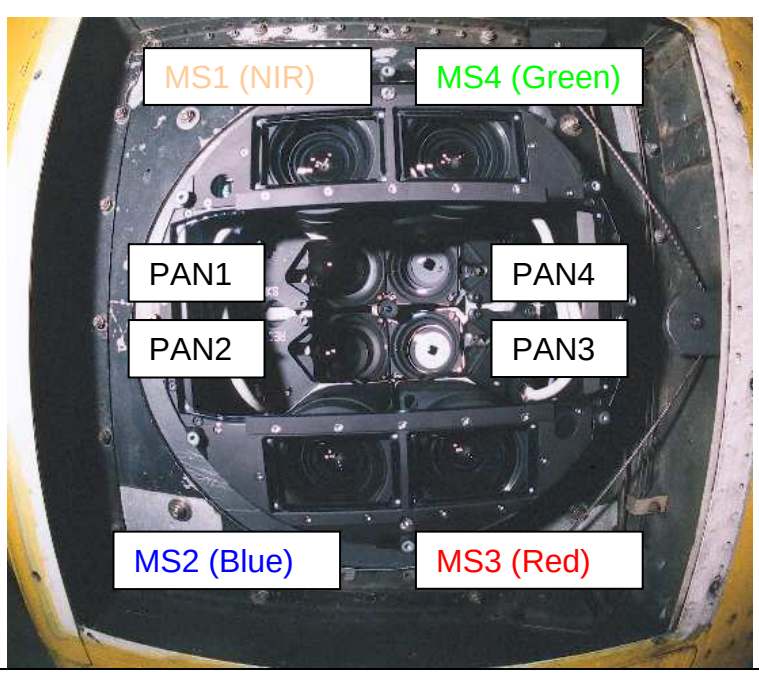


Figure: System Overview

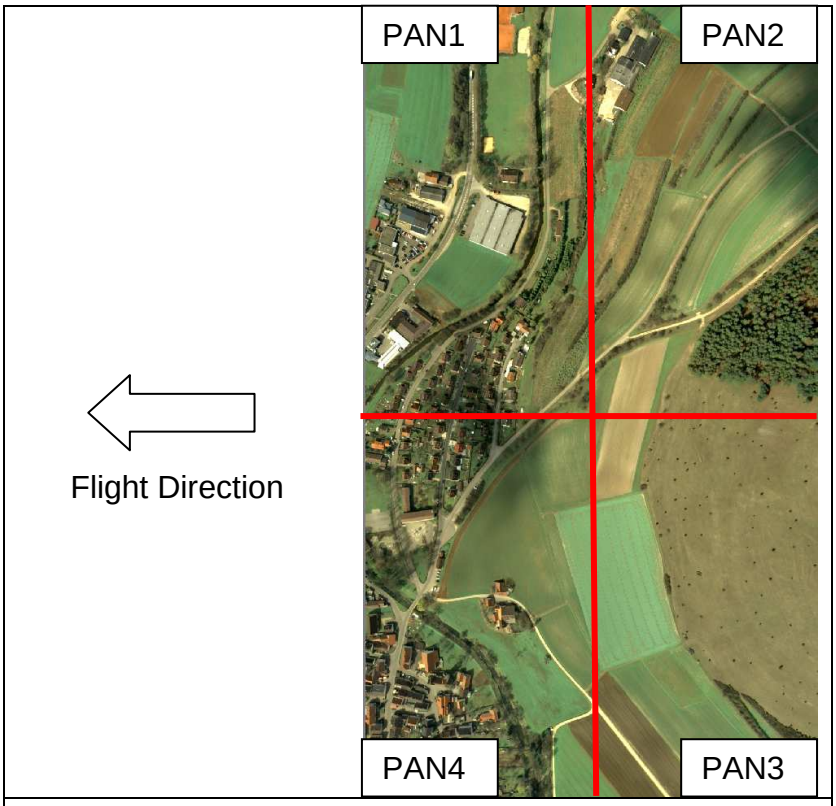


Figure Image Overview (Pan Camera)

Camera Parameter for Virtual Image (High Resolution)

Virtual Focal Length [m]	0.12
Virtual Sensor Size [Pixel]	13824 x 7680
Virtual Pixel Size [µm]	12
Virtual Principle Point [mm]	X = 0.0 Y = 0.0
Distortion Parameter	Distortion Free

Camera Parameter for Virtual Image (Color Resolution) before Version PPS 5.0.10.3

Virtual Focal Length [m]	0.12 / 4.75
Virtual Sensor Size [Pixel]	3072 x 2048
Virtual Pixel Size [µm]	12
Virtual Principle Point [mm]	X= -0.646 Y=0.646
Distortion Parameter	Distortion Free

Camera Parameter for Virtual Image (Color Resolution) after Version PPS 5.1.10.3

Virtual Focal Length [m]	0.030
Virtual Sensor Size [Pixel]	3456x1920
Virtual Pixel Size [µm]	12
Virtual Principle Point [mm]	X = 0.0 Y = 0.0
Distortion Parameter	Distortion Free

Camera Serial Number and Burn-In flights

	Burn In Flight: 13.04.2010					
Camera	Serial Number	Calib. Date				
PAN1	00110011	26.04.2004				
PAN2	00110023	26.04.2004				
PAN3	00110036	26.04.2004				
PAN4	00110034	26.04.2004				
MS1 (NIR)	00109982	27.04.2004				
MS2 (Blue)	00109998	27.04.2004				
MS3 (Red)	00114304	13.08.2008				
MS4 (Green)	00109992	07.06.2004				

Calibration Protocol
DMC01 - 0008

Camera Orientation PAN-Cameras (Burn-In Flight 13.04.2010)

Camera (Serial Number)	X [m] (Accuracy)	Y [m] (Accuracy)	Z [m] (Accuracy)	Omega [Deg] (Accuracy)	Phi [Deg] (Accuracy)	Kappa [Deg] (Accuracy)
PAN1 (00110011)	0.064 (0)	-0.079 (0)	1000 (0)	17.976296 (0.001)	10.130598 (0.001)	86.983071 (0.001)
PAN2 (00110023)	-0.064 (0)	-0.079 (0)	1000 (0)	17.959538 (0.001)	-10.164193 (0.001)	92.882666 (0.001)
PAN3 (00110036)	-0.064 (0)	0.079 (0)	1000 (0)	-18.001623 (0.001)	-10.101944 (0.001)	-92.699751 (0.001)
PAN4 (00110034)	0.064 (0)	0.079 (0)	1000 (0)	-17.931060 (0.001)	10.138554 (0.001)	-87.060029 (0.001)

The data is connected to the virtual projection center of the virtual image.
The above Platform calibration values are initial values and are be liable to slight fluctuations between project images and between different projects. The position is fix and error free. The rotation axes of the angles are (in this order)

Omega	x-Axis
Phi	y-Axis
Kappa	z-Axis

The results of the Platform calibration were generated with DMC Postprocessing SW (PPS), Version 6.1, from Intergraph Z/I Imaging photogrammetric product suite.

Platform calibration performed by

Dipl. Ing. C. Müller

29.04.2010
Date

Calibration Protocol
DMC01 - 0008

Aerotriangulation Results (Burn-In Flight 13.04.2010)

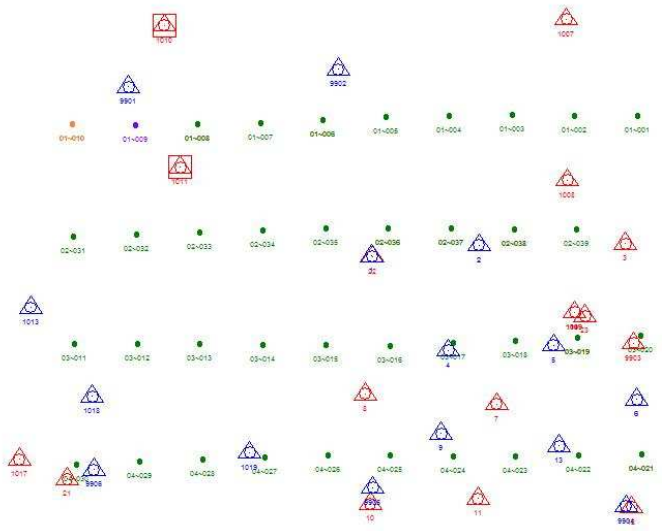


Photo Scale	1:5000
Flying Height [m]	2000 AGL
Flying Altitude [m]	2050 AMSL
Run-Spacing [m]	1105.9
Base-Length [m]	614.4
Number of Exposures	40
Side-lap [%]	60
End-lap [%]	60
Terrain Height [m]	50
Number of strips	4
Photos in one strip	4 x 10 W-E
Photos Used	40
Control Points Used	14
Check Points Used	
GSD [cm]	20

Statistic results:

Matching results: 0 Weak Areas – covered with clouds
Whole Block 40 exposures used
0 exposures not used

Whole Block Sigma relativ: 2.287 um

Whole Block Sigma absolut: 2.398 um

Whole Block

```
Photo-T Parameters and Results for Project 10imuzx08

PhotoT Triangulation Options

Adjustment Mode       : Absolute
Precision Computation : Enabled
Error Detection       : Enabled
Camera Calibration    : Disabled
Self-Calibration      : Disabled
Given EO/GPS          : Enabled
Antenna Offsets       : Disabled
GPS Shift/Drift Correction : Enabled
INS Shift/Drift Correction : Enabled


Parameters
                  Parameter X/Omega Y/Phi Z/Kappa    XY
                RMS Control   0.068 0.050   0.073 0.059
                  RMS Check
                 RMS Limits   0.100 0.100   0.150
          Max Ground Residual   0.121 0.094   0.202
              Residual Limits   0.200 0.200   0.200
          Mean Std Dev Object   0.034 0.042   0.081
           RMS Photo Position   0.039 0.023   0.034
           RMS Photo Attitude   0.003 0.003   0.008
```

Calibration Protocol
DMC01 - 0008

```
 Mean Std Dev Photo Position   0.033 0.032   0.033
 Mean Std Dev Photo Attitude   0.001 0.001   0.001

Key Statistics

       Sigma:         2.4  um
       Number of iterations: 4
       Degrees of Freedom:   8404
```

The results of the Aerotriangulation were generated with ImageStation Automatic Triangulation (ISAT), Version 6.1, from Intergraph Z/I Imaging photogrammetric product suite.

Aerotriangulation performed by

Dipl. Ing. C. Müller

29.04.2010
Date

Calibration Protocol
DMC01 - 0008

Calibration Certificate N° 00110011

Object	Digital Aerial Survey Camera
Manufacturer	Z/I Imaging D-73431 Aalen
Type	DMC Panchromatic
Serial Number	00110011

Calibration performed at:
Deutscher Kalibrierdienst (DKD)
Kalibrierstelle für Meßgrößen der geometrischen Optik
at Carl Zeiss, Oberkochen (DKD Registration No. : DKD-K-0502)

Number of pages of the certificate 38

Date of Calibration 26.Apr.2004

CertifiedDate	Division Head	Person in Charge
30.Apr.2010	(L. Bihlmaier)	(S. Schröder)

Calibration Protocol
DMC01 - 0008

Cameratype: DMC Serial no.: 00110011

Lenses mounted: PAN f=120 mm

Calibration Parameters:

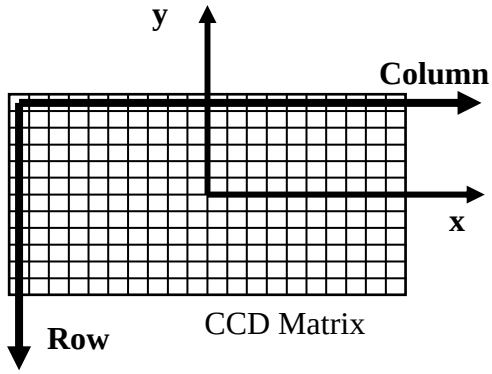
Calibrated Brown Parameters

Camera ID : 00110011

	Param	Adjusted	Std.dev.	
Principal Point [mm]	Dxp	-2.706e-004	1.186e-005	is significant
	Dyp	1.016e-004	7.201e-006	is significant
Focal Length [mm]	Dc	-3.158e-004	1.424e-006	is significant
Radial Distortion	K1	6.164e-001	2.083e-002	is significant
	K2	-3.653e+002	7.988e+000	is significant
	K3	0.000e+000	1.000e-031	is eliminated
Decentring distortion	P1	-8.041e-004	2.703e-004	is significant
	P2	8.834e-004	1.369e-004	is significant
In Plane Distortion	b1	0.000e+000	1.000e-031	is eliminated
	b2	-4.486e-005	8.369e-006	is significant

Adjusted Focal length = 120+ dc =119.9996842 [mm]

Definition of coordinate system:



Distortion Model:

$$\begin{bmatrix} \bar{x} \\ \bar{y} \\ \bar{z} \end{bmatrix} = \begin{bmatrix} x - x_0 \\ y - y_0 \\ -f \end{bmatrix} \qquad r = \sqrt{\bar{x}^2 + \bar{y}^2}$$

$$\Delta x = \Delta x_0 - \frac{\bar{x}}{\bar{z}}\Delta f + \bar{x}(r^2 K_1 + r^4 K_2 + r^6 K_3) + (r^2 + 2\bar{x}^2)P_1 + 2\bar{x}\bar{y}P_2 + \bar{x}B_1 + \bar{y}B_2$$

$$\Delta y = \Delta y_0 - \frac{\bar{y}}{\bar{z}}\Delta f + \bar{y}(r^2 K_1 + r^4 K_2 + r^6 K_3) + 2\bar{x}\bar{y}P_1 + (r^2 + 2\bar{y}^2)P_2$$

Note:

DMC Virtual Images get computed from 4 (pan) up to 8 (pan + multi spectral) cameras. During generation of virtual images (image mosaics) lens distortion gets completely eliminated. The resulting virtual image is a distortion free image rectified to a nominal focal length of 120 mm [Dörstel, Jacobsen, Stallmann, 2003; Zeitler, Dörstel, Jacobsen, 2002].

Camera calibration must not be applied during data compilation as the virtual images have nominal focal length, are distortion free and have no fiducial marks.

Camera Calibration Parameters listed referring to DMC intermediate images!

DMC geometric calibration is performed at the Carl Zeiss Calibration laboratory. The instruments used are calibrated items and being certified for camera calibration by *Deutscher Kalibrier Dienst* with permission of *Physikalisch-Technische Bundesanstalt*. The Brown Parameter Model (so called Australis Parameter) is used to model the camera geometry. The algorithms used to compute the Australis Parameters is developed by ifp (Stuttgart Institute for Photogrammetry) and published at [Dörstel et al. 2003]. The resulting DMC image mosaics are corrected for all geometric influences.

Dörstel C., Jacobsen K., Stallmann D. (2003): DMC – Photogrammetric accuracy – Calibration aspects and Generation of synthetic DMC images, Eds. M. Baltsavias / A.Grün, Optical 3D Sensor Workshop, Zürich

Zeitler W., Dörstel C., Jacobsen K. (2002): Geometric calibration of the DMC: Method and Results, Proceedings ASPRS, Denver, USA.

Calibration Protocol
DMC01 - 0008

Calibration Certificate N° 00110023

Object	Digital Aerial Survey Camera
Manufacturer	Z/I Imaging D-73431 Aalen
Type	DMC Panchromatic
Serial Number	00110023

Calibration performed at:
Deutscher Kalibrierdienst (DKD)
Kalibrierstelle für Meßgrößen der geometrischen Optik
at Carl Zeiss, Oberkochen (DKD Registration No. : DKD-K-0502)

Number of pages of the certificate 38

Date of Calibration 26.Apr.2004

CertifiedDate	Division Head	Person in Charge
30.Apr.2010	(L. Bihlmaier)	(S. Schröder)

Calibration Protocol
DMC01 - 0008

Cameratype: DMC Serial no.: 00110023

Lenses mounted: PAN f=120 mm

Calibration Parameters:

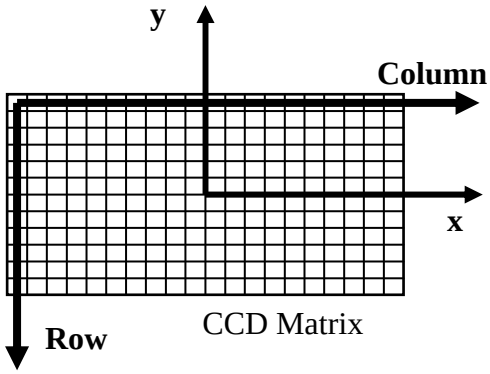
Calibrated Brown Parameters

Camera ID : 00110023

	Param	Adjusted	Std.dev.	
Principal Point [mm]	Dxp	1.001e-004	2.259e-006	is significant
	Dyp	1.835e-004	7.867e-006	is significant
Focal Length [mm]	Dc	-3.974e-004	1.893e-006	is significant
Radial Distortion	K1	6.577e-001	2.437e-002	is significant
	K2	-3.993e+002	9.275e+000	is significant
	K3	0.000e+000	1.000e-031	is eliminated
Decentring distortion	P1	0.000e+000	1.000e-031	is eliminated
	P2	4.227e-004	1.487e-004	is significant
In Plane Distortion	b1	-5.227e-005	1.781e-005	is significant
	b2	5.187e-005	9.000e-006	is significant

Adjusted Focal length = 120+ dc =119.9996026 [mm]

Definition of coordinate system:



Distortion Model:

$$\begin{bmatrix} \bar{x} \\ \bar{y} \\ \bar{z} \end{bmatrix} = \begin{bmatrix} x - x_0 \\ y - y_0 \\ -f \end{bmatrix} \qquad r = \sqrt{\bar{x}^2 + \bar{y}^2}$$

$$\Delta x = \Delta x_0 - \frac{\bar{x}}{\bar{z}}\Delta f + \bar{x}(r^2 K_1 + r^4 K_2 + r^6 K_3) + (r^2 + 2\bar{x}^2)P_1 + 2\bar{x}\bar{y}P_2 + \bar{x}B_1 + \bar{y}B_2$$

$$\Delta y = \Delta y_0 - \frac{\bar{y}}{\bar{z}}\Delta f + \bar{y}(r^2 K_1 + r^4 K_2 + r^6 K_3) + 2\bar{x}\bar{y}P_1 + (r^2 + 2\bar{y}^2)P_2$$

Note:

DMC Virtual Images get computed from 4 (pan) up to 8 (pan + multi spectral) cameras. During generation of virtual images (image mosaics) lens distortion gets completely eliminated. The resulting virtual image is a distortion free image rectified to a nominal focal length of 120 mm [Dörstel, Jacobsen, Stallmann, 2003; Zeitler, Dörstel, Jacobsen, 2002].

Camera calibration must not be applied during data compilation as the virtual images have nominal focal length, are distortion free and have no fiducial marks.

Camera Calibration Parameters listed referring to DMC intermediate images!

DMC geometric calibration is performed at the Carl Zeiss Calibration laboratory. The instruments used are calibrated items and being certified for camera calibration by *Deutscher Kalibrier Dienst* with permission of *Physikalisch-Technische Bundesanstalt*. The Brown Parameter Model (so called Australis Parameter) is used to model the camera geometry. The algorithms used to compute the Australis Parameters is developed by ifp (Stuttgart Institute for Photogrammetry) and published at [Dörstel et al. 2003]. The resulting DMC image mosaics are corrected for all geometric influences.

Dörstel C., Jacobsen K., Stallmann D. (2003): DMC – Photogrammetric accuracy – Calibration aspects and Generation of synthetic DMC images, Eds. M. Baltsavias / A.Grün, Optical 3D Sensor Workshop, Zürich

Zeitler W., Dörstel C., Jacobsen K. (2002): Geometric calibration of the DMC: Method and Results, Proceedings ASPRS, Denver, USA.

Calibration Protocol
DMC01 - 0008

Calibration Certificate N° 00110036

Object	Digital Aerial Survey Camera
Manufacturer	Z/I Imaging D-73431 Aalen
Type	DMC Panchromatic
Serial Number	00110036

Calibration performed at:
Deutscher Kalibrierdienst (DKD)
Kalibrierstelle für Meßgrößen der geometrischen Optik
at Carl Zeiss, Oberkochen (DKD Registration No. : DKD-K-0502)

Number of pages of the certificate 38

Date of Calibration 26.Apr.2004

CertifiedDate	Division Head	Person in Charge
30.Apr.2010	(L. Bihlmaier)	(S. Schröder)

Calibration Protocol
DMC01 - 0008

Cameratype: DMC Serial no.: 00110036

Lenses mounted: PAN f=120 mm

Calibration Parameters:

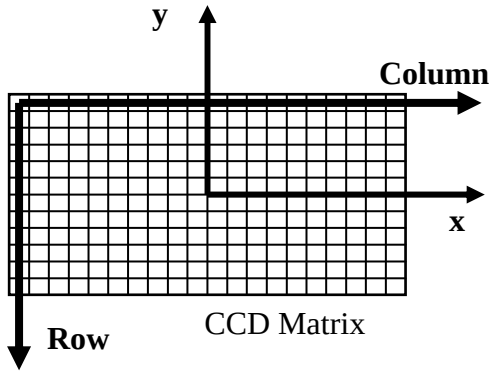
Calibrated Brown Parameters

Camera ID : 00110036

	Param	Adjusted	Std.dev.	
Principal Point [mm]	Dxp	2.106e-004	2.533e-006	is significant
	Dyp	1.919e-004	5.104e-006	is significant
Focal Length [mm]	Dc	-2.485e-004	1.742e-006	is significant
Radial Distortion	K1	6.208e-001	2.553e-002	is significant
	K2	-3.802e+002	9.813e+000	is significant
	K3	0.000e+000	1.000e-031	is eliminated
Decentring distortion	P1	0.000e+000	1.000e-031	is eliminated
	P2	0.000e+000	1.000e-031	is eliminated
In Plane Distortion	b1	0.000e+000	1.000e-031	is eliminated
	b2	2.513e-005	1.011e-005	is significant

Adjusted Focal length = 120+ dc =119.9997515 [mm]

Definition of coordinate system:



Distortion Model:

$$\begin{bmatrix} \bar{x} \\ \bar{y} \\ \bar{z} \end{bmatrix} = \begin{bmatrix} x - x_0 \\ y - y_0 \\ -f \end{bmatrix} \qquad r = \sqrt{\bar{x}^2 + \bar{y}^2}$$

$$\Delta x = \Delta x_0 - \frac{\bar{x}}{\bar{z}}\Delta f + \bar{x}(r^2 K_1 + r^4 K_2 + r^6 K_3) + (r^2 + 2\bar{x}^2)P_1 + 2\bar{x}\bar{y}P_2 + \bar{x}B_1 + \bar{y}B_2$$

$$\Delta y = \Delta y_0 - \frac{\bar{y}}{\bar{z}}\Delta f + \bar{y}(r^2 K_1 + r^4 K_2 + r^6 K_3) + 2\bar{x}\bar{y}P_1 + (r^2 + 2\bar{y}^2)P_2$$

Note:

DMC Virtual Images get computed from 4 (pan) up to 8 (pan + multi spectral) cameras. During generation of virtual images (image mosaics) lens distortion gets completely eliminated. The resulting virtual image is a distortion free image rectified to a nominal focal length of 120 mm [Dörstel, Jacobsen, Stallmann, 2003; Zeitler, Dörstel, Jacobsen, 2002].

Camera calibration must not be applied during data compilation as the virtual images have nominal focal length, are distortion free and have no fiducial marks.

Camera Calibration Parameters listed referring to DMC intermediate images!

DMC geometric calibration is performed at the Carl Zeiss Calibration laboratory. The instruments used are calibrated items and being certified for camera calibration by *Deutscher Kalibrier Dienst* with permission of *Physikalisch-Technische Bundesanstalt*. The Brown Parameter Model (so called Australis Parameter) is used to model the camera geometry. The algorithms used to compute the Australis Parameters is developed by ifp (Stuttgart Institute for Photogrammetry) and published at [Dörstel et al. 2003]. The resulting DMC image mosaics are corrected for all geometric influences.

Dörstel C., Jacobsen K., Stallmann D. (2003): DMC – Photogrammetric accuracy – Calibration aspects and Generation of synthetic DMC images, Eds. M. Baltsavias / A.Grün, Optical 3D Sensor Workshop, Zürich

Zeitler W., Dörstel C., Jacobsen K. (2002): Geometric calibration of the DMC: Method and Results, Proceedings ASPRS, Denver, USA.

Calibration Protocol
DMC01 - 0008

Calibration Certificate N° 00110034

Object	Digital Aerial Survey Camera
Manufacturer	Z/I Imaging D-73431 Aalen
Type	DMC Panchromatic
Serial Number	00110034

Calibration performed at:
Deutscher Kalibrierdienst (DKD)
Kalibrierstelle für Meßgrößen der geometrischen Optik
at Carl Zeiss, Oberkochen (DKD Registration No. : DKD-K-0502)

Number of pages of the certificate 38

Date of Calibration 26.Apr.2004

CertifiedDate	Division Head	Person in Charge
30.Apr.2010	(L. Bihlmaier)	(S. Schröder)

Calibration Protocol
DMC01 - 0008

Cameratype: DMC Serial no.: 00110034

Lenses mounted: PAN f=120 mm

Calibration Parameters:

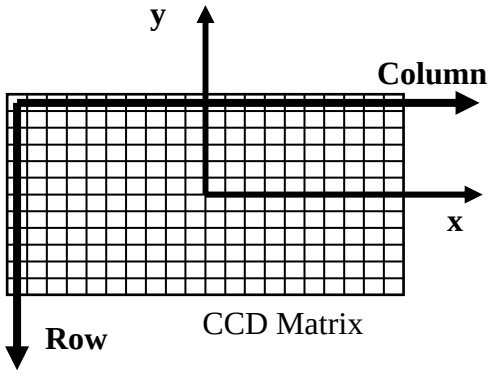
Calibrated Brown Parameters

Camera ID : 00110034

	Param	Adjusted	Std.dev.	
Principal Point [mm]	Dxp	-8.946e-006	2.176e-006	is significant
	Dyp	2.683e-004	7.620e-006	is significant
Focal Length [mm]	Dc	-2.471e-004	1.833e-006	is significant
Radial Distortion	K1	6.582e-001	2.358e-002	is significant
	K2	-3.967e+002	8.972e+000	is significant
	K3	0.000e+000	1.000e-031	is eliminated
Decentring distortion	P1	0.000e+000	1.000e-031	is eliminated
	P2	8.060e-004	1.439e-004	is significant
In Plane Distortion	b1	-8.662e-005	1.725e-005	is significant
	b2	0.000e+000	1.000e-031	is eliminated

Adjusted Focal length = 120+ dc =119.9997529 [mm]

Definition of coordinate system:



Distortion Model:

$$\begin{bmatrix} \bar{x} \\ \bar{y} \\ \bar{z} \end{bmatrix} = \begin{bmatrix} x - x_0 \\ y - y_0 \\ -f \end{bmatrix} \qquad r = \sqrt{\bar{x}^2 + \bar{y}^2}$$

$$\Delta x = \Delta x_0 - \frac{\bar{x}}{\bar{z}}\Delta f + \bar{x}(r^2 K_1 + r^4 K_2 + r^6 K_3) + (r^2 + 2\bar{x}^2)P_1 + 2\bar{x}\bar{y}P_2 + \bar{x}B_1 + \bar{y}B_2$$

$$\Delta y = \Delta y_0 - \frac{\bar{y}}{\bar{z}}\Delta f + \bar{y}(r^2 K_1 + r^4 K_2 + r^6 K_3) + 2\bar{x}\bar{y}P_1 + (r^2 + 2\bar{y}^2)P_2$$

Note:

DMC Virtual Images get computed from 4 (pan) up to 8 (pan + multi spectral) cameras. During generation of virtual images (image mosaics) lens distortion gets completely eliminated. The resulting virtual image is a distortion free image rectified to a nominal focal length of 120 mm [Dörstel, Jacobsen, Stallmann, 2003; Zeitler, Dörstel, Jacobsen, 2002].

Camera calibration must not be applied during data compilation as the virtual images have nominal focal length, are distortion free and have no fiducial marks.

Camera Calibration Parameters listed referring to DMC intermediate images!

DMC geometric calibration is performed at the Carl Zeiss Calibration laboratory. The instruments used are calibrated items and being certified for camera calibration by *Deutscher Kalibrier Dienst* with permission of *Physikalisch-Technische Bundesanstalt*. The Brown Parameter Model (so called Australis Parameter) is used to model the camera geometry. The algorithms used to compute the Australis Parameters is developed by ifp (Stuttgart Institute for Photogrammetry) and published at [Dörstel et al. 2003]. The resulting DMC image mosaics are corrected for all geometric influences.

Dörstel C., Jacobsen K., Stallmann D. (2003): DMC – Photogrammetric accuracy – Calibration aspects and Generation of synthetic DMC images, Eds. M. Baltsavias / A.Grün, Optical 3D Sensor Workshop, Zürich

Zeitler W., Dörstel C., Jacobsen K. (2002): Geometric calibration of the DMC: Method and Results, Proceedings ASPRS, Denver, USA.

Calibration Protocol
DMC01 - 0008

Calibration Certificate N° 00109982

Object	Digital Aerial Survey Camera
Manufacturer	Z/I Imaging D-73431 Aalen
Type	DMC MS-NIR
Serial Number	00109982

Calibration performed at:
Deutscher Kalibrierdienst (DKD)
Kalibrierstelle für Meßgrößen der geometrischen Optik
at Carl Zeiss, Oberkochen (DKD Registration No. : DKD-K-0502)

Number of pages of the certificate 38

Date of Calibration 27.Apr.2004

CertifiedDate	Division Head	Person in Charge
30.Apr.2010	(L. Bihlmaier)	(S. Schröder)

Calibration Protocol
DMC01 - 0008

Cameratype: DMC Serial no.: 00109982

Lenses mounted: MS f=25 mm

Calibration Parameters:

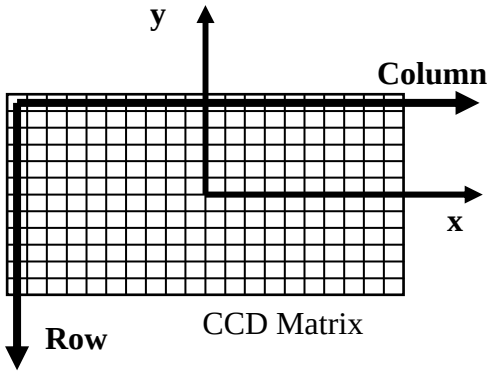
Calibrated Brown Parameters

Camera ID : 00109982

	Param	Adjusted	Std.dev.	
Principal Point [mm]	Dxp	-1.684e-004	2.151e-006	is significant
	Dyp	3.856e-005	1.551e-006	is significant
Focal Length [mm]	Dc	2.436e-005	9.797e-007	is significant
Radial Distortion	K1	-1.420e+002	5.639e-001	is significant
	K2	2.154e+005	2.447e+003	is significant
	K3	-1.283e+008	3.074e+006	is significant
Decentring distortion	P1	-4.606e-003	1.115e-003	is significant
	P2	-1.466e-002	6.839e-004	is significant
In Plane Distortion	b1	6.549e-005	3.024e-005	is significant
	b2	4.532e-005	1.742e-005	is significant

Adjusted Focal length = 25+ dc =25.00002436 [mm]

Definition of coordinate system:



Distortion Model:

$$\begin{bmatrix} \bar{x} \\ \bar{y} \\ \bar{z} \end{bmatrix} = \begin{bmatrix} x - x_0 \\ y - y_0 \\ -f \end{bmatrix} \qquad r = \sqrt{\bar{x}^2 + \bar{y}^2}$$

$$\Delta x = \Delta x_0 - \frac{\bar{x}}{\bar{z}}\Delta f + \bar{x}(r^2 K_1 + r^4 K_2 + r^6 K_3) + (r^2 + 2\bar{x}^2)P_1 + 2\bar{x}\bar{y}P_2 + \bar{x}B_1 + \bar{y}B_2$$

$$\Delta y = \Delta y_0 - \frac{\bar{y}}{\bar{z}}\Delta f + \bar{y}(r^2 K_1 + r^4 K_2 + r^6 K_3) + 2\bar{x}\bar{y}P_1 + (r^2 + 2\bar{y}^2)P_2$$

Note:

DMC Virtual Images get computed from 4 (pan) up to 8 (pan + multi spectral) cameras. During generation of virtual images (image mosaics) lens distortion gets completely eliminated. The resulting virtual image is a distortion free image rectified to a nominal focal length of 120 mm [Dörstel, Jacobsen, Stallmann, 2003; Zeitler, Dörstel, Jacobsen, 2002].

Camera calibration must not be applied during data compilation as the virtual images have nominal focal length, are distortion free and have no fiducial marks.

Camera Calibration Parameters listed referring to DMC intermediate images!

DMC geometric calibration is performed at the Carl Zeiss Calibration laboratory. The instruments used are calibrated items and being certified for camera calibration by *Deutscher Kalibrier Dienst* with permission of *Physikalisch-Technische Bundesanstalt*. The Brown Parameter Model (so called Australis Parameter) is used to model the camera geometry. The algorithms used to compute the Australis Parameters is developed by ifp (Stuttgart Institute for Photogrammetry) and published at [Dörstel et al. 2003]. The resulting DMC image mosaics are corrected for all geometric influences.

Dörstel C., Jacobsen K., Stallmann D. (2003): DMC – Photogrammetric accuracy – Calibration aspects and Generation of synthetic DMC images, Eds. M. Baltsavias / A.Grün, Optical 3D Sensor Workshop, Zürich

Zeitler W., Dörstel C., Jacobsen K. (2002): Geometric calibration of the DMC: Method and Results, Proceedings ASPRS, Denver, USA.

Calibration Protocol
DMC01 - 0008

Calibration Certificate N° 00109998

Object	Digital Aerial Survey Camera
Manufacturer	Z/I Imaging D-73431 Aalen
Type	DMC MS-Blue
Serial Number	00109998

Calibration performed at:
Deutscher Kalibrierdienst (DKD)
Kalibrierstelle für Meßgrößen der geometrischen Optik
at Carl Zeiss, Oberkochen (DKD Registration No. : DKD-K-0502)

Number of pages of the certificate 38

Date of Calibration 27.Apr.2004

CertifiedDate	Division Head	Person in Charge
30.Apr.2010	(L. Bihlmaier)	(S. Schröder)

Calibration Protocol
DMC01 - 0008

Cameratype: DMC Serial no.: 00109998

Lenses mounted: MS f=25 mm

Calibration Parameters:

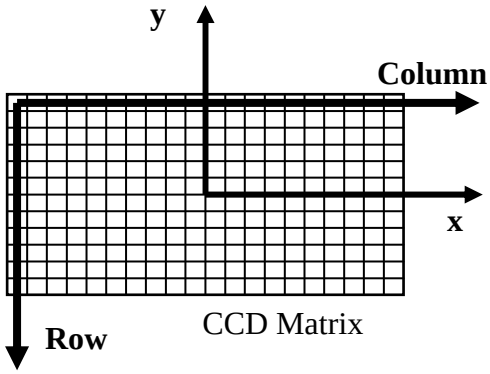
Calibrated Brown Parameters

Camera ID : 00109998

	Param	Adjusted	Std.dev.	
Principal Point [mm]	Dxp	4.274e-005	2.890e-006	is significant
	Dyp	-5.789e-006	2.081e-006	is significant
Focal Length [mm]	Dc	-1.993e-005	1.208e-006	is significant
Radial Distortion	K1	-1.384e+002	7.536e-001	is significant
	K2	2.075e+005	3.272e+003	is significant
	K3	-1.263e+008	4.099e+006	is significant
Decentring distortion	P1	6.538e-003	1.499e-003	is significant
	P2	-7.727e-003	9.180e-004	is significant
In Plane Distortion	b1	0.000e+000	1.000e-031	is eliminated
	b2	0.000e+000	1.000e-031	is eliminated

Adjusted Focal length = 25+ dc =24.99998007 [mm]

Definition of coordinate system:



Distortion Model:

$$\begin{bmatrix} \bar{x} \\ \bar{y} \\ \bar{z} \end{bmatrix} = \begin{bmatrix} x - x_0 \\ y - y_0 \\ -f \end{bmatrix} \qquad r = \sqrt{\bar{x}^2 + \bar{y}^2}$$

$$\Delta x = \Delta x_0 - \frac{\bar{x}}{\bar{z}}\Delta f + \bar{x}(r^2 K_1 + r^4 K_2 + r^6 K_3) + (r^2 + 2\bar{x}^2)P_1 + 2\bar{x}\bar{y}P_2 + \bar{x}B_1 + \bar{y}B_2$$

$$\Delta y = \Delta y_0 - \frac{\bar{y}}{\bar{z}}\Delta f + \bar{y}(r^2 K_1 + r^4 K_2 + r^6 K_3) + 2\bar{x}\bar{y}P_1 + (r^2 + 2\bar{y}^2)P_2$$

Note:

DMC Virtual Images get computed from 4 (pan) up to 8 (pan + multi spectral) cameras. During generation of virtual images (image mosaics) lens distortion gets completely eliminated. The resulting virtual image is a distortion free image rectified to a nominal focal length of 120 mm [Dörstel, Jacobsen, Stallmann, 2003; Zeitler, Dörstel, Jacobsen, 2002].

Camera calibration must not be applied during data compilation as the virtual images have nominal focal length, are distortion free and have no fiducial marks.

Camera Calibration Parameters listed referring to DMC intermediate images!

DMC geometric calibration is performed at the Carl Zeiss Calibration laboratory. The instruments used are calibrated items and being certified for camera calibration by *Deutscher Kalibrier Dienst* with permission of *Physikalisch-Technische Bundesanstalt*. The Brown Parameter Model (so called Australis Parameter) is used to model the camera geometry. The algorithms used to compute the Australis Parameters is developed by ifp (Stuttgart Institute for Photogrammetry) and published at [Dörstel et al. 2003]. The resulting DMC image mosaics are corrected for all geometric influences.

Dörstel C., Jacobsen K., Stallmann D. (2003): DMC – Photogrammetric accuracy – Calibration aspects and Generation of synthetic DMC images, Eds. M. Baltsavias / A.Grün, Optical 3D Sensor Workshop, Zürich

Zeitler W., Dörstel C., Jacobsen K. (2002): Geometric calibration of the DMC: Method and Results, Proceedings ASPRS, Denver, USA.

Calibration Protocol
DMC01 - 0008

Calibration Certificate N° 00114304

Object	Digital Aerial Survey Camera
Manufacturer	Z/I Imaging D-73431 Aalen
Type	DMC-MS-Red
Serial Number	00114304

Calibration performed at:
Carl Zeiss Jena

Number of pages of the certificate 38

Date of Calibration 13.Aug.2008

CertifiedDate	Division Head	Person in Charge
30.Apr.2010	(L. Bihlmaier)	(S. Schröder)

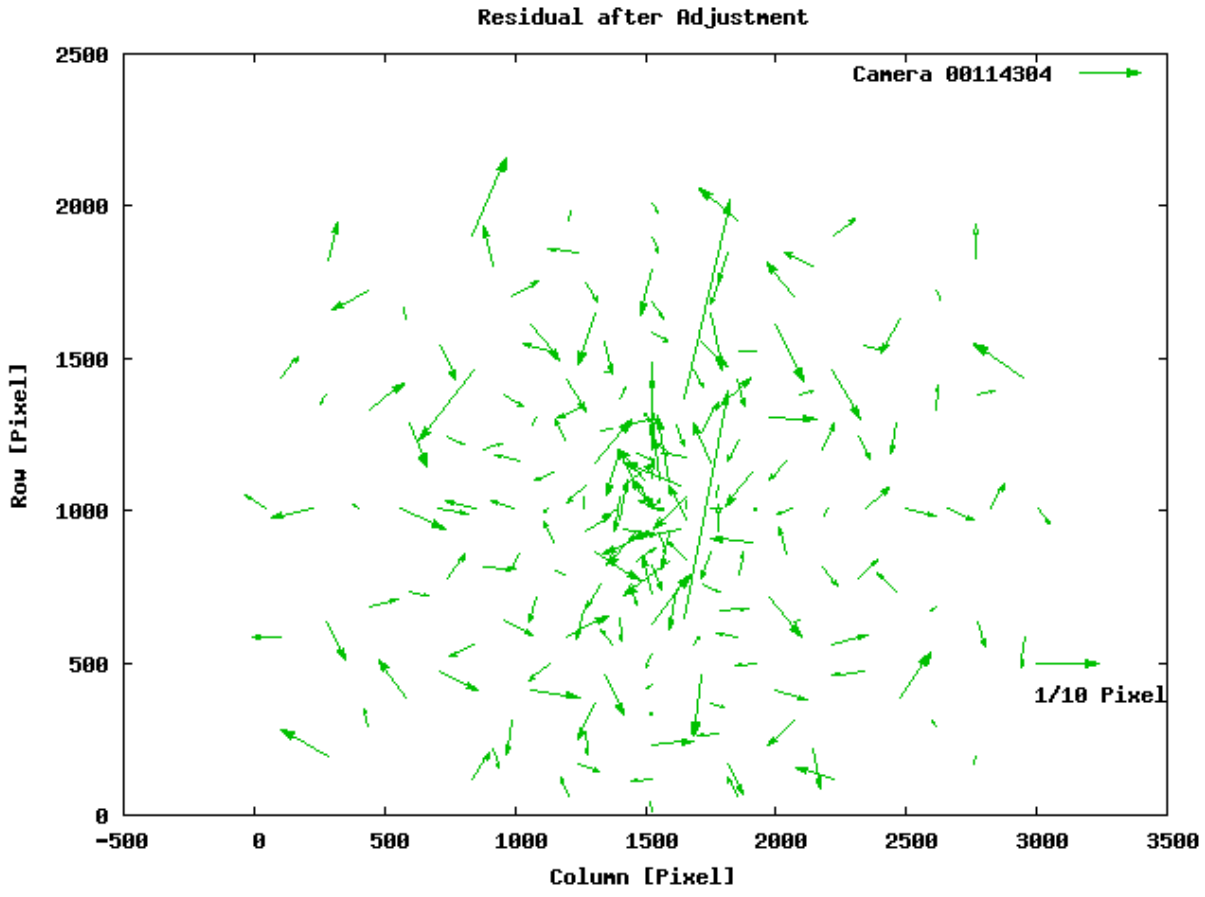
Geometric Calibration Protocol

Calibration Parameters for single camera head

Camera Type	DMC-MS-Red
Nominal Focal Length	0.025 m
Serial Number	00114304

	Param	Adjusted	Std.dev.
Principal Point [m]	x_0	-9.891E-05	1.416E-06
	y_0	0.0001593	9.998E-07
Focal Length [m]	Δf	-3.174E-05	5.24E-07
Radial Distortion	K_1	-138.6	0.4406
	K_2	219800	2810
	K_3	-145600000	5058000
Decentring distortion	P_1	6.054E-05	0.0007361
	P_2	0.0006945	0.0004569
In Plane Distortion	B_1	0.0001468	1.296E-05
	B_2	-3.375E-05	1.048E-05

Adjusted Focal length = 0.025+ dc =0.02496826 [m]



Residuals in Image after Adjustment

Max Residual [µm]: 3.8

Threshold [µm]: 8.5

Remarks:

The images after the post processing are distortion free. For interior orientation parameters of the DMC virtual image see section: “Calibration Parameter of the virtual images”.

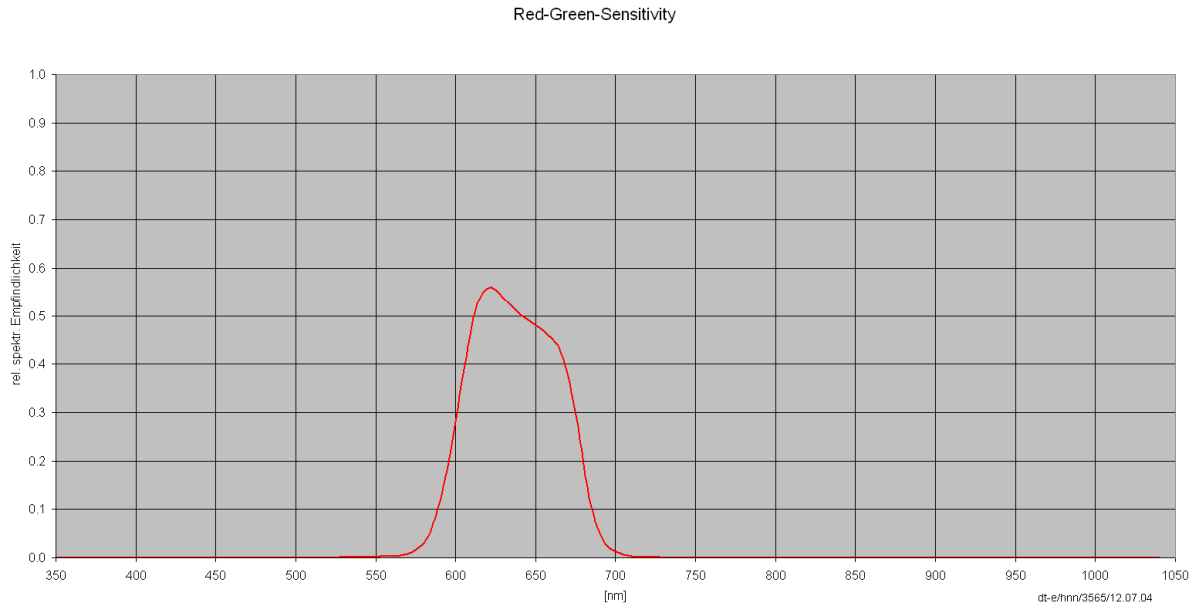
The calibration model is explained in the section “Calibration Model” at the end of this documentation.

Radiometric Calibration Protocol

In this section you’ll find the radiometric calibration results.

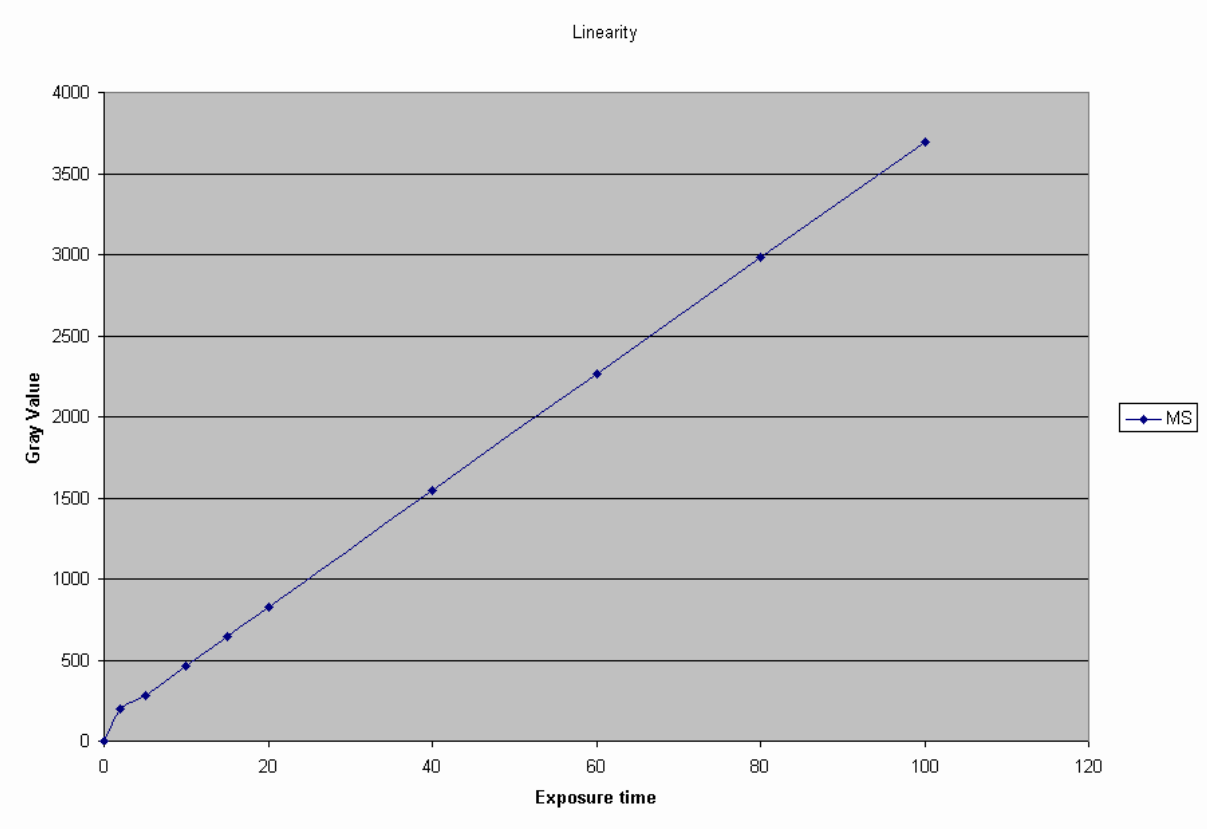
Camera ID	00114304
Sensor Revision Number	0
Lens Revision Number	1
Filter Revision Number	1
Aperture Revision Number	1

Sensitivity of camera



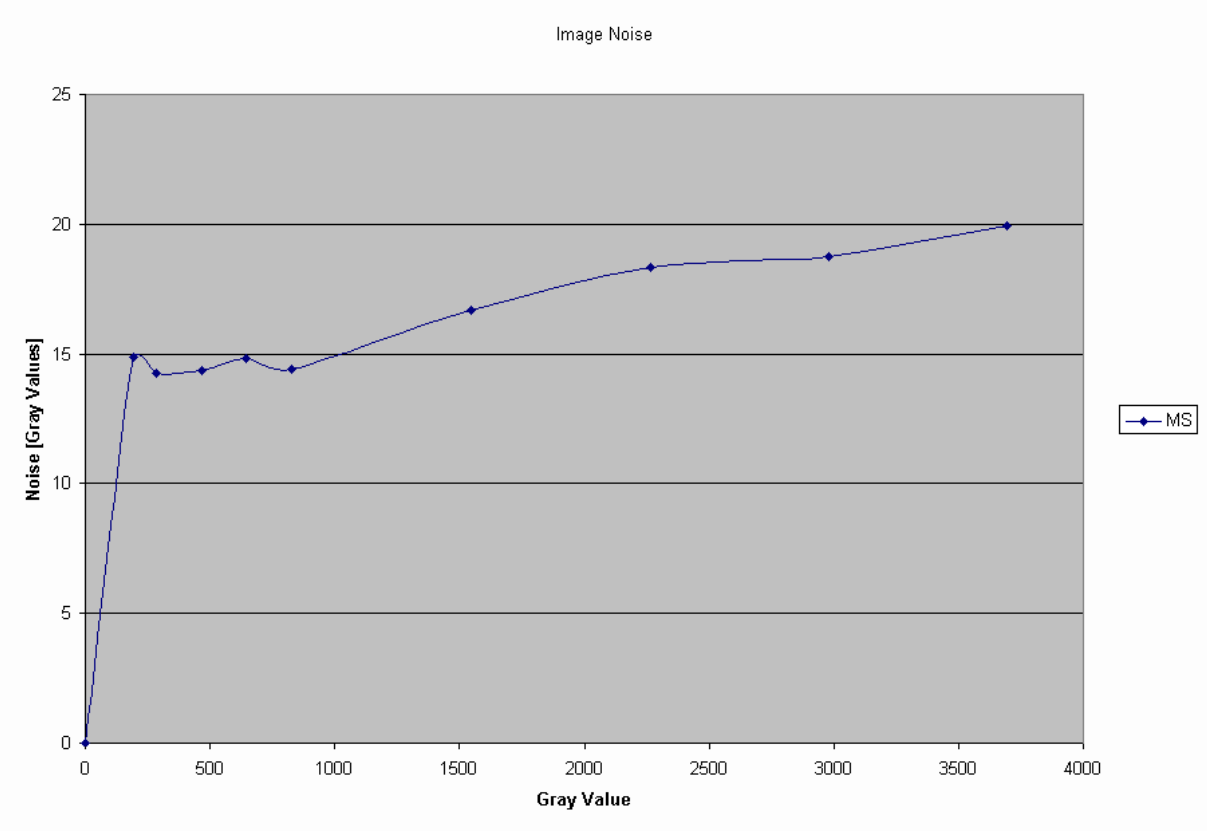
Remark:
Measurement is done without the influence of the shutter and the Analog/Digital converter. This graph is similar for the same lens and filter revision numbers. For more details see Appendix: “Radiometric Calibration Model”.

Sensor Linearity



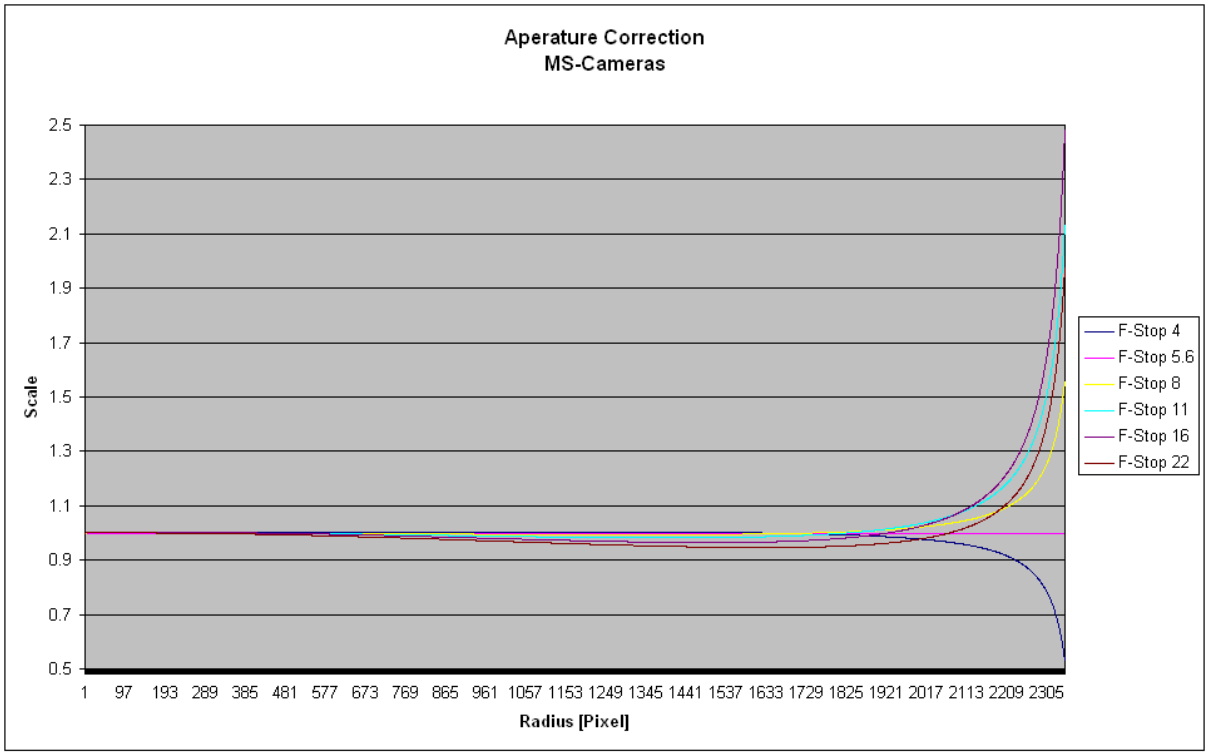
Remark:
The sensor linearity is measured for each camera. For more details see Appendix: “Radiometric Calibration Model”.

Sensor Noise



Remark:
The sensor noise is measured for each camera. For more details see Appendix: “Radiometric Calibration Model”.

Aperture Correction



Remark:
This measurement is similar for the same aperture revision number. For more details see Appendix: "Radiometric Calibration Model".

Defect Pixel List

Number of defect pixels: 4

Number of defect clusters: 0

Number of defect columns: 1

Nr	Row	Column
0	569	1651
1	570	1651
2	569	1653
3	570	1653

Calibration Protocol
DMC01 - 0008

Defect Column	RowStart	ColumnStart	RowEnd	ColumnEnd
0	568	1652	1952	1652

Remark

See Appendix for definition of defect pixels and maximal allowed numbers.

Calibration Protocol
DMC01 - 0008

Calibration Certificate N° 00109992

Object	Digital Aerial Survey Camera
Manufacturer	Z/I Imaging D-73431 Aalen
Type	DMC MS-Green
Serial Number	00109992

Calibration performed at:
Deutscher Kalibrierdienst (DKD)
Kalibrierstelle für Meßgrößen der geometrischen Optik
at Carl Zeiss, Oberkochen (DKD Registration No. : DKD-K-0502)

Number of pages of the certificate 38

Date of Calibration 07.Jun.2004

CertifiedDate	Division Head	Person in Charge
30.Apr.2010	(L. Bihlmaier)	(S. Schröder)

Calibration Protocol
DMC01 - 0008

Cameratype: DMC Serial no.: 00109992

Lenses mounted: MS f=25 mm

Calibration Parameters:

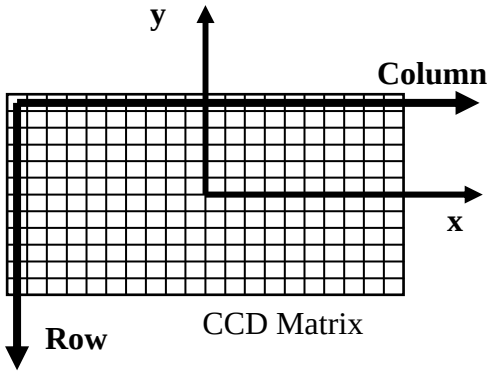
Calibrated Brown Parameters

Camera ID : 00109992

	Param	Adjusted	Std.dev.	
Principal Point [mm]	Dxp	8.055e-006	6.883e-007	is significant
	Dyp	5.556e-005	1.983e-006	is significant
Focal Length [mm]	Dc	-7.767e-005	1.258e-006	is significant
Radial Distortion	K1	-1.378e+002	7.242e-001	is significant
	K2	2.063e+005	3.143e+003	is significant
	K3	-1.216e+008	3.948e+006	is significant
Decentring distortion	P1	0.000e+000	1.000e-031	is eliminated
	P2	-9.712e-003	8.745e-004	is significant
In Plane Distortion	b1	1.085e-004	3.882e-005	is significant
	b2	0.000e+000	1.000e-031	is eliminated

Adjusted Focal length = 25+ dc =24.99992233 [mm]

Definition of coordinate system:



Distortion Model:

$$\begin{bmatrix} \bar{x} \\ \bar{y} \\ \bar{z} \end{bmatrix} = \begin{bmatrix} x - x_0 \\ y - y_0 \\ -f \end{bmatrix} \qquad r = \sqrt{\bar{x}^2 + \bar{y}^2}$$

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$$\Delta y = \Delta y_0 - \frac{\bar{y}}{\bar{z}}\Delta f + \bar{y}(r^2 K_1 + r^4 K_2 + r^6 K_3) + 2\bar{x}\bar{y}P_1 + (r^2 + 2\bar{y}^2)P_2$$

Note:

DMC Virtual Images get computed from 4 (pan) up to 8 (pan + multi spectral) cameras. During generation of virtual images (image mosaics) lens distortion gets completely eliminated. The resulting virtual image is a distortion free image rectified to a nominal focal length of 120 mm [Dörstel, Jacobsen, Stallmann, 2003; Zeitler, Dörstel, Jacobsen, 2002].

Camera calibration must not be applied during data compilation as the virtual images have nominal focal length, are distortion free and have no fiducial marks.

Camera Calibration Parameters listed referring to DMC intermediate images!

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Zeitler W., Dörstel C., Jacobsen K. (2002): Geometric calibration of the DMC: Method and Results, Proceedings ASPRS, Denver, USA.

Defect Pixel Recognition

	Description	CCD Spec	Radiometric Calibration
Pixel	Bright image	Pixel whose signal, at nominal light (illumination at 50% of the linear range), deviates more than ±30% from its neighboring pixels.	Using a lower threshold for image quality
	Dark image	Pixel whose signal, in dark, deviates more than 6mV from its neighboring pixels (about 1% of nominal light).	
	Max Count	PAN < 1000 MS < 36	

	Description	CCD Spec	Radiometric Calibration
Column	Definition	A column which has more than 12 pixel defects. Column defects must be horizontally separated by 3 columns.	Using a lower threshold for image quality
	Recognition (bright and dark)	Same as defect pixel recognition	
	Max Single column	PAN ≤ 50 MS ≤ 1	
	Max double Column	PAN ≤ 4 MS ≤ 0	

Bibliography

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Dörstel C., Jacobsen K., Stallmann D. (2003): DMC – Photogrammetric accuracy – Calibration aspects and Generation of synthetic DMC images, Eds. M. Baltsavias / A.Grün, Optical 3D Sensor Workshop, Zürich

Fraser C., Digital Camera sel-f calibration. ISPRS Journal of Photogrammetry and Remote Sensing, (997, 5284): 149-159

Zeitler W., Dörstel C., Jacobsen K. (2002): Geometric calibration of the DMC: Method and Results, Proceedings ASPRS, Denver, USA.