Appendix

In this chapter you will find technical details about the calibration procedure and the used mathematical model. Calibration parameters listed in this document are valid for this camera head only!

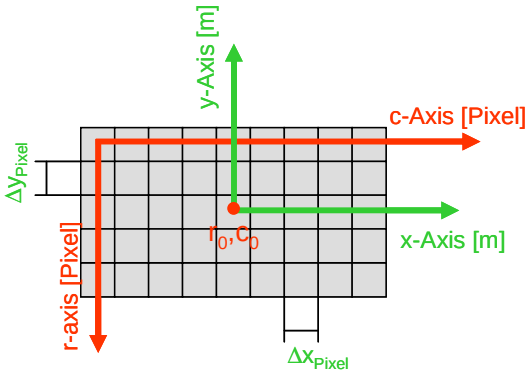
Geometric Calibration Model

Image-Coordinate system

This system is given by the structure of the digital sensor. The origin of the system is in the mid of the lower-left pixel in the image. The positive c-Axis (Column) goes over the columns (from left to right) the positive r-Axis (Row) goes from the top to the bottom. The Unit of this system is Pixel. It is a left-hand system.

Photo-Coordinate system

The origin of this system is in the mid of the image in the principal point. The positive x-Axis goes to the left while the positive y-Axis goes to the top. This system has a metrical [m] Unit and is right-hand-system.



Transformation from Image Coordinate System to Photo Coordinate System

$$x = -(r - r_0)\Delta y_{Pixel}$$
$$y = (c - c_0)\Delta x_{Pixel}$$

Distortion Model:

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

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

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

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.

Radiometric Calibration Model

This chapter describes the different approach of the radiometric camera calibration.

Camera Sensitivity

The measurement is done in 5 nm steps, separately for the imager, lens and filter.
For the lens and filter the relation between the input and output signal is recorded. For the imager the relative count of electrons in comparison to the maximal count during the measurement is used.

Sensor Linearity and Noise

This is measured for each camera separately. The measurement range is from dark images (closed shutter) to an illumination which indicates an 80-90 percent saturation of the image. The measurement is done with an Aperture of 5.6. The exposure time changes from 2 to 122 ms. The measurement with closed shutter is in the graphic with an exposure time of 0 ms. In real the exposure time is 5 ms.

Aperture Correction

This graphics shows the correction of the different aperture in comparison to the standard aperture of 5.6.

Defect Pixel Recognition

For Panchromatic Camera

Description		CCD Spec	Radiometric Calibration
Pixel	Bright image	±40 % of Q_{max} in quadrant	Using a lower threshold for image quality
	Dark image	±15 % of Q_{max} in quadrant	
	Max Count	1000	

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 qualtiy
	Recognition (bright and dark)	Same as defect pixel recognition	
	Max Single column	50	
	Max double Column	4	
	Wide	0	

For Multi-Spectral Camera

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	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	1	
	Max double Column	0	
	Wide	0	

Bibliography

Brown D. C. Close-Range Camera Calibration, Photogrammetric Engineering 37(8) 1971

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.