PROPERTY OF THE LARGE FORMAT DIGITAL AERIAL CAMERA DMC II

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ABSTRACT:

Z/I Imaging introduced with the DMC II 140, 230 and 250 digital aerial cameras with a very large format CCD for the panchromatic channel. The CCDs have with 140 / 230 / 250 mega pixel a size not available in photogrammetry before. CCDs in general have a very high relative accuracy, but the overall geometry has to be checked as well as the influence of not flat CCDs. A CCD with a size of 96mm x 82mm must have a flatness or knowledge of flatness in the range of 1µm if the camera accuracy in the range of 1.3µm shall not be influenced. The DMC II cameras have been evaluated with three different flying heights leading to 5cm, 9cm and 15cm or 20cm GSD, crossing flight lines and 60% side lap. The optimal test conditions guaranteed the precise determination of the object coordinates as well as the systematic image errors. All three camera types show only very small systematic image errors, ranging in the root mean square between 0.12µm up to 0.3µm with extreme values not exceeding 1.6µm. The remaining systematic image errors, determined by analysis of the image residuals and not covered by the additional parameters, are negligible. A standard deviation of the object point heights below the GSD, determined at independent check points, even in blocks with just 20% side lap and 60% end lap is standard. Corresponding to the excellent image geometry the object point coordinates are only slightly influenced by the self calibration. For all DMCII types the handling of image models for data acquisition must not be supported by an improvement of the image coordinates by the determined systematic image errors. Such an improvement up to now is not standard for photogrammetric software packages. The advantage of a single monolithic CCD is obvious.
An edge analysis of pan-sharpened DMC II 250 images resulted in factors for the effective resolution below 1.0. The result below 1.0 is only possible by contrast enhancement, but this requires with low image noise, demonstrating the very good radiometric image quality.

1. INTRODUCTION

Digital frame cameras nearly totally replaced analog photogrammetric cameras. Even if digital line scan cameras as the Leica ADS40/80 and the Jena Optronik-JAS150 do have a satisfying performance (Jacobsen et al. 2010) they are not so much accepted as replacement of analog cameras. Digital mid-format cameras and combinations of mid-format cameras found a niche in smaller projects, but they do not dominate the market as the large format digital frame cameras. The capacity of the large format cameras recently has been extended with the DMCII versions and the UltraCam Eagle. With the DMII a paradigm change to very large CCD-area happened while the UltraCam Eagle extended the concept by reducing the pixel size for the same CCD-size. Very large digital frame cameras have an extended requirement for the sensor geometry. Large format CCD-arrays must be very flat or the deviations against the flatness must be known and stable to reach a satisfying geometric performance. In the case of a reduction of the pixel size smaller systematic image errors are extending their size in relation to the pixel size. By these reason geometric tests for the new cameras are required.

2. OVERVIEW ABOUT LARGE FORMAT DIGITAL FRAME CAMERAS

The DMCII versions are based on the new developed large size CCD-arrays of DALSA having a size of approximately 96mm x 82mm (Fig. 1). Before such large format CCD-arrays have been too expensive, had a too high failure rate and had a too long read time and partially limited quality. The lithographic masks for the exposure of such large CCD-arrays do not have a satisfying size, so they have to be exposed step by step. The accuracy of the stepwise exposure shall have a geometric performance of 0.1µm (Stoldt 2010) which can be neglected.

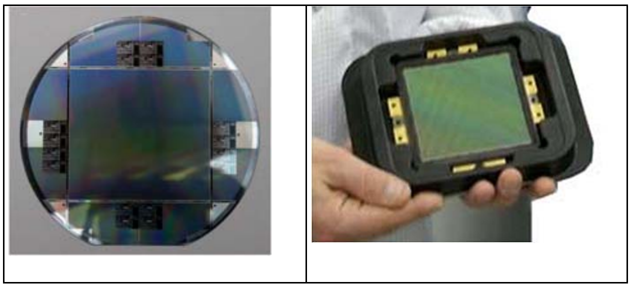


Fig. 1: waver for DMCII DMCII-CCD

The monolithic DMCII CCD shows in all investigations no tendency of the stepwise exposure that means the mentioned accuracy is realistic. The location accuracy of a pixel within the CCD is quite below the required performance, but the flatness of the CCD has to be respected. If the CCD is fixed at the corners, as it is the case for some mid-format cameras, a thermal change of the camera causes a deformation of the CCD because of the difference of the thermal coefficient for the camera body and the ceramic base of the CCD. Such effects have to be checked under different flying conditions, especially different flying heights.
Opposite to the DMCII the UltraCam Eagle is based on the old concept of stitching 9 sub-images from 4 sub-cameras together. This geometric difficult procedure now is improved by stitching

the 9 panchromatic sub-images in relation to the lower resolution monolithic green CCD (Ladstätter et al. 2010).

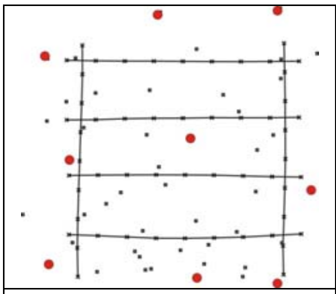
camera	Number of pixels x	Number of pixels y	Focal length [mm]	Pixel size [µm]	Base to height	Mega-pixels
DMC	7680	13824	120	12.0	1:6,1	106
DMCII 140	11200	12096	92	7.2	1:2.8	135
DMCII 230	14144	15556	92	5.6	1:2.9	220
DMCII 250	14656	17216	112	5.6	1:3.4	249
UC D	7500	11500	101.4	9.0	1:3.8	86
UC X	9420	14430	100.5	7.2	1:3.7	136
UC Xp	11310	17310	100	6.0	1:3.7	196
UC Eagle	13080	20010	80 / 210	5.2	1:2.9 1:7.7	261

Tab. 1: technical data of DMC and UltraCam cameras

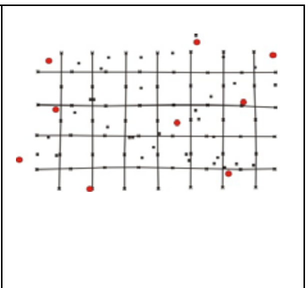
The size of the stitched UltraCam images is approximately 68mm x 104mm for all versions.

3. TEST DATA SETS

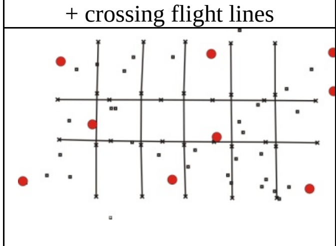
The geometric potential of the three DMCII versions was checked with test flights and an operational flight over the city of Hannover with the DMCII 230. For the analysis of the DMCII 140 and 250 test flights of the same area with three different flying heights corresponding to approximately 5cm, 9cm and 15cm ground sampling distance (GSD) and for the DMCII 230 a test flight with 5cm and an operational flight with 7cm GSD have been used.



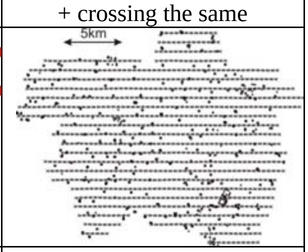
DMCII 250 5cm GSD
60% end lap, 40% side lap
+ crossing flight lines



DMCII 250 9cm GSD
60% end lap, 60% side lap
+ crossing the same



DMCII 250 15cm GSD
80% end lap, 80% side lap +
crossing flight lines

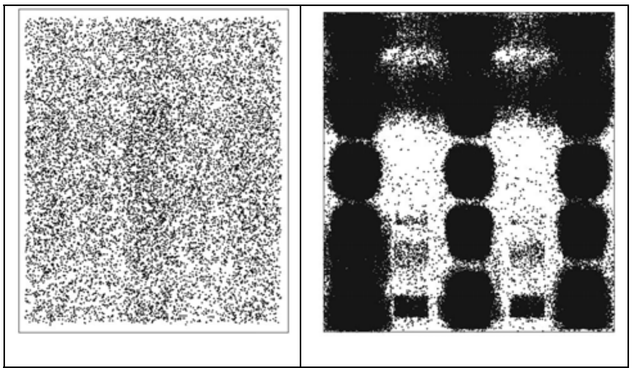


DMCII 230 7cm GSD
61% end lap, 40% side lap

Fig. 1: flight and control/check point configuration of the DMCII 250 test flights and the DMCII 230 operational flight

The flight configuration of the DMCII 140 is similar to the configuration shown for the DMCII 250 in figure 1 and the flight configuration of the DMCII 230 is similar to the DMCII 250 with 5cm GSD.

The test flights have a similar tie as the detailed mentioned DMCII 250 block with 9.4cm GSD, while the operational flight with the DMCII 230 has only an end lap of 61% and a side lap of 40%.



DMCII 250, 9.4cm GSD | DMCII 230, operational block

Fig. 2: overlaid image point distribution

The image point distribution of the DMCII-blocks is approximately equal with slightly over 200 points per image, while the in average 710 points per image of the operational block are not equal distributed (Fig. 2).

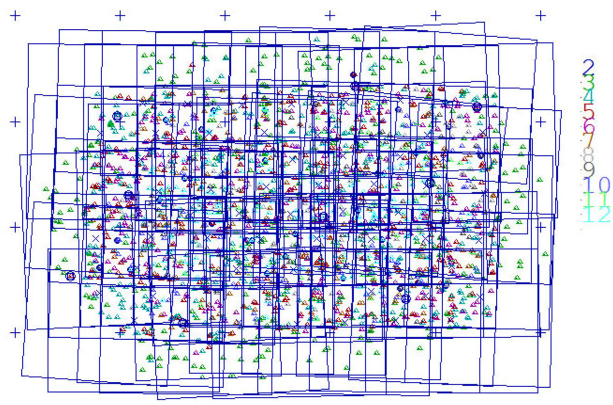


Fig. 3: footprint overlap, DMCII 250 9.4cm GSD with object points color coded depending upon number of images / point

The image tie of the test blocks is optimal, so the DMCII 250 block with 9.4cm GSD (Fig. 3) contains points located in up to 12 images. Only the operational block taken with the DMCII 230 has depending the stepwise progress few strips which are only poorly connected.

4. SELF CALIBRATION

The bundle block adjustments have been computed with the Hannover program system BLUH. BLUH includes a standard set of 12 additional parameters which are a combination of geometrical and mathematical justified formulas. This set can be used for any type of images and not as the Ebner set of parameters only for the classical image type. In addition some digital cameras have problems with the flatness of the CCD, causing some deformations especially at the image corners. For this the additional parameters 81 up to 88 have been introduced into BLUH (Jacobsen et al. 2010). For any image corner a radial and a tangential component is available.

Program BLUH is using the selected additional parameters only as start information. All not significant or too highly correlated parameters are automatically removed from the adjustment, so finally only a reduced number of parameters are used.

5. CAMERA GEOMETRY

The camera geometry is expressed by the image geometry that means the systematic image errors describing the difference between the real image geometry and the mathematical model of perspective geometry. Systematic image errors can be determined by self calibration with additional parameters but this only can show effects able to be described by the set of additional parameters. In any case systematic image errors not respected by self calibration influence the residuals of bundle block adjustment – the remaining image discrepancies. If the residuals are overlaid corresponding to their image position and averaged in small image sub-units by averaging the random errors are reduced, but the systematic image errors are remaining, indicating the size and type of systematic image errors. So they can be analyzed without any hypothesis.

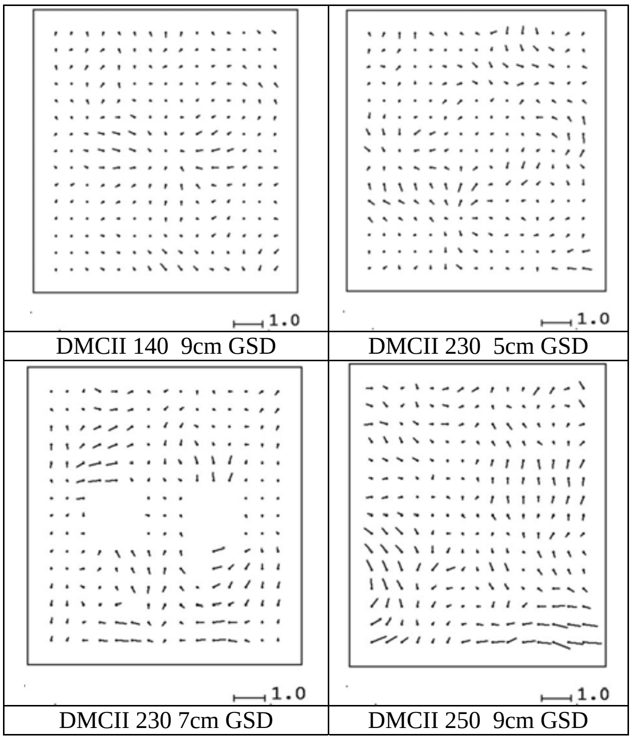


Fig. 4: overlaid and in image sub-areas averaged residuals of bundle block adjustments without self calibration

The overlaid and averaged residuals shown in figure 4 in the root mean square have just a size of 0.2µm and the largest value reaches 1.6µm. In the case of the DMC140 a small radial symmetric distortion is available. Of course the averaged residuals are smaller as the systematic image errors because by the adjustment parts of the systematic errors are hidden by the least squares adjustment, but the character of the systematic is clearly shown. In the case of the operational block (DMCII 230 with 7cm GSD) some gaps are in the presentation (Fig. 4) because of the not equal image point distribution which can be seen in figure 2. Vectors in figure 4 are only shown if at least 10 observations are in a sub-image area to reduce the influence of random errors. The other block adjustments with different GSD not shown in figure 4 have similar characteristics.

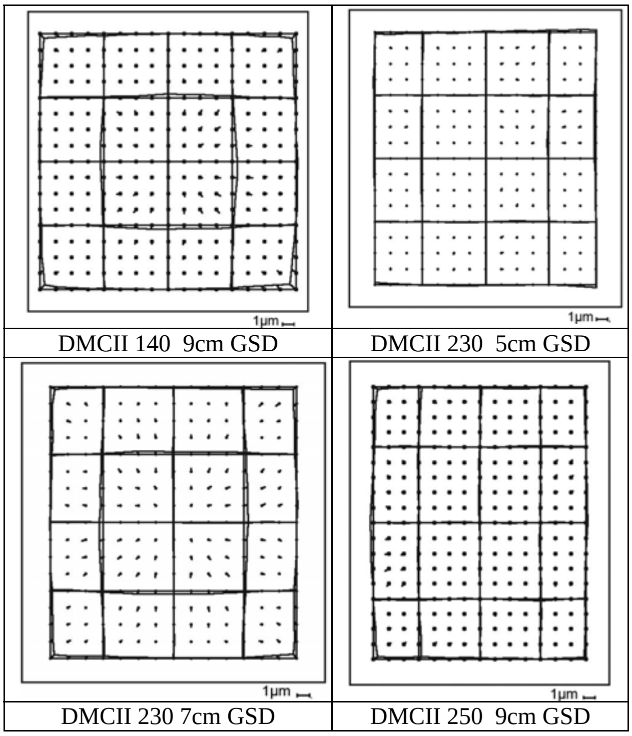


Fig. 5: systematic image errors based on standard additional parameters 1 - 12

Also the systematic image errors based on the standard set of 12 additional parameters are small in size as it can also be seen in table 2.

	GSD [cm]	Systematic image errors based on additional parameters 1 – 12 [µm]			Systematic image errors based on additional parameters 1 – 12 + 81-88 [µm]		
		Sx	Sy	Max	Sx	Sy	Max
DMC II 140	5.7	0.31	0,30	0,90	0,46	0,42	1,74
	9.5	0.22	0,18	0,60	0,15	0,16	0,84
	20,2	0.62	0,63	1,60	0,68	0,65	1,90
DMC II 230	5.4	0.19	0.11	0,50	0,13	0,18	0,90
	7	0.22	0,15	0,50	0,21	0,31	0,90
DMC II 250	5.4	0.23	0,37	0,90	0,23	0,37	0,90
	9.4	0.17	0,23	0,50	0,23	0,22	1,10
	15.6	0.13	0,16	0,50	0,14	0,42	1,80
	2/5.3	0.21	0,36	0,90	0,21	0,27	0,70

Tab. 2: root mean square size of systematic image errors

The root mean square values of the systematic image errors are a little larger for the DMCII 140. As visible in figure 4 there are small radial symmetric components. Especially the data set with 20.2cm GSD shows with radial symmetric components up to 1.3µm in the image corners. Without the radial symmetric components the root mean square value of the systematic image errors is just in the range of approximately 0.15µm. Nevertheless these values are quite smaller as for any other photogrammetric camera handled before. The significance test reduced the 12 selected additional parameters in the average to 7 finally used parameters.

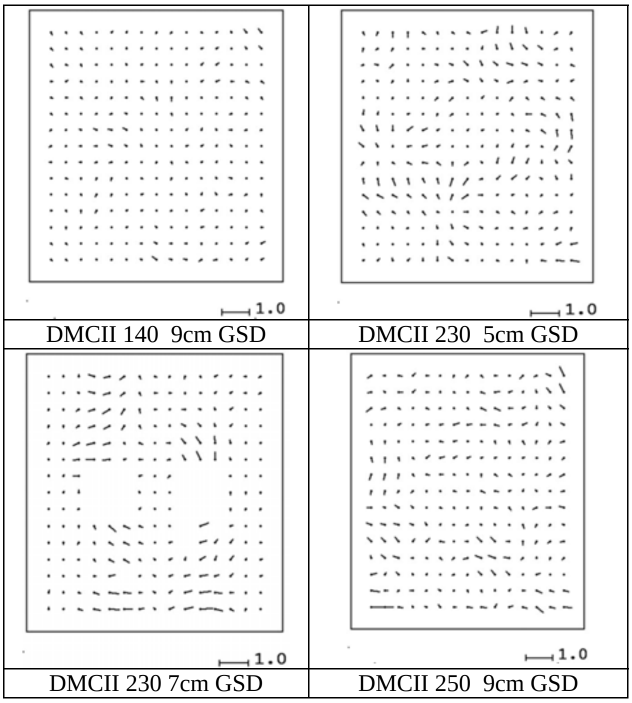


Fig. 6: overlaid and in image sub-areas averaged residuals of bundle block adjustments with parameters 1 - 12

All 9 analyzed data sets have been adjusted in addition to the 12 standard parameters also with the additional parameters 81 up to 88 able to cover systematic effects in the individual image corners which may be caused by not respected deformation of the CCD against a plane. As visible in table 2 this enlarges the size of the systematic image errors slightly.
The overlaid and averaged residuals after block adjustment with the additional parameters 1 – 12 are getting very small as shown by figure 6 which can be compared with figure 4. Also the largest values have been reduced to below 1µm.
The systematic image errors of the adjustments with the additional parameters 1-12 in addition to 81-88 are a little larger as shown in table 2, but the special additional parameters are not improving the object coordinates of block adjustments.
The systematic image errors are clearly smaller as reported by Passini et al. 2012 for the UltraCam Eagle.

6. ACCURACY OF OBJECT POINTS

It is difficult to compare the accuracy of object coordinates determined by bundle block adjustment in different projects because of the different block configurations (image overlap and number and distribution of control points), the identification and accuracy of the control and check points and the support by direct sensor orientation. For the analysis no direct sensor orientation has been used for support because this hides the property of the cameras. In any case a relative comparison of different configurations is possible. Block adjustments with different overlaps have been handled to avoid unrealistic results based on high overlap of images. Blocks with 60% end lap and side lap below 50% are named as single blocks, while blocks with more as 60% side lap are named as double blocks, including twice as much image as single blocks. Any fourfold block has 60% side lap and crossing flight lines also with 60% side lap.

The used control point configurations can be seen in figure 1 with the small points being independent check points. In following only the root mean square differences at independent check points are shown.
The results shown in figures 7 to 9 are typical for all results. The values achieved with 15cm (DMCII 250) and with 20cm GSD (DMCII 140) are not shown because of the limited number of images and the strong overlap not being typical for usual blocks. Reverse the block adjustments with 5cm GSD suffer with the limited accuracy of the control and check points. Nevertheless the image geometry can be determined with these different resolutions in the same way as with 9cm GSD images.

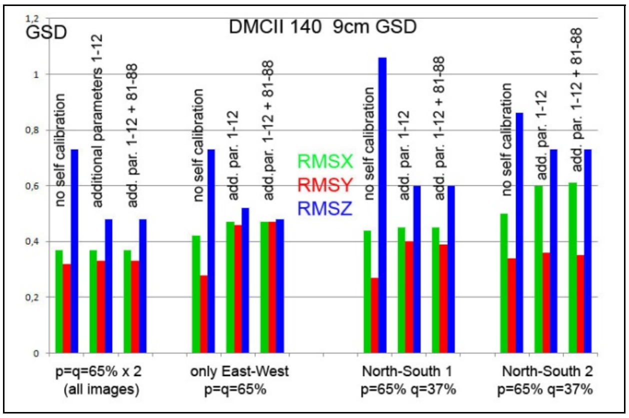


Fig. 7: Root mean square differences at check points, adjustments with DMCII 140 9cm GSD images (p=end lap, q=side lap)

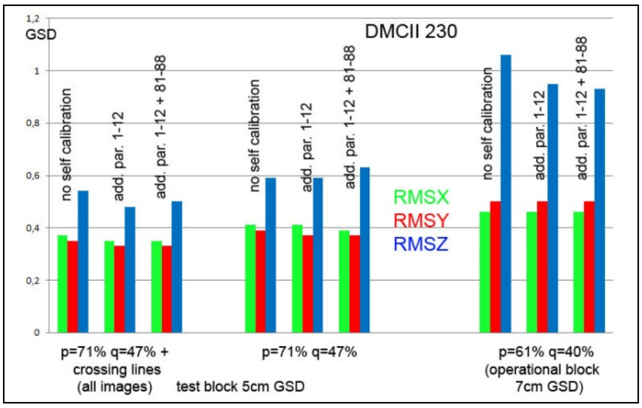


Fig. 8: Root mean square differences at check points, adjustments with DMCII 230, test block with 5cm GSD images and operational block with 7cm GSD

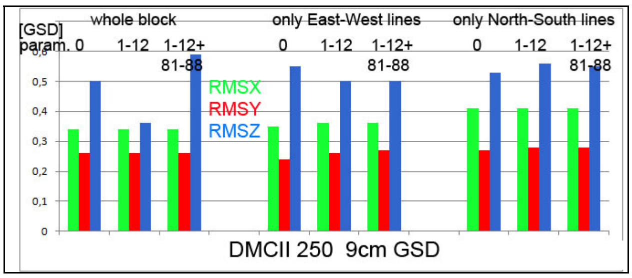


Fig. 9: Root mean square differences at check points, adjustments with DMCII 250 9cm GSD images

All the handled bundle block adjustments of the used test field and the operational block taken with the DMCII 230 show no improvement of the horizontal accuracy by block adjustment with self calibration. The self calibration improves only the vertical accuracy and there is no improvement by the special additional parameters 81 up to 88 for the geometric improvement of the image corners.

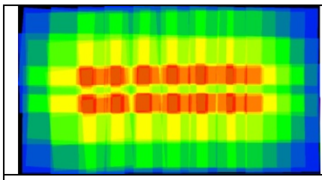
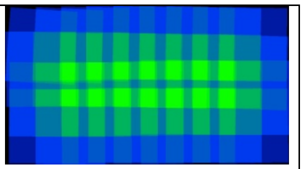
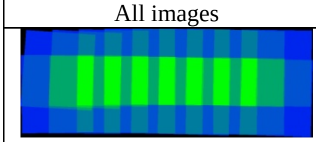
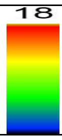
	
All images	Only East-West flight lines
	
East-West with q=37%	Color scale for image overlap (0 – 18 images)

Fig. 10: overlap of images, DMCII 140 with 9cm GSD

The block adjustments with reduced image overlap (double and single blocks) have a smaller number of images per object point as it can be seen in figure 10. In the case of all images object points are located in up to 18 images, in the case of only the EAST-West flight lines in up to 9 images and in the case of the single block in up to 6 images. Corresponding to this lower object point accuracy is expected in the case of a reduced image overlap. This also can be seen, but the reduction of the accuracy is below the expectation.
The operational block (DMCII 230, 7cm GSD) is less accurate as the test data sets, but this is caused by the limited ground control point accuracy.
In general the bundle block adjustment should be done with the standard set of 12 additional parameters, with this the root mean square differences at the check points is for X and Y between 0.25 and 0.6 GSD depending upon the image overlap and the GCP accuracy, for the always more critical Z-component it is between 0.5 and 0.9 GSD. The more square size of the DMCII leads to a base-to-height-relation which is the same for the DMCII 140 and the DMCII 230 as for the wide angle UltraCam Eagle. This equalizes also the effect of the small difference in time interval between these cameras. As reported in Passini et al. with the UltraCam Eagle wide angle camera even with a larger image overlap the vertical accuracy was in the range of 1.1 GSD.

7. EFFECTIVE IMAGE RESOLUTION

The nominal image resolution must not be the same as the effective resolution caused by loss of radiometric image quality by the optics and the imaging process. By edge analysis the effective resolution can be determined. If the gray value profile perpendicular to an edge is differentiated, this leads to the point spread function. The width of the point spread function gives the factor for effective resolution (Fig. 11). This factor multiplied with the pixel size or the GSD leads to the effective resolution which is important for the identification of objects. By simple theory this factor should not be below 1.0, but an image enhancement may lead to smaller values. Reverse image enhancement enlarges the signal to noise relation.

camera	blue	green	red
DMCII 230	0.98	0.97	0.98
DMCII 250	0.87	0.88	0.84

Tab. 3: factor for effective resolution

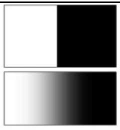
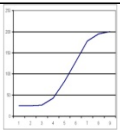
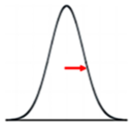
			
Above: grey value object Below: grey value image	Edge in image	Grey value profile across edge	Point spread function

Fig. 11: edge analysis – edge → point spread function

Some fused RGB-images have been analyzed for the effective resolution (Tab. 3). For the DMCII 230 the factors are slightly and for the DMCII 250 clearly below 1.0. That means there is no loss of resolution against the nominal resolution. The values for the different spectral bands are close together because they are dominated by the fused panchromatic band. The factors of the effective resolution of the DMCII 250 of approximately 0.86 indicate an image enhancement which is also shown by some image details. On the other hand no enlarged noise can be seen, which is only possible by the high quality optics with larger aperture especially designed for the individual camera types.

CONCLUSION

All analyzed blocks taken by the different DMCII versions have systematic image errors clearly smaller as for all other handled cameras. Only the sensitive height component is improved by block adjustment with self calibration. For the handling of individual photogrammetric models following the determination of the image orientation, the use of systematic image errors is not any more important as it is the case for other cameras. This confirms the advantage of the monolithic CCD and the precise system calibration automatically respected for the output images.
The image format closer to a square enlarges the base to height relation, improving the geometric conditions for the object height. So even with the single blocks the accuracy of object height is below one GSD.
The radiometric image quality is without any problem, being a large advantage for this digital camera.

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