POTENTIAL OF LARGE FORMAT DIGITAL AERIAL CAMERAS

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Introduction:

Digital aerial cameras are replacing traditional analogue film cameras for photogrammetric purposes in a fast manner. The change to digital cameras is driven by economic advantages – even if the large format digital aerial cameras are more expensive as analogue metric cameras, they do not need film, there is no loss of time and no cost for film development and digital images don't have to be scanned. In addition the image quality of original digital images is better as scanned analogue photos and digital cameras are more light sensitive, extending the daily flight time. Also the accuracy of digital cameras usually is better, even if here some open points have to be discussed. For the use in production the relation between ground sampling distance and photo scale is important; here often a misunderstanding of the relation exist because it is more complex as just the mathematical relation.

Existing digital large format aerial cameras:

Only digital aerial cameras especially designed for photogrammetric purposes are respected here. They have a solid camera body and cannot be focussed. Any not fix-focus camera has a changing and not well defined inner geometry; they should not be used for metric purposes. There is a general difference between array and line scan cameras. Line scan cameras have to be supported by direct sensor orientation based on a combination of relative kinematic GPS-positioning and inertial measurement systems, while array cameras can be used like analogue photos also without direct sensor orientation. Array cameras have to be separated between large format and medium format digital cameras. But there is also a tendency that the medium format cameras are used in a combination of 2 up to 4 cameras. Here only the large format digital cameras are investigated.

camera	f [mm]	image size x [pixel]	image size y [pixel]	pixel size [µm]	h/h for p=60%	remarks
DMC	120.0	7 680	13 824	12.0	3.2	oblique sub-cameras
UltraCamD	105.2	7 500	11 500	9.0	3.7	parallel sub-cameras
UltraCamX	100.5	9 420	14 430	7.2	3.7	
UltraCamXp	100.5	11 310	17 310	6.0	3.7	

Table 1. technical data of large format digital array cameras

The serious of Microsoft Vexcel-Imaging UltraCam-cameras has a development from the UltraCamD with 9µm pixel size to smaller pixel size down to 6µm for the UltraCamXp. The image size stays unchanged, leading to a higher number of pixels. A smaller pixel size must not be an advantage even if it corresponds to a higher number of pixels. The optics must be able to use such a small pixel size. Caused by the modulation transfer function (MTF), with smaller pixel size - that means with higher frequency - the contrast is reduced and this may cause a not negligible reduction of the image quality.

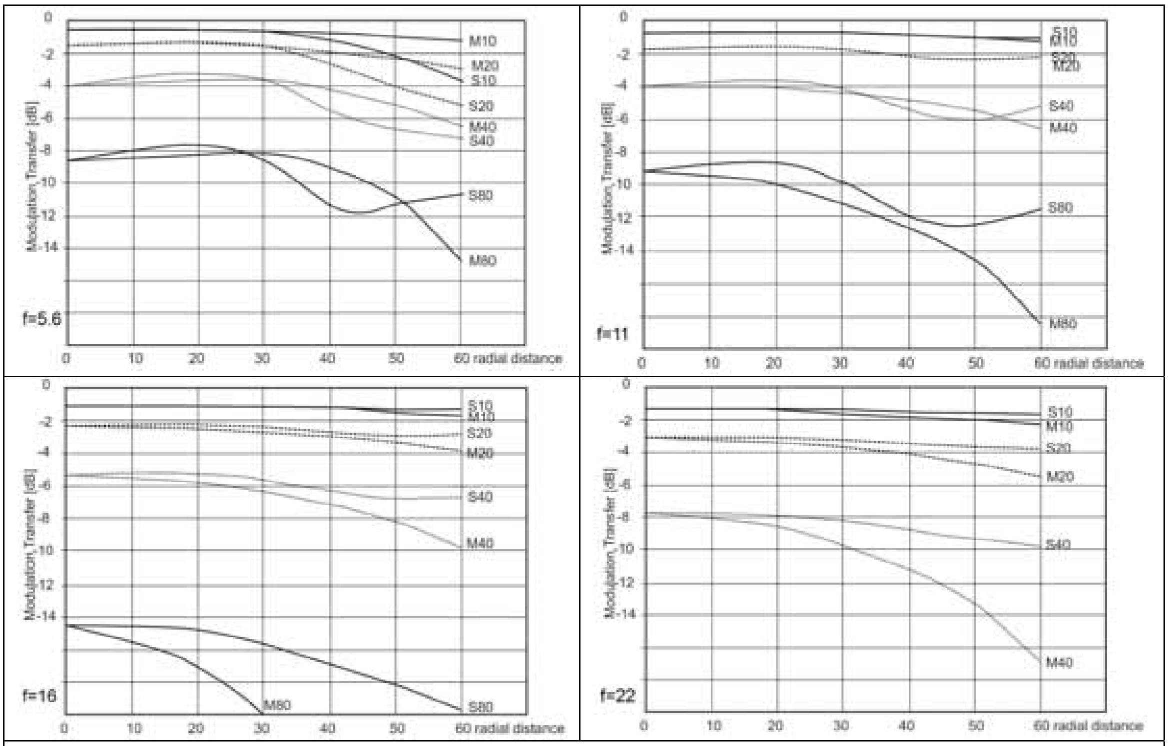

Figure 1: modulation versus radial distance
of UltraCamX for aperture f=5.6, f=11, f=16 and f=22
M10=meridional (tangential direction) 10 linepairs/mm S10=sagital (radial direction) 10lp/mm M20/S20 for 20 lp/mm, M40,S40 for 40lp/mm M80/S80 for 80 lp/mm

As it is obvious in figure 1, the modulation gets worse for higher frequency (more lp/mm) and with larger radial distance from the image centre. A pixel size of 7.2µm corresponds to 69 linepairs/mm (lp/mm), while a pixel size of 6µm corresponds to 80 lp/mm. All UltraCam have an image size of 67.8mm x 103.9mm, corresponding to a maximal radial distance of 62mm. This even exceeds the recommendation of the optics producer. If the aperture has a smaller diameter (larger f-stop number) for the low frequency the modulation is improved, but for the high frequency (80 lp/mm are corresponding to 6µm pixel size) it is getting worse, caused by the diffraction limited resolution. The diffraction limited resolution can be estimated for the wavelength λ=0.55µm with the formula d=115”/D with D as diameter of the diaphragm. This leads for the UltraCam and the f-stop of 5.6 to 3µm, for 11 to 6.2µm, for 16 to 8.9µm and for the f-stop of 22 to 12µm. With the optics, which is identical for all UltraCam, a reduction of the pixel size to 6µm only can lead to a slight improvement in the image centre and the f-stop of 5.6 and with a lower amount to f=11, but not for f=16 or even f=22. The f-stop of 5.6 is not used very often under operational conditions, so with the UltraCamXp more or less no improvement of the image information contents can be expected against the UltraCamX.

Line scan cameras have to be used in combination with direct sensor orientation (combination of GPS with inertial system) to enable a correct geo-reference. They are imaging permanently the flown area. The sampling rate determines the possible object pixel size in flight direction. The ADS40 and the JAS150S have a maximal sampling rate of 800 lines/sec, the ADS80 is in the range of 1000 lines/sec while the 3DAS-1 has 250 up to 750 lines/sec. This limits the smallest object pixel size in flight direction to approximately 8cm for the low flight speed of 250km/h.

	pixels	Focal length	Pixel size	Pan, view direction	Colour
Leica Geosystems ADS40 / ADS80	12000	62.5mm	6.5µm	+27°; +2°; -16°	2 x RGB, NIR
Jena-Optronic JAS150S	12000	150mm	6.5µm	+/-20.5° ; +/-12.0°; 0°	RGB, NIR
Wehrli Ass. 3DAS-1	8023	110mm	9µm	+26°; 0°; -16°	3X RGB

Table 3: aerial line scan cameras

Geometric potential:

In a cooperation of the Leibniz University Hannover with BAE SYSTEMS GP&S, Mount Laurel, NJ, USA, the geometric potential of a DMC, UltraCamD, UltraCamX, ADS40 and an analogue RC30 have been investigated over the Franklin Mills test field (Passini, Jacobsen 2008). All images have approximately the same ground pixel size (GSD) - the distance of the neighboured pixel centres projected to the ground.

camera	flight	Images	GSD
DMC	July 2007	72	54mm
UltraCamD	February 2006	66	42mm
UltraCamX	April 2007	66	37mm
RC30	September 2007	35	49mm
ADS40	September 2007	5 lines	53 x 91mm²

Table 4: photo flights over test area Franklin Mills

With the ADS40 5 parallel flight strips have been flown having approximately 25% sidelap, while all other flights have been made with parallel flight lines and 60% sidelap as well with 60% endlap. Approximately 42 control points having a standard deviation of the coordinate components not exceeding 2cm are available. Block adjustments with a smaller number of control points have been made and the not used points are handled as independent check points. The following shown results are based on independent check points.

The geometric potential was determined by bundle block adjustment. By self calibration with additional parameters systematic image errors (difference between real image geometry and mathematical model of perspective) can be determined. Obvious systematic image errors can be seen at the DMC, the UltraCam and the RC30. To reach optimal adjustment results, for the special geometry of the DMC and the UltraCam, camera-specific additional parameters were added to the Hannover program for bundle block adjustment BLUH (Jacobsen 2007). For the DMC just 2 camera specific additional parameters are sufficient in addition to the standard set of additional parameters used in BLUH. They improved the accuracy achieved at check points slightly. For the UltraCam a set of 32 camera specific parameters could not improve the accuracy against the standard set of additional parameters. For both UltraCam the self calibration by additional parameters is required; in the case of the UltraCamX the height accuracy could be improved by the factor of 2. With the exception of the ADS40 the block adjustments have been made without support of direct sensor orientation. Of course this makes the comparison between the ADS40-results and the other data sets difficult. The adjustment of the ADS40-data with ORIMA required strong weights of the used control points to avoid a constant height shift of the block.

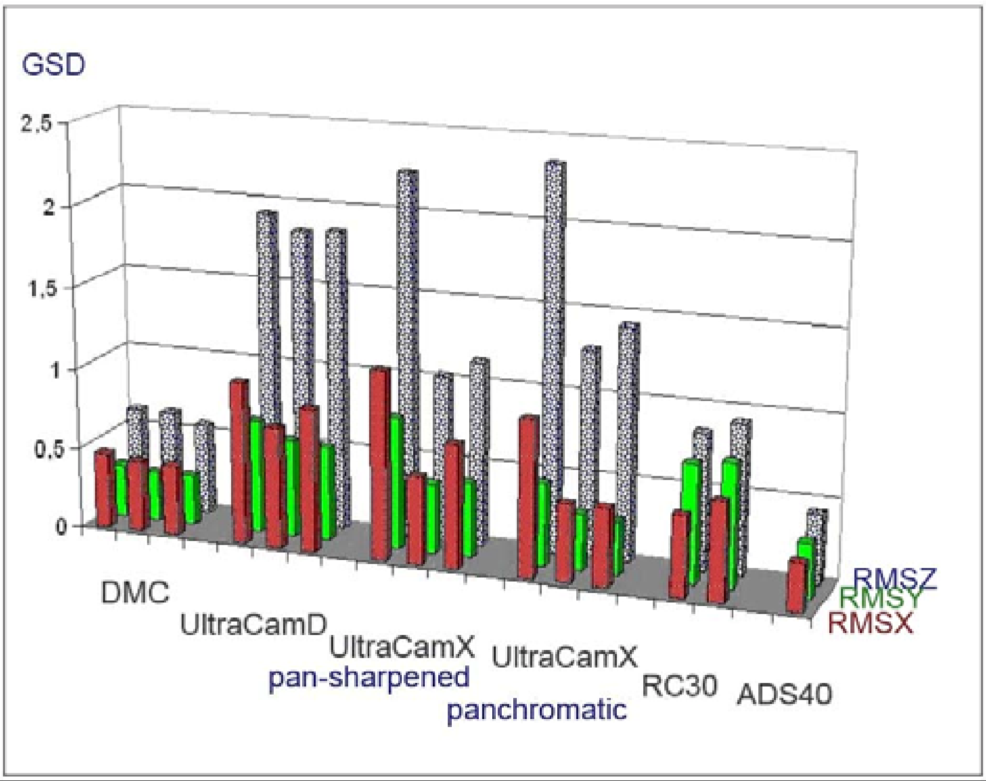

Figure 2: comparison of results at independent check points of block adjustments with 8 control points achieved in test area Franklin Mills **[GSD]**

Within the groups from left to right: without self calibration / with standard additional parameters / with standard parameters + camera specific parameters

The comparison of the results presented in figure 2 shows approximately the same horizontal accuracy for the DMC, the UltraCamX and ADS40 for a block adjustment with self calibration. The self calibration especially is important for the UltraCam because of quite larger systematic image errors. The slightly better accuracy achieved with the ADS40 can be explained with the larger GSD, reducing the not negligible effect of the check point accuracy and the support by direct sensor orientation. The UltraCam shows some problems with the vertical accuracy, but as mentioned by Vexcel Imaging this should be improved now. With the DMC and the ADS40 better accuracy as with the analogue RC30 has been reached.

Information contents:

The image quality can be checked by edge analysis. A sudden change of the object brightness causes a continuous change of the grey values in the image. The grey value profile in the image can be differentiated, leading to a point spread function (Jacobsen 2008). The width of the point spread function includes the information about the image quality. Table 5 shows the factor in relation to the pixel size, leading to the effective pixel size corresponding to the image quality. The nominal number of pixels has to be divided by this factor to give the information about the effective, comparable number of pixels per image. Panchromatic UltraCamX images have at the image corner a lower resolution as also visible in figure 1. For the effective number of pixels per image of the RC30 the results of the following described topographic data acquisition are respected by an additional factor of 1.5. The comparison shows, that the nominal number of pixels does not say everything about the image information and that all large size digital cameras include more information as the analogue RC30 scanned with 12µm pixel size.

camera	Sun elevation	Image type	Factor for effective pixel size	effective number of image pixels
DMC	43°	pan	0.92	7680 x 13824
UltraCamD	27°	pan-sharpened	1.16	6455 x 9914
UltraCamX	27°	pan-sharpened	1.23	7658 x 11731
UCX centre	27°	panchromatic	1.03	(9140 x 14010)
UCX corner	27°	panchromatic	1.24	(7600 x 11640)
RC30	46°	RGB colour	1.43 (*1.5)	(8520 x 8520)
ADS40	46°	pan	1.02	11764
ADS40	46°	colour	1.07	11215

Table 5. factor for effective pixel size, Franklin Mills - corresponding to information contents

The meaning of the effective number of pixels has to be checked by mapping. The image information content in the Franklin Mills test field was investigated by topographic data acquisition with on-screen digitizing of well defined areas (Sabbagh 2008). In some areas the objects could not be identified – especially in shadow areas. The information contents in general can be compared with the sum of all achieved vectors – if more details can be seen, the vector length is larger.

Figure 3 shows a clear tendency – in the DMC-images also in shadow regions some information could be achieved. In the case of the UltraCamX slightly better results could be reached with pan-sharpened as with panchromatic images. The poorest result was caused by analogue RC30 photos. The sum of the vector length confirms this result; it shows exactly the same trend. Even with a larger GSD with DMC-images more details have been identified. This result is confirmed by other test areas (Oswald 2007).

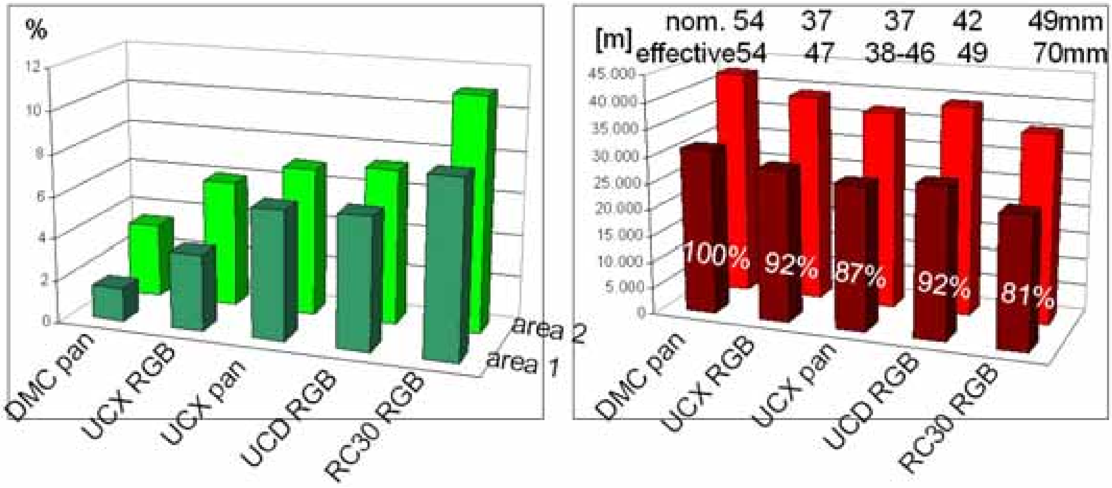

Figure 3: information contents of mapping in test area Franklin Mills
left: percentage of not identified areas right: sum of vector length

Conclusion:

Obvious advantages of digital large format cameras against scanned analogue aerial photos have been shown. With original digital images at least the same horizontal accuracy can be reached with the same GSD. With DMC- and ADS40-images also a better vertical accuracy as with scanned analogue wide angle photos is possible, even if the height to base relation of the DMC corresponds to analogue normal angle cameras.

A very clear advantage of the original digital images against scanned photos exists for data acquisition of topographic maps. The effective information content of a scanned analogue aerial photo is below the information contents of an original digital large format image. In addition to these advantages even with the high cost for the cameras, digital large format cameras lead to a cost reduction of photogrammetric projects.

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