TELLS THE NUMBER OF PIXELS THE TRUTH? – EFFECTIVE RESOLUTION OF LARGE SIZE DIGITAL FRAME CAMERAS

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ABSTRACT

The photo scale or the ground sampling distance (GSD) usually is the dominating factor for the specification of photo flights. For a comparison of cameras not only the nominal number of pixels is important, also the image quality has an influence. The effective resolution, respecting the image quality, can be determined by edge analysis. A sudden change of the brightness in the object space is causing a continuous change of the gray values in a profile across the edge. A differentiation of the gray value profile lead to the point spread function, including the information of effective resolution.

DMC, UltraCamD and UltraCamX-images as well as analog aerial photos have been investigated. Of course the effective resolution is depending upon the illumination condition, expressed by the sun elevation, and the atmospheric condition. For the DMC only in one case with 20° sun elevation the effective GSD was 5% larger than the nominal value; this is different for both UltraCam. The calibration reports shows lower modulation transfer functions in the image corners. Under optimal light conditions, with 60° sun elevation, the UltraCamD in the center has a loss 4% of the effective GSD against the nominal value, but in the image corners a loss of 28% exists. With 20° and 27° sun elevation an overall loss of resolution by 16% respectively 24% has been detected. The same effect exists for the UltraCamX, showing an effective resolution 28% less than the nominal value over the whole image format. Similar investigations have been made for analog photos.

Keywords: digital cameras, analog camera, resolution, edge analysis, point spread function

INTRODUCTION

Photogrammetric data acquisition today is based digital or digitized images. Analog aerial photos can be compared with the image scale, because they have a standard format of 230mm x 230mm and approximately the same image quality. This simple comparison is not possible with original digital images having quite different size of image pixels.

As it can be seen in figure 1, the image scale linear depends upon the image pixel size, so for the same ground sampling distance (GSD) the image scale may be quite different. The information about the object, in other words the information content, depends upon the GSD, so the image scale is not any more important for original digital images; instead of this the GSD has to be used for comparing different images. This becomes obvious, if the Z/I Imaging DMC, the Microsoft Photogrammetry UltraCamD and the UltraCamX are compared. For the DMC 12cm GSD corresponds to the image scale 1 : 10 000 and for the UltraCamX to 1 : 16 667. The reason for this is the different pixel size, which varies between 12µm and 7.2µm. Of course the pixel size cannot be minimized; this would influence the sensitivity of the sensor and reduce the image quality.

For the panchromatic channel, the large size digital frame cameras are based on a combination of 4 cameras. In the case of the DMC four slightly oblique arranged sub-cameras, having a nadir angle of 10° in flight direction and 18° across, are combined, while the UltraCam sub-cameras are oriented parallel, leading to a larger field of view. With growing field of view the modulation transfer is reducing to the image corners (figure 3).

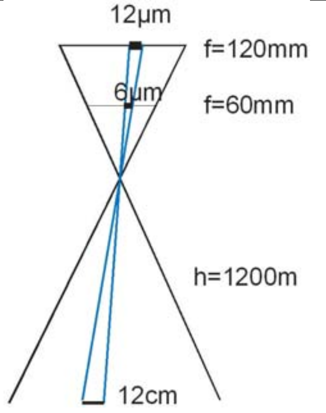


Figure 1. image scale for different image pixel size, but same GSD.

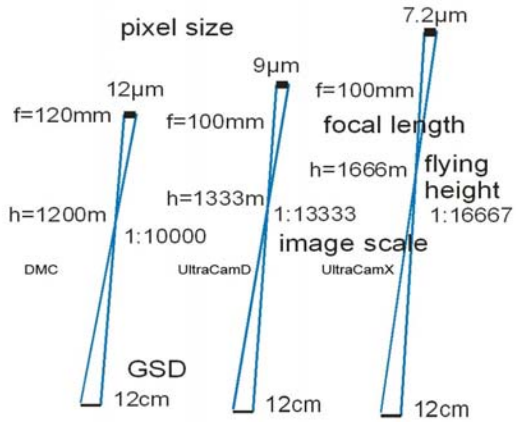
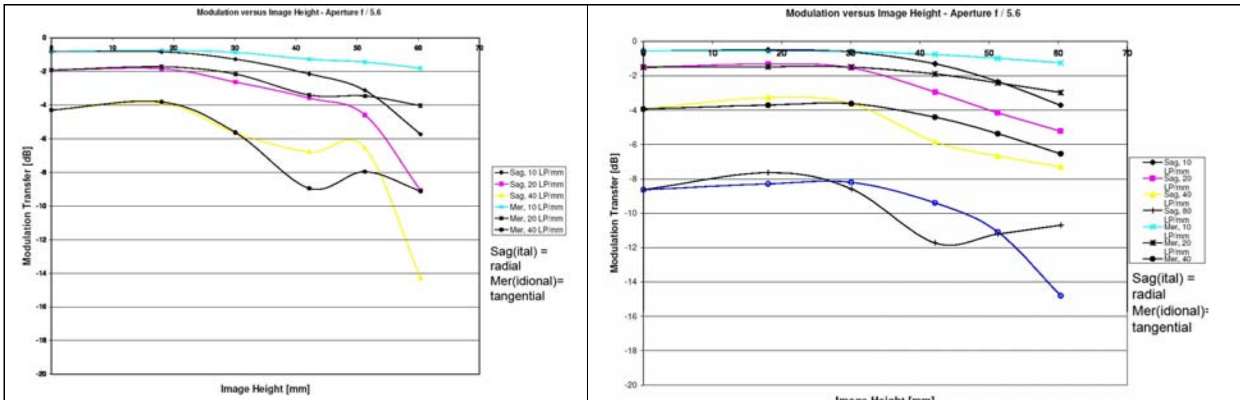


Figure 2. image scale and flying height for same GSD of 12cm - for DMC, UltraCamD and UltraCamX.

Table 1. technical data of large size digital frame and CCD-line cameras

camera	f	image size x [pixel]	image size y [pixel]	pixel size	sub-camera field of view x	sub-camera field of view y
DMC	120.0 mm	7680	13824	12.0 µm	23.1°	39.4°
UltraCamD	105.2 mm	7500	11500	9.0 µm	35.6°	52.4°
UltraCamX	100.5 mm	9420	14430	7.2 µm	37.3°	54.7°



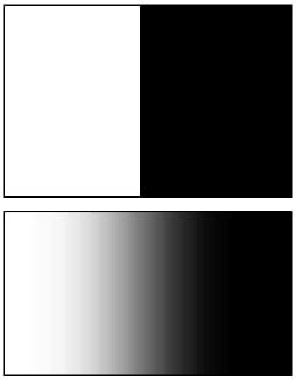
UltraCamD UCD-SU-1-0031 | UltraCamX UCX-SX-1-3091 4061

Figure 3. modulation transfer function for f/5,6 from calibration certificate, for different resolution, in radial and tangential direction.

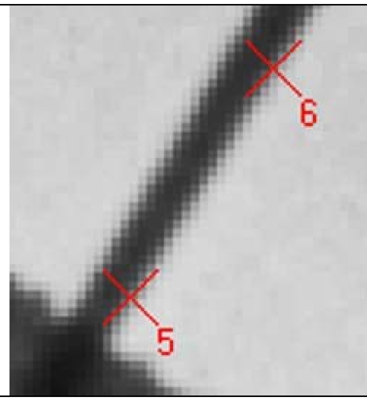
Especially the modulation transfer function for higher resolution decrease to the image corner (figure 3). Because of the smaller field of view, the larger aperture and the more advanced optics, the reduction of the modulation transfer function to the corners is negligible for the DMC. By this reason the number of pixels for the virtual image must not be the only criteria for the information content of a digital image. More difficult is the comparison of the information content between scanned analog photos and original digital images. At first there is the question about the justified pixel size for scanning and then the comparison of the information content – finally this only can be answered by the use of the images for mapping; that means what details can be identified in the images. This is also depending upon the film grain, disturbing the possibility of identifying small details, the contrast and the gray value range.

RADIOMETRIC COMPARISON

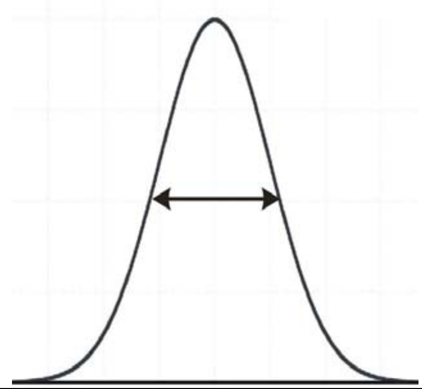
The radiometric resolution can be investigated by edge analysis. A sudden change of the brightness in the object from one location to the neighborhood (figure 4, upper left), e.g. from a bright roof to a dark shadow, is causing a continuous change of the gray value profile in the image (figure 4, lower left). The gray value profile can be differentiated, leading to the point spread function (figure 4, right). The width of the point spread function includes the information of the resolution. With digital images this will be done in relation to the pixel size in the image. The width of the point spread function will be named as factor for effective resolution.



Edge in object space
Edge in image space

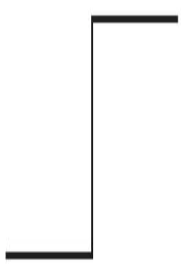


specification of edge in RC30-image

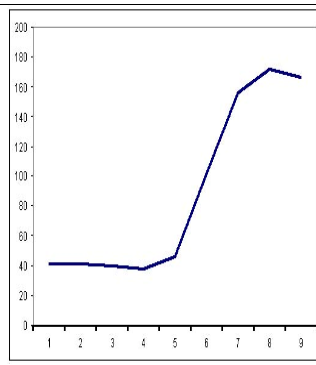


Point spread function

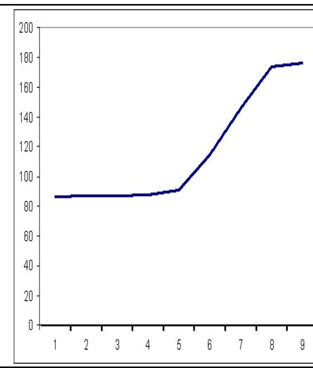
Figure 4. edge analysis.



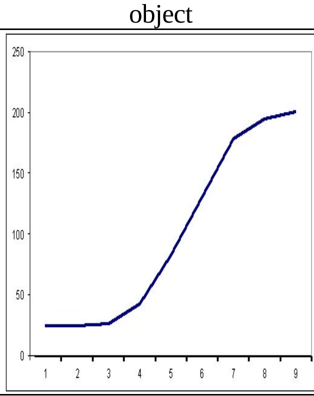
object



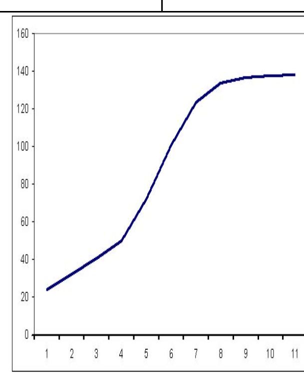
DMC



UltraCamD



UltraCamX



RC30

Figure 5. typical gray value profiles at edges, images of test area Franklin Mills.
Vertical: gray values horizontal: relative pixel position across edge

For the analysis an edge is specified by 2 points in the image (figure 4, center). All gray value profiles between these both points, perpendicular to the edge are used for the analysis. All gray value profiles of an edge are averaged before computation of the point spread function, reducing the noise especially of scanned photos.

In cooperation with BAE Systems GP&S, Mt. Laurel, NJ, in the test field Franklin Mills (north of Philadelphia) images have been taken with the DMC, UltraCamD, UltraCamX and the analog RC30. The GSD of the images is in the same range, allowing a comparison of the systems, but nevertheless, the imaging conditions have not been the same. Especially the light conditions have to be respected; it is mainly depending upon the sun elevation during imaging. The used GSD cannot be reached without problems with line scanner cameras. For example the ADS40 has a sampling rate of 800 lines per seconds, corresponding to 90mm GSD in the flight direction for the flying speed of 140 knots (72 m/sec). Of course across the flight direction the GSD is just a question of the flying height and also 50mm can be reached with good image quality.

Table 2. image flights over test area Franklin Mills

camera	flight	sun elevation	ground sampling distance
DMC	July 2007	~ 43°	54mm
UltraCamD	February 2006	~ 27°	42mm
UltraCamX	April 2007	~ 27°	37mm
RC30	September 2007	~ 46°	49mm

The edge analysis can be manipulated by image enhancement. As it can be seen in figure 6, the gray value profiles are changing. A contrast enhancement (see also figure 6) is enlarging gray value difference between bright and dark parts, but it has no influence to the width of the point spread function – the factor for effective information content. The image elements seem to become clearer, but a mapping in fact becomes more difficult and any detail in shadow area is lost. An edge enhancement is reducing the gray value of the dark part just before the edge and is enlarging the bright part just behind the edge, as it can be seen in figures 6 to 8. This is raising the inclination of the gray value profile at the edge and is reducing the width of the point spread function – the factor for the effective information content is enlarged. A limited edge enhancement is simplifying the object identification, but if it is made too strong, it has a negative influence to the object identification. Of course elements in shadow areas are becoming more clear (figure 6, right), but a too strong edge enhancement makes the identification of other elements difficult. In general the influence of image enhancement can be seen in the images, especially at the gray value profiles across the edges. In the test field Franklin Mills approximately the same condition exists for all images.

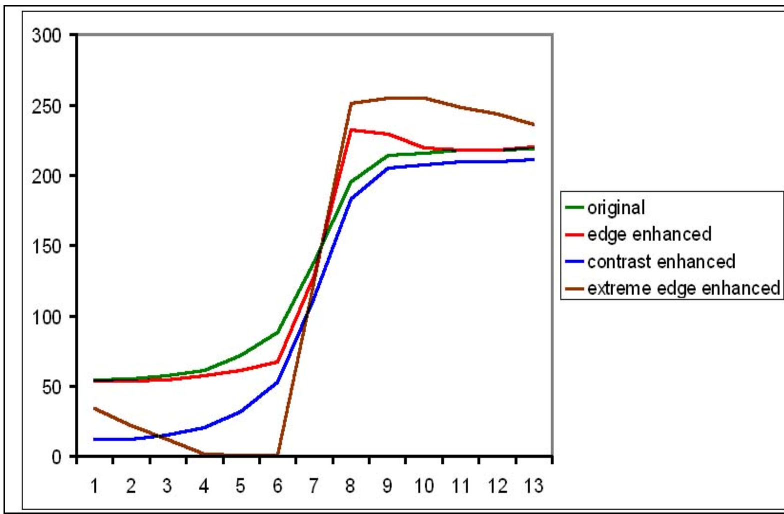


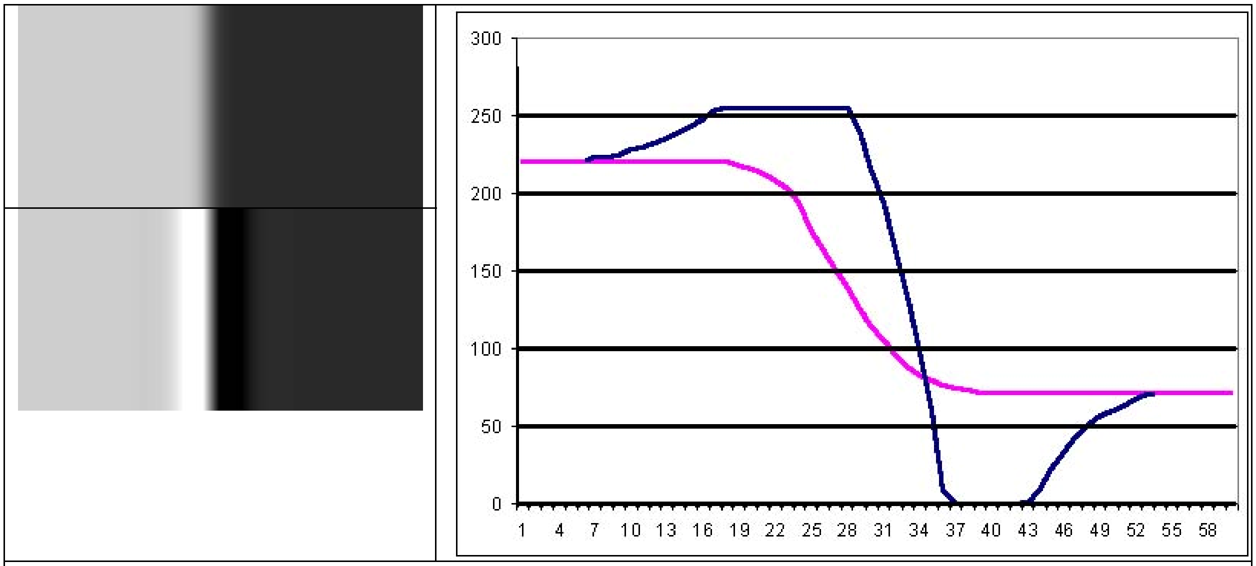
Figure 6. grey value profile of same edge, manipulated by image enhancement.
vertical: gray values
horizontal: pixel position in profile across edge

factor for effective information content (width of point spread function):

original	1.11
contrast enhanced	1.11
strong edge enhanced	0.98
extreme edge enhanced	0.93

original	contrast enhanced	strong edge enhanced	extreme edge enhanced

Figure 7. influence of image enhancement to image – part of UltraCamD.



Above: original artificial edge   profile of original (red) and extreme enhanced (dark) edge
Below: extreme enhanced edge
Figure 8. extreme edge enhancement of artificial edge.

Against the expectation, no significant variation of the effective resolution in the UltraCam images from the center to the image corners can be seen in the test field Franklin Mills. This was different in UltraCamD-images taken over Istanbul under 60° sun elevation. Here in the image centers the factor for the effective resolution was 1.04, while it was 1.28 in the corners – this corresponds to the modulation transfer function (figure 3). Also in the EuroSDR test area Frederiksstad, where the images have been taken under 20° sun elevation, a variation of the image quality depending upon the radial distance from the image center has been seen in UltraCamD-images. In the center the factor for the effective information content is 1.21, while it is 1.43 in the corners. In DMC-images such an effect has not been recognized, but it is also not expected because of the convergent arrangement and the smaller field of view of the sub-cameras.

A factor below 1.0 usually is caused by edge enhancement, by this reason it is only counted in the column for the effective number of pixels with the factor 1.0. The tendency of the effective number of pixels, corresponding to the information content, listed in table 3, has been confirmed by other data sets and also with the completeness of topographic maps based on such images. Only based on RC30 photos the mapping is still more difficult like discussed below. The image quality is not the same for all spectral ranges, like expected by theory.

Table 3. Effective number of pixels corresponding to information content for panchromatic band, test field Franklin Mills			
camera	factor for information content	nominal number of pixels in image	effective number of pixels in image
DMC	0.92	7680 x 13824	7680 x 13824
UltraCamD	1.16	7500 x 11500	6465 x 9914
UltraCamX	1.28	9420 x 14430	7360 x 11273
RC30 scanned with 12.5µm pixel size	1.43	18400 x 18400	12870 x 12870 (8580x 8580)

Table 4. Effective number of pixels corresponding to information content, test area Franklin Mills						
	pan	blue	green	red	near infrared	
DMC	0.92	0.94	0.95	0.93	0.94	separate channels
UltraCamD	1.16	1.11	1.12	1.25		pan-sharpened channels
UltraCamX	1.28	1.22	1.24	1.34		pan-sharpened channels
RC30	1.43	1.51	1.43	1.74		pan based on RGB

The results of the UltraCamD and UltraCamX are based on pan-sharpened images and pan has been reconstructed from the pan-sharpened images. Of course this may influence the results, but it is realistic for practical application where in most cases only pan-sharpened images are available. The same situation we have with the RC30 color photo. For all cameras the green channel is close to the optimal channel (table 4). For both UltraCam and the RC30 the red channel has the lowest resolution. The variation of the DMC-channels is not significant.

INFORMATION CONTENT DETERMINED BY MAPPING

The meaning of effective number of pixels corresponding to the information content has to be checked by mapping. For the UltraCamD, the DMC and analog aerial images this has been done in the EuroSDR test area Frederikstad, and for the UltraCamD together with an aerial camera also in a production area in Germany (Oswald 2006).

Table 5. comparison of photogrammetric data acquisition, EuroSDR test area Frederikstad			
	GSD	not identified	total length of vectors
photo [scanned with 20µm]	20 cm	6.9 %	3898 m
DMC	18 cm	2.9 %	4648 m
UltraCamD	17 cm	6.0 %	4639 m
photo [scanned with 20µm]	10 cm	3.6 %	4610 m
DMC	9.2 cm	1.3 %	5074 m
photo [scanned with 12µm]	6.5 cm	2.6 %	4670 m

Table 6. comparison of photogrammetric data acquisition, production area in Germany			
	GSD	not identified	total length of vectors
photo [scanned with 20µm]	8.5 cm	12,9 %	6202 m
UltraCamD	9.0 cm	3,6 %	6907 m

Analog photos have been scanned with 20µm and separately with 12µm pixel size by a Vexcel scanner. The visual inspection as well as the result from mapping (table 5) showed only negligible improvements of the photos scanned with 12µm against the same photos scanned with 20µm pixel size. This corresponds to the result of edge analysis (table 3) – the RC30 photo, scanned with 12.5µm, has a factor for the effective information contents of 1.43. 12.5µm times 1.43 leads to an effective pixel size of 17.9µm, which is very close to the here used 20µm pixel size. That means a scan with a smaller pixel size than 18µm should not improve the results. But even scanned with 20µm, the image quality of the scanned photos is not the same like for the original digital images. The photos are disturbed by the film grain, has lower contrast and problems in shadow areas. The influence of the film grain is not included in the above mentioned edge analysis because several profiles are averaged for the computation of the point spread function. In general a relation of the information content between digital and analog photos, scanned with 20µm pixel size, of 1.5 has been found and confirmed in other areas – in a scanned photo with 10cm GSD the same information content is available like in a direct digital image having 15cm GSD. If this factor is respected, the effective number of pixels in an analog photo is only 230mm / 17.9µm / 1.5 = 8560 (table 3, value in brackets), or a single UltraCamD-image has a similar information content like a scanned aerial photo.

Table 5 shows also slightly better results for the DMC with 18cm GSD like for the UltraCamD with 17cm GSD. This confirms the slightly different image quality of both digital cameras. The small advantage of the DMC information content against the UltraCamX and UltraCamD can be seen also in the geometric property (Passini et al 2008).

CONCLUSION

The characterization of a digital camera should not just be limited to the simple technical specifications, like the pixel number of the digital camera; also the imaging quality is important. Only the analysis of the information content by edge analysis and mapping under comparable conditions gives the correct information. This is the case for the digital cameras, but also for the comparison of digitized analog aerial photos with original digital images. It has been shown, that the information content of an aerial photo is in the same range like the content of an UltraCamD image. The UltraCamX and the DMC images have higher information content like an aerial photo. The smaller pixel size of the UltraCamX, the larger field of view of the sub-cameras and the used optics seems to influence image quality, so that the nominal number of pixels has to be reduced for a comparison with other digital aerial cameras. Nevertheless the UltraCamX is a clear improvement against the UltraCamD.

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