

EFFECTIVE RESOLUTION OF DIGITAL FRAME IMAGES

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corrected version

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ABSTRACT:

The nominal resolution of digital aerial images does not always correspond to the effective resolution. This can be tested by edge analysis, but the resolution is just one figure about the image quality. A more detailed information is included in the modulation transfer function (MTF), showing also the image quality for lower image frequency. The MTF is quite dependent upon the used aperture. If the diameter of the aperture is reduced against the full opening, at first the image quality is improved, shown by the MTF, but if the opening of the aperture is reduced too much, the image quality is reduced. This effect is caused by the diffraction limited resolution, linear dependent upon the wave length. It shows very well that a reduction of the pixel size in the image for the same size of the CCD-array may not improve the image information contents even if the nominal number of pixels is enlarged. The limitation of the image quality caused by the optics is not a new effect for now proposed 6µm pixel size, also with 7.2µm and even 9µm pixel size under some imaging conditions the effective resolution does not correspond to the simple nominal values. The MTF as function of radial distance from principal point usually shows a loss of quality in the image corners. These effects are obvious by a visual inspection of the images – a specification is possible by the MTF and also edge analysis over the whole image areas. The situation for the large format digital cameras is discussed.

The reduced effective resolution causes a loss of details for topographic mapping. The results of mapping with images taken by the DMC, UltraCamD, UltraCamX and the analogue RC30 are shown. It confirms the result of the edge analysis and the MTF, as well as the influence of diffraction limited resolution.

1. INTRODUCTION

For topographic application the image resolution is more important than the accuracy. At least the horizontal accuracy usually can be reached if the information content of the images is satisfying for mapping.

The information content of images, or in other words the objects which can be identified in the images, depends upon the ground sampling distance (GSD). But the nominal GSD does not reflect the situation totally; the image quality has to be respected. It may be influenced by the atmosphere, the optical system and the image motion which is not compensated by transfer delay and integration (TDI) or the mechanical forward motion compensation (FMC). The optical system may have a not satisfying resolution, which may be dependent upon the location in the image, especially the in the image corner it may be not as good, but it may be influenced also by the diaphragm limited resolution, depending upon the f-stop. By this reason the effective resolution of images has to be checked.

2. MODULATION TRANSFER FUNCTION

Simplified the quality of an optical system or the images is described by the resolution in linepairs/mm, but this is only describing the quality at the limiting high image frequency and not for the lower image frequency. For the whole range of image frequency the modulation transfer function (MTF) has to be used. It can be determined by means of standard test targets with darker and brighter bars with changing width (figure 1).

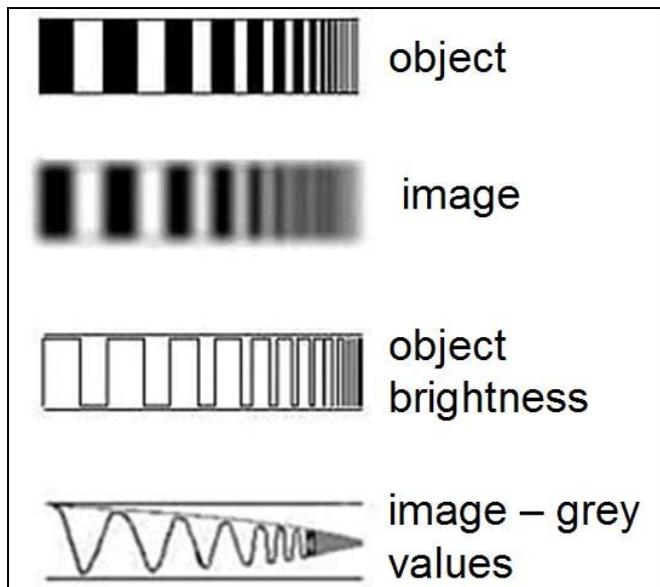


Fig. 1: resolution test target in the object and the image space together with the profiles of the grey values (Nasse, 2009)

$$\text{Contrast} = \frac{\text{grey value maximum} - \text{grey value minimum}}{\text{grey value maximum} + \text{grey value minimum}}$$

Formula 1: contrast

The contrast of an image can be described by formula 1. This is valid only for one width of the bars or in other words, the corresponding image frequency. As it is obvious in the lower

part of figure 1, the contrast is changing with the image frequency. For higher frequency (smaller bar), the contrast is going down to 0.0. The quality of an optical system is described by the modulation transfer function depending upon the image frequency. Under modulation we understand the relation between image contrast and object contrast.

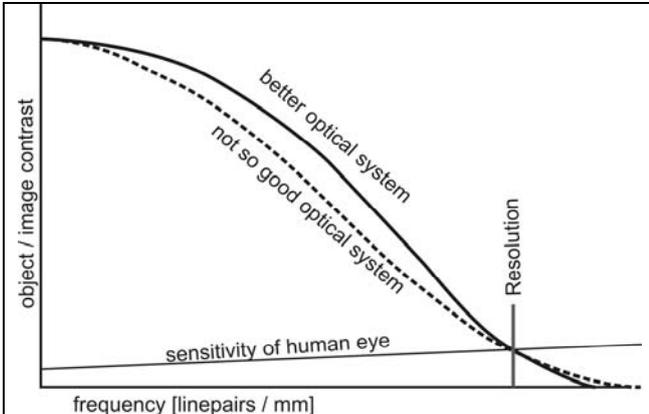


Fig. 2: modulation transfer function

As it can be seen in figure 2, two different optical systems may have the same resolution, but still different quality. The dashed line shows a MTF with lower modulation for lower image frequency. So a complete description of an optical system requires the information about the MTF, but this cannot be investigated in an easy manner.

3. DIFFRACTION LIMITED RESOLUTION

An optical system can be described by the geometric optics, but this is limited for smaller apertures where the character of the light as a wave front cannot be neglected.

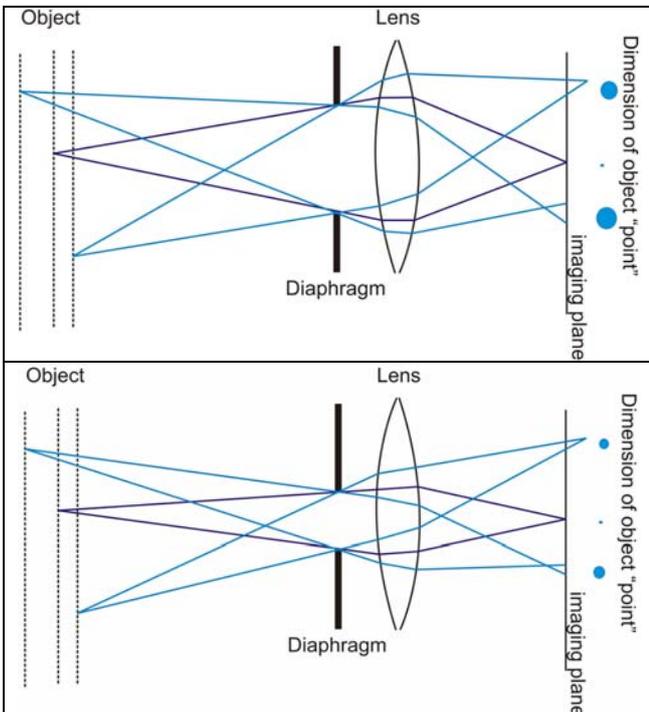


Fig. 3: image quality corresponding to geometric optics – above image quality for larger aperture, below for smaller aperture

As obvious in figure 3, corresponding to the geometric optics with a larger aperture the image quality is not as good as with a smaller aperture.

The handling of light in form of straight lines is a simplification of the geometric optics which still has some limitations. Light is available in form of waves which especially has to be respected for a small diaphragm which leads to the diffraction limited resolution.

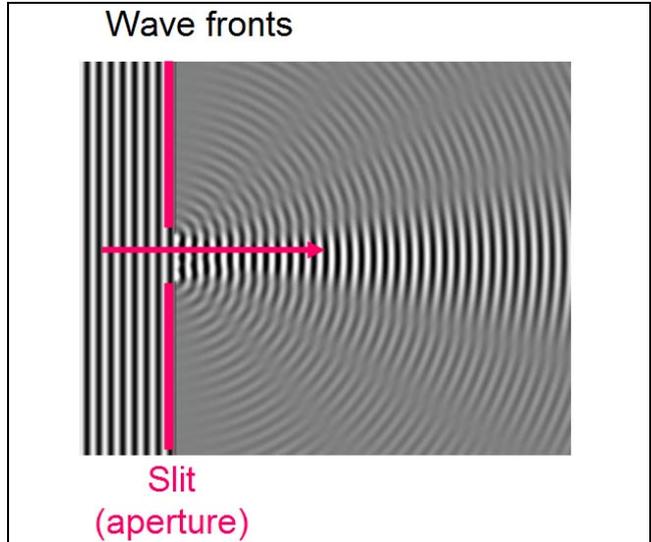


Fig. 4: behaviour of the light passing an aperture

If a parallel wave front of the light is passing through a small slit, which may be an aperture, the wave front will be deformed as shown in figure 4. This causes the change of the point image of an indefinitely small “point” to a larger area, the so called airy (figure 5). As diameter of the airy, the diameter of the centre with the first maximum is used.

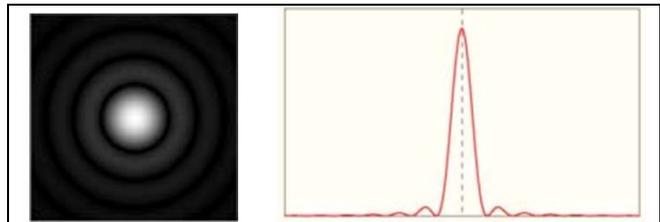


Fig. 5: left: “airy” = point image after passing of the wave front through a small slit right: cross section through the airy

If the small slit which is passed by the wave front is a diaphragm, the diameter of the airy is also named diffraction limited resolution.

$$d = 115'' / D \text{ [mm]} \quad \text{formula 2: diffraction limited resolution for } \lambda = 0.55\mu\text{m (green light)}$$

The diffraction limited resolution is linear depending upon the wavelength, with a larger value for a larger wavelength.

f-number	$\lambda=0.55\mu\text{m}$ (green)	$\lambda=0.65\mu\text{m}$ (red)
5.6	3.1 μm	3.7 μm
8	4.5 μm	5.3 μm
11	6.1 μm	7.2 μm
16	8.9 μm	10.5 μm
22	12.2 μm	14.4 μm

Table 1: diffraction limited resolution for f=100mm up to f=120mm

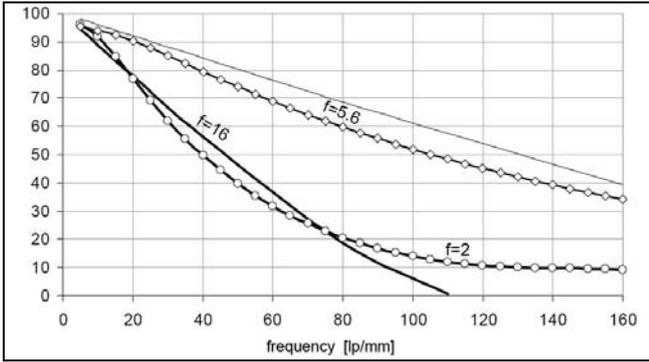


Fig. 6: effect of the diffraction limited resolution to the MTF (Nasse, H.H. 2009)

The influence of the diffraction limited resolution to the MTF can be seen in figure 6. Corresponding to the geometric optics, which is not respecting the wave nature of the light, the MTF will be better with a larger f-stop number (smaller aperture), but this is not the fact for the diffraction limited resolution as it can be seen in figure 6. The thin line above the MTF for f-stop 5.6 shows the diffraction limited resolution for the f-stop number 5.6. The MTF for the f-stop 5.6 is quite better as for the f-stop 2, but for the f-stop 16 it is reverse caused by the diffraction limited resolution. The MTF for the f-stop 22 is even not as good as for the f-stop 16.

4. OPTICAL BEHAVIOR OF APO-SIRONAR-S 100MM

As example for the influence of the diaphragm limited resolution to the image quality the APO-Sironar-S 100mm of LINOS Rodenstock is used. This optics was used for the UltraCam-D. With the published MTF-information of this system the influence of the diaphragm limited resolution can be demonstrated. The UltraCam-X and -Xp are using different optics, but the same limiting f-stop numbers.

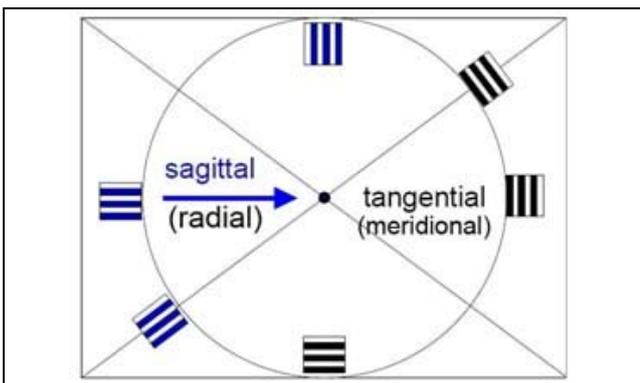


Fig. 7: definition of sagittal (radial) and meridional (tangential) direction in the image plane

The resolution of an optical system is different for the sagittal (radial) and meridional (tangential) direction in the image plane (figures 7 and 8).

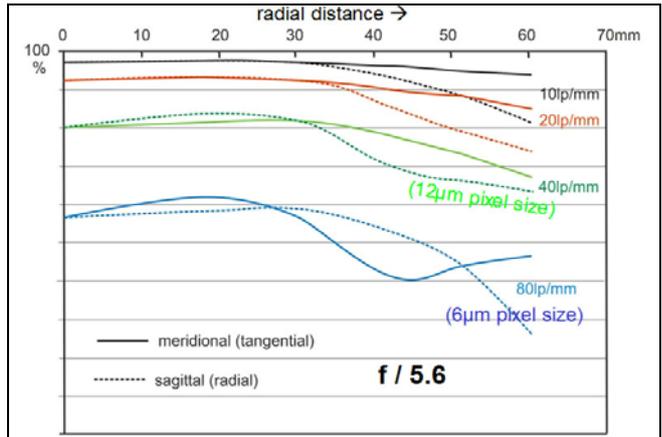
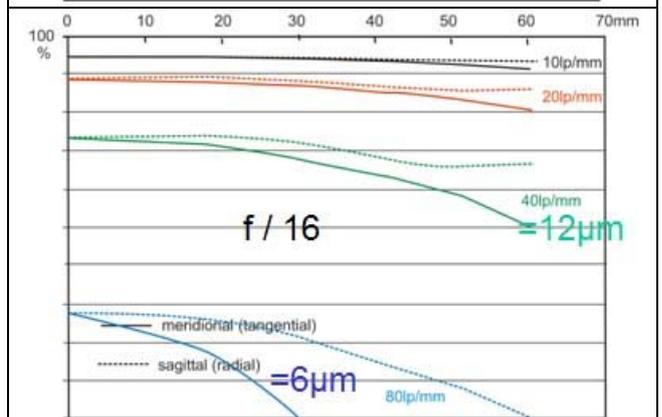
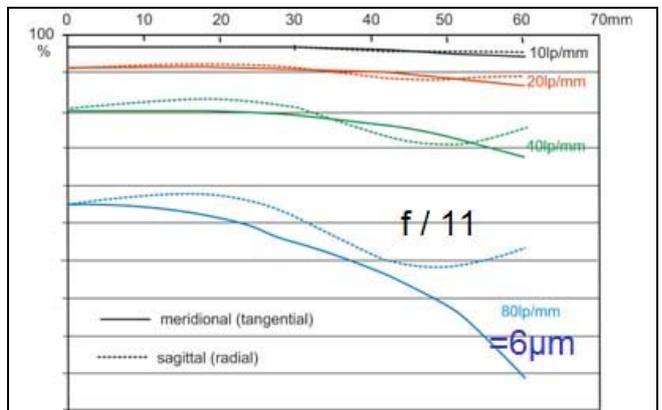


Fig. 8: MTF of APO-SIRONAR-S 100MM as function of radial distance for f-stop 5.6

Figure 8 shows the MTF of the APO-SIRONAR-S 100MM as function of the radial distance for the f-stop 5.6 (LINOS). For the higher frequency the modulation transfer is reduced as usual.



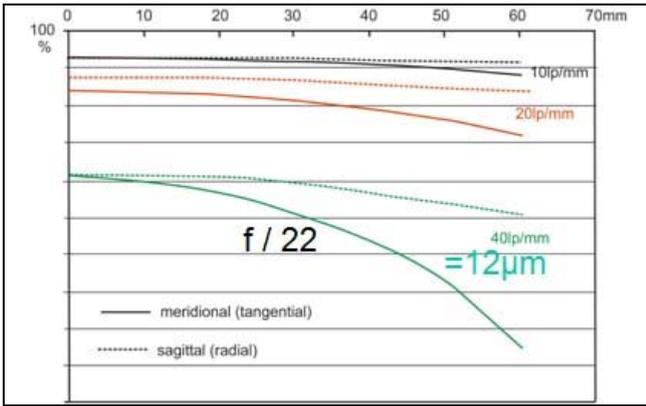


Fig. 9: MTF of APO-SIRONAR-S 100MM as function of radial distance for different f-stops

Opposite to simple expectation the modulation transfer of the APO-SIRONAR-S 100MM shows even for low image frequency or large pixels (10 lp/mm are corresponding to 50µm pixel size, 20lp/mm are corresponding to 25µm pixel size) not an improvement of the image quality. For the higher image frequency corresponding to 6µm and 12µm pixel size the modulation transfer is reduced for larger f-stop numbers or for the f-stop 11 6µm pixel size in the image corners are not realistic and for the f-stop 16 and 22 the optical characteristics, especially determined by the f-stop number, of the APO-SIRONAR-S 100MM does not allow a pixel size of 6µm. For the f-stop 22 even 12µm pixel size are at the limits. The explanation for such a lens characteristics is shown above with the diffraction limited resolution.

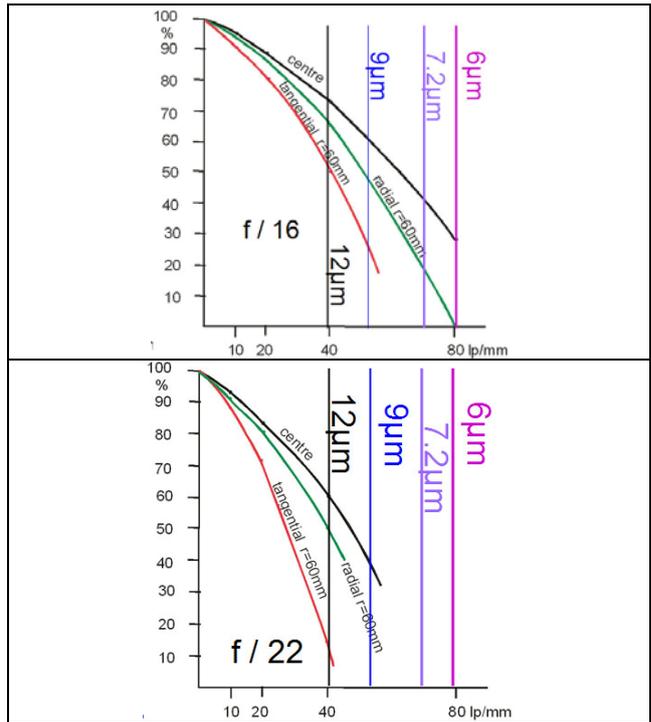
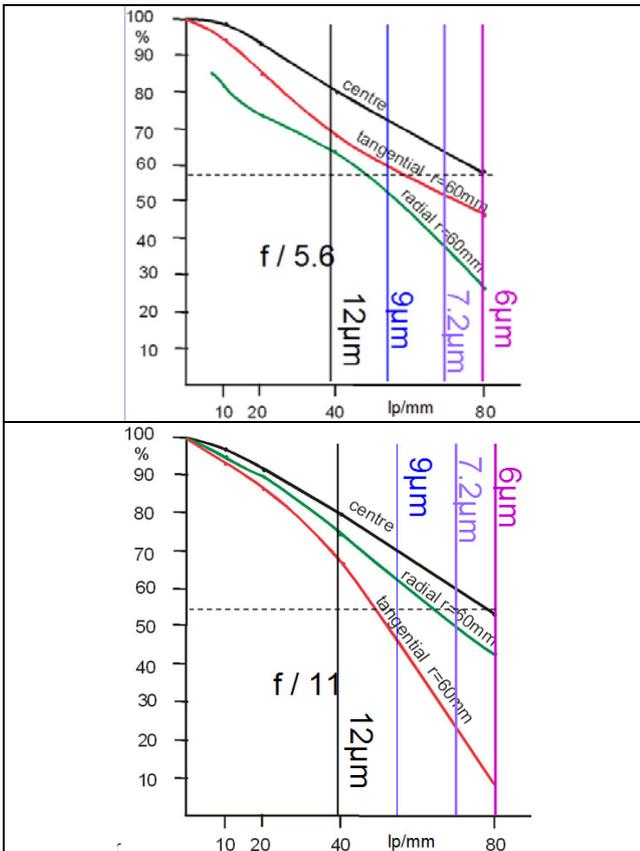


Fig. 10: MTF of APO-SIRONAR-S 100MM shown as function of image frequency for the image centre and the radial distance of 60mm with the radial (sagittal) and tangential (meridional) component

Also the more traditional presentation of the MTF as function of the image frequency in figure 10 demonstrates the very limited improvement of the information contents by the reduction of the pixel size from 7.2µm to 6µm. The reduction of the pixel size to 6µm pretends only an improvement by the higher number of pixels, but under usual conditions an improvement of the information contents cannot be expected with 6µm pixel size against 7.2µm pixel size.

5. EMPIRICAL TEST OF RADIOMETRIC QUALITY BY EDGE ANALYSIS

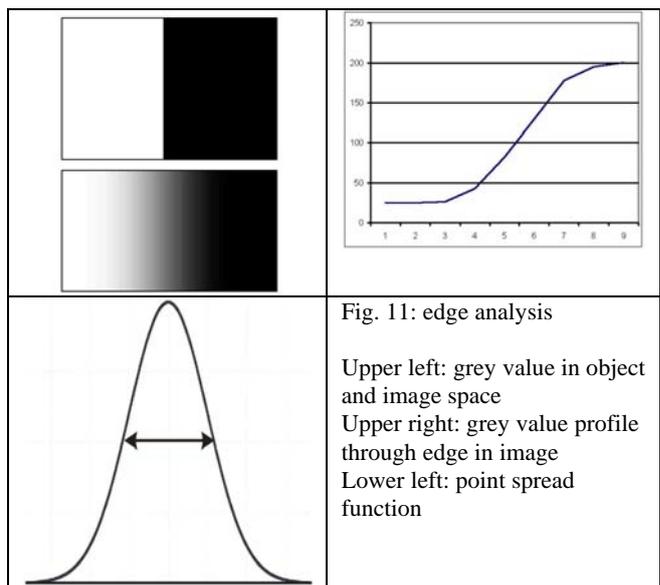


Fig. 11: edge analysis

Upper left: grey value in object and image space
 Upper right: grey value profile through edge in image
 Lower left: point spread function

The radiometric quality of different digital cameras has been analyzed by edge analysis for different digital cameras within a test in cooperation with BAE SYSTEMS GP&S (Passini, Jacobsen 2008), confirmed by other data sets. An edge is defined by sudden changes of the brightness in object space (figure 11 upper left), above. In the image such an edge is blurred by all effects of imaging, dominated by the optical system and the CCD-array (figure 11 upper left, below). A typical grey value profile of an edge imaged by a RC30 is shown in figure 11 upper right. If this grey value profile is differentiated, a point spread function is generated (figure 11 below). The width of the point spread function describes the quality of the images. This quality information is related to the pixel size. If no quality is lost by imaging, the width should have the value 2.0. In table 2 this quality information shown as factor for the effective pixel size. The nominal pixel size or ground sampling distance (GSD) has to be multiplied with this factor to give the effective pixel size or GSD, or reverse the nominal number of pixels have to be divided by this factor to give the effective number of pixels of the sensor in relation to the information contents of the image. By theory the factor for the effective pixel size should not be below 1.0, but it can be manipulated by edge enhancement. The edge enhancement is obvious in the images, but in general all used images have been improved in a similar manner.

camera	Sun elevation	Image type	Factor for effective pixel size
DMC	43°	pan	0.92
UltraCamD	27°	pan-sharpened	1.16
UltraCamX	27°	pan-sharpened	1.23
UltraCamX centre	27°	panchromatic	1.03
UltraCamX corner	27°	panchromatic	1.24
RC30	46°	RGB colour	1.43
ADS40	46°	pan forward 2°	0.99
ADS40	46°	pan after 14°	0.95
ADS40	46°	pan forward 27°	1.11

Table 2: factor for effective pixel size, Franklin Mills - corresponding to information contents (Passini, Jacobsen 2008)

The factor for the effective pixel size, listed in table 2, shows the lower image quality of the panchromatic UltraCamX-images in the image corner. The overall reduced image quality of the pan-sharpened UltraCam-images seems to be improved now; in a new test over the same test field with very high resolution images of the UltraCamX (Passini, Jacobsen 2009), the pan-sharpened images show an overall factor for the effective pixel size of 1.14. Additional tests of pan-sharpened DMC-images also showed a factor below 1.0 with no significant loss of image quality at the corners. But in general the image quality of the analogue camera RC30, scanned with 12µm pixel size, is quite below all original digital images.

6. EXPERIMENTAL MAPPING RESULTS

The practical meaning of the effective pixel size has been checked by topographic mapping of exactly the same area with images taken by different cameras with 5.4cm GSD for the DMC, 4.2cm GSD for the UltraCamD, 3.7cm GSD for the UltraCamX, 44.9cm GSD for the RC30 related to 12µm pixel size and 5.3cm x 9.1cm GSD for the ADS40. As first criteria

the completeness of mapping has been used in relation to the results achieved by the camera which was leading to the highest number of details. The second criteria is the sum of the vector length – if more details of an object have been identified, the sum of the vector length is larger, allowing to use this also for the comparison. The test was done with images taken over the test field Franklin Mills close to Philadelphia (Jacobsen 2008) and it was confirmed by the EuroSDR-data set taken over Frederikstad (Jacobsen 2007 + 2009).

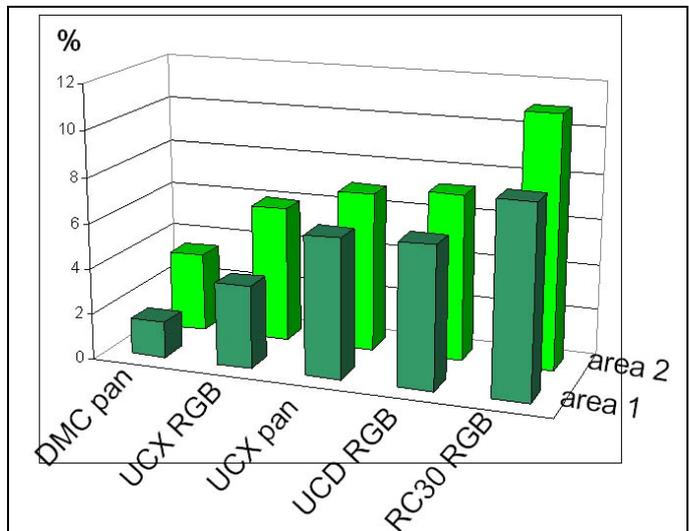


Fig. 12: percentage of not identified areas, test field Franklin Mills

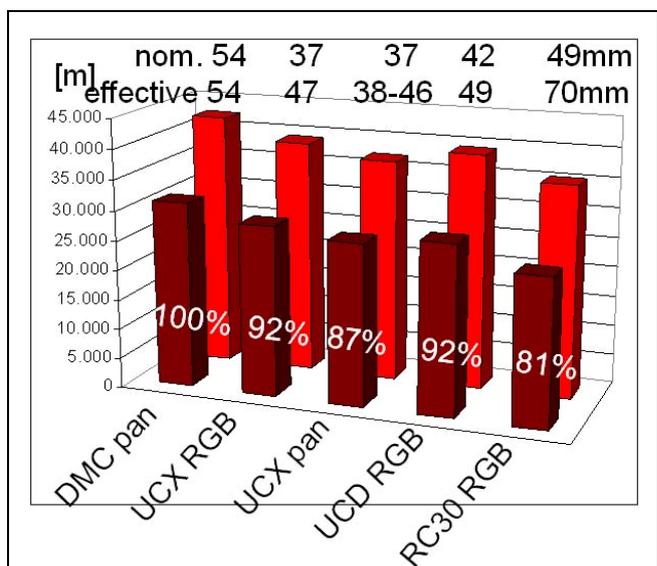


Fig. 13: sum of vector length achieved by mapping of exactly the same areas with different cameras

Figure 12 shows the percentage of not identified areas of the two used sub-areas in Franklin Mills. The nominal and the effective GSD was a little varying as listed in figure 13. In figure 13 the sum of the vector length of the two sub-areas is presented. All results are showing the same tendency that even the effective GSD seems to be a too optimistic result and a larger differentiation of the factor for the effective pixel size would be justified.

7. CONCLUSION

The nominal pixel size of a digital image may not be the same as the effective pixel size describing the information contents of a digital image. At least the effective pixel size has to be used for project planning to guarantee the identification of the objects which have to be mapped. The size of the pixel in the image is important for the diffraction limited resolution. Based on the geometric optical relations, the resolution should be improved with a smaller aperture or a higher f-stop number, but the wave structure of the light limits this by the diffraction, so with small pixels the effective resolution may become worse for higher f-stop numbers. The UltraCamX still has some limited resolution problems in the image corners, especially for a smaller aperture. With the reduced pixel size of just 6 μm for the UltraCamXP only a limited improvement of the information contents for imaging with a larger aperture has to be expected – for smaller aperture (larger f-stop number) no improvement can be expected; only the nominal numbers of pixels is larger. With 12 μm pixel size the DMC has quite less problems with the diffraction limited resolution.

The experimental tests for mapping have confirmed the investigation of the effective pixel size and is still pointing out, that the factor for the effective pixel size even may be too optimistic for the effective information contents of the images.

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