RADIOMETRIC QUALITY COMPARISON OF ULTRACAM-D AND ANALOG CAMERA

L. Markelin*, E. Ahokas, E. Honkavaara, A. Kukko, J. Peltoniemi

Finnish Geodetic Institute, Geodeetinrinne 2, FIN-02430 Masala Finland – (lauri.markelin@fgi.fi, eero.ahokas@fgi.fi, eija.honkavaara@fgi.fi, antero.kukko@fgi.fi, jouni.peltoniemi@fgi.fi)

Commission I

KEY WORDS: Aerial, Analog, Digital, Camera, Comparison, Radiometric, Quality, Film

ABSTRACT:

In this article preliminary results of the in-flight radiometric quality comparison of UltracamD and analog photogrammetric camera are given. The radiometric quality was evaluated using a grey scale with 8 intensity steps with nominal reflectance 5-70%; the BRDF-properties of the grey scale were measured in laboratory. The test flights were performed in ultimately poor illumination conditions in late autumn; the cameras were operated simultaneously. The evaluation showed that the performance of low-resolution multispectral UltraCamD images was quite linear. In the highest reflectance values the panchromatic channel was saturated in several images. The pan-sharpening process clearly altered the DNs of multispectral images. It appeared that the radiometric quality of UltraCamD was better than the radiometric quality of RC20.

1. INTRODUCTION

The development of digital photogrammetric cameras has made the radiometric properties of digital airborne images of great interest. The advantages of digital cameras over the analog ones include lower noise level (e.g. no granularity), linearity, better accuracy, better radiometric resolution and larger dynamic range. The expectation is that the improvement of radiometric quality improves the usability of the images both in visual and automatic interpretation tasks. Recently also the improvements of the analog image production have been reported, based on the new improvements in films and the scanning with larger radiometric resolution.It is also ambiguous how significant is the superiority of the digital sensors, and what is the impact of the improved quality in practice, if the images are after all transformed to 8 bit pixel depth using non-linear radiometric transformations.

Several factors affect the radiometric properties of images; these include the flying conditions, sensor properties and post-processing. Important in-flight factors are atmospheric conditions, exposure settings and solar altitude. For all the sensors the important sensor properties are the lens and filter quality. Specific factors for CCD-sensors are the radiometric quality of the CCD-array and the effects of post-processing (e.g. calibration based radiometric correction and quantization of the digital numbers to the final grey value scale, e.g. 16 bit to 8 bit conversion). The film images have many more processing phases affecting the radiometric quality, such as film, film development and the scanning process.

Thus far no rigorous comparative tests of performance of digital and analog cameras in in-flight conditions have been reported. In order to evaluate the performance of UltraCamD digital large format camera, excessive series of test flights were executed in October 2004 in Finland over the comprehensive photogrammetric Sjökulla test-field of the Finnish Geodetic Institute (FGI) and some other additional test-fields. The test participants were FGI, FM-Kartta Ltd, Geotec Vermessungsgesellschaft mbH and National Land Survey of Finland (NLS). The aim was to include many aspects of digital camera performance evaluation to the same test. The both cameras were operated simultaneously and they provided the same image widths on ground. Honkavaara *et al.* (2005) have reported the results of the analysis of geometric accuracy and spatial resolution.

The goals of our radiometric studies are twofold. First of all, our goal is to utilise the radiometric information in advanced interpretation methods. Advantages of the improved radiometric quality are that the data is more quantitative and provides more accurate spectres of objects. By rigorously utilising the BRDF information and atmospheric corrections, very accurate information of the objects can be provided. Our second goal is a practical one. Guidelines and tolerances are needed for the radiometric processing of the new types of images. The results will also give information for the further improvement of the film based digital image production.

In this study the radiometric quality of the images was evaluated using a transportable grey scale. The work included also the laboratory measurements of the BRDF (bidirectional reflectance distribution function) of the grey scale. The materials and methods are described in Chapter 2. The obtained results are given in Chapter 3 and discussed in Chapter 4.

* Corresponding author

Table 1. Image material.

Date	Camera	Number of images	GSD (cm)	FH (m)	Exposure (s)
14.10.	UC	10	4	450	1/125
	RC (pan)	4	4,2	450	1/500
14.10.	UC	15	8	900	1/125
	RC (pan)	8	8, 4	900	1/500
15.10.	UC (man)	15	8	900	1/90
	RC (col)	10	8, 4	900	1/300

2. MATERIALS AND METHODS

2.1 Imagery

The test flights were performed in the Sjökulla test field of the Finnish Geodetic Institute (FGI) (Kuittinen *et al.* 1994 and Ahokas *et al.* 2000). The test-flights took place in late autumn (October 11th-15th) mostly at noon. The sun angle was approximately 20˚, thus the illumination conditions were ultimately poor. For instance, in Finland 33˚ sun angle from horizon is the minimum recommendation for mapping flights.

UltracamD of GeoTec and RC20 of NLS were operated simultaneously in the OH-ACN aircraft of NLS. RC20 was equipped with intermediate angle optic (214 mm) thus the image widths of UltracamD and RC20 were approximately the same on ground. The aperture setting was 5.6 for the both systems, the exposure times are shown in Table 1.

Total number of UltracamD test images was over 800. Number of RC20 images was about 100. Details of the images used in this study are shown in Table 1. The GSDs of UltracamD images were 4 cm and 8 cm. In the case of RC20 images the scanning with 20 µm pixel size gave the same GSD as UltracamD; the use of 10 µm pixel size halved the GSD.

Further details of the test flights are described by Honkavaara *et al.* (2005).

2.1.1 UltracamD: UltracamD consists of 4 optical cones for high-resolution panchromatic image and 4 cones to produce individual red, green, blue and near infrared colours. PAN-image is stitched together from 9 individual CCDs resulting imagesize of 11500 x 7500 pixels. One CCD for each colour channel produces RGB and CIR images of size 3680 x 2400 pixels. These images can be PAN-sharpened to produce high-resolution colour images. The radiometric resolution of CCDs is 12 bits or more and images are stored in standard 16 bit – format. (Leberl *et al.* 2003) Spectral sensitivities of the channels are: 390 – 690 nm (PAN), 390 – 530 nm (blue), 470 – 660 nm (green), 570 – 690 nm (red) and 670 – 940 nm (nir).

Image processing was done with the UltracamD Office Processing Center software version 1.3.2. First, level_00 raw-images were processed to level_2 images. This stage adds camera calibration data to images, combines 9 different PAN-CCDs to one image and does some internal radiometrical corrections to images. User cannot alter any parameters affecting image quality in this phase.

In processing from level_2 to final level_3 images the following parameters were used:

- File: tiff, 16 bit, tile/interleaved (tile size 256),

Figure 1. Grey scale in field. Photo by Harri Kaartinen.

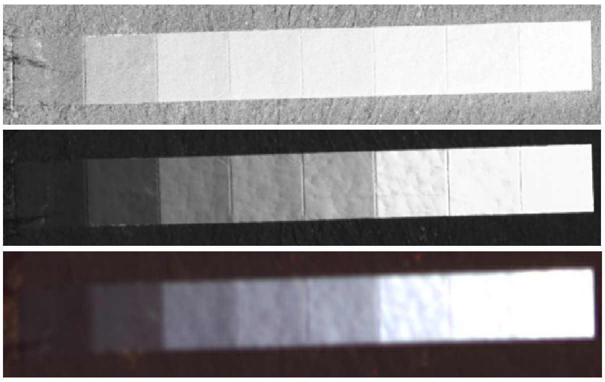

Figure 2. Examples of grey scale in images. From top to bottom (14.10.): RC20 pan 12 bit 20 um, UC hi-pan 16 bit, UC lo-cir 16 bit. Images are radiometrically enhanced for visualisation.

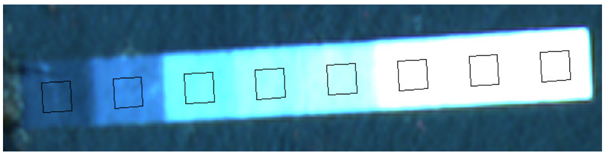

Figure 3. Grey scale and vectors. Lo-resolution CIR UltracamD image.

- Radiometry: absolute, highlight 65535, shadows 0, gamma 1.0, gradation type linear.

These parameters were chosen to assure as original images as possible without any radiometric adjustments. High resolution (PAN sharpened) PAN, RGB and CIR and low resolution (no PAN sharpening) RGB and CIR UltracamD images were produced.

2.1.2 RC20: RC20 images were acquired on panchromatic (Kodak Double-X Aerographic Film 2405, 400 ASA) and colour (Kodak Aerocolor III Negative Film 2444, 300 ASA) films. The images were scanned using Leica Geosystems DSW 600 scanner using the standard workflow of NLS. The scanning was performed using 20 µm and 10 µm pixel sizes and 8 bit and 12 bit radiometric resolution; 12 bit images were scanned using linear LUT.

2.2 Radiometric quality measurement methods

In this study the radiometric quality of the images was evaluated using the transportable grey scale of FGI. The grey scale has been painted on tarp and it consists of 8 density steps of size 5 m x 5 m; the nominal reflectances are 5%, 10%, 20%, 25%, 30%, 45%, 50% and 70% (Figure 1, Figure 2). This study included the BRDF measurement of the grey scale in laboratory as well as the image quality evaluation using the grey scale.

Kaasalainen *et. al.* (2005) has recently used the same grey scale in the evaluation of the laser intensity back scattering properties. A detailed study of the deployment of reference reflectance tarps with airborne imaging sensors was performed by Moran *et al.* (2001).

2.2.1 BRDF laboratory measurement of grey scale: BRDFs were measured in laboratory under artificial light using the ADS Field Spec Pro FR spectrogoniometer of FGI (Figure 4). The instrumentation is described in detail by Peltoniemi *et al.* (2005).

All eight panels of grey scale were measured with spectrogoniometer using the following parameters: illumination angle 50° (from zenith); azimuth angles 0°, 10°, 20°, 30°, 50°, 70°, 90° and 120°; observing angles +70° to -70°. The darkest and the lightest panel were also measured using illumination angle 70°. Targets were illuminated with 800 W lamp. The measurements were normalized using Labsphere Spectralon white reference panel, which reflectance is very close to 1.0.

2.2.2 Image measurement of grey scale. The most rigorous method would be to transform the DNs to surface reflectance factors and to evaluate these. In this study the DNs were evaluated without any processing. A vector layer containing 8 square polygons of size 2 m x 2m on ground, one for each density step, was created for every image with Erdas Imagine 8.7 (see Figure 3). For these polygons the following statistics were calculated: mean, standard deviation, min, max.

3. RESULTS

3.1 Laboratory measurements of BRDF

First results of the BRDF laboratory measurements of the grey scale are shown in Figure 5 and Figure 6. Reflectance of grey scale appeared to be clearly directionally dependent. The reflectances were higher than the nominal values, but the relations of the various steps were in general similar to nominal ones (Figure 5). In the spectral area of UltracamD, 390 – 940 nm, the reflectances were more or less uniform. Shapes of reflectance spectra in Figure 6 corresponds well with the spectra presented by Kaasalainen *et. al.* (2005).

3.2 UltracamD

Results of various flights and GSDs were similar, so only the results of the flight with GSD 8 cm (14.10.) are shown.

The response of the low-resolution multispectral sensors is almost linear. Only the highest reflectance deviates from the expected behaviour. Visual evaluation indicated that the green channel deviated the most and the nir channel the least.

Performance of the PAN channel (Figure 8) was not as good as of MS-channels. The performance began to disperse already with nominal reflectance value of 45%. Several images were saturated with reflectance value 50%.

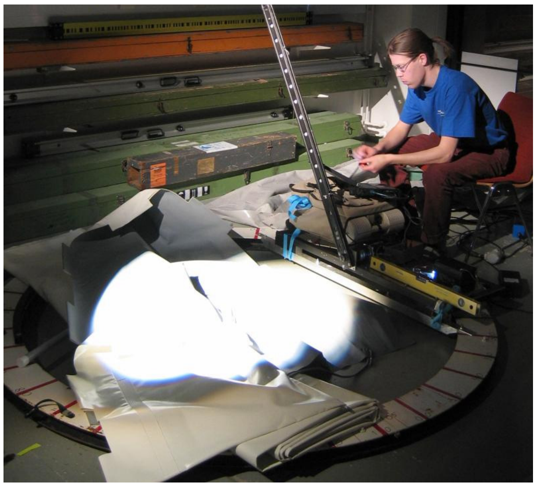

Figure 4. Laboratory measurements of grey scale. Photo by Antero Kukko.

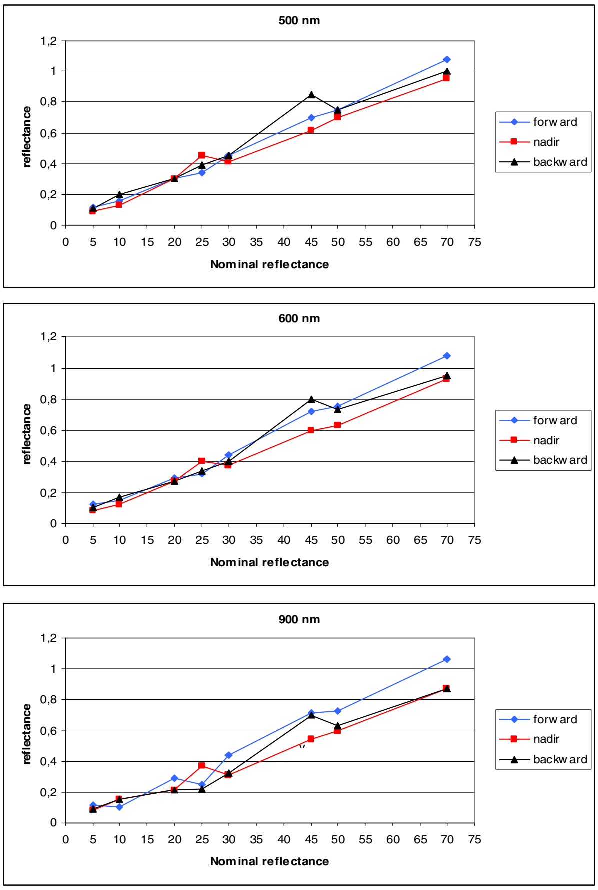

Figure 5. Grey scale reflectance's measured in laboratory.

The PAN-sharpening process changed the DNs clearly. In high-resolution images the DNs were significantly lower than in the low-resolution images, and the DNs dispersed in the high reflectance values clearly more than in the low-resolution images. The green and nir channels had the worst performance; in several cases the 70%-reflectance has smaller DNs than the 50%-reflectance.

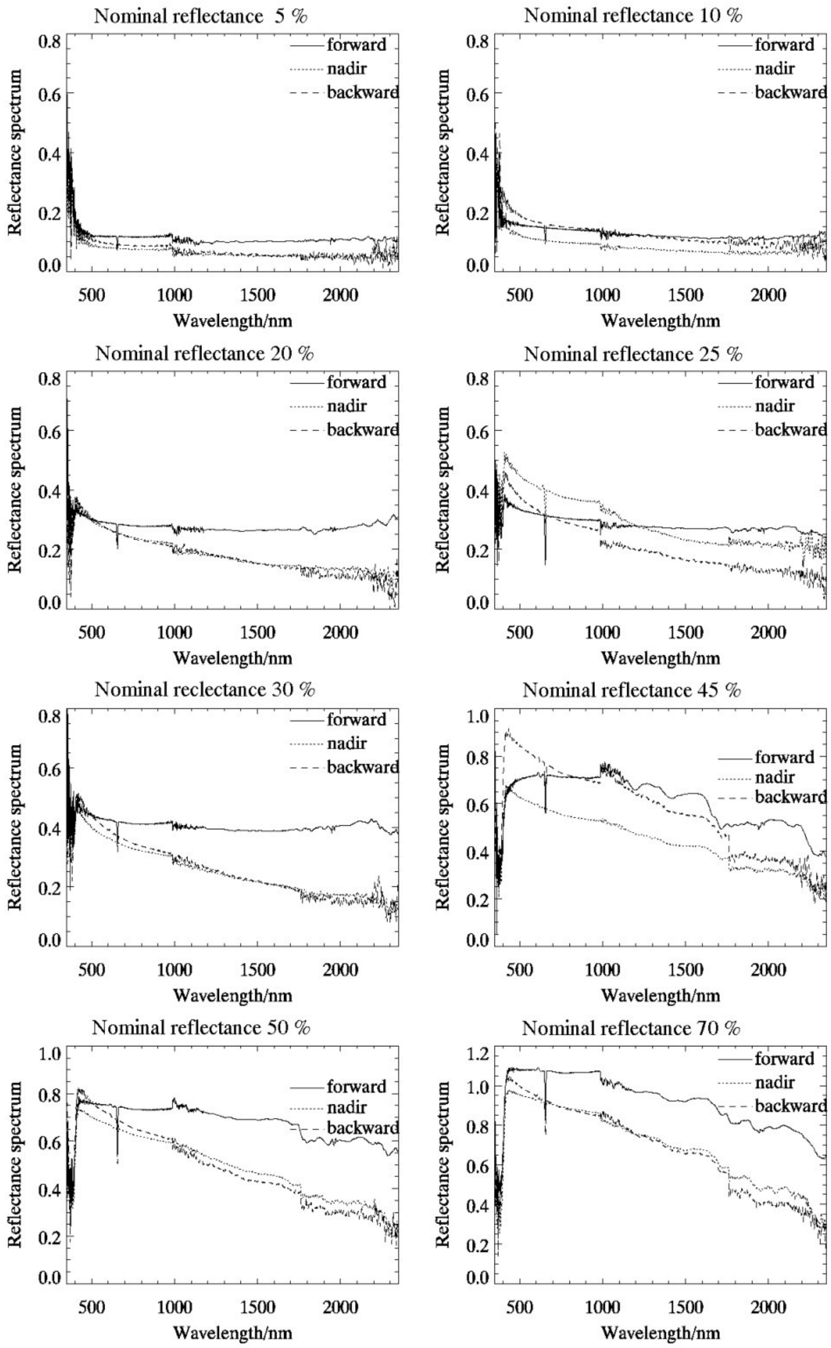

Figure 6. BRDFs for illumination angle 50˚, forward and backward directions 40˚ from zenith.

3.3 RC20

The scanning with 10 μm and 20 μm pixel sizes gave similar results. Also results of the consecutive flights with 450 and 900 m flying heights were similar, so only the results of images acquired in the 8 cm GSD UltracamD flight (14th Oct.) are shown.

The results of the panchromatic film with 8 and 12 bit pixel depth are shown in Figure 9. The differences of the DNs of steps with nominal reflectances greater than 20% were very small and the images were saturated at the latest on the nominal reflectance of 45%. The shape of the curves was logarithmic in both cases, as expected.

The performance of the film images appeared to be poorer than that of UltracamD images. One problem obviously was the poor illumination conditions, which were far below the normal practises. The test images were compared to older images (2002) from the test field, which were acquired under normal illumination conditions. In both data the DNs of the black and white gravel in the test field was measured. In the test images (2004) the DNs of the black gravel were 50 numbers larger than in the older images; difference between white and dark gravel was approximately 30 DNs smaller than in the older images. It is very likely that the poor illumination has affected the processing of the film images.

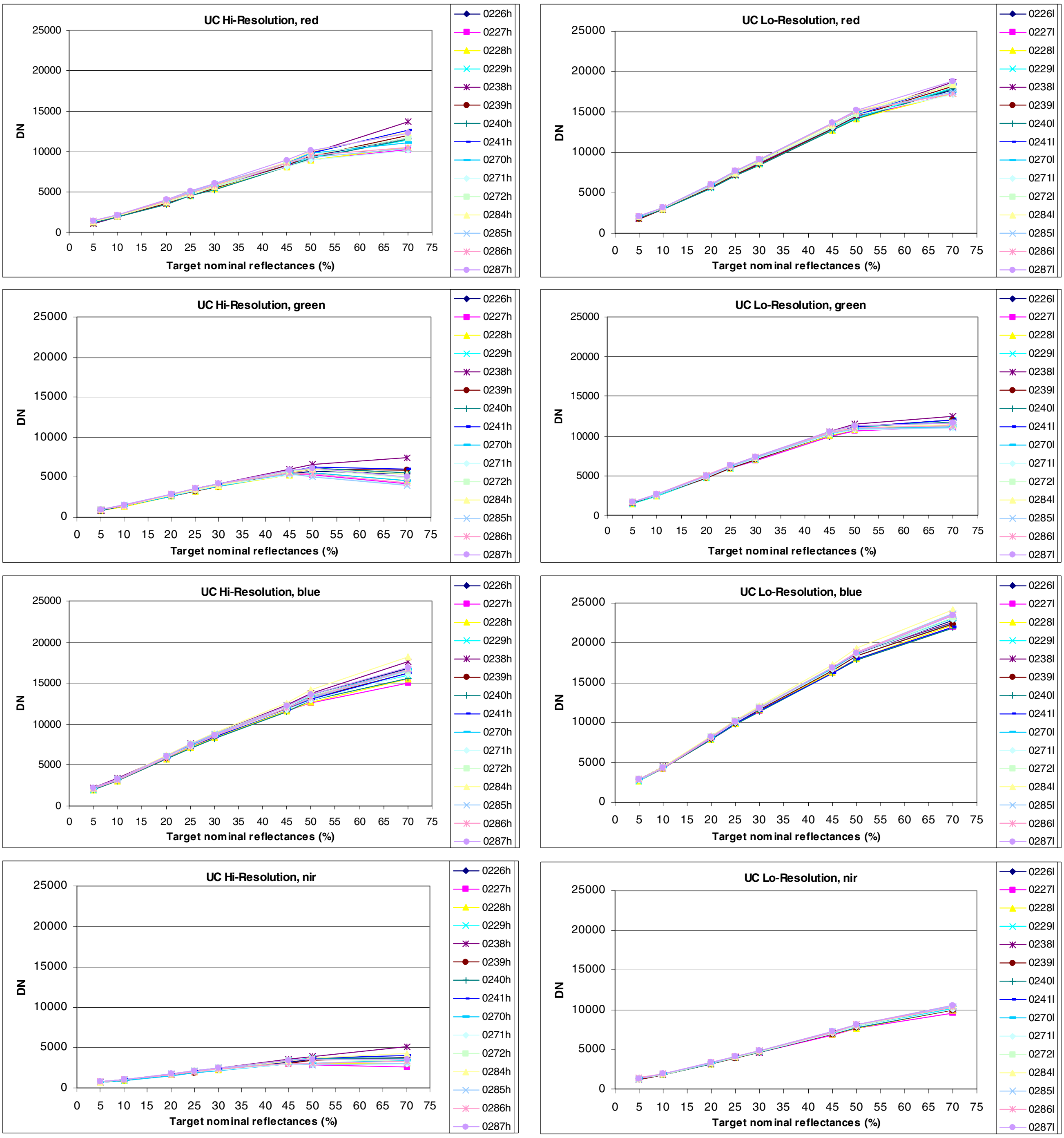

Figure 7. Grey scale measurements on UltracamD images. Left: high resolution images, right: low resolution images. Channels from top to bottom: red, green, blue, nir.

4. DISCUSSION

In this article the first results of the evaluation of radiometric quality of digital images using a transportable grey scale with 8 density steps have been given. The evaluation process is still in progress.

The preliminary laboratory measurement results of grey scale BRDF were in line with their expected reflectances. The lightest 70%-panel showed exceptionally high reflectance in extreme illumination and observing angles. More detailed analysis of directional dependencies of grey scale reflectance is still needed. Also the polarization of artificial light, reflectance of white reference and their effects to the results has to be investigated.

The linearity and the response of the UltracamD low-resolution images were mostly very good. Non-linear performance was present only with the largest reflectance values 50-70%. The performance of the panchromatic channel was not as good. The images were saturated in the many cases already with the reflectance value of 50%.

The PAN-sharpening process deteriorated the colour information. Especially it appeared that NIR- and green-channels were affected, and the effect was the largest in the highest reflectance values. The studies of Hirschmugl *et al.* (2005) gave similar results. In that study the deterioration of DNs of various colour channels was numerically evaluated; the NIR-channel was affected the most, the green-channel was the second worst and the red-channel was very close to green-channel. Blue-channel was affected clearly the least (half of red-channel). According to Hirschmugl *et al.* (2005) the reason for the weak performance of the NIR-channel was that the NIR and PAN-channels are not spectrally overlapped.

The radiometric performance of the film appeared to be poorer than of UltracamD. It can be expected that the photographing under more favourable conditions will improve the results. It is also possible, that some changes are needed to the photographic processing in order to optimise the images for the 12 bit process.

Despite of the very poor illumination conditions, good results were obtained with UltracamD 16 bit images. This supports the understanding that the digital sensors can be operated in poorer illumination conditions than the conventional film cameras. Further studies will be performed on this topic.

Important question is also how well the high radiometric quality of 16 bit images can be utilised; the generally performed conversion from 16 to 8 bits is not unambiguous and compromises in radiometric details have to be accepted.

The grey scale appeared to be an efficient tool for the radiometric quality evaluation. In the following studies the BRDF information and atmospheric corrections should be rigorously applied in order to obtain surface reflectance and to perform more accurate evaluations.

5. CONCLUSIONS

Radiometric quality of UltracamD digital large format camera and RC20 analog camera was evaluated using a method based on transportable grey scale. Radiometric quality of UltracamD images was very promising even though the images were acquired in late autumn under extremely poor illumination conditions. Radiometric performance of the UltracamD appeared to be better than that of RC20 film camera.

REFERENCES

Ahokas, E., Kuittinen, R., Jaakkola, J. 2000. A system to control the spatial quality of analogue and digital aerial images. In: International Archives of Photogrammetry and Remote Sensing, Vol. 33. Pp. 45-52.

Hirschmugl, M., Gallaun, H., Perko, R., Schardt, M. 2005. “Pansharpening” – Methoden für digitale, sehr hoch auflösende Fernerkundungsdaten. Angewandte Geographische Informationsverarbeitung XVII (Proceedings of AGIT Symposium 2005)(in press)

Honkavaara, E., Markelin, L., Ilves, R., Savolainen, P., Vilhomaa, J., Ahokas, E., Jaakkola, J., Kaartinen, H. 2005. In-flight performance evaluation of digital photogrammetric sensors. This proceedings.

Kaasalainen, S., Ahokas, E., Hyyppä, J., Suomalainen, J. 2005. Study of surface brightness from backscattered laser intensity: calibration of laser data. IEEE Transactions on Geoscience and Remote Sensing Letters. (in press)

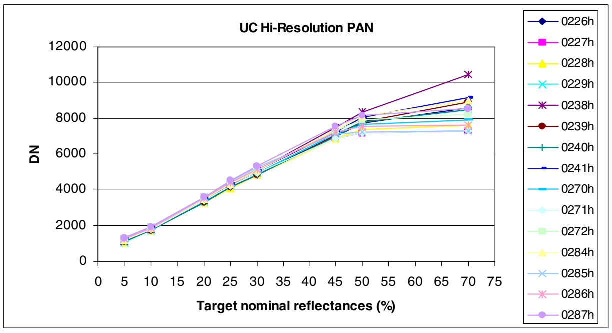

Figure 8. UltracamD PAN results.

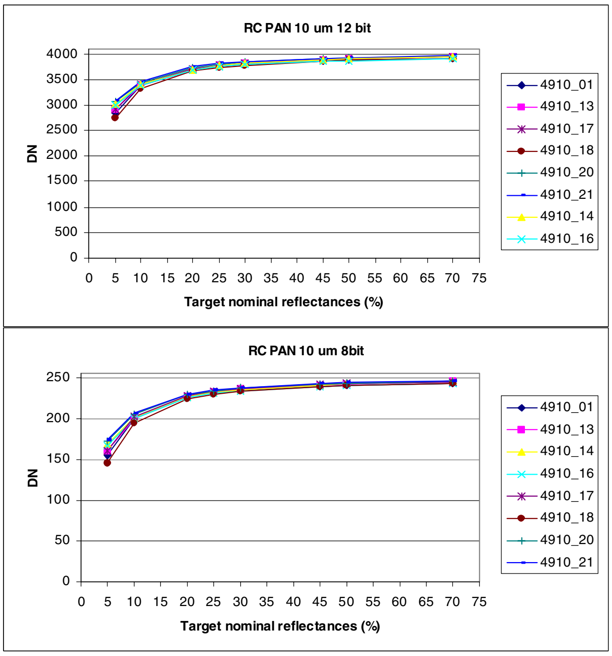

Figure 9. RC20 results

Kuittinen, R., Ahokas, E., Högholen, A., Laaksonen, J. 1994. Test-field for Aerial Photography. The Photogrammetric Journal of Finland. Vol. 14, No 1, pp. 53-62.

Leberl, F., Gruber, M. 2003. Flying the new large format digital aerial camera Ultracam. In: Photogrammetric Week ´03

Moran, M. S., Ross, B. B., Clarke, T., R. and Qi, J., 2001. Deployment and Calibration of Reference Reflectance Tarps for Use with Airborne Imaging Sensors. Photogrammetric Engineering & Remote Sensing. Vol. 67, No. 3, pp. 273-286.

Peltoniemi, J., Kaasalainen, S., Näränen, J., Rautiainen, M., Stenberg, P., Smolander, H., Smolander, S., Voipio, P. 2005. BRDF measurement of understory vegetation in pine forests: dwarf shrubs, lichen and moss. Remote Sensing of Enviroment, Vol. 94 Issue 3 (2005) p.343-354

ACKNOWLEDGEMENTS

The test participants FM-Kartta Ltd, Geotec Vermessungs-gesellschaft mbH and National Land Survey of Finland are gratefully acknowledged for the support. Help of several persons from FGI is appreciated.