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Status Report on the Evaluation of the Radiometric Properties of Digital Photogrammetric Airborne Cameras

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Summary: The new digital airborne sensors will open up new applications for photogrammetric sensors. This paper outlines the requests and the realisation of the radiometric analyses as part of the DGPF-project "Evaluation of digital photogrammetric aerial cameras systems". In order to learn the system properly sensor testing in operational conditions is essential. A short overview on the ground truth is provided. Investigations and results of the radiometric sensor evaluation – as far as available – will be presented and classified. At the end of the report some facts that should be improved in a subsequent mission are pointed out. The evaluation has not yet been finished.

Zusammenfassung: *Statusreport zur Evaluierung der radiometrischen Eigenschaften digitaler photogrammetrischer Luftbildkameras.* Digitale Luftbildkameras können neue photogrammetrische Anwendungsfelder erschließen. Dieser Aufsatz präsentiert Anforderungen und Realisierung der radiometrischen Qualitätsuntersuchungen als ein Teil des DGPF-Projekts zur „Evaluierung digitaler photogrammetrischer Kamerasysteme". Um die Eigenschaften eines digitalen Sensors zu erfassen, sind Testflüge unter operationellen Bedingungen unerlässlich. Die durchgeführten Untersuchungen und Ergebnisse zum radiometrischen Test – sofern sie vorliegen – werden dargestellt und eingeordnet, wenn auch die Evaluierung zum gegenwärtigen Zeitpunkt noch nicht vollständig abgeschlossen ist. Am Ende des Berichts werden Verbesserungsvorschläge für eine nachfolgende Kampagne gegeben.

1 Introduction

The German Society of Photogrammetry, Remote Sensing and Geoinformation has initiated a project to test digital airborne cameras. An overview on the whole concept of the project and the airborne cameras and spectrometers participated in the test is given by CRAMER (2010) in the issue. This report covers only the activities of the radiometric team for the radiometric evaluation of the airborne digital cameras.

Digital airborne cameras are increasingly coming into operation to meet demands for remote sensing. Analogous cameras have been used for remote sensing applications to a much lesser extent due to the complexity of their radiometry. The expectation is that the new features of the digital cameras like linearity, lower noise level and better radiometric resolution improve the image quality and the accuracy of the derived products and hence permit more remote sensing applications. However these aspired applications require a growing awareness of all involved persons for the problems of radiometry and radiometric calibration. The possibility to convert the digital numbers into radiation units opens up new and more sophisticated applications and allows us to realise the well-defined standards of digital image processing. For example, a challenging remote sensing task could be the estimation of the chlorophyll content of leaves or the determination of the leaf area index (MALENOVSKY et al. 2007, ZHANG et al. 2008, HUNT et al. 2008, ARS PROJECT 2009). Standard algorithms, applied previous to digital imaging processes, are for instance an atmospheric correction or a correction caused by the dependence of the reflection factor on the angles of illumination and observation which is known as BRDF (Bi-Directional Reflectance Distribution Function) correction (BEISL 2001, YENN et al. 2004, SCHÖNERMARK 2005, GARCIA-HARO et al. 2006, BEISL et al. 2008, ATCOR 2009). Calculations by YENN et al. 2004 for low flight altitude remote sensing data, have demonstrated that "Scattering and absorption due to aerosols can account for ~20% loss in the detected signal." Calibrated digital data of the cameras opens the possibility to correct this loss. Due to the BRDF a ground target may have a different look if the Sun or observer position changes. A normalisation of all data to a fixed illumination and viewing angle improves the possibility of correct comparison of different datasets and avoids the appearance of edges in the process of image mosaicking.

The consideration of increasing importance of the radiometric properties of digital air-borne cameras has resulted into the decision to expand the evaluation of digital airborne cameras also within the DGPF-project into the region of radiometric review.

The idea to involve the radiometric properties into the evaluation process of digital cameras is not new. Since the availability of digital cameras on the market in-flight radiometric quality comparisons have been carried out (MARKELIN et al. 2008, EMMOLO et al. 2008, HONKAVAARA et al. 2007, MARKELIN 2006). In the initiative on camera certification of the European Spatial Data Research Network the radiometric performance and calibration of digital airborne cameras is one of the main topics and is fulfilled by E. HONKAVAARA, R. REULKE & M. P. DESSEILLIGNY. A report about these activities can be found by CRAMER (2009).

2 Concept of radiometric evaluation

2.1 Classification in the frame of the DGPF project

One of the main goals of many users of digital airborne cameras is the classification according to classes or states of objects, provided by a statement of requirements. As an example one could consider the classification of land use or a vitality-classification of crown trees. The selection of a digital camera for such remote sensing tasks will be determined by its radiometric properties, such as the layout and the width of the spectral channels, the radiometric dynamics, the signal to noise ratio and the linearity of the response function. In addition, the importance of planning, scope of image processing and costs are decisive factors, however these points are not under discussion here.

Depending on demands some decent land cover or land use classifications can be processed using digital numbers (KLONUS 2009, LIM et al. 2009) if they are supported by significant operator intervention. For other tasks, such as the estimation of a crown tree's vitality, a pre-processing is necessary, for instance a BRDF correction (GERAD & NORTH 1997, SCHOMAKER 2007, GOUGEON 2009). A BRDF correction means a correction of the reflectance factor, which depends on the illumination and observation angle. Such a pre-processing requires a radiometric calibration of the sensor first, because the radiation units are needed for the calculations.

In order to minimise the different working teams the project leader set up a group of specialists for classification within the team of radiometric evaluation. Hence the report begins with some main activities of this group. The members of the classification group did a lot of ground truth work in order to allocate training data sets which can be used for a supervised classification. Furthermore data sets for the validation of classification accuracy are required. Due to bad weather conditions and subsequently a long period of evaluation flights, the ground truth work had to be repeated in dependence on occurrence of maturity or harvest. Afterwards the ground truth data sets of the different groups were harmonised and electronically stored (JORDAN et al. 2009). Fig. 2 and fig. 3 depict for land use classification the selected classification area and the distribution of trainings/validation sets.

First results of land use classifications using the data of different digital airborne cameras (DMC, RMK-TOP, Quattro DigiCAM, JAS-150 and Ultracam-X) over the test site Vaihingen/Enz can be found in KLONUS et al. (2009) and KLONUS (2009) and in the issue on hand (WASER et al. 2010).

In Fig. 3 an example is given for the class "Shadow" taken from the work of KLONUS (2009). The different digital cameras took the flights over the test sites under different atmospheric conditions and at different time (Sun position). Problematic regions as shadows could be better separated by using an atmospheric and BRDF-correction. But unfortunately, up to now an atmospheric or BRDF-correction of the data of the different cameras has not yet been performed.

Fig. 1: Vaihingen /Enz und selected classification area in red (Klonus 2009)

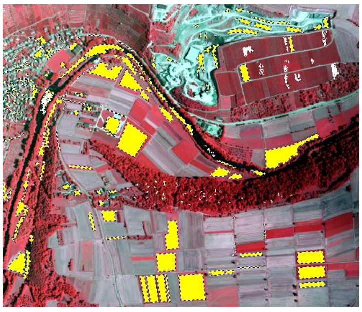

Fig. 2: Orthophoto of the distribution of the data sets in yellow which can be used for training or validation (with best thanks to Mr. Klonus)

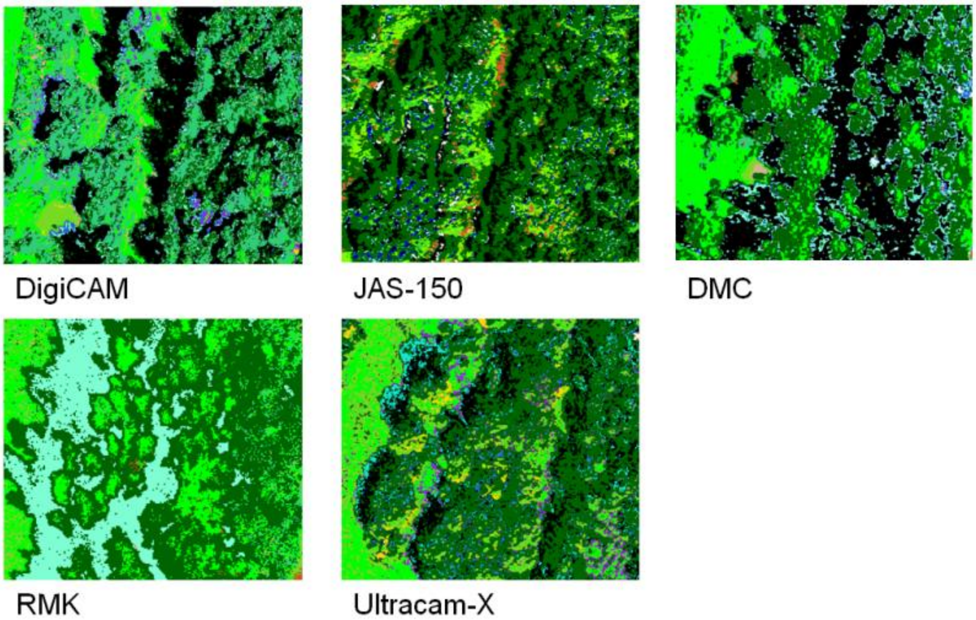

Fig. 3: Class "shadow" (for more explanations see Klonus 2009), obtained from the data sets of the DGPF-evaluation project. The differences result on the one hand from the various properties of the cameras and on the other hand from the different weather conditions.

2.2 Ground truth

In order to achieve the aim of the radiometric evaluation, a programme of ground truth measurements was installed on the so called radiometric field (CRAMER 2010). Coloured artificial planes and a large Siemens star were spread over the test site (s. Fig. 2 in CRAMER 2010, this issue). Using the spectrometer AvaSpec-128-USB2 the spectral surface-leaving radiance of the coloured planes, of the white and black parts of the Siemens star and of some natural surfaces as grass, bare field and asphalt were measured (Fig. 4).

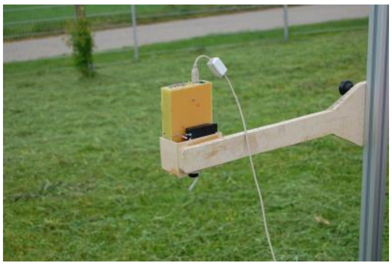

Fig. 4: Spectrometer AvaSPEC in operation at Vaihingen/Enz

In addition to these spectrometric measurements conducted by the Universität Stuttgart during every overflight, spectrometric reflectance measurements of different surfaces were performed sporadically by two other experts (Leica/Geosystems, University Halle, ASD Field Spec FR). Some measured ground truth spectra you can find in SCHOENERMARK 2008 und SCHWARZBACH 2008. The whole data set is stored at the Universität Stuttgart, Institute of Space Systems. The performed spectrometric ground truth measurements of the artificial coloured planes were compared with the laboratory spectral measurements of the German Aerospace Center, DLR (JUNG 2008). The differences were within the limits of the accuracy of the instruments and the laboratory calibration equipment (Ulbricht sphere).

In addition the so called bi-directional reflectance factor (BRF) was determined above grass. The BRF describes the reflected radiance in dependence on the illumination and observation conditions. The BRDF measurements were carried out with the instrument GRADIS (Ground Reflectance Angular Distribution Investigation System) which was built at the Universität Stuttgart, Institute of Space Systems. It is a lightweight transportable instrument with a central sensor design (Fig. 5). It collects data in the blue, green, red and NIR region (SCHWARZBACH & SCHOENERMARK 2009A, 2009B).

Fig. 5: BRDF-instrument GRADIS in operation

Furthermore a Sun photometer of the Schulz&Partner GmbH (Fig. 6) was used to measure the aerosol optical depth. These measurements allow us to evaluate the presence of clouds in front of the Sun. The knowledge of the aerosol optical depth is required to calculate the radiative transfer through the atmosphere with sufficient accuracy. The results of these calculations are needed for the calculation of the surface reflectance using the measured surface-leaving spectral radiance (GEIGER 2001, SCHÖNERMARK 2004).

Fig. 6: Sun photometer on the test site at Vaihingen/Enz

2.3 Radiometric tests

The radiometric evaluation provides a basis for the further image processing. Topics as the histogram analysis, detection of artefacts, noise analysis and the linearity of the response function of sensors are investigated. The data analysed showed that the compression of the data have to be done very carefully. Often it is a source of error. Detailed information is given by HANUSCH & BALTSAVIAS (2009) and ZHOU (2009). Furthermore the analysis demonstrated that better and more comprehensive information from the manufacturers of the cameras and a closer cooperation is necessary to clarify some peculiarities of the different cameras. Details of the analysis can be found in HANUSCH & BALTSAVIAS (2009), who investigated DMC, ADS 40 and UltraCamX, SCHOENERMARK et al. (2009) looked at the linearity of DMC and JAS-150. ZHOU (2009) discussed some radiometric properties of DMC and JAS-150. The investigations of the last two authors mentioned are not comprehensive, they are a by-product of the efforts, to organise an in-flight-calibration.

The DGPF- project of evaluation digital cameras is a project without financial support. Unfortunately some institutions did not have the possibility to participate in the project or they were only able to operate on a small scale or they had to reduce the scale of operations in the course of time. This holds particularly for the radiometric evaluation of the digital airborne cameras. In addition some scientific institutions having volunteered for the evaluation had to concentrate on specific tasks linked up with their basic research. Therefore no complete radiometric evaluation can be expected in this project; desirable investigations are missing up to now. However without an optional participation of some institutions, radiometric investigations of digital airborne cameras would not exist at all!

In support of the radiometric evaluation two hyperspectral measurement flights were performed over the area of Vaihingen/Enz. On the 2nd of July the AISA+ sensor, provided and maintained by Hochschule Anhalt, took a spectral data set. The flight with the ROSIS sensor of the German Aerospace Center (DLR) was on the 15th of July. Currently the data sets of these two flights are being analysed. First results are expected in July 2010.

2.4 In-flight calibration

Another goal of the radiometric team was the in-flight-calibration of the digital airborne cameras. With exception of the ADS40 a relationship between grey levels (Digital numbers DN) in each channel and radiation units is not applicable for the users up to now. As it has been already mentioned, such a relationship presents a basis for challenging image processing inclusive pre-processing. In the frame of our project the information about the absolute values in radiation units of each camera channel would have been the ideal initial point for comparing the cameras and interpreting the different classification results.

To realise an in-flight-calibration, the properties of the surfaces (spectral surface-leaving radiance respectively the spectral reflectance) as well as the properties of the atmosphere (aerosol optical depth) have to be measured reliably. Based on these input data the radiance coming into the sensor of the airborne camera must be calculated using a precise radiative transfer code (no analytical solution is possible). The calculated radiance at the sensor has to be compared with the digital numbers registered by the sensor. Doing this procedure over different surfaces one will obtain a relationship between the radiance and the DN. This is the general concept of the so-called reflectance-based in-flight-calibration (BIGGAR et al. 1994, SLATER et al. 1987). For an airborne sensor flying in low altitudes one has to use this method. Special methods and algorithms for this procedure (for instance ATCOR 2009) exist for special conditions. The equations used for in-flight–calibration in the special programme ATCOR presume isotropic reflectance of the surface. Natural surfaces exhibit more or less anisotropy; however the artificial coloured planes displayed a very strong anisotropy (Fig. 4). Unfortunately the team carrying out the spectrometer measurements at the ground quantified mainly the spectral reflectance of the artificial planes and only a few of natural surfaces. Therefore our in–flight-calibration using the programme ATCOR failed. Generally the author and Dr. Richter have learned that an in-flight calibration using the ATCOR-programme requires the spectral reflectances of natural surfaces.

Another possibility to solve the problem would be the use of another appropriate algorithm for the correction of the influence of the atmosphere and the calculation of the reflectivity. Taking the equations of FRASER & KAUFMAN (1985) an appropriate algorithm has to be derived and calculated for the actual case. This is a very time consuming work and up to now no scientific institution could invest the necessary time into this task, hence an atmospheric or BRDF-correction has not been carried out up to now.

Fig. 7: Strong anisotropy of the artificial planes

3 Constraints of the radiometric evaluation

The bad weather conditions in summer 2008 were the most serious obstacle. In Fig. 8 the measured aerosol optical depth at the wavelength of 533 nm is plotted. It can be seen, that a stable and low aerosol optical depth exists only on four or five days (2.7., 24.7., 9.9., 19.9. and constricted on 15.7.). A stronger variability and high values suggest evidence for clouds in front of the Sun. In this case the illumination conditions changed drastically and along with that also the reflectance of the surface depending on the illumination condition.

In order to minimize Sun glint the flight lines over the radiometric test site were flown North-South.

The team for the radiometric evaluation advised the flight over the radiometric test site at the true local midday time. This should guarantee that the changes of the Sun position can be kept at a low level so that all evaluation flights meet approximately the same illumination conditions. Fig. 9 depicts the reflection of a pinewood. It can be seen, that the time of least change in the reflectivity is noon. Furthermore the figure depicts the differences between cloudy and cloud free conditions. Hence the importance of the weather conditions for the in-flight calibration may be understood. In addition the different reflections under different conditions of cloudiness and Sun position also influence the results of the classifications (see fig. 3).

Due to the appearance of clouds in the morning, the flights over the radiometric test site were often earlier than advised or they were skipped completely.

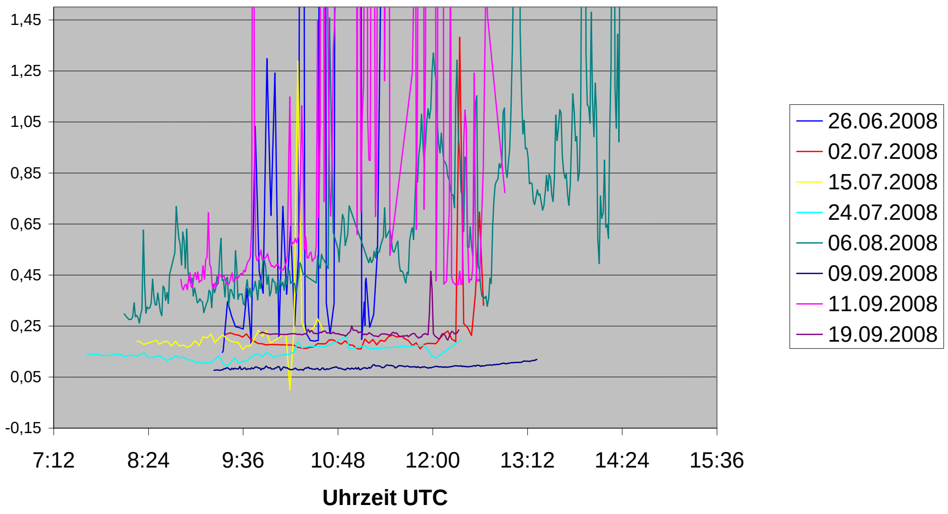

Fig. 8: Aerosol optical depth at 533 nm on the different days of evaluation flights, measurement at Vaihingen/Enz radiometric test site.

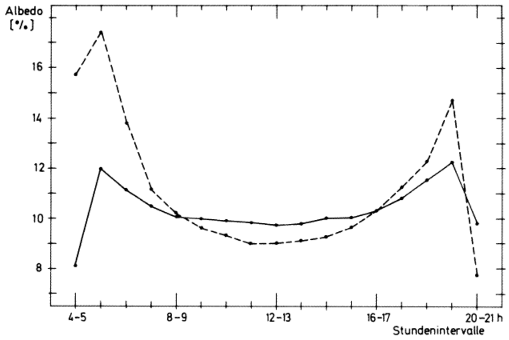

Fig. 9: Averaged diurnal variation of the reflectance (albedo) of a pinewood (Kessler 1985). The continuous line holds for the situation of strong cloudiness (7/8 to 8/8), the dashed line for cloudless conditions (0/8 to 1/8).

4 Conclusions – Lessons learned by the team

The radiometric evaluation has not yet been brought to an end.

First results about sensor evaluation are published; partly these documents carry a preliminary character, because in the discussions with the manufacturers some misunderstandings could be resolved.

Hence it would be advantageous, if information about the preprocessing of the data sets was provided by the manufacturers at the beginning of the next campaign.

By analysing the data sets it has become apparent that for a next campaign of experimental radiometric evaluation of airborne cameras it would be favourably to have available larger homogeneous radiometric test sites.

The usefulness of the artificial coloured planes is an issue under discussion. The advantage of these planes is that their spectral behaviour can be determined in the laboratory and does not change within the vegetation period. Here we have to assume, that the planes are well cleaned before each overflight. The planes used in our evaluation period had a strong BRDF. One could be on the lookout for other planes with a less BRDF effect (BEISL 2009) or try to get information by the defence industry. The size of our planes were too small (2x2m) for the spectrometers mounted on the airplanes.

Natural targets have the disadvantage that they rapidly change with the vegetation period and the measuring persons have to be careful to keep off the target. For a serious camera evaluation (for instance for a histogram analysis or the detection of artefacts) one needs large widely homogeneous targets, but for this purpose it is not necessary to control the spectral characteristics of these large targets. In contrast for an in-flight calibration the reflectivity of the natural targets must be known very exactly. They should exhibit widely isotropic behaviour, if one wants to apply atmospheric correction programmes which are available within the community. Otherwise one has to invest time into basic research or come into contact with military research.

The pros and cons of the use of asphalt, rock plateaus or concrete have to be taken into considerations also.

If one decides to use natural targets the operators shall reconsider how to take such measurements. Due to the inhomogeneity of natural targets, several measurements should be taken which have to be averaged afterwards.

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