Geometry Perfect – Radiometry Unknown?

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ABSTRACT

Digital airborne imaging is established in practice. Still there are continuous changes in the layout of the digital sensors itself, but also in the processing chains and calibration processes. This current status will shortly be highlighted within this paper. No empirical results are given but a more general overview with focus on the differences between geometric and radiometric aspects of digital airborne images. Both two aspects are discussed from a manufacturer's, user's and standard's point of view. The paper will show, that geometry and radiometry still are not yet perfect, but also not unknown. As with most of the new technologies sensor geometry and radiometry and according processing are still improved to finally lead to a most comprehensive, productive and efficient digital airborne sensor system.

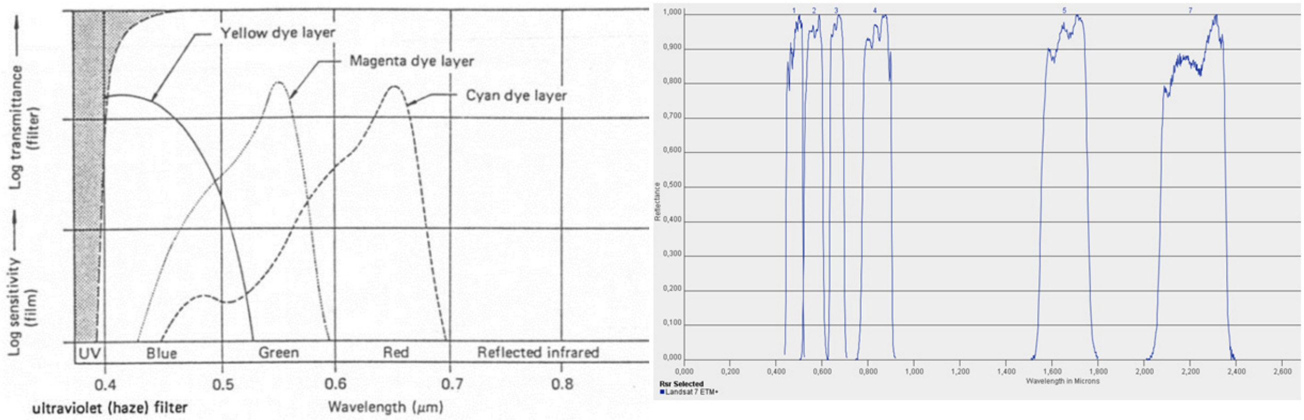
1. INTRODUCTION

Geometry perfect, radiometry unknown – this is the maybe slightly provocative title for this paper which may illustrate some sort of "dilemma" between geometry on the one and radiometry on the other hand. More generally speaking, the two aspect geometry and radiometry also indicate the clear separation between classical photogrammetry focusing on the geometric properties of objects and remote sensing based on their radiometric characteristics. With the new digital airborne cameras this clear separation, which to a certain extend was due to the available sensor technologies, now is close to vanish. It is the move from analog to digital airborne imaging forcing this change.

1.1. Remote sensing versus photogrammetry?

Digital airborne imaging now has replaced standard analog mapping cameras. In almost all countries (at least from European point of view) it is only digital systems, which are used in operational mapping now. Different to their analog predecessors, the digital imaging sensors provide extended multi-spectral capabilities, in addition to large format pan-chromatic imaging. Independently from the individual system layout, whether it is frame based multi-head or line scanning configuration, all sensors provide four separate spectral bands, which acquire spectral information in the blue, green, red and near infrared band. With that the new digital airborne cameras are getting close to the classical satellite based remote sensing systems, which from the very beginning offered multiple color (multi-spectral) bands, sometimes hyper-spectral. The imaging sensors in the LANDSAT satellite program like the Multi-Spectral Scanner MSS and the Thematic Mapper / Enhanced Thematic Mapper TM / ETM+ are some of the best-known multi-spectral sensors in orbit. The MSS system already was part of the first LANDSAT mission, launched in 1972. Since then remote sensing mainly used digital satellite images only. At that time airborne imaging was purely analog, based on film technology, with some limitations in the acquisition of clearly separated spectral information.

The succeeding Fig. 1 illustrates the different spectral characteristics a natural color film (left) to six of the overall eight channels of the Landsat ETM+ sensor by comparing their spectral response. Notice, the PAN channel (band 8) and the thermal infrared channel (band 6) are not depicted in the ETM+ figure (right). The differences are clearly obvious: The analog film has quite broad, strongly overlapping bands, whereas the ETM+ has very narrow bands. Its bandwidth is in the range of about 70nm for the three bands in the visible part of the electromagnetic spectrum. This comparison also shows, that remote sensing satellites typically offer more than only 3-4 bands, in this case it is spectral information in the near infrared (NIR) and two additional bands in the short wave infrared part of the spectrum (band 5 and 7). NIR information can also be detected with color infrared film (CIR) material which also is sensitive to electromagnetic radiation in the NIR. Longer wavelengths could not be registered with film. The clear separation of narrow bands is one pre-requisite for the later successful classification of object based on their radiometric characteristics.



Spectral sensitivity for natural color film.[1] Spectral response Landsat 7 ETM+.[2]

Figure 1: Spectral sensitivity of natural color film (left) compared to Landsat ETM+ sensor (right).

Even though this comparison of spectral bands is just an example, it is obvious, why film based imaging was focused on geometrical reconstruction mostly. This is one reason for the clear separation between remote sensing and photogrammetry.

In this context it may be interesting to re-call the definition of remote-sensing: Following the German Standard (DIN 18716-3) the term remote sensing is defined like: “Remote sensing embraces all methods of acquiring information about the Earth’s surface by means of measurement and interpretation of electromagnetic radiation either reflected from or emitted by it (Kraus 2007)”. As one can see, the definition itself does not separate between the acquisition of geometric or radiometric information, thus photogrammetry in principle is also included here. Still the applications dealing with geometric reconstruction then were assigned to photogrammetry which separates from the more general remote sensing definition.

1.2. Geometry versus radiometry?

With this to a certain extend sensor-technology driven background, photogrammetry people were closer looking on the most perfect geometric modeling of their sensors always, in order to obtain highest possible 3D point accuracy from 2D imagery. This already starts with the special design of the optical systems. The analog camera systems were designed as almost perfect cameras in terms of imaging, with high quality lens systems to a priory avoid or minimize any remaining systematic errors. This also was supported by geometric laboratory calibration. In addition self-calibration parameters were introduced for extended bundle adjustment to overcome the remaining systematic

[1] Source http://www.geog.ucsb.edu/~jeff/115a/lectures/cameras_films_filter/film_colorfilm_spectral_senstivity_with_uv_haze_filter.jpg
[2] Source http://landsat.usgs.gov/tools_viewer.php

errors. The radiometric calibration of these analog systems was limited to resolution measures of the optical lens and the characterization of the film material.

This now has changed for the digital sensors. The much better radiometric quality of digitally recorded image data in comparison to scanned analog imagery is commonly accepted. But this only is one part of the advantage of digital image recording. The other aspect is that photo sensitive electronic devices have a linear characteristic curve describing the relation between exposure and density. This is different to film, where the light is recorded in an s-shaped logarithmic curve, dependent on the settings of the exposures and the later film development. In digital imaging this curve is linear per se, i.e. the relation between exposure and density does not change. If this function is known from radiometric calibration, the light rays, which are measured by individual pixels directly relate to a physical property of the imaged object. In addition the multi-spectral capabilities should be mentioned. In the digital world filters could be defined exactly to the user's need, which is much more complicated with color sensitive emulsions of a color film. This advantage of electro-optical sensors offers new fields of application in remote sensing, which already is established in satellite imaging for decades but new for the airborne imaging sensors. But all this also requests for extended radiometric calibrations of digital cameras in additional to the former geometric calibration only.

1.3. Paper outline

This paper now tries to give a short, snap-shot like overview on the current situation with special focus on geometric and radiometric system characteristics. The next section briefly re-calls the situation regarding the status of the main current digital airborne sensor systems, with focus on the large format mapping sensors. Here especially efforts of system providers in the calibration of their systems are mentioned. The third section then will look on the user's perspective. This also will include some details on empirical tests performed by users and/or scientific research organizations. Finally some remarks on current standardization activities are mentioned in section 4.

2. THE MANUFACTURER'S PERSPECTIVE

Digital large format imaging is available for about 10 years now. It was in 2000 when the first close to operational systems were introduced, the first considerable market sales were in 2003 then. As known to almost everybody, the large frame technology is based on line or frame sensors alternatively. Until recently, the frame sensors were combined in multi-head configurations to obtain large but virtual image formats. With the new DMC II system the first camera using only one very-large frame CCD for pan-chromatic image acquisition is available (Neumann 2011a). These sensors provide up to 250 Mpix and now allow for such large image formats without the need to undergo additional image stitching to obtain virtual images. Still, both concepts, namely very large sensors and multi-head configurations relying on image stitching will be available in future frame based imaging. Nevertheless, whether it is single- or multi-head pan-chromatic imaging, additional sensor heads are necessary to obtain separate color channel information. This is different to the line scanning technology where all color bands realized by individual CCD lines are arranged in one focal plane, using one optical system only.

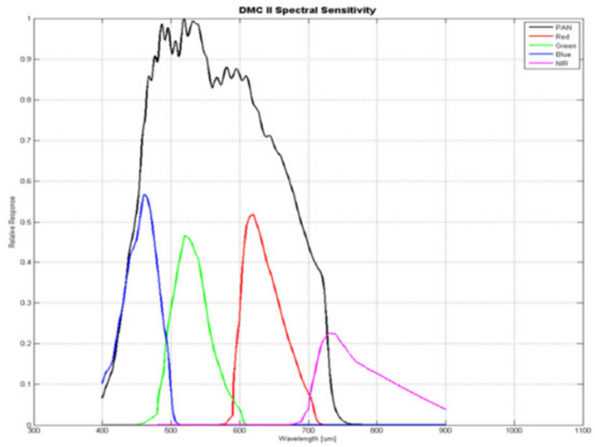
2.1. Current system layout

There is some significant improvements in the current system layouts of the three main large format airborne mapping systems DMC (Intergraph/ZI, now Hexagon Geosystems), Ultracam (Vexcel Imaging) and ADS (Leica Geosystems now Hexagon Geosystems). The most prominent system change was the introduction of the single very large format CCD for DMC II system design. This sensor system is the only frame based system now providing the full pan-chromatic image format with one single frame CCD only. It is based on the world largest monolithic single frame CCD sensor in series production. The following Tab. 1 lists the main characteristics of the latest technology large format digital mapping cameras, as they are provided by the current three main system suppliers. More individual sensor technical details can be seen from the according papers (also this proceeding). Tab. 1 again indicates the already known clear differences in the sensor layouts, which affect the system calibration as well as the later processing of the imagery.

Sensor	concept	Image extension		# camera heads
		PAN	MS (original resolution) / Pan-sharpening ratio	
UltraCam-Eagle Vexcel Imaging	frame pan multi-head virtual images	20010 x 13080 pix at 5.2 µm, 104.052 x 68.016 mm²	6670 x 4360 pix at 5.2 µm, 34.684 x 22.672 mm² PAN:MS 1:3	4 (pan) 4 (MS)
DMC II 250 Intergraph/ZI	Frame Pan single head No virtual images	16768 x 14016 pix at 5.6 µm, 93.900 x 78.489 mm²	6800 x 6096 pix at 7.2 µm pixel size, 48.960 x 43.891 mm² PAN:MS 1:2.4	1 (pan) 4 (MS)
ADS80 Leica Geosystems	Line Single head Line images	12000 pix at 5.6 µm, 78.000 mm (no staggering applied here)	12000 pix at 5.6 µm, 78.000 mm PAN:MS 1:1	1

Table 1: Main parameters of current large format digital mapping systems.

In addition to the table, Fig. 2 exemplarily compares the design of the individual spectral bands of the DMC II and the Ultracam-Eagle camera to the ADS40 sensor, which is still valid for the ADS80 camera too. Even though the systems all provide the true color spectral bands (red, green, blue and additional NIR) their color bands are defined quite different. The clearly shaped rectangular MS bands of the ADS are narrow and spectrally non-overlapping. Their bandwidth ranges between 60 nm to about 90 nm for the MS bands which is very similar to what is known from remote sensing sensors (compare to the Landsat ETM+ spectral bands in Fig.1). The DMC and Ultracam spectral bands on the other hand are more close to the traditional natural color film (again Fig. 1). This obviously was one of the manufacturer's strategic decisions in the system design: Remote sensing application was one of the intended application fields for the ADS, where the other sensors primarily tried to reach natural color imagery, close to the human perception. Notice, this does not mean, that ADS is only for remote sensing and DMC and Ultracam are only for photogrammetric, geometry related applications.



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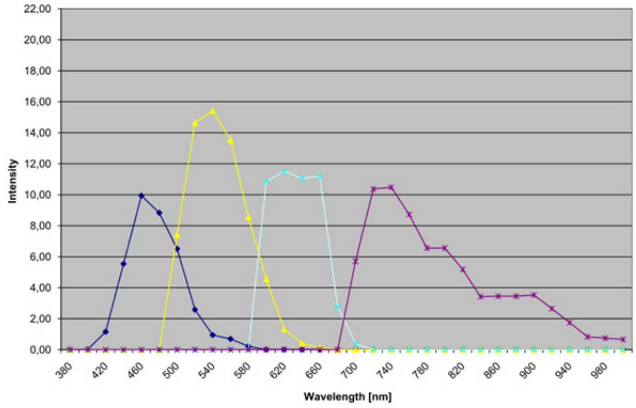

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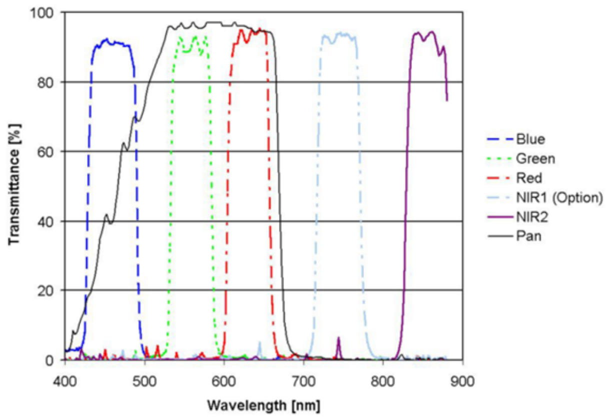

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Figure 2: Spectral bands of DMC II (upper left), Ultracam-Eagle (upper right) compared to ADS (lower left).

2.2. Geometric calibration

As already mentioned in the introductory section the calibration is one essential pre-requisite for both, photogrammetric and remote sensing sensor systems. The geometric calibration was exclusively of airborne mapping camera was exclusively done from lab environments. Interesting to see, that DMC and ADS cameras in their first years were geometrically calibrated with the same collimators also used for the Zeiss and Wild analog mapping cameras (Cramer, 2004). It is quite clear, that Intergraph/ZI (former Zeiss) and Leica Geosystems (former Wild) with their strong origins in analog camera design and mapping tried to transfer the long experienced analog camera calibration set-ups for their new digital successors. This from the very beginning was different for the Ultracam sensor. Even though the geometric calibration by Vexcel Imaging is done in a laboratory, it is based on traditional close-range concepts: multiple images are taken from 3D lab test field set-up to form a strong photogrammetric block. Then self-calibrating bundle adjustment is used to determine the camera specific parameters based on appropriate parameter models.

It is also quite interesting to see, that Leica Geosystem later has modified its ADS geometric calibration approach. The whole geometric calibration is now obtained from calibration flights, which in principle can be flown in any area with sufficient terrain texture to guarantee strong connections between overlapping images via tie point matching and following special flight patterns (Tempelmann & Hinsken, 2007). Vexcel and Intergraph/ZI also are doing test flights before their systems are delivered to the customer, the so-called burn in flights, where at least the geometric calibration is verified from true flight data.

It seems to be a somewhat settled situation with the geometric calibration of sensors, but still there is quite some continuous refinement in the calibration and succeeding processing steps. Exemplarily the monolithic stitching could be mentioned, which was introduced by Vexcel Imaging to refine the process of virtual image generation for the Ultracam sensors (Ladstädter et al., 2010). Intergraph/ZI now also is adopting the calibration model used for their DMC II sensor. The former Australis parameter model (close to the Brown physical self-calibration parameters) is exchanged by a thin spline polynomial model now (Hefele, 2011). Also worth to mention, that Intergraph/ZI also is planning to obviously shift significant parts of the current geometric calibration (principal point and focal length calibration) from laboratory to test flight calibration (Neumann, 2011b). For sure, new sensors need modified calibration processes, still the clear trend from lab to the test field calibrations, at least when focusing on geometry, could also be seen as a more general paradigm shift. Obviously the more complex digital system layout, consisting of typically multiple camera head arrangements with additional GPS/inertial components, requests for such calibrations to consider the overall system calibration in its operational environments. Nevertheless, it also should be mentioned, that it was at least partially financial issues also that forced system providers to change from laboratory to in flight calibration. In case of the ADS the formerly used goniometer had to be replaced; in case of DMC II the geometric calibration of the individual camera heads so far is done as a service by Zeiss Jena. Shifting parts of this calibration to test site approaches or at least minimize the current effort for this lab calibration would again allow cost savings for Intergraph/ZI. For sure all this is only a little note on the margin of the history of camera development and for sure similar things also have happened in the past; still it is interesting to see which the forces behind some pushing technologies sometimes are.

From manufacturer's point of view the geometry of the new digital sensors is under full control. Even though there is some significant changes in the way how to geometrically calibrate the new digital sensor systems, these methods, quite different to the analog world, seem to be accepted by the system users. The users still fully rely on the calibration reports provided by the system provider's This is a little surprising since the "value" of the current manufacturer calibration report differs from the former calibration certificate which certified the result of an officially defined calibration process following accepted standards. Obviously the later empirical system tests (see Section 3) have proven the high performance of the new digital sensor, thus the calibration report seems to have some decreased importance to today's users?

2.3. Radiometric calibration

The radiometric calibration is something new from the photogrammetric point of view as already mentioned in the introductory section. It provides a relation between the incoming radiation, i.e. the electromagnetic energy entering the imaging system, and its output, which are the gray values or digital numbers. An increase in radiometric performance opens new fields of applications, which are essential for the business model of system manufacturers. This is why radiometric calibration gains in importance and continuously is refined – not only for the ADS sensor, which obviously has one main field of application in the remote sensing, but also for the other systems like DMC and Ultracam. Still, it should be mentioned that Leica Geosystems already from the very beginning started to put reasonable effort in the radiometric calibration of their sensor system (Schuster & Braunecker, 2000) and also were the first to provide a full radiometric process chain (Beisl, 2006). Within radiometric calibration the sensor linearity, its spectral sensitivity, flat field correction and normalization, and the dependency of the gray values to aperture and exposure time are determined.

In its last step a linear transformation is determined which represents the widely linear characteristics of digital sensors to link their gray values to final physical units (radiance).

One of the main calibration devices is the integrating sphere which provides the well defined and uniform light source as reference for the gray value calibration. The following Fig. 3 illustrates the main component of the radiometric calibration setup at Leica Geosystems and Intergraph/ZI. It is both Ulbricht spheres but they do differ in size, which is due to the individual size of the optical systems, and use different light sources. Within the Intergraph/ZI installation (51cm diameter) it is a combined Tungsten and Xenon light source (Ryan & Pagnutti, 2009), where the Leica Geosystems integrating sphere (90cm diameter) uses Tungsten lamps combined with blue power LEDs (Beisl, 2006). Since the Ulbricht sphere provides the reference light source for calibration certain requirements like light source homogeneity, stability, lambertian behavior covering the full entrance angle have to be fulfilled. Typically the reference light source itself is monitored (i.e. calibrated) to trace it back to national standards.

Radiometric calibration can be divided into relative or absolute calibration. The relative calibration performs a flat field calibration, to provide a uniform response when the sensor is irradiated with a uniform radiance field (Honkavaara et al., 2009). Ryan & Pagnutti (2009) more pragmatically define the relative calibration for airborne multispectral sensors to “cosmetically correct image defects”. All this is to limit the variations between pixel values, which are especially obvious when uniform areas are covered by imagery. Within the absolute calibration the pixel gray values are directly related to physical units, namely physical radiance obtained from the digital numbers. Absolute calibration – if applied – is performed after relative calibration and is critical for the remote sensing applications. If an airborne imaging system is absolutely calibrated users in principle would be able to perform remote sensing tasks which so far were only possible with the remote sensing satellite data.

As already may be noticed from the previous paragraphs the radiometric calibration is mainly obtained from laboratory approaches. Nevertheless radiometric calibration also is (partially)

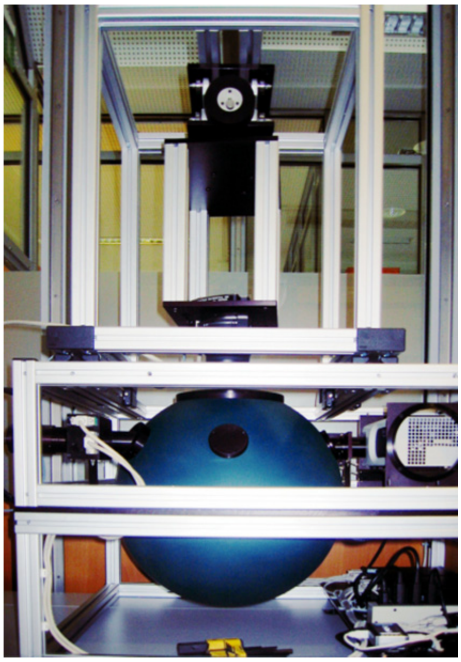

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Figure 3: Integrating sphere (Ulbricht sphere) for ADS (left) and DMC (right) radiometric calibration.

possible from flight data. This is clear when looking on the space-borne imaging systems which cannot be re-calibrated in laboratory again once they have reached their orbit. Thus on-board (using natural or artificial on-board light sources) or test site (vicarious) calibrations are also implemented. For vicarious calibration or validations reference targets of sufficient size with known spectral behavior have to be supplied. Typically it is large natural surfaces like salt lakes or sand deserts; alternatively also (artificial) targets such as painted concrete, fabrics or other materials like gravel might be used (Honkavaara et al., 2010). In all cases their spectral response needs to be known for the time of the flight. As far as it is known to the author it is mainly Leica Geosystems already spent considerable effort in this vicarious calibration and validation of their ADS system.

The radiometric calibration is obviously one of the aspects in digital camera design where manufacturers really increased their efforts. The evolution in the DMC radiometric calibration may serve as an example, where there was basic radiometric corrections applied within the first years (Diener et al., 2000) and now they provide the full radiometric correction chain (Ryan & Pagnutti, 2009). Still the question is there whether the majority of systems users already noticed the effort spent to this radiometric calibration and the possibilities rose by this? This will shortly be mentioned in the following section.

3. THE USER'S PERSPECTIVE

Current digital camera users seem to have a quite pragmatic perspective. This partially is due to the fact, that there is no more alternative to digital imaging, thus users are "forced" to move to digital technology, even though the official, former quality concepts defined by standards and well established certification processes are still not, or only partially available. Thus the users typically request on empirical tests, often done by themselves and/or they rely on experiences from larger, mostly independent test campaigns which are done by universities and other research organizations. If the empirical performance for these new digital systems is within the expectations of the individual user, then the new technology is accepted.

Again, the situation is different when considering geometrical and radiometric performance tests. From the very beginning test flights focusing on the geometric accuracy performance were done. One of the first more internationally designed and independent empirical tests was the EuroSDR activity on Digital Camera Calibration, which was based on early test flights from years 2003 and 2004 flown in the Norwegian test site Frederikstad and the German test site Vaihingen/Enz. At that time it was DMC (1st generation), Ultracam-D and ADS40 participating (Cramer, 2009). It should be mentioned that the flight data was kindly provided by users, who already did those flights as potential customers on a bi-lateral agreement with the system manufacturers only. Even though the project was generally named "camera calibration" it was only the geometric calibration and validation part considered there. Quite similar to other tests the analyses have shown that digital sensors are fully comparable to their analog predecessors but additional and careful effort has to be spent to self-calibration parameters, especially for those cameras based on a multi-head concept. This motivated the users / research teams / software providers to improve or develop special parameter sets to consider this special image geometry and on the other hand also forces the manufacturers to refine their ways of virtual image generation and camera calibration to really get rid of the remaining systematic errors within the virtual imagery.

Different to this, the later German, broader designed test on the evaluation of digital photogrammetric airborne camera systems not only considers the geometrical evaluation, but also, and most likely for the first time, was intended to analyze the radiometric performance and the quality of products derived from this type of sensor data. The test flights were done in 2008 with almost all at that time available digital airborne camera systems. Numerous users and research institutions, also involving the system providers, were actively participating (Cramer, 2010). Again the geometric performance of the cameras was confirmed (Jacobsen et al., 2010). The results from DSM from stereo matching were very promising (Haala et al., 2010) and besides that significantly pushed the efforts in the field of DSM generation from image based dense point matching. The radiometric performance test, especially the part dealing on the vicarious sensor calibration and validation, was partially affected by the non favorable weather conditions and some drawbacks in the ground truth measurements (Schönermark, 2010). Still Waser et al. (2010) were able to prove the potential of this data for land cover and tree classification, which also was similarly done by others.

Some of the most comprehensive and user driven analyses related to the radiometry of digital sensors are done in Finland and Spain, with strong contributions of the Finnish Geodetic Institute (FGI) Masala, Finland and the Institute Cartographic Catalunya (ICC) Barcelona, Spain. The most important project is their EuroSDR project on Radiometric Aspects of Digital Photogrammetric Images, which was started in 2008 and recently finished. This project thoroughly was focused on a review of the current situation / concepts for radiometric image correction and a comparison of these techniques on defined data sets. This then was followed by an analysis of the benefits of such calibrations in order to use the digital sensors for the already addressed new fields of application. The practically oriented second part fully relied on the analyses of empirical data sets flown in three different test sites. Due to its extent and complexity the reader is referred to the publication. Honkavaara (2011) concludes like follows (see also Honkavaara et al., 2011): The EuroSDR test was able to demonstrate the new ways of utilizing photogrammetric blocks. The results of reflectance calibration are promising. Its efficiency is dependent on the used software. The efficiency of the Leica Geosystems Xpro was especially highlighted within this context. This also proves that the already announced software to consider of the full radiometric process chain (Beisl, 2006) is really operational. The reflectance calibration allows for optimal automation of interpretation application and thus is a controlled way for image processing. Still, challenges are that methods are different (depending on the manufacturers), are still under development and most important there is no updated standards available to cover this radiometric processing of photogrammetric blocks.

Nevertheless, it is Markelin et al. (2010) concluding: “It can be expected that the future of radiometrically quantitative photogrammetry is bright.” This should also be used to summarize this paper section. Even though only a short, surely no representative part of the geometric and radiometric applications of digital airborne sensors are illustrated, it is seen, that both performance in geometry and also radiometry is proven and obviously accepted. It was mainly users from mostly scientific background cited here, still their expertise will help to also develop commercial applications, which still might be necessary in terms of radiometric image processing and product generation.

4. THE STANDARD’S PERSPECTIVE

It was already mentioned in some of the previous sections: The lack of standards and thus of more formal certification processes, which implement those standards, is a problem in both the geometric and radiometric part of digital airborne imaging. For sure there are activities in standard developments both on national and international stage. The German standards institute for example was one of the first providing a new standard on digital airborne imaging (DIN 18740-4 standard) with one focus on the requests for geometric and radiometric calibration of digital photogrammetric imagers. Additional standards to extend the already available series were recently issued or are still under current development. For example the part 5 of this standard's series is on the classification of remote sensing data, which shows one of the applications of digital imagery. The upcoming next parts will then cover requirements of digital height models and requirements on pan-sharpening.

In case international like ISO standards will become available they may replace national standards. Within this context the ISO TS 19159 "Geographic information – Calibration and validation of remote sensing imagery sensors – Part 1: Optical sensors" is of special interest, which is under approval currently. It is such types of standards which are necessary to provide appropriate rules for system certification procedures. Still this certification of digital sensors, which is not yet available, even though some activities are on their way since quite some time now (Cramer, 2008). Some recent developments in the US should be mentioned within this context. The US Geological Survey was responsible for the analog camera calibration. Similar to the mapping camera calibrations done by Zeiss or Leica the USGS calibration was commonly accepted as proof of the sensor's quality, even though USGS never was asked to become official certifier of analog cameras. But it was established and sort of quasi-standard process. With the advent of digital cameras USGS started its quality assurance plan, which was originally designed as very comprehensive process covering both the data procurement and data capture domain (Stensaas & Lee, 2008), but was slightly modified later. It is now mainly "Independent Sensor Evaluation", including flight tests of the camera over a USGS range and reporting on the accuracy of products derived from those flights (Christopherson, 2011). In addition to this private companies now also have started to offer such camera calibrations. This is very new, at least for the digital mapping cameras. It was the company Navmatica announcing a new service of geometric digital mapping camera calibration based on test field in-situ calibration in May 2011 (Navmatica, 2011). Their services include "in-situ camera calibration for analog and digital mapping cameras and independent accuracy validation of map products produced by airborne cameras." It is mentioned here just to illustrate the quite heterogeneous and demanding world of digital imaging also covering the quality assurance, with changing methods and processes almost everywhere. This again helps to maybe understand the quite pragmatic user's behavior. On the other side this also clearly shows that there really is the need for standards and officially agreed certification processes. The question is, whether the customers will (start to) insist on this, or still feel comfortable with their current situation? As long there is no strong(er) request from systems users on the manufacturers this situation will not change. For sure, all this includes standards and certifications both on the geometry and radiometry of airborne sensors.

5. SUMMARY

The paper tried to more generally illustrate the current status of digital airborne imaging with special emphasis on the geometric and radiometric part. It was shown, that geometry – as originated from the classical photogrammetric applications – was first and with that seemed to be solved to a large extend. The radiometric processing of digital imagery on the other hand was not of primary interest from the very beginning, at least for some of the digital camera providers. Nevertheless, throughout the years the radiometric processing of digital imagery really evolved, pushed by manufactures and also some of the system user, who really would like to get the full information from the digital data. Still, there might be some deficiencies on mainly user's side, maybe partially also with some of the manufacturers, regarding the understanding of the full camera radiometry, but this is definitely decreasing. Radiometry is not yet completely solved, there are still ongoing improvements, but this is quite similar for the sensor's geometry as it was pointed out earlier. Thus coming back to the title of this paper, to the author's point of view, geometry and radiometry both are not yet perfect but also not unknown. As with most of the new technologies there will be quite some changes and improvements in future. But one thing is quite clear, there will be no alternative to digital imaging including applications relying on the geometry as well as on the radiometric performance.

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