

IN SITU DIGITAL AIRBORNE CAMERA VALIDATION AND CERTIFICATION – THE FUTURE STANDARD ?

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ABSTRACT:

Digital airborne photogrammetric imaging systems are operational and already have substituted the analogue mapping cameras in many countries and applications. The high potential of digital airborne imaging was already evaluated through several empirical tests. Compared to the former analogue mapping cameras, which all provide standard analogue images using one single optic only, the new digital airborne cameras follow very different sensor designs and processing concepts, which requests for flexible and system driven calibration and certification approaches. In situ calibrations obtained from well defined test ranges will play an important role in future system validation and certifications, still guidelines for optimal test site layout and evaluation concepts are almost missing. This motivates the European Spatial Data Organization (EuroSDR) to compile several projects first looking on the more technical aspects of radiometric and geometric digital airborne sensor system performance. From that optimal and operational in situ test site layouts and corresponding evaluation processes are derived, whose first concepts are presented in this paper. Both geometry and radiometric aspects are covered. This also is linked to other certification approaches like the US Geological Survey Digital Camera Quality Assurance Plan and to new national and international standards.

1. INTRODUCTION

Similar to other fields in metrology substantial changes in sensor technology have taken place in the last few years when moving from analogue to digital data acquisition. The digital airborne photogrammetric sensors allow for the almost automatic, close to real-time mapping with the highest resolution and accuracy, including high quality multi-spectral data – merging (airborne) photogrammetric (geometry) and (space-borne) remote sensing (radiometry) capabilities within one single sensor system, which not only supports space-borne sensors but also develops completely new application fields. Especially in densely populated urban areas the need for high resolution data with small ground sampling distances (GSD) from airborne sensors is obvious. Developments in the sector of digital globes are just first demonstrations of the new requirements, possibilities and new levels of detail for image based modelling, monitoring and analysis of our environment. Most of the European countries collect nation-wide airborne image data (GSD of ~20cm mostly) with an update cycle of typically 1-5 years. Cities typically request for even higher resolution (GSD 5-20cm).

High resolution digital airborne imaging is now available and fully established in the market. Many of the European National Mapping and Cadastral Agencies (NMCA) have switched to fully digital image data recording and abandon old analogue cameras. Other NMCAs or other organizations and companies requesting airborne data for later mapping have completely changed to contracting of digital image flights only.

Compared to the former analogue mapping cameras, which all provide standard analogue images using one single optic only, the new digital airborne cameras follow very different sensor designs. Digital airborne imaging obviously is more complex now, which also prevents the new systems from the classical

calibration and certification process, established for the analogue mapping cameras. In situ system evaluation offers the only way to flexibly deal with the individual and heterogeneous sensor design of the different airborne cameras. Due to these different camera concepts, the link between sensor related processing software and the sensor itself is much closer than for former analogue mapping cameras. Thus, sensor related calibration concepts are necessary, which request special measurement set-ups to be adapted for each type of digital camera. Each system provider has developed his own calibration approach, some parts of the calibration already are exclusively derived from real flight data using in situ calibration approaches, but such methods currently are not yet officially certified through independent metrology institutions at least from the European point of view. This is different to traditional laboratory calibration of analogue mapping cameras, which is certified by official metrology organizations, internationally accepted through common agreements and the derived calibration protocol, thus certificate, automatically serves as official evidence of correct system functioning during tenders. The need for such well-defined digital airborne camera certification processes, accepted through the individual national metrology institutes and based on the already existing agreements also world-wide is obvious and this also is the driving force for the presented activities. Even though the title question on the future standard of in situ calibration/certification cannot fully be answered here, this paper will clearly point out their importance for digital photogrammetric airborne imaging.

Within the next section the current status in digital camera validation, certification and standard development is briefly described to illustrate this studies' surrounding. Section 3 then introduces the EuroSDR concept. Details on the geometric and radiometric test site design are following in Section 4. The final section 5 than concludes this paper, also summarizing some of the open topics to be addressed.

2. CURRENT STATE-OF-THE-ART

This section will briefly introduce the current status of the sensor calibration/validation, development of standards and already available certification processes. Even though different activities and concepts are already available they are not yet coordinated. International cooperation to establish preferable world-wide standards and concepts are necessary and will support both, system providers and data users.

2.1 Manufacturer sensor calibration

Traditionally, analogue mapping cameras are certified through the laboratory calibration, which documents the traceability to national standards. Calibration certificates are requested during contracting to guarantee sufficient camera performance, especially when mapping has to be done in conformity to national rules. The calibration set-ups and processes used in calibration are certified. This now has changed completely, since digital camera manufacturers have established their own calibration processes for digital sensors. Some are still using collimator techniques close to the approach known from analogue cameras. Quite often the geometric laboratory calibration is based on three-dimensional test sites, as it is known from close-range photogrammetry. Those set-ups are installed in the manufacturer's lab environments.

More important, manufacturers of digital airborne cameras are striving for to minimize the need for laboratory calibration and have already implemented approaches from flight data only using self-calibrating aerial triangulation (in situ calibration). This is sometimes done in designed test sites – manufacturers have established their own test ranges, used for their so-called internal system acceptance tests or burn-in flights. In some cases the systems can be flown in any area but following given flight pattern to obtain sufficient block geometries (e.g. Fuchs & Adigüzel (2010), Ladstädter et al. (2010)). Such test site approach in principle offers the highest flexibility and fulfils the need for system calibration instead of a component driven calibration process considering the multi-sensor system design (single or multi-head imaging and sensor orientation components, like GNSS or GNSS/inertial units). Nevertheless, applied methods so far are individually developed by the system manufacturers, standards for test site calibrations do not yet exist, and the repeatability and traceability has not yet been shown in general.

2.2 Standards and quality assurance concepts

Standards related to digital mapping cameras and digital images and other quality assurance concepts have realized changes in sensor calibration and (partially) tried to adapt to this new situation. The German standard "DIN 18740 Part 4 – Photogrammetric products: Requirements of digital aerial cameras and digital aerial photographs" (DIN 2010) for example still requests a calibration certificate (!) provided through the manufacturer which may not be past longer than two years. This is a one-to-one copy of the analogue world, but at least today the calibration report is not yet certified through metrology institutes thus the above naming should not be used. Alternatively the validity of the (geometrical) calibration at the time of the image flight can be proven by a validation over a signalized test site, which may not be past longer than one year. Still the relevant processes to a large extend are neither defined, nor certified for the digital systems. Requirements on test site design also are not defined.

The most comprehensive approach is the Digital Airborne Camera Quality Assurance Plan driven by the US Geological Survey (Stensaas & Lee, 2008). The concept consists of different parts. The certification of the sensors is done in the so-called sensor type certification, with main focus on the quality management during sensor manufacturing and calibration. This type certification is done for the sensor type/model class provided by the manufacturer, thus does not relate to the individual sensor (serial number), which is used in the later project. This validation of individual sensor quality will be done separately using in situ approaches from test flights in designed test sites. USGS already has published first guidelines for the design of (geometrical) in situ test sites (USGS 2010).

The International Standards Organisation (ISO) Technical Committee (TC) 211 "Geographic information / Geomatics" is most relevant for the development of ISO standards and technical specifications related to photogrammetry and remote sensing. ISO/TC 211 is currently working on the development of the new technical specification ISO/TS 19159 named "Calibration and validation of remote sensing imagery sensors and data", which should later turn into an ISO standard (Kresse 2010). Originally, system certification was proposed as the third part besides calibration and validation, but was then excluded since ISO is not a certification body itself. Again, the certification part has to be added.

2.3 International networks and cooperation

A world-wide calibration site network established by CEOS is available for satellite imaging systems but not applicable for locally operated much higher resolution airborne imaging systems. The concept of publicly available permanent test sites of airborne imaging systems has already been empirically proven. First test sites are available in the US, Germany and Finland. Many scientific campaigns carried out in these test sites have led into improvements in sensors and processing software and sometimes are also used operationally for providing improved sensor geometric calibration parameters to be used in production. There are also initiatives in several European countries to install permanent test sites, but not yet harmonized.

In general, test site infrastructures and quality processes should be established and harmonized preferable world-wide. The new ISO activities and the already established cooperation between Europe (EuroSDR), North-America (US and Canada) and Australia are facing into this direction. Commonly defined standards and quality assurance processes will be beneficial for sensor providers, flying companies and data users.

3. THE EUROSDR APPROACH

One of the most relevant current projects in EuroSDR is the development of future certification strategies of digital airborne cameras (EuroDAC² activity). The core competence team consists of international experts from science, national mapping and private industry (Cramer 2008). In fall 2009 the EuroDAC² group presented the concept to representatives from the main digital airborne camera system suppliers. They all agreed on the use of test sites following common layout and the definition of corresponding test guidelines. This is the only way to deal with the specific sensor designs. Still, some open topics were also mentioned and discussed. The main question was who will be the later authorized institution to be responsible for these additional system performance evaluations? For sure it is clear, that all these in situ tests will only be accepted if they become

part of the international network of metrology institutes. Within Europe the individual national metrology institutes (NMI) are responsible for national metrology tasks. These national bodies then will define and accredit national organizations which are then responsible for tasks in their corresponding country. All these NMIs are organized through the European Association of National Metrology Institutes EURAMET (EURAMET 2010). The EuroDAC² core group now is aiming on the integration of this in situ calibration concept within the EURAMET processes. In cooperation with representatives from German and ISO standards and two European NMIs a first proposal on the future European network of test sites and standardized processes for performance evaluation of imaging sensors was prepared and submitted. Still, this proposal does not contain detailed concepts, which to a certain extent will be presented in the following, but firstly aims on the need for these in situ approaches and motivates the construction of traceable test sites and standardized processes for the quality managing of imaging sensors including geometric and radiometric measurements.

4. TEST SITE INFRASTRUCTURES

As already pointed out in Section 2 test site definitions are requested as one major part of system validation and in-situ certification. Test sites should provide sufficient reference data, including traceable reference targets and in situ measurement equipment. The required accuracy and density of reference data is dependent on the targeted resolution and type of data delivered by the sensor. In order to provide controlled signal inputs for repeatable and stable measurements, optimal (artificial) reference targets have to be defined and installed in the test sites. The need for artificial reference targets is different to the sites used for space-borne sensor calibration, which mostly use natural targets in defined areas (see Section 4.2), but they are not available world-wide. Integrating the airborne test sites to local and global level Earth observation systems may also be of interest.

Airborne in situ test sites in principle should be made available throughout the whole world, not only to provide reasonable infrastructure for the system providers and flying companies, but also to allow for the system quality assurance within various climate zones and geographical areas. Ideally, sites should be available within a distance of 1h of flight, i.e. with about 300km radius from the aircraft base station and each country should at least provide one field to avoid crossing of borders, which sometimes may cause problems.

4.1 Geometric test sites

According to the literature and the current test range design of large format camera suppliers a test range should enable a well-defined photogrammetric block. The block of quadratic or rectangular shape should cover 5 – 7 strips in the alternate direction (Figure 1). The layout of a test range should allow for test flights with end lap of 60 – 80 % and a side lap of 60 – 80 %. The cross strips provide additional information for calibration of interior orientation, the image quality and even more important information of the GPS-drift, if present.

The test sites dimensions are fully dependent on the spatial resolution (GSD) of the data. Assuming that the length of a flight line should allow the about 15-20 images and larger GSD values >30cm are requested the test sites easily may reach extensions up to 300 km².

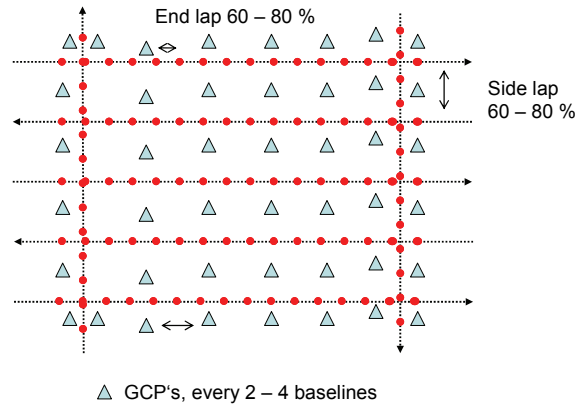


Figure 1: Layout for test flight.

In order to achieve good determinability and accuracy from the self-calibrating bundle block adjustment, a calibration set-up with highly convergent imaging configuration, orthogonal sensor angles around height axis, four or more images, and an object point field well distributed in three dimensions should be used (Fraser 1997). In the airborne conditions the calibration set-up does not typically fulfill these recommendations. The target is flat compared with the object distance and the images have typically parallel optical axes; this results in strong correlations between the interior orientation parameters and the perspective center coordinates. Possible ways for carrying out interior orientation determination are the application of GPS or GPS/IMU observations of the perspective center coordinates (Heipke, *et al.*, 2002; Merchant *et al.*, 2004), the use of a test field with large height differences, and the use of an image block with vertical and oblique images. The best option for test ranges in flat areas is flights at two different altitudes to overcome the lack of missing height differences and ensure for an in depth calibration of focal length, and other systematical errors (Figure 2). The block at the higher altitude should cover the same area as the block at the lower altitude and therefore consists of 2 – 4 strips in either N-S or E-W direction. The end lap shall be 60 – 80 % and a side lap also 60 – 80 %.

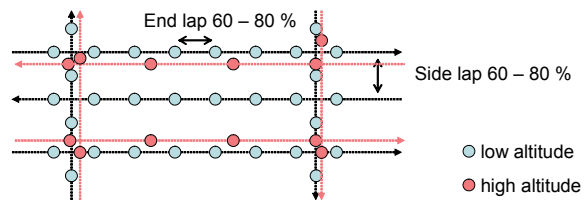


Figure 2: Layout for test flight at 2 different elevations.

The number and distribution of the ground control points is related to the GSD and the type of camera to be calibrated. In order for be able to calibrate a large variety of camera systems as well as images of different GSD a nested ground control point distribution is necessary, see for an idealized schema in Figure 3. Alternatively test site might be specialized for certain sensor types and spatial resolutions.

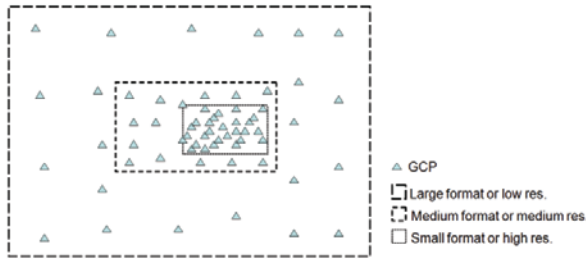


Figure 3: Idealized distribution of GCPs in a multi-resolution, multi-sensor test site.

Spatial resolution and sensor size not only limits the distribution of GCP but also the required accuracy of their reference coordinates and their size, if signalized points are used. For aerotriangulation the positional accuracy of the GCP's should be determined with accuracy 10 times higher than the pixel resolution (Ackermann, 1997). Commonly the accuracy of the GCP's of existing test fields is in the range of 1cm or less, e.g. Cramer, 2009. Due to the increasing demand on very high resolution airborne image data, reference coordinates have to be provided with an accuracy of 1mm – 1cm to handle images with a GSD of 1–10cm, which will increase the effort for GCP object coordinate determination.

In order to obtain most objective and operator independent results, the measurement of GCP coordinates in image space, which currently is done mostly manual or semi-automatic, should be done fully automatically. For a human operator the signalized point should have a size of min. diameter of 3 pixels in the image. The accuracy of the human operator is approx. 1/3 of a pixel. Jacobsen et al. (2010) has analyzed differences in manual image point measurements of signalized points. The agreement between different operator measurements is between 0.15 – 0.4pix, which exactly reflects the above manual pointing accuracy. Accuracy of image point measurements in the range of 0.05 – 0.1pix can be easily achieved with different automatic algorithms (Luhmann 2003), but these algorithms request for much larger target sizes between 5-25 pix diameter, which yields in 2.5m targets (max.) even when 10cm GSD image data is considered. From practical point of view the size of signalized targets on the ground should not exceed 1m. Due to high object contrast the GCP will appear bigger in the resulting image, factor 1 – 1.5. Assuming a target with 1m in diameter the resulting size of the template will allow for automatic centroid determination at GSD of 3-20cm (=7-32 pix). Coded targets, which are standard for close range applications, may also help to automate airborne sensor in-site calibration processes. Nevertheless, restrictions due to maximum size of targets (related to the aspired GSD ranges) and the increased effort in maintenance (especially when using complex target structures) have to be considered.

Alternatively well defined but natural structures can be used as image control patches. In principle the size can be defined arbitrarily thus automatic detection and measurement is possible. Since flights always are done in the same test sites with similar block layouts these natural targets will appear in similar positions in the same images always, which supports the automatic detection and measurement, especially when there are exterior orientations from direct sensor orientation available.

4.2 Radiometric test sites

The fundamental requirements for radiometric test sites are to provide traceable radiance and reflectance values of targets over the specified angular range (e.g. the entire hemisphere) and targets for point spread function measurement.

The operational CEOS network of radiometric test sites is available for the space-borne imaging systems (Chander et al., 2007). Basic requirements for radiometric calibration sites are given in Teillet et al. (2007). Following those guidelines such radiometric sites should be located in arid regions at high altitudes, far away from oceans and populated areas, with horizontal surfaces of almost Lambertian reflectance and high reflectance values. The sites should have high spatial uniformity, with temporarily invariant surfaces properties. An online catalogue providing easy public Web access to the necessary information is a central component of the system. Depending on the test site characteristics, the CEOS sites are useful for absolute calibration, pseudo-invariant calibration or cross-calibration. The desert sand sites and playa (dry lake beds) have shown the most stable performance and thus considered as the prime test sites (Smith et al., 2002; Teillet et al., 2007). In the case of the European airborne imaging system test site network, requirements related to stability, location, terrain height and climate/atmospheric properties are the most difficult to realize. It is likely that the test sites have to be built on suboptimal climate and meteorological conditions, being subject to rain, dust, pollutions, salinity, snow, frost, heat, sun-shine etc. The permanent airborne radiometric test site in Sjökkulla, established in 1994, is an example of airborne radiometric test fields constructed under these restrictions (Figure 4, Honkavaara et al., 2008).



Figure 4: Sjökkulla image quality test field in September 2008. White line is drawn around non-permanent targets.

Central tasks of vicarious radiometric calibration are to calibrate and validate the absolute radiometric response of an imaging system. The calibration can be carried out using reflectance or radiance-based methods (Dianguirard and Slater, 1999). Reflectance reference targets are needed in the calibration. For determining absolute calibration parameters, the minimum requirement is to have white target (0.5 reflectance) and black target (<0.05 reflectance). The required size of targets is related to the maximum GSD to be used; in principle, they should be larger than 10 x 10 GSD in size. As the calibration sites are not likely to be optimal with respect to stability and climate, they should contain devices for the measurement of the reflectance of the ground target, illumination at target, and properties of the atmosphere when a scene is imaged.

Various targets can be used for the point spread function (PSF) and modulation transfer function (MTF) determination. Typical targets are point source targets, edge targets, line targets, pulse targets, and contrast transfer function targets (e.g. Siemens star or square wave targets). The size of the target should be related to the GSD-range being evaluated. Examples of PSF/MTF targets (edge, Siemens star, square wave) are shown in Figure 4.

The central challenge is to find appropriate materials for targets. They should have favourable and stable reflectance properties, including spectral characteristics and bidirectional reflectance distribution function (BRDF), and sufficient spatial uniformity. The BRDF is of importance with photogrammetric systems having viewing angles typically of up to $\pm 40^\circ$, if areas outside nadir region are of interest. With remote sensing systems like multi-angle imaging spectrometers or oblique looking cameras even larger viewing angles have to be considered. With high-resolution airborne systems mostly artificial targets are needed. A popular approach is to use targets painted on a concrete slab (Pagnutti et al., 2003); in Finland targets constructed out of gravel are used (Figure 4) (Peltoniemi et al., 2007; Honkavaara et al., 2008).

A study was carried out in 2009 in Finland to assess the spectral, anisotropic and temporal performance of various gravel, concrete and painted concrete targets (Figure 5). Transportable samples were constructed of targets to enable characterization in laboratory in controlled conditions; characterizations were carried out in spring, summer and autumn using the FIGIFIGO goniospectrometer of the FGI (Suomalainen et al., 2009). The dark gravels are backscatters, typically providing reflectance of approximately 0.05 at nadir and anisotropy factors of 80%, 40% and $<10\%$ in 60° , 30° and 10° backward direction, respectively, and less than $\pm 20\%$ in forward direction up to 60° ; they provide stable spectrum especially on visual wavelengths. The white gravel and painted white concrete tiles had lower anisotropy of less than 50% in $\pm 60^\circ$ viewing directions, relatively flat reflectance spectrum with reflectance of 0.4-0.7 in visible to near infra red wavelength area (Figure 6). With the evaluated materials, due to anisotropy, if better than 5% reflectance accuracy is required, the nadir spectrums can be used for observer zenith angles lower than $\pm 10^\circ$; outside this region the anisotropy has to be taken into account. In most cases temporal changes of targets were higher than 5% and especially moisture caused radical changes in spectrums and anisotropy of most of the targets (Figure 6). Important conclusion of the study was that different targets have different temporal performance and the targets and in situ measurement equipment should be designed together. Management of object anisotropy, and its temporal changes, was considered as a significant challenge, when better than 5% reflectance accuracy is required. A manuscript is under preparation about the results by Honkavaara et al. (2010). Similar considerations have been made in the cases of spaceborne test sites (Cosnefroy et al., 1996, Smith et al., 2002).

Various issues of radiometric calibration of airborne imaging systems are investigated in the EuroSDR project "Radiometric aspects of digital photogrammetric airborne images" (EuroSDR Radiometry 2010; Honkavaara et al., 2009, Markelin et al., 2010, Arbiol et al., 2010). Here some conclusions about ADS40 validation campaign carried out in the Hyttiälä test site in 2008 in Finland are given. The Leica Geosystems is the first manufacturer of photogrammetric systems providing a complete, physically based, radiometric-processing chain for the ADS40 (Beisl et al., 2008). The processing is automatic and does not require any in situ control information. Central outputs

of the process are multi-angular reflectance and BRDF corrected reflectance. Images were collected from 1, 2, 3 and 4 km flying heights. Nadir images were evaluated in the first study (Markelin et al. 2010). At the lowest flying altitude better than 5% reflectance accuracy was obtained, but flying height, amount of cloudiness, and wavelength influenced the accuracy. The important conclusions related to radiometric test sites were that to assess the performance of the entire imaging system, it is important to measure the performance at typical operating condition (atmosphere, flying height). It was also considered that it is advantageous to have more than white and black reference target. The execution of the characterization in a test site, which belongs to the AEROSOL ROBOTIC NETWORK (AERONET 2010), was considered as functional.

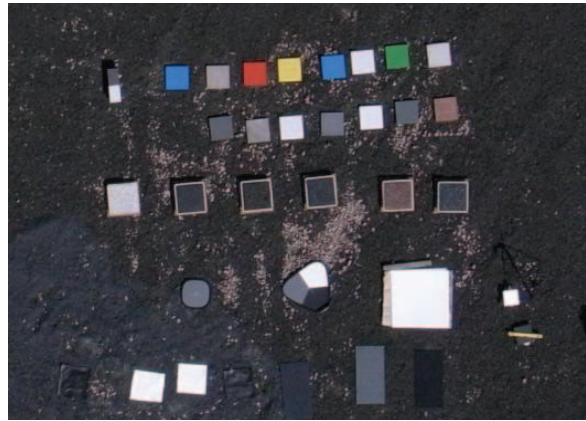


Figure 5: Samples of reference targets in test field. From top: rows 1 and 2: painted and unpainted concrete tiles, row 3: baskets of gravel, rest of the materials are transportable targets.

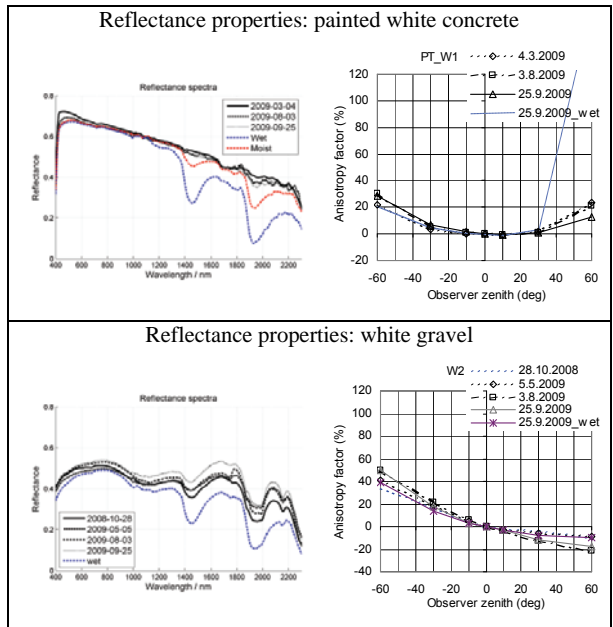


Figure 6: Examples of measured reflectance properties at different times. On left: spectrum, right: anisotropy factor at principal plane (from Honkavaara et al., 2010).

Good practices have been developed for various remote sensing systems for radiometric calibration. And for separate test sites functional approaches are available. Many new issues have to be taken into account when establishing a European wide test site network with similar layouts for photogrammetric systems. Various available materials provide good reflectance properties, but with many known materials the anisotropy has to be taken care of if larger than 10° observer zenith angles are of interest. In the determination of optimal test site layouts the construction and maintenance efforts have to be considered to find the most cost-efficient approaches. For this, empirical studies on short- and long-term temporal characteristics of the radiometric calibration systems (reference materials, in situ measurement equipment) and radiometric calibration campaigns under various conditions (e.g. rain, snow, frost, urban pollutions, humidity, salinity and sunshine) are necessary. As far as possible, the test sites should be developed in context of global atmospheric observation network (such as AERONET). Real time control and online access should be possible for in situ reference measurements and test field monitoring.

5. CONCLUSIONS

This paper focused on the current status of digital airborne camera calibration and in situ validations. From that the strong need for standardized processes for individual sensor certifications becomes obvious. This already is agreed within the sensor provider and data user community and several groups and initiatives activities are working on this topic, still common, harmonized guidelines are currently not available, which then have to be implemented as corresponding standards.

Besides definition of the later certification body, which at least for European context is currently discussed, deeper discussion on the later certification processes itself is necessary. If the certification focuses on the sensor quality itself, which should be expected, the quality of the “most raw” sensor deliverables should be evaluated. This should be properties like the signal-to-noise ratio (SNR), photo response non uniformity (PRNU), modulation transfer function (MTF), at-sensor-radiance and accuracy from independent check point differences. Still, for in situ tests those properties always are influenced from environmental (atmospheric) conditions during data acquisition. Such influence has to be measured carefully and corrected to obtain traceable results. Even though the above listed properties are close to the sensor’s “raw” output data, some processing is or has to be applied to perform the quality analyses. For geometric performance estimation the image data for example have to be triangulated to perform check point difference analysis. Thus, this quality measure not only relies on the sensor itself but also the processing. Since the sensors are of different design it is not possible to define only one single software which then is used for the triangulation, which again illustrates the much closer link between digital sensors and software. This also has to be discussed.

The concepts presented within this paper almost exclusively deal on airborne digital imaging, with aspired ground resolutions between a few [cm] to few [dm] up to the sub-meter level. Thus, in principle they could also include the group of high-resolution satellites. Furthermore similar concepts also should be made available for other sensor types, like LiDAR (often coupled with digital cameras), SAR/InSAR and hyper-spectral instruments.

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