

STATUS REPORT OF THE EUROSDR PROJECT “RADIOMETRIC ASPECTS OF DIGITAL PHOTOGRAMMETRIC AIRBORNE IMAGES”

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ABSTRACT:

Digital photogrammetric sensors offer a great potential for automatic, quantitative processing and utilization of image radiometry. The photogrammetric production lines with efficient, repetitive data collection, rigorous geometric processing, great geometric accuracy and reliability, high spatial resolution, and stereoscopy with large observation angles is an appealing and practical environment for the accurate radiometric processing and utilization. European Spatial Data Research (EuroSDR) organization launched a collaborative investigation project on radiometric aspects digital photogrammetric airborne images in May 2008. This article gives a brief summary of results of a query to data providers and users that was carried out in the framework of the project. The results showed that improvements are requested on the entire process, including sensors, calibration, data collection, data post-processing and data utilization. The fundamental problems are the insufficient information of the radiometric properties of photogrammetric sensors and processing of the image data, and inadequate radiometric processing lines. The basic products requested by users are true color images and reflectance images. The query suggested that in order to develop products that truly serve the community and applications that fully utilize the radiometric potential of images, it is of great importance to detect requirements of various interest groups and to develop standardized, transparent processes. Also examples of new-generation radiometric test flight campaigns are given. Expected benefit of accurate radiometric processing is more automatic and efficient imagery post-processing, better visual image quality and more accurate, automatic interpretation. Many developments are in operation in the field of radiometrically quantitative photogrammetry and the future prospects are promising.

1. INTRODUCTION

Digital imaging is rapidly replacing film imaging in photogrammetric data capture. The special advantage of the new imaging technology is the excellent radiometric properties, including multispectral imagery, linear response, large dynamic range, great radiometric resolution, and low noise level. The high radiometric performance potential of digital photogrammetric sensors was verified by Honkavaara (2008) and Markelin et al. (2008).

Radiometry is the key issue, which opens great prospects for the utilization of the photogrammetric imagery. They can be utilized in classical photogrammetric tasks, but with improved automation and quality level, and they can be utilized also in many new application areas, such as automatic change detection for map updating, classification, and environmental change monitoring.

The distracting influences of sensor, illumination and atmosphere have to be corrected from the imagery in order to obtain the full benefit of the image radiometry. Accurate radiometric processing is necessary for both visual and quantitative applications. The rigorous treatment of image radiometry is a new issue in photogrammetric processing lines.

Well-established radiometric correction methods exist for the remote sensing systems (e.g. satellite and airborne hyperspectral imaging systems) (Schowengerdt, 1997; Liang, 2004), but they are not directly applicable in photogrammetric processing lines due to the special features of photogrammetric data acquisition. Hundreds of constantly improving photogrammetric sensors is in operation. Large number of data providers collects imagery from different platforms, using different systems and principles. For a typical photogrammetric

Table 1. Responses for the query.

Participant	Abbreviation	Organization	Role
Institut Cartogràfic Catalonia	ICC	NMA	Software develop, Data provider, Data user, Research
Institut Géographique National, France	IGN	NMA	Sensor manufacturer, Software developer, Data provider, Data user, Research
National Survey and Cadastre, Denmark	KMS	NMA	Data user
National Land Survey, Finland	NLS,	NMA	Data provider, Data user
Ordnance Survey, Great Britain	OS	NMA	Data provider, Data user
Swisstopo, Swizerland	Swisstopo	NMA	Data provider, Data user
ReSe Applications Scläpfer, Swizerland	ReSe	Company	Software, consultant
Finnish Geodetic Institute, Finland	FGI	Research	Research
Institut für Geoinformatik und Fernerkundung, Universität Osnabrück	IGF	University	Research

project even thousands of images are collected during several acquisition days. In many processes huge amount of data is collected yearly, e.g. over entire countries every few years as a repeat cycle. Because of high productivity requirements, the image collection is not always carried out in optimum conditions. Photogrammetric sensors have large field of view, which highlights BRDF-effects. Images are typically arranged in image blocks with 20-80% side and forward overlaps, providing multiple views to the object.

EuroSDR launched a project on radiometric aspects of digital photogrammetric airborne images in May 2008 (EuroSDR Radiometry, 2009). Objectives of this investigation are to:

1. Improve knowledge on radiometric aspects of digital photogrammetric cameras.
2. Review existing methods and procedures for radiometric image processing.
3. Compare and share operative solutions through a comparison of these techniques on a same test data set.
4. Analyse the benefit of radiometric calibration and correction in different applications (classification, quantitative remote sensing, change detection etc.).

The project is realized in two phases. First, a review is made on the theory of image radiometry, radiometric processing methods, and applications. Secondly, an empirical investigation is conducted to study the radiometric properties and correction of digital photogrammetric images and the potential of using the images in various applications.

The first phase is completed in early 2009, and based on obtained results the exact objectives for the second phase will be set. In this presentation we report the central results of the query on radiometric processing in photogrammetric production lines (Section 3); a manuscript is under preparation to present the detailed results. For the empirical part, great endeavours took place in summer/autumn 2008 to provide state-of-the-art image materials (Section 4).

2. QUERY ON RADIOMETRIC PROCESSING IN PHOTOGAMMETRIC PRODUCTION LINES

Part of the EuroSDR project is a query to various interest groups dealing with photogrammetric images. The query was delivered to several large and medium format photogrammetric sensor manufacturers, photogrammetric software providers, National Mapping Agencies (NMAs) and Universities in October 2008. Objectives of the query were to:

1. Obtain a picture of the actual situation.

2. Detect main weaknesses of existing digital camera radiometric processing.
3. Look for main trends on existing and future development in this field.
4. Know what are the advantages of better radiometric processing and find which applications ask for better radiometric processing.

The questions were classified under themes: sensor, calibration, data collection, post-processing and utilization of the images. Under each theme the questions were further divided to questions related to current situation and to desired situation.

The organizations that replied the query are shown in Table 1. The widest response was obtained from NMAs, most of which are both data providers and users; some have also own software development and IGN is manufacturing its own sensor. ReSe is a software company behind the atmospheric correction software ATCOR (1-4) for spaceborne and airborne images (ReSe, 2009). They are specialized in processing and utilization of hyper spectral images. Finally, two research organizations IGF and FGI responded the query. IGF's focus is to use imagery in land cover and land use identification and classification at different scales. FGI is specialized in photogrammetric test fields, extensive empirical campaigns and goniospectrometry, and utilize images in interpretation applications. In total, 5 responses were obtained from data providers, 6 from data users, one from sensor manufacturer, one from radiometric software manufacturer, and two from research organizations.

3. RESULTS OF THE QUERY

3.1 Sensor

The questions concerned the sensor construction, technical details of various sensor components, and taking the radiometric aspects into account in sensor construction. Furthermore, recommended system set up (e.g. camera mount), operating conditions, performance indicators, and intended application areas were enquired.

Three of the NMA:s has their own DMC (Diener et al., 2000), one has ADS40 (Beisl et al., 2008), IGN develops imaging systems themselves (Paparoditis et al., 2006), and KMS purchases the imagery collected with frame sensors (DMC or UltraCam). DMC related issues are dominating the analysis.

As improvements to the current situation the participants were requesting more channels, non-overlapping channels, better correspondence to visual color perception (DMC), better

pansharpening ratio (DMC), larger image format (e.g. wider than 12000-14500 pixels), and similar viewing angle for panchromatic and multispectral channels (ADS).

For the conventional photogrammetric applications, the large image format, good spatial resolution, high geometric accuracy, and true colours are important. DMC, UltraCam and IGN's camera have been optimized for these requirements. Most of these requirements are in contradiction with the optimal, quantitative remote sensing sensor, where the large number of narrow, non-overlapping bands is of interest (Reulke et al., 2000; Shaepman et al., 2006).

3.2 Calibration

Questions concerned the phases (laboratory, on-board, test field, self-calibration) of the radiometric, colour, spectral and spatial resolution calibration of the sensor and system. For each phase and property, the details of calibration method (instrumentation, calculation method), parameters and their accuracy, and quality indicators, and recommended calibration interval were requested.

The general problems related to the current calibration procedures were that all necessary parameters are not determined, there are not accepted/standard procedures for the calibration, the calibration documentation of different systems are not comparable nor complete and there is not sufficient information about the quality of the calibration.

The fundamental problem is that for most systems only relative radiometric calibration is performed; the traceable absolute radiometric calibration has been realized only for the ADS40 (Beisl et al., 2008). There is need for both absolute and colorimetric calibration and quality indicators.

The laboratory calibration is practically the only calibration method, even though in truly quantitative process calibration and evaluation should be performed in various phases of the process (in-flight, platform, test field and self-calibration). Only a few radiometric test field calibration campaigns have been performed (Markelin et al., 2008; Martinez et al., 2007; Arbiol and Martinez, 2009; Section 4). Many questions concern all calibration steps: reference targets, methods and parameters.

3.3 Data collection

Several factors influence the radiometry in data collection phase. The questions concerned system configuration, conditions where the image collection is carried out, the system settings, and the on-the-fly quality control methods. Furthermore, descriptions of reflectance reference targets and reference measurements during the data collection were enquired.

It appeared that for the frame sensors the variable aperture and exposure times are issues that should be properly treated; at the moment these are not adequately treated in the evaluated systems. For the ADS40 different data collection modes can be selected; the most frequently used method uses lossy compression method, which causes radiometric artefacts. On the fly quality control methods are crucial, and digital technology provides many possibilities for that; currently the capabilities of all systems are not yet sufficient. Important parameters related to imaging conditions are the flight height, solar elevation angle, atmospheric state, clouds, and season. Currently

reflectance reference targets and in-situ measurements are not used in mainstream photogrammetric data collection.

3.4 Post-processing

Two types of post-processing are relevant: the post-processing of the data acquisition system and the post-processing of the image product generation system (Honkavaara, 2008). Different post-processing steps (atmospheric and BRDF correction, pansharpening, gamma correction, restoration, sharpening, tonal enhancements etc.) and the specific processes for various image products (orthophotos, stereomodels) and different applications (aerial triangulation, visual interpretation, classification) were requested. Finally, methods and indicators to characterize the quality of the imagery and quality requirements were enquired.

The post-processing in the data acquisition process is performed using the manufacturer provided software utilizing mostly laboratory calibration information. For data users the post-processing steps are not always clear.

The following processing is dependent on the application. The output image products were divided to stereo models, orthophotos/orthophoto mosaics and quantitative images; two first are intended mainly for visual applications and the last one for quantitative applications. Orthophotos and stereo models are standard products of all photogrammetric image providers; only ICC and IGN discussed about quantitative products.

Leica Geosystems has developed for the ADS40 a rigorous radiometric processing chain to produce reflectance images (Beisl et al., 2008). ICC (Martinez et al., 2007) and IGN (Chandelier and Martinoty, 2009) are developing radiometric block adjustment methods for frame sensors. Performance of these methods has not yet been proven by objective evaluation. Each of these methods still requires improvements to correct rigorously all the distracting influences. Other methods were the statistical adjustment methods (e.g. Inpho Orthovista and Socet Set Dodger) and interactive correction with PhotoShop. Various enhancements are performed for visual applications.

Central requirements for the post-processing system are: reliable, automatic and efficient post-processing, minimum number of resampling stages, interactive tools and efficient graphical interfaces.

3.5 Interest groups

The results indicated that it is necessary to classify the interest groups based on their activities in the entire photogrammetric processing chain. The fundamental processes are the sensor manufacturing, software development, photogrammetric image acquisition (unprocessed images), photogrammetric image product generation (orthophotos, stereomodels), applications and research. The main interest groups are data users, data providers, sensor manufacturers, software developers and research organizations. Each interest group can be further divided to different subclasses based on the tasks they undertake. E.g. the data user can undertake all phases of the process (sensor manufacturing, data collection, image product generation, applications) or he can concentrate only the application.

Each of these groups has different possibility to influence or know the details of the radiometric processing chain. As the use of the imagery is the fundamental issue, the radiometric



Figure 1. DMC image from Banyoles 2008 campaign of the ICC. Photo by ICC.



Figure 2. DMC image from the Sjökuilla test field in 1.9.2009. Photo by NLS.



Figure 3. ADS40 image from the Hyytiälä test site 23.8.2009. In co-operation with Estonian Land Board, FGI, Ilkka Korpela, Leica Geosystems, University of Joensuu. Photo by Estonian Land Board.

processing chains should be developed so that the image products are usable in different applications by different users.

All data users (except IGN) were concerned about the traceability of the radiometry. The complete documentation of the image formation is asked for. It is desirable to have standardized, transparent processes. An important comment comes from the KMS who purchases all the imagery "We lack information on the entire data processing and also lack technical

information on the integrated sensor system (e.g. position of IMU/GPS related to the image sensor) and how the resulting image frame is computed". The traceability and comparability of data collected with various sensors is especially a problem for users that order images. These users require transparency from both manufacturers and data providers for the entire image processing chain. The ideal situation would be to have standardised and internationally accepted procedures.

4. CONTROLLED PHOTOGRAMMETRIC TEST FLIGHT PROJECTS IN SUMMER 2008

In summer/autumn 2008 several radiometrically controlled test flights were conducted in Catalonia, Finland and Germany (DGPf, 2009). In the following, the campaigns carried out in Catalonia and Finland and their scientific objectives are briefly described. Also some difficulties that were faced in these campaigns are described because they are typical for radiometric campaigns, and they are important issues when developing radiometric correction methods and test field calibration/validation procedures. This data will be partially available for the evaluations by the EuroSDR radiometry project participants. ICC data is already available on request.

4.1 Integrated DMC and CASI test flight with comprehensive in-situ measurements

ICC executed extensive radiometric test flights with DMC and Compact Airborne Spectrographic Imager (CASI) in Banyoles in 15 July, 2008 (Arbiol and Martinez, 2009). The imagery was collected from 820, 1125, 2250 and 4500 m flying heights. Various manmade reflectance targets as well as several artificial and natural stable covers were available around the test field, including a lake (Figure 1). In addition, a Siemens star was installed in the test field. Two groups carried out the radiance and reflectance ground-truth data acquisition with spectroradiometers. Atmospheric state was directly measured by several groups, instruments and techniques. An atmospheric Lidar provided aerosol profiles and two automatic sun tracking photometers provided column integrated values of Aerosol Optical Thickness (AOT) for the optical spectrum. Simultaneous to the airborne sensors overflight an atmospheric radiosounding were carried out. Objectives of these rigorous test flights were:

1. Radiometric calibration of a DMC by the radiance and the reflectance methods. Validation with radiometric targets. Radiance method will be performed with the simultaneous acquisition of CASI.
2. Spectral characterization of CASI regarding bandwidth and smiling effect. Comparison with laboratory results.
3. Atmospheric correction of CASI imagery with aerosol distribution and load, and water vapour derivation by an inversion method. Validation with radiometric targets and atmospheric measurements.
4. Atmospheric correction of DMC images by using CASI derived atmosphere parameters. Validation with radiometric targets.
5. Colorimetric calibration of DMC towards CIE standard colour space. Validation with radiometric targets.
6. Resolution studies by means of Siemens star and edge targets. Study of the relationship between atmosphere state and resolution. Comparison with computer radiative transfer simulations.
7. Application of DMC radiance and reflectance images to remote sensing studies.

4.2 DMC test flights with BRF targets and various exposure and aperture settings

The National Land Survey of Finland carried out acceptance testing of their new DMC in 1st September and 25th September 2008 at the Sjökölla test field of the FGI (Honkavaara et al., 2008; Honkavaara, 2008). The reflectance reference targets included the permanent BRF targets of gravel at the test field, several transportable BRF targets and several natural targets (Figure 2). Targets were monitored using an ASD field spectrometer during the flights. A Siemens star, edge target and line bar targets were available for the spatial resolution evaluations. The scientific objectives of this campaign were:

1. Absolute radiometric calibration of the DMC by the reflectance method.
2. Spatial resolution studies of the DMC using Siemens star, edge targets and resolution bar targets.
3. Evaluation of the influences of various exposure and aperture settings on the radiometric performance and spatial resolution of the DMC.
4. Evaluation of the BRF measurement potential of the DMC.
5. Geometric characterization of the DMC.

There were many difficulties in this campaign. The acceptance testing was scheduled for the beginning of August. Unfortunately the weather conditions were too poor in August, so the campaign could not be executed before September; the field measurement team was ready for takeoff for more than month and three field campaigns were carried out unnecessarily. In the first successful airborne campaign the sensor settings were not optimum, and the images were saturated in worst cases already with 25% reflectance value. To obtain unsaturated images and to allow proper acceptance testing, second campaign was carried out in the end of September. The field measurement team was not prepared for this campaign and the spectrometer was not available, so only reflectance targets were installed in the test field. The plan was also to collect imagery in the urban area test field of the FGI; this campaign failed completely due to poor weather conditions and flight restrictions.

4.3 Integrated ADS40/ALS50 test flight with atmospheric observations

The test flight with ADS40 (SH 52) and ALS50 was carried out at the Hyytiälä forestry test field in co-operation with Leica Geosystems, Ilkka Korpela, University of Joensuu, Estonian Land Board and FGI. The test site is 3300 m x 8500 m in size and it contains more than 200 forest plots and over 15000 trees that have been measured for position and basic variables, in different forest conditions (density, age, species mixture, silvicultural history) (Korpela, 2009). A state-of-the-art weather station (atmospheric research) runs at the area of interest (SMEAR II). FGI's BRF calibrated reflectance targets and Siemens star were installed at the test field (Figure 3). The reflectance/radiance of the targets as well as various homogeneous land covers (asphalt, gravel, grass) were monitored by FGI and Leica Geosystems using spectroradiometers. ADS40 data was collected with the uncompressed mode from 1000, 2000, 3000 and 4000 m flying altitudes providing 10 cm, 20 cm, 30 cm and 40 cm GSD. Objectives of these flights included:

1. Absolute radiometric calibration of the ADS40 by the reflectance method and comparisons to laboratory calibration.
2. Evaluation of the performance of the semiempirical XPRO software (Beisl et al., 2008) for the radiometric correction

of the ADS40 imagery using the reflectance reference targets.

3. Correcting the imagery utilizing correction method based on radiative transfer modelling. Evaluating the performance with the reflectance reference targets.
4. Evaluation of the BRF measurement potential of the ADS40.
5. Spatial resolution studies of the ADS40 using Siemens star.
6. Geometric characterization of the ADS40.
7. Comparisons of the physical and semiempirical radiometric correction methods on the forestry applications.
8. Further objectives of the entire campaign include the radiometric calibration of ALS50 and its utilization in forestry applications, which is out of scope of this project.

The poor weather conditions caused problems in this campaign as well. The field measurement team was ready for takeoff for one week; the campaign could be carried out in one Saturday morning. The positive feature of this campaign was that continuously operating sun photometer and weather station are permanent equipment at the test site, which helped greatly the field operations. After the airborne campaign clouds entered rapidly to the test site, thus complete BRF characterization of the natural targets at the test site could not be carried out. The plan was to carry out a test flight in the urban area test site of the FGI, as well, but again, at this time after waiting for one additional week, this campaign had to be cancelled due to the poor weather conditions. Additional efforts were needed in this campaign due to the limited data storing speed of the ADS40: to obtain non-compressed data for the nadir and backward R, G, B, NIR channels at 10 and 20 cm GSDs, the same flight lines had to be collected using repetitive passes.

5. DISCUSSION AND CONCLUSIONS

5.1 Status of photogrammetric systems

The results showed that there are several fundamental problems in photogrammetric processes, which hinder the quantitative utilization of image radiometry, make the radiometric correction complicated and laborious, and decrease quality of the output products. The systems are not optimum with respect to the quantitative utilization of the image radiometry in none of the evaluated aspects, i.e. the sensor, calibration, data collection and data post-processing. The most fundamental problems are the insufficient information of the sensor and system and the non-existing processes for efficient data processing. There are differences in sensors, e.g. Leica Geosystems has implemented a traceable laboratory calibration and developed a process for reflectance image generation for the ADS (Beisl et al., 2008) but for other systems manufacturers have not developed such processes.

Honkavaara (2008) and Markelin et al. (2008) made baseline evaluations on radiometric properties of the first generation photogrammetric systems using imagery collected in 2004 and 2005. Since then many improvements have been taken place in sensors and processing and more information is available, but still similar questions are faced as in the very first evaluations. To summarize, these include the insufficiently described sensors and processing lines, insufficient calibration, and insufficient processing methods. Special sensor related issues are still causing problems; these include the sensitivity of frame sensors

to aperture and exposure time settings and the limited possibility of the ADS to collect uncompressed data.

5.2 Future prospects

The data users' and data providers' aspects should be taken into account in the future developments of radiometric processing lines. Data users need validated, reliable products. Data providers need validated, reliable, efficient production lines. An attractive situation would be if the data providers could produce different types of data products (radiance images, true color images, reflectance images).

The advantages of the improved radiometric processes should be evaluated and applications should be developed simultaneously. The limitations caused the complexity of the photogrammetric data collection process has to be taken into account; fundamental difficulties include the varying atmospheric conditions, and variability of sensors and systems.

It is also possible that in the future the radiometric correction aspects will be taken into account in the sensor and system configurations (e.g. additional irradiance sensors, additional channels). This will make the radiometric correction easier and improve the quality.

The international initiatives that aim at development of standardized radiometric processing methods, such as the EuroSDR European digital aerial camera certification (EuroDAC) initiative (EuroDAC, 2009), are of great importance in development of widely accepted procedures.

To validate sensors, systems and data post-processing methods, controlled flight campaigns are necessary; an attractive approach is to use appropriate test fields. The results of the rigorous flight campaigns (Section 4) will provide new recommendations for the radiometric processing and test field calibration.

Expected benefit of accurate radiometric processing is more automatic and efficient imagery post-processing, better visual image quality (less visual "colour-borders" in orthophoto mosaics, true colors) and more accurate, automatic interpretation.

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