THE EUROSDR APPROACH ON DIGITAL AIRBORNE CAMERA CALIBRATION AND CERTIFICATION

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KEY WORDS: Digital Camera, Calibration, Validation, Certification, Standardization

ABSTRACT:

The comprehensive analysis of new digital airborne photogrammetric camera systems is an important topic right now. Faster than originally expected the new digital sensors phased into market and are already used in production processes. Furthermore, some national mapping agencies or system flyers have already decided to exclusively use digital imagers in future and already started to sell their analogue cameras and analogue film developing equipment. Still, the performance of individual systems in specific applications is not fully proven, which emphasises the need for empirical tests and detailed investigations. The EuroSDR organization also focused on this topic of digital camera calibration and validation. About three projects have been done or still are under investigation, one focusing on the analysis of geometric large-format digital camera performance, the second dealing with radiometric aspects of large-format cameras, and the third focusing on medium-format based camera systems. The main results and status of these technology driven projects are given in the paper. All these technical investigations finally culminate in the new EuroSDR initiative on European Digital Airborne Camera Certification (EuroDAC²) which is also introduced in the paper. The development, current situation and upcoming activities are described. Since the EuroDAC² project is still underway, the paper only gives a short snapshot illustrating the situation at the time of paper compilation.

1. INTRODUCTION

Digital airborne imaging has grown in importance over recent years. Large-format digital cameras like Leica Geosystems ADS40 or Intergraph/ZI DMC and Vexcel Imaging Ultracam can fully compete with analogue mapping cameras, and for many applications their performance is even better. However, methods of calibration and certification used for analogue cameras are not individually transferable as they are based on laboratory calibration, while for digital cameras the whole system covering the complete data generation process has to be considered. The design of large-format digital cameras differs greatly from their analogue counterparts. Besides, there is a significant increase in medium-format digital cameras, often used in combination with airborne laser scanning or as multi-head installations (like IGI DigiCAM-H/39 dual-head or Rolleimetric AIC-x4 four-head installations), which are in terms of area coverage already close to those systems primarily designed for large image format like DMC or Ultracam. In general, the refinement, modification and new-development of digital airborne camera systems still is very viable and it is expected that modified or new systems will phase into operation almost continuously through the next years. These continuous changes have to be considered in the calibration and later certification processes.

Calibration of mapping cameras is well established for the traditional analogue frame cameras but the process has to be modified when dealing with new digital sensors. Since the principle architecture of such digital systems is fairly heterogeneous (i.e. line scanning systems versus frame based solutions, multi-head large format systems versus single-head medium to small format systems, synchronous versus syntopic image data acquisition) individual procedures for system calibration are necessary. With an optional combination and in case of line scanning systems mandatory tight integration of additional GPS/inertial components this situation becomes even more complex. Within this context a need for new and accepted calibration procedures as well as certification processes is evident. Additionally such processes have to be more flexible than in the past to be able to adapt to the different sensor layouts. Such procedures will not only support digital camera system suppliers but are also of help for potential digital camera users. All these facts defined the background where EuroSDR decided to start an initiative on digital camera calibration and validation which later than was proceeded by the European initiative on Digital Airborne Camera Certification (EuroDAC²). This latest initiative aims at a European-wide certification procedure for digital airborne mapping cameras. A core competence group was formed to closely interact between National Mapping and Cadastre Agencies (NMCAs) and all relevant digital airborne mapping camera suppliers and other experts.

The remaining part of the paper is structured like follows. After giving some basic information on the EuroSDR organization itself a quick review on the former and ongoing EuroSDR activities in digital airborne camera calibration is given. Those projects are typically more technology oriented. After that the focus is laid on the EuroDAC² initiative which is already running since spring 2007. Besides pure technology driven activities, this certification now also covers legal aspects.

2. THE EUROSDR ORGANIZATION

The EuroSDR organization (European Spatial Data Research, see www.eurosdr.net) is a European user driven organization already founded in 1953 (formerly known as the Organisation Europeenne d'Études Photogrammetriques Expérimentales (OEEPE)). As of today 17 European countries are official members of the organization, where each member state is typically represented by two delegates in the EuroSDR science and steering committee: One from the national mapping agency and the second representative from research institutions or companies, respectively.

The mission of the organization is two-fold:

1. Develop and improve methods, systems and standards for the acquisition, processing, production, maintenance and dissemination of core geospatial information and promote applications of all such data, with special emphasis on the further development of airborne and spaceborne methods for data acquisition.
2. Encourage interaction between research organizations and the public and private sector to exchange ideas about relevant research problems and to transfer research results obtained to geoinformation production organizations.

The EuroSDR research activities are conducted by 5 scientific research commissions. These commissions are responsible for the initiation and coordination of scientific projects and workshops. From the very first beginning the main focus in research was laid on empirical performance tests in Europe. Substantial results for later practical use of new technologies for example were obtained in the field of analytical bundle block adjustment, GPS-supported aerial triangulation and GPS/inertial-based direct georeferencing. From this, recent and past projects in digital camera calibration/validation and certification continue former research projects and fully correspond to the aims of the organization.

3. DIGITAL CAMERA CALIBRATION AND VALIDATION

3.1 Network Digital Camera Calibration

In the year 2004 EuroSDR already started a project dealing with the *calibration and validation of digital airborne cameras*. At that time the first of the new digital photogrammetric airborne cameras phased into practice and there was an obvious need to independently analyse the performance of such sensor systems in especially in comparison to the well established analogue mapping cameras. Special focus should have been laid on the system calibration aspects, where at that time large knowledge deficiencies were present, especially on user's side. This was due to the fact, that calibration performed by the manufacturers for the new digital sensors was not well known and documented. The necessary calibration steps were quite different to the traditional analogue mapping camera calibration, which is well known and consistently documented in calibration certificates. Such differences are mainly due to the different and heterogeneous sensor designs and their pan-chromatic and multi-spectral capabilities. Thus the expert network on Digital Camera Calibration was established, with the following two main objectives:

1. Collection of publicly available material on digital airborne camera calibration to compile an extensive report describing the current practice and methods (Phase 1).
2. Empirical testing with focus on the development of commonly accepted procedure(s) for airborne camera calibration and validation, based on the experiences and advice of individual experts (Phase 2).

Both phases have already been finished, the extended phase one report is available (Cramer, 2004). The empirical phase 2 results have to a major extend been published in Cramer (2007b). The final project report will be made available through the official EuroSDR publication series in 2008.

Since some of the project findings are of relevance for the later certification process, the majors should be re-called here. The first conclusions were drawn from the theoretical phase 1 research, mainly focussing on the technologies of digital camera calibration, as they are performed by manufacturers themselves. With respect to this calibration aspect a decreased use of standard collimator based laboratory calibration seems to be evident, whereas the importance of in-situ calibration is definitely increasing. Such in-situ calibrations, i.e. self-calibration determined from dedicated calibration flights, have to be done by the users regularly, in order to validate and refine the manufacturer's system calibration parameters. Due to the fact, that such self-calibrating techniques are not as common in the traditional airborne photogrammetry, clear knowledge deficits, concerning the features and advantages of system calibration in flight, are present especially on the user's side.

The second step of the project then focused on the empirical analyses of real test flight data, to validate the a priori calibration parameters from operational tests and if necessary include additional self-calibration to even refine the overall performance of the analysed systems. Flight data from three systems have been taken into consideration, namely the ADS40 (1st generation, sensor head SH40), DMC and UltracamD cameras. It has to be mentioned, that the empirical results have been obtained from a somewhat limited data base, because at the time the data was collected for the project only a limited number of test flights have been made available flown in photogrammetric test sites, and there was no financial budget to perform own test flights. Especially for the DMC and UltracamD data sets flown in the Norwegian test site Fredrikstad, the conditions during the image acquisition were limited (i.e. sun light conditions), which negatively influences the image radiometry and the later identification of image points. The ADS40 was flown in the German Vaihingen/Enz test field, in much better airborne conditions. Since the flights were already done in 2003 and 2004 respectively, the sensors (and the obtained results) did not fully reflect the today's state of the art of sensor technology any more. This especially is obvious for the ADS40, which in the meantime has been modified to ADS40 2nd generation (with sensor heads SH51 and SH52) and the Ultracam, which now is available as UltracamX version. Thus the following findings might be slightly different from today's test flights, nevertheless the general trends are obvious and have already been verified from alternative tests in the meantime.

Major role during the empirical tests in phase 2 was the analysis of influence of additional parameters and optimal models for system self-calibration. One important finding was that self-calibration is obviously necessary to improve the quality of object point determination for all three tested camera systems ADS40, DMC and UltracamD. With self-calibrating aerial triangulation for the ADS40 flight the horizontal accuracy is in the range up to 1/5 pixel (GSD) and the vertical accuracy in the range of 1/3 pixel (GSD), corresponding to 0.04‰ of flying height. It should be mentioned that the later accuracy measure "‰ of flying height" for the vertical component is not as meaningful for digital cameras then for the former analogue mapping cameras. The digital cameras are of quite different design, resulting in different flying heights necessary to acquire same ground sampling distances. For DMC the accuracy is about 1/4 - 1/3 pixel (GSD) horizontally and 0.5 - 1 pixel (GSD) vertically, corresponding to 0.05-0.1‰ of flying height. And finally in case of UltracamD the resulting accuracy is about 1/4 - 1/2 pixel horizontal and 1/3 of a pixel in vertical component (corresponding to 0.03‰ of flying height for vertical component). Again note, these values are obtained from the three empirical test data sets only and are always dependent on the applied mathematical model. Each block has its own geometry. In case of UltracamD and DMC the radiometric quality might also be of influence on the obtained accuracy. Thus, those numbers cannot be transferred to other projects in general and have to be checked individually. In all cases the above values were obtained with use of additional self-calibration parameters which seems to be a necessity for all tested systems, to get highest absolute accuracy. Since this effect has also be proven from other independent investigations, it seems to be a general fact.

The obtained accuracy increase in object point determination using self-calibration is higher for DMC and UltracamD compared to ADS40. Additionally, the systematic corrections for UltracamD are more significant compared to DMC.

In some cases specially designed self-calibration parameter sets adapted to sensor geometry are necessary. For ADS40 the standard model based on Brown parameters is sufficient. For the frame based systems DMC and UltracamD extended or modified self-calibration models had been used. Alternatively high order correction polynomials like the 44 parameter Grün model in some cases also lead to accurate results. The use of only 12 additional parameters like Ebner or the BLUH standard parameters definitely is not sufficient to compensate for the systematic errors, at least from the findings of the analysed three data sets.

Besides self-calibration model the a priori weighting of observations is of larger influence. In some case the choice of weighting factors even exceeds the influence of the applied self-calibration model.

The network Digital Camera Calibration has clearly emphasized the important role of system validation from real flight data flown in well controlled photogrammetric test ranges. The influence and importance of additional parameter sets for the final geometric accuracy has clearly pointed out. In-situ system calibration and validation will gain in importance in future. Obviously, such processes have to be checked in detail.

3.2 Medium format digital airborne cameras

Unfortunately, the investigations performed in this project only covered the geometrical aspects of only three camera systems, with technical status of almost 5 years ago. Later sensor developments and other recently introduced large format sensors, like Jenaoptronic JAS-150 have not been considered. Additionally the very viable group of camera systems based on medium format sensors was not involved. As already mentioned in the introductory part of the paper, currently considerable developments in medium format cameras are obvious (several systems providing up to 39Mpix resolution (for one single camera head) like IGI DigiCAM-H/39, Rolleimetric AIC-x, DiMAC Systems DiMAC, Applanix DSS and others). Many of them are also available in multi-head configurations (dual-head to four-head installations) which will increase in use in future photogrammetric applications. Thus these types of imaging sensors will be investigated in the new EuroSDR project *geometric and radiometric performance of digital medium format cameras*. The project is already running since fall 2007 under the leadership of Universität Rostock, Germany. Dr. Görres Grenzdörffer, Institute for Geodesy and Geoinformatics is the project leader. Similar to the Network Digital Camera Calibration a first theoretical phase, documenting the current status of medium format airborne imaging and available systems, will be amended by practical investigations focussing on both geometric and radiometric aspects. The first phase is already finished and major findings are documented in Grenzdörffer (2008).

3.3 Radiometric performance of digital cameras

The radiometric performance of the new digital airborne sensors also was not analysed in the Camera Calibration project although originally planned. This gap now is being closed through another EuroSDR technical project focusing on the *radiometric performance of large format digital cameras* in detail. The project is headed under the joint leadership of Eija Honkavaara and Lauri Markelin, Finnish Geodetic Institute (FGI), Finland and Roman Arbiol, Institut Cartogràfic de Catalunya (ICC), Spain. This radiometric project has been started in spring 2008 and will run for an approximately 2 years period of time. Again, a two phase project set-up is preferred. The first step will focus on the methodology itself. A report will be compiled based on literature research and a query to sensor manufacturers, image providers, image users, etc. This should become available in late 2008.

Based on the results from phase 1 analyses the empirical phase 2 investigations will focus on the processing of real data by test participants. The acquisition of empirical data sets will become necessary, i.e. strong image blocks preferable flown in different flying heights and covering several acquisition days to improve robustness of results. Additional equipment like reference targets has to be supported. To enable absolute radiometric calibration, either airborne hyperspectral data by e.g. CASI or AISA (radiance based method) or field radiance and atmospheric data (reflectance based method) should be collected simultaneously during flights.

4. DIGITAL AIRBORNE CAMERA CERTIFICATION

The previous chapter has illustrated the technology driven activities in the EuroSDR group with focus on the new digital airborne camera technologies and their comprehensive performance testing. The findings of all these closely related activities finally lead to the decision of EuroSDR to go one step behind the pure technical investigations and also focus into the legal aspects of camera certification. Quite interesting to note that at the time of initialization of the Digital Camera Calibration Network such aspects were put to the background for the time being. Thus, EuroSDR decision was to officially instigate a project to take forward the issue of *European Digital Airborne Camera Certification – EuroDAC²* by EuroSDR. The coordination is between the European National Mapping and

Cadastre Agencies (NMCAs) while cooperating closely with all relevant digital airborne mapping camera suppliers and other experts. As NMCAs from seventeen states are currently members of EuroSDR most European NMCAs are involved in this project already. The initiative will lead to a European wide accepted certification procedure substituting the traditional analogue mapping camera certification. This project is also pushed by other certification activities like the Quality Assurance Plan driven by the US Geological Survey (USGS). Co-operations have already been established between both organizations to align the concepts as much as possible. Details on the most recent steps in the USGS certification initiative are published in Stensaas & Lee (2008) and Christopherson (2007).

The EuroDAC² project was officially launched at the 110th meetings of the EuroSDR Science Committee and Board of Delegates in Rotterdam, The Netherlands, May 24, 2007. A position paper was compiled and distributed in the EuroSDR member states (Cramer 2007a). Within this paper the main ideas of the EuroDAC² initiative were briefly introduced and the concept was related to other ongoing certifications, mainly from the US Geological Survey. Since end of 2007 a competence group of international experts from science, national mapping and private industry is completed. As one can see from the following
Table 1, the EuroDAC² competence team in general consists of 6 people, supplemented by the current leaders of the projects medium-format cameras and radiometric performance of digital large-format cameras (see previous sub-sections 3.2 and 3.3). The team competence almost covers the whole spectrum of today's digital photogrammetric cameras, including the medium-format, line scanning and large-format multi-frame based technologies. Since many of the members are also linked to national mapping, they in parallel also represent the system user's side. R. Reulke additionally is involved in the German standardization organization, where he currently is chairing the standards group in Photogrammetry and Remote Sensing.

#	Member	Expertise
1	**R. Alamus** ICC Barcelona Spain	NMCA, DMC user
2	**L.-E. Blankenberg** BLOM Geomatics Norway	Commercial company, UltracamD/X user, science
3	**D. Boldo** IGN France	NMCA, medium format camera development/testing
4	**S. Bovet** Swisstopo Switzerland	NMCA, ADS40 user
5	**M. Cramer** Universität Stuttgart Germany	Science, head of core group & EuroSDR commission I
6	**R. Reulke** Humbolt Universität Berlin Germany	Science, German (DIN) standards
7	**G. Grenzdörffer** Universität Rostock Germany	Science, Project leader: Medium Format Cameras
8	**E. Honkavaara,** L. Markelin & R. Arbiol FGI Finland & ICC Spain	NMCA, Project leaders: Radiometric Performance

Table 1: The members of the EuroDAC² competence group

The first group meeting took place at January 30, 2008, parallel to the EuroCOW workshop held in Castelldefels, Spain. The full group met, where D. Boldo and R. Reulke were replaced by one of their colleagues, respectively. Additionally one representative from the US also involved in the USGS Quality Assurance Plan was attending, physically representing a link between both European and US certification strategies.
Figure 1 shows the group members (from left to right): N. Paparonditis (IGN France, in place of D. Boldo), S. Bauer (DLR Berlin, Germany, in place of R. Reulke), G. Grenzdörffer (Universität Rostock, Germany), L.-E. Blankenberg (Blom Geomatics, Norway), M. Cramer (Universität Stuttgart, Germany), R. Alamus (ICC Barcelona, Spain), D. Moe (guest, involved in the US Geological Survey Quality Assurance Plan) and E. Honkavaara (FGI Finland, Masaala). S. Bovet (Swisstopo, Switzerland) was also attending but is missing on the photo.

Figure 1: The EuroDAC² core competence team meeting in Castelldefels (Jan 30, 2008).

During this meeting the current project status has been reflected and the next steps have been defined. The current situation is illustrated in the following subsections 4.1-4.5.

4.1 Calibration processes

Digital camera systems are calibrated through the manufacturers, parts of the calibration is done in their laboratories typically amended by in-situ calibrations. A clear trend towards in-situ calibrations is obvious. The ADS40 2nd generation for example is the first large format digital photogrammetric sensor whose geometry exclusively is calibrated from in-situ calibration flights. Besides geometry the overall image quality including spatial resolution and radiometry are crucial for any user. Thus a high-level radiometric calibration comparable to geometric calibration is also of concern but only treated exceptionally.

Such processes and calibration setups are currently not certified.

4.2 Calibration protocols

Calibration results are documented by camera manufacturers. They all have defined their individual system specific calibration protocols. These documents sometimes are very extensive especially for multi-head cameras. Since layout of all of them is quite different, direct comparison between different camera type calibrations is limited. The unique definition of the calibration parameters, the transparency of the calibration processes, the completeness and non-ambiguity of calibration information so far is not analyzed. Thus today's calibration protocols are away from calibration certificates.

4.3 In-situ test ranges and flight layouts

Test flights in well-defined and controlled test areas offer the only possibility to check the overall systems performance in true operational environments. They will also gain in importance for in-situ system calibration process. Furthermore, test site validations already have been introduced in new national standards. For example the new German standard DIN 18740 – Photogrammetric Products, Part 4: Requirements for digital aerial cameras and digital aerial photographs (established September 2007, the full standard (in German only) can be digitally ordered through www.beuth.de) defines the following: "The calibration of the camera has to be documented by the manufacturer's calibration certificate. The validity of the geometrical calibration at the time of flight has to be proven by a validation test (less than one year ago) or a new calibration (less than two years ago). The validation has to be done in a signalized test area. The horizontal and vertical accuracy obtained from the validation test has to coincide with the quality specs given in the manufacturer's calibration, which serves as the reference. The maximum tolerance between validation flight and calibration has to stay below 25%." Above paragraph is following section 4.1.3 in DIN 18740-4. Still, the optimal layout of validation fields and the definition of appropriate validation processes, not only for geometry but also covering radiometry and sensor products, are not defined. Furthermore, the maximum allowable tolerance of 25% is not explained or defined in more detail. This also leaves much open for interpretation.

4.4 Sensor development

The new digital sensor technology is developing rapidly. Some of the systems are based on non-photogrammetric off-the-shelf sensors, so-called medium-format type systems. They also increasingly seem to be used in geospatial imaging, especially when several of such medium format cameras are combined in one platform to obtain larger field of views and area coverage. So far mostly 2-4 head installations are realized, but some already have announced camera clusters of up to eight systems (Tölg 2007). There is a place for these sensors and their users would also like to certify/validate their systems/products as well. But certification processes have to be flexible to take care of the different and (evolving) new sensor designs.

4.5 User specific requirements

In addition the digital sensors are offering a broad variety of application fields. Users sometime have very different demands on their flight designs and corresponding GSD and accuracy requirements or classes. In some cases the users have full control to the data process when the whole data processing is done in-house, in other cases users will order the final end product only. Especially for high accuracy requirements the individual sensor used during data acquisition will have significant influence on the later product. This again motivates an individual sensor related (i.e. sensor/camera number instead of type approach) validation process. Test flights again offer the only way not only to validate the performance of the sensor data and to point out the individual camera strengths and weaknesses. In addition, the data generation not only relies on the sensor itself, but the post processing, the airborne component and the operating environment also is of influence. Test field validation also allows for the analysis of the later products including the whole sensor systems with corresponding data flow.

4.6 EuroDAC² decisions and next steps

The above sub-sections tried to point out gaps or lacks in today's verification/certification processes that should be closed by activities like EuroDAC². First of all EuroDAC² fully agrees with the effort already done in USGS Quality Assurance Plan, especially the so-called manufacturer certification (now renamed to sensor-type certification), which in general checks the process of sensor manufacturing for continuous quality control but is related only to the product series as a whole not on each individual sensor number. EuroDAC² most likely will not undergo this effort again, which obviously would also be supported by the system manufacturers.

Instead of that the core competence team decided to focus on the following fairly concrete steps, which seem to be manageable to be solved in near future:

Work on transparent and completely described calibration processes and the unique, comparable and unambiguous presentation of calibration results in calibration protocols. So far the results from manufacturer calibrations are listed in sometimes very extensive calibration protocols, and this information is presented in quite heterogeneous ways as described before. A more unified way of result presentation and uniquely definition of parameters will directly influence the user friendliness and acceptance of systems.

Work on the optimal design of airborne calibration and validation test fields and the corresponding test methods to comprehensively validate the system performance. The future role of test fields for in-situ calibrations and comprehensive performance tests of individual sensor is obvious from the above discussions. Still the processes and the final layout have to be defined. Note, that performance tests have to cover the geometry and radiometry as well. First substantial evaluations on the layout of such test procedures are already done by Honkavaara et al (2008). EuroDAC² developments will be founded on this investigations.

Work on the formation of a network of international calibration and validation test field providers. All test fields have to be independent, of comparable layout and will offer identical user policies. EuroDAC² has identified four primary test fields already used for the last years for European airborne tests. These test fields are maintained by

- the Finnish Geodetic Institute (Masaala, Finland), namely the Sjökulla test site
- the University of Pavia (Pavia, Italy), namely the Pavia test site
- the Universitaet Stuttgart (Stuttgart, Germany), namely the Vaihingen/Enz test site, and
- the University of Life Sciences (Aas, Norway), namely the Fredrikstad test site.

It is quite interesting to note that just recently a new test field was already established in Spain, due to the impact of EuroDAC² (Nafria Garcia 2008). This test site is located north of Valladoid and maintained through Instituto Technologico Agrario (itacyl). So far its spatial extension is smaller than the before mentioned test sites. Nevertheless EuroDAC² will work on the regular distribution of similar test sites throughout Europe, which then can be used under comparable conditions.

5. CONCLUSIONS

This paper briefly summarizes the most recent investigations in digital airborne camera calibration and certification performed in the frame of the EuroSDR organization. Only a small overview on the current status could be given. Since three of the projects are still on their way, each interested person is cordially invited to participate in passive or even active way. This is especially of concern for the development and implementation of the EuroDAC² process. If the process itself is based on a broad foundation, the later implementation and overall acceptance will become much easier.

The certification itself is quite a complex field, which is also re-confirmed from the first experiences from certifications performed by the USGS. It will take certain time to establish the processes, which on the other hand is not available since the use of the new sensors immediately forces the availability of such independent certification procedures. Nevertheless, with the European and also international network of certification activities a final concept, which is accepted in many countries throughout the world might become possible.

Still the official implementation of such processes has to be done country specific, because it is dependent on national authorities. For the EuroDAC², which clearly focuses on the European point of view, we are planning to get the process certified through the European Committee for Standardization (CEN).

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