CALIBRATION AND VALIDATION OF DIGITAL AIRBORNE CAMERAS

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ABSTRACT

With the growing use of digital airborne imagers in daily operational data acquisition and processing the need for the development of guidelines and procedures for quality assurance and quality control is clearly obvious. Several national and international organizations are dealing with those topics, where focus is laid on the calibration, validation and certification of the new sensors. As an example the activities from USGS (United States) and EuroSDR (Europe) are presented within this article. Since both projects are still under current processing, only an overview and snap-shot of the status and preliminary results are given.

1. INTRODUCTION

The use of digital airborne imaging sensors for photogrammetric data acquisition is rapidly growing. So far altogether 100 systems of the three large format imagers DMC, ADS40 and UltracamD are sold and in operational use (status end of 2005). Although standard procedures like orthophotomosaic generation or stereo-plotting are routinely performed with digital sensors now, commonly accepted definitions or processes for quality assurance and quality control are not yet available. Therefore a certain number of initiatives have been started to prepare guidelines to control the new digital data process chain. In this context calibration and validation is one topic of concern. This will briefly be discussed in Section 2.

In the following, the activities of the United States Geological Survey USGS and the European Organization of Spatial Data Research EuroSDR are presented as two examples for such projects. The emphasis of the USGS activity is on the certification side and will be presented in Section 3. This is due to the long year’s responsibility at the USGS for the photogrammetric camera calibration and certification process in the US.

The EuroSDR initiative focuses on the calibration and validation of sensors from empirical data sets. A special network formed by representatives from camera manufacturers, industry and academia was established to collect information on the calibration of new digital sensors first. Within the second step commonly accepted procedure(s) for airborne camera calibration and testing should be generated. All this, based on the experiences and advice of individual experts, obtained from empirical data processing. The current status of this second project phase is discussed in Section 4. Obviously, main focus of the EuroSDR initiative is laid on knowledge transfer. The project should offer the possibility to interested users to increase their experience when dealing with digital sensor data. This close link to operational practice is due to the long history of the OEEPE (Organization of Experimental Photogrammetric Research), who was the predecessor organization of EuroSDR.

Since USGS as well as EuroSDR projects are currently under work, the paper has to be seen as snap-shot of the current situation only. More detailed results are expected in the second half of 2006.

2. CALIBRATION AND VALIDATION

Calibration is defined as the process of quantitatively defining a systems response to known, controlled signal inputs. The system parameters are obtained from well-defined conditions. From remote sensing point of view, calibration of sensors has to be solved for geometric and radiometric purposes. This is done by using calibration facilities to determine for example the camera distortion parameters from the obtained discrepancies between measured coordinates or angles versus their a priori known values.
System validation is described as the process of assessing the quantity of the data products derived from system outputs. Such system validation typically is performed using in-situ approaches.

From more traditional viewpoint the calibration of airborne cameras used in photogrammetric applications is done in the laboratory exclusively. From this, the interior orientation parameters including lens distortions are determined. In later processing these values are normally assumed as constant values, mainly due to their strong correlations with the parameters of exterior orientation (as long as data from one flying height is available only). The relatively weak geometry of airborne blocks prevents the simultaneous estimation of camera calibration parameters and orientation elements. This situation is different for terrestrial applications. Here camera calibration typically is obtained from in-situ approaches, where physically meaningful additional parameters are introduced and estimated during the triangulation of image blocks. With the availability of directly observed exterior orientations with sufficient accuracy using GPS or integrated GPS/inertial sensors, the influence of self-calibration parameters is decoupled from the sensors exterior orientation elements. Hence, the use of physical relevant parameter sets is possible even in airborne environments.

The situation becomes more demanding if digital cameras are considered. The well-established way of analogue camera calibration, finally leading to the individual camera certificate provided by special certification institutions, is not capable for digital camera systems. This is mainly due to the following:

In the analogue world the different analogue frame cameras (Zeiss RMK and LMK series, Leica RC series) are of quite similar system design. Once the calibration facility is available in principle all types of analogue sensors could be calibrated with such calibration set-up. Today the totally different design of digital airborne camera systems almost prevents the use of one calibration set-up for several types of digital sensors. This becomes obvious if one briefly reflects the different types of sensors: Line based versus frame based sensor technology, multi-head configurations versus single head set-ups, large format versus medium to smaller format imaging sensors. Hence there is obviously a strong need to provide a system-built calibration facility for each of those different systems individually. If one certification institution will become capable to calibrate all types of digital sensors, several set-ups have to be provided for calibration purposes. This will be somehow more cost intensive and less effective.
Furthermore, different to the traditional analogue cameras additional integrated GPS/inertial components are combined with the imaging component almost regularly. Such combination is even mandatory for pushbroom sensors. Such additional sensors also have to be included within the overall system calibration.

All this clearly illustrates the more complex and heterogeneous digital sensor system layout and consequently the higher demands for their calibration and validation. There is a clear need to shift from the more component driven calibration approaches to system oriented calibration. The overall workflow of digital camera calibration has to be re-designed. The well-established way of analogue camera calibration leading to the individual camera certificate provided by special certification institutions is not capable for digital sensors. A future trend from standard lab to in-situ approaches might become visible, where the effort in sensor lab calibration is restricted on the calibration of radiometric properties only, whereas the whole geometric calibration part is solved by in-situ calibration technologies.

Apparently, the development of a digital sensor calibration workflow and the corresponding certification procedures and standards is a complex and time consuming process. From that the strong need for initiatives in this context is obvious.

3. THE DIGITAL CAMERA CALIBRATION AND CERTIFICATION ACTIVITIES IN THE US

Since the beginning of the 1970ties the (North-American) mapping community relies on the USGS (US Geological Survey), providing necessary (analogue) camera calibrations to ensure quality of final products. In the upcoming digital world similar standards and certifications are also expected for the digital sensors and products. This motivates USGS in activities in assessment of existing calibration standards and new digital camera/sensor technologies. Already in 2000 USGS and ASPRS (American Society of Photogrammetry and Remote Sensing) established an expert group from industry, academics and governmental organizations to address such digital sensors calibration topics. In 2005 an Inter-Agency Digital Imagery Working Group (IADIWG) was formed by USGS including the main government agencies involved in airborne imaging. The purpose of this group is to identify requirements and issues relating to digital imagery acquisition, guidelines, and policies that are common to all agencies and to work together toward solutions (IADIWG 2006). The USGS activities in quality assurance of digital imaging sensors, described in the following, are approved and supported by the IADIWG. The text in the following part of Section 3 is close to the presentations given in Stensaas (2006), Stensaas et al (2006), IADIWG (2006), USGS (2006).

The USGS plan for quality assurance of digital imagery products is composed of four phases and can be viewed as a continuum of best practices which contribute to the overall quality of end-products. Two major processes are covered within four different steps.

1) Data production
   a) Manufacturers' certification
   b) Data Providers' certification
2) Data Purchasing & Acceptance
   a) Contract selection process and digital specifications
   b) Inspection and acceptance of deliverables

Their chain of interaction is depicted in Figure 1. Quite interesting to note, that besides all this, education and training of the end- users is also considered of major concern.

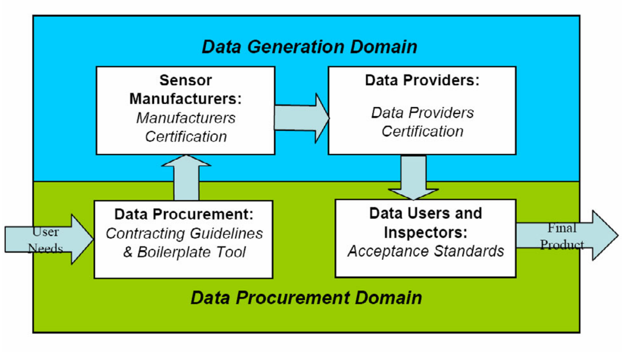

Figure 1, The USGS plan for quality assurance of digital airborne sensors (Stensaas 2006).

3.1 Quality Assurance in Data Production

The first part is focusing on the data production part itself. Here the quality of the sensor's manufacturing process and the data acquisition are of major concern. In order to evaluate and finally certify the sensors production line a clear understanding of the individual sensor specifications and the performed calibration steps is necessary. A special USGS digital sensor certification team was formed to review and carefully analyse the materials provided by the different manufacturers, like sensor specific user documentations and recommendations for the data providers. In addition to that a factory inspection of the manufacturer's calibration process is done, to understand details on the design, development and calibration of the individual sensor type. It is obvious, that different to the former individual sensor's certification now the whole process of manufacturing and calibration of a certain type of digital sensor is covered. Therefore the certification is shifted from each given individual sensor of one sensor family to a type certification of the whole digital sensors line.

Such type certification is defined like follows (USGS 2006): “Type certification covers all identical systems. Thus once a particular make and model digital aerial system is ‘type certified’, all copies of that item, whether made prior to certification or following, are also considered to be certified. However, systems that differ significantly in how they operate or produce data are not covered under the ‘type certification’ given for a different sensor model.”

Type certification eliminates burden of calibration of each particular sensor itself. There is no more need to provide custom-built calibration set-ups for certification institutions like USGS. The type certification should guarantee that under normal operational requirements a certain data quality sufficient for mapping applications is obtained routinely. With the USGS certification the manufacturer obtains an independent evidence of system performance which also might be helpful to promote the system itself. Nevertheless, as it is already given in the type certification definition above, re-certification might be necessary dependent on the extent and impact of system level changes, since the certification is issued based on a distinct sensor and model type.

So far USGS already completed the factory visit of two digital image sensor providers, Applanix Corp. (DSS) and Intergraph/ZI-Imaging (DMC) namely. The compiled reports and official USGS certifications have been announced at this years ASPRS meeting in Reno, US. The visits of the two remaining main digital large format airborne imaging system providers Leica Geosystems (ADS40) and Vexcel (UltracamD) are scheduled for the second half of 2006.

The second step covering the data production part is dealing with the certification of the data providers. This type of certification is focussing on processes and process control. It ensures that the individual data providers (i.e. companies flying the digital sensors only and/or processing the data to obtain the final product) are operating the digital sensors in accordance with the manufacturer’s guidelines and certain quality procedures are followed. The sensor is within its specifications and remains in good calibration and operation conditions. The routinely generation of mapping quality data is guaranteed by analysing the whole process from flight planning, flight execution, sensor and data handling and processing. Procedures used for quality assurance and control have to be provided for all process steps. Similar to the independent certification of camera manufacturers, the data provider’s certification is of positive influence on the data provider’s capabilities. The certification also serves to demonstrate the sensor’s ability to achieve accuracy levels for a specific product or range of products.

The USGS is in the process of establishing a data provider certification team. The initial certification is based on the review of the provider’s documentation and an optional on-site visit. The USGS is working with several initial digital image data providers in the US to work out the details of this certification process before offering it to the rest of the industry. Re-certification is required every three years.

3.2 Quality Assurance in Data Procurement

The second major process in quality assurance is the data purchasing and acceptance domain. The new concepts and features of digital airborne sensors are not able to adapt to the standard contracting guidelines used so far. In addition, there is no information on how to judge on the performance of the digital data and products. Obviously, there is a certain lack of knowledge at the user’s side on how to contract such new sensors for their upcoming projects and whether these new technologies are capable to fulfil their performance needs. Many of the typical aerial imagery users right now do not know in detail on the sensor specific strengths and maybe weaknesses in specific applications. This might build up some sort of barriers in using those new technologies with their at least equivalent and quite often superior quality performance compared to the traditional analogue image based data processing.

From that USGS is starting to develop contracting guidelines, using standardized terms and descriptions to make the contracting process easier and more uniform. Furthermore, the use of clear definitions and standardized performance measures will allow for non-ambiguous descriptions of user’s needs. This will increase the acceptance of digital sensors and encourage digital imaging. The already described manufacturers and data provider’s certification documents will support a large reduction in proposal documentation. In its final stage these contracting guidelines will become available as a web based tool that enables potential customers of digital aerial sensors and products to use those pre-defined text passages to generate parts of their contract documents.

The ultimate assurance of quality is the inspection and acceptance of deliverables. There is a need for uniform definitions and approaches to evaluate the quality of image data. So far, a different terminology is used from different users or data providers and sometime things are ambiguous and interpreted differently. USGS together with IADIWG is working on the development of acceptance standards, which finally should be offered as web based tool illustrating the quality problems, measurement techniques and standards. All this leads to more consistent acceptance/rejection criteria among contract agencies, helps to minimize false expectations, ensures high quality products and increases the customer’s satisfaction and data acceptance.

4. THE EUROSDR NETWORK ON DIGITAL CAMERA CALIBRATION

In fall 2003 the EuroSDR (European Spatial Data Research, formerly known as OEEPE) has established a network of experts in the field of digital camera calibration and calibration with the goal to derive the technical background for calibration procedures of digital cameras based on scientific theory and empirical investigations. Legal and organizational aspects for certification are put to the background for the time being. Up to now (May 2006) experts from already 42 different institutions from research, industry, system providers and users like national mapping agencies joined the network. At the time of writing the project is within its second phase. The time before was primarily used to establish the network itself, to prepare an extended report on the methods used for calibration of digital airborne mapping sensors and finally to acquire appropriate empirical data sets for the practically oriented second phase of the initiative. The phase 1 report, dated from October 2004, is amended by exemplarily attached calibration protocols as provided by the manufacturers, namely Leica, Intergraph/Z/I-Imaging and Vexcel. Information on former project progress and general remarks on the calibration of digital sensors as performed today are given for example in Cramer (2004, 2005a).

In addition to the more theoretically oriented investigations of phase 1 the second phase is focused on empirical analysis of individual flight data sets. Here the EuroSDR focus is laid on a quite restricted number of test flights only, which have already been distributed within the network. The individual network members should then apply their specific software tools, methodologies and knowledge to obtain overall best system calibration for the individual system at the evaluated flight campaign. These results are then validated by the Pilot Centre of the project and documented and discussed within the final project report.

4.1 The EuroSDR phase 2 data sets

Several European national mapping agencies besides other companies and institutions kindly provided access on different digital test flight data sets. Finally, two data sets acquired within the Norwegian Fredrikstad test site were chosen for DMC and UltracamD sensor. The Fredrikstad test site is a specially designed photogrammetric test area with sufficient number of ground control points and already well-known to the EuroSDR user community from former tests (i.e. the OEEPE test on integrated sensor orientation (Heipke et al 2002)). The ADS40 data set was flown in the German test field Vaihingen/Enz. This field is maintained from Institut für Photogrammetrie (ifp) at Universität Stuttgart and is also quite known from former tests of digital airborne sensors or independent performance evaluations of integrated GPS/inertial systems (Cramer 2005b). Both test areas provide a sufficient number of control and check point information, all of them signalized, and therefore might serve as independent control for geometric quality assurance. Since no radiometric targets were available for the time of flight data acquisition only the geometry should be analysed within the first steps of phase 2. The basic geometric parameters for the three different data sets are given in Table 1. The ground sample distance GSD is the theoretical value obtained from sensor pixel size and image scale. In case of ADS40 this value is related to the non-staggered image data. The succeeding Figure 2 and Figure 3 illustrate the block geometry for the two frame based systems DMC and UltracamD, respectively. The image coverage depicted there corresponds to the approximately 0.2m GSD flights from close to 2000m flying height above ground.

#	Altitude [m]	GSD [m]	# Strips long/cross	% Overlap long/cross
DMC test Fredrikstad (October 10, 2003)				
1	950	0.10	5	60 / 30
2	1800	0.18	3	60 / 30
UltracamD test Fredrikstad (September 16, 2004)				
1	1900	0.17	4 / 1	80 / 60
2	3800	0.34	2	80 / 60
ADS40 test Vaihingen/Enz (June 24, 2004)				
1	1500	0.18	4 / 2	100 / 44
2	2500	0.26	3 / 3	100 / 70

Table 1: Basic flight parameters of distributed EuroSDR phase 2 digital sensor flights.

It has to be mentioned that the frame based images were acquired relatively late in the year (September 16 and October 10 for Ultracam and DMC respectively) at 60deg northern latitude. This results in sun angles between 25–30deg maximum which are quite demanding environmental conditions. From this, the image material is appropriate to really demonstrate the radiometric potential of digital sensors on the one hand. On the other hand, the radiometric image data quality is definitely influenced by these conditions. Therefore the data material is

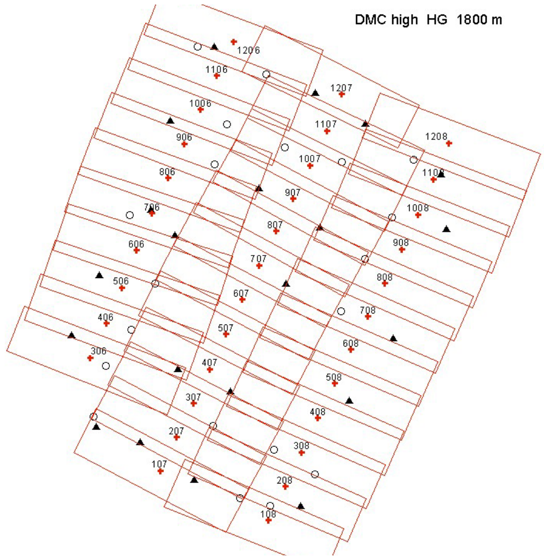

Figure 2, DMC test Fredrikstad (data provided by TerraTec/Norway).

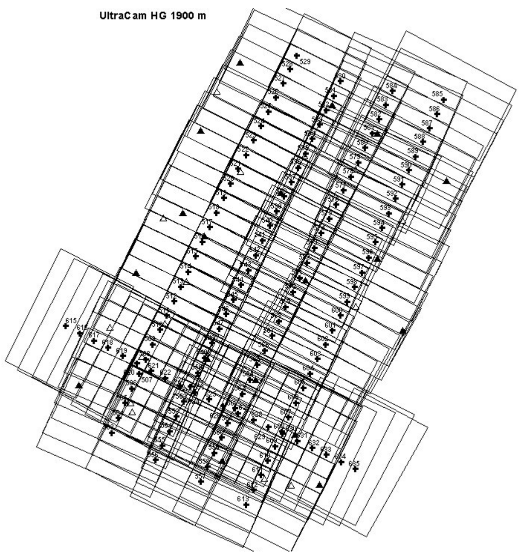

Figure 3, UltracamD test Fredrikstad (data provided by IFMS/Germany).

not being used for the analysis of radiometric performance of digital airborne imaging.

At the time the final decision on the phase 2 data sets to be distributed within the community was done, this was the only data available to the EuroSDR project core team which was acquired in photogrammetric test sites and offered two different flight heights. In the meantime some more data sets appeared, in some cases even more appropriate. Especially the extended test flight initiative from Finnish Geodetic Institute FGI within their Sjökulla test site has to be mentioned within this context (i.e. Honkavaara et al 2006).

4.2 The EuroSDR phase 2 data processing

In the meantime the data presented above was announced within the EuroSDR network community and distributed to participants who requested the data. In order to obtain first results and individual participant's feedback within relatively short time after data distribution only one data set was given to each participant in the first round. In addition to the data sets provided to the individual system manufacturer another 16 network participants requested active participation in the phase 2 empirical testing. As shown in Table 2 the DMC and UltracamD framing sensors were requested most, the ADS40 data were only requested by 4 institutions. This is exactly what has been expected from the EuroSDR core project team. Most of the aerial image users are already familiar with frame based sensors, they have experiences with such type of data and the appropriate process flows are already established. From that the step from scanned analogue to digital image should be easier and there might be a less high barrier when performing this step. For people without any prior information on line based imagery the whole process flow has to be changed and even more important there might be a larger knowledge deficit on the individual users side. Nevertheless the possibility of free data availability should encourage potential digital sensor users to take this opportunity to become familiar with this type of data without too much financial risks and effort.

#	Data set	Requests
1	DMC	7
2	UltracamD	5
3	ADS40	4

Table 2: EuroSDR phase 2 data requests.

After receiving the data each participant will start processing of the individual data set requested before. The focus has to be laid on the geometrical aspects of the sensor data first. The main part of the processing is most likely performed via bundle adjustment. Different configurations are possible. One main focus has to be laid on the effects of additional parameters on the final object point accuracy. The different configurations have to be reported and the optimal processing result has to be identified from participants' point of view.

Each participant provides the final object coordinates from all check points to the pilot centre. In addition and as important as the pure object coordinates a report is submitted discussing the main topics of evaluation strategy as well as more general remarks like:

- What processing software was used for data evaluation (i.e. point transfer, bundle adjustment)?
- What kind of parameter set was used for AT? Is the use of additional parameters necessary? Which model was applied?
- In case additional parameter sets are introduced within processing, how will these additional parameters be used within the further processing chain like DTM generation?
- Were the two flying heights used separately or in a combined approach?
- What are the general findings obtained from this specific data set? What is the personal feeling on the data quality and performance of this specific data set?
- What are the personal experiences with other digital sensor flights of the same type of sensor (in case such experience is available)? Does this result match the experiences from former flights?
- What is the personal recommendation on optimal processing flow for this specific type of digital sensor data?

The individual results and recommendations from the participants will be compiled in an extended report by the pilot centre. Besides the pure technical part, including the documentation of individual camera specific results, comparison of camera specific results and analogies in evaluation strategies and modelling, the report will focus on a more general part, namely further experiences of individual network participants, derivation of recommendations for an 'optimal' camera specific process chain and ideas for the consideration of additional calibration parameters during later processing.

Based on the results of this first processing round the following future activities might be possible in phase 2 of this EuroSDR network:

- Processing of a second data set from another sensor. This data is available on demand, as soon as one participant has finished the processing and report of his first requested data set.
- Distribution of alternative data sets, which might have been made available from other system providers (i.e. medium format sensors).
- Focus on other technical purposes besides geometry, like radiometry, colour and resolution. This might be the most important topic to be covered.

The overall schedule is to provide first information on preliminary results during the ISPRS commission I meeting in Paris, July 2006. The final report covering all geometric aspects of digital camera calibration is compiled close to that and will be made available through the project homepage (see below).

5. SUMMARY

The paper reflects the status of two activities dedicated to the topics of digital airborne sensor quality assurance and sensor certification. The chosen projects of the USGS and the EuroSDR are only examples. Besides those other activities i.e. groups working on national standards are present but not covered in this article. The paper emphasises the need to deal with such topics, in order to somehow structure the quite complex world of digital airborne imaging right now. Nonetheless, all these activities always rely on any kind of support from all those people already involved in the processing of digital sensors data. Even at this stage of project, the USGS as well as EuroSDR is happy on any kind of active comments, remarks, advice or general support. Anyone who is interested in those activities is kindly invited to actively participate. For more information the reader is invited to visit the following homepages: http://calval.cr.usgs.gov/ (USGS) and www.ifp.uni-stuttgart.de/eurosdr (EuroSDR project).

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