DIGITAL AIRBORNE CAMERAS – STATUS AND FUTURE

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ABSTRACT

The traditional way of airborne photogrammetric imaging is undergoing major changes currently. With the advent and operational availability of digital (large-format) imaging sensors a strong and powerful alternative to the standard way of analogue imaging appeared. The direct digital imaging not only closes the final chain link in the full digital workflow of image acquisition and processing, even more important, obtained results showed significant advantages of digital imaging compared to scanned analogue images. Nevertheless, long-term experiences using such sensors in operational airborne environments and production are not yet available, from that these new sensors still have to prove their long-term performance compared to the analogue mapping cameras. The paper tries to briefly reflect the today's situation of digital airborne imaging and the role of digital sensors in future market. Since the empirical investigation of these sensors is still of major concern and necessity some exemplarily results from such performance studies are briefly cited. Within the second part the ongoing activities in development of user guidelines for digital airborne sensors and standardization needs are given, where a certain focus is laid on the topic of digital sensor calibration and validation.

1. INTRODUCTION

It was only less then 5 years ago when the very first two commercial large format digital imaging airborne sensors were launched into the market. In the meantime the ADS40 (Leica Geosystems) line scanner system and the DMC (Intergraph/ZI-Imaging) frame based sensor are fairly well introduced and several systems have already been sold for operational use. Nonetheless, besides these two major players (at least when looking for the traditional airborne analogue imaging sector, namely RC30 and RMKTop cameras) a further increase in number of new digital airborne sensor system providers and concepts is clearly obvious.

From traditional photogrammetric point of view especially large format systems are of interest. The UltracamD (Vexcel Corp.) and DiMAC (DiMAC Systems) have to be mentioned as new-comers in the field of large format photogrammetric camera providers. UltracamD is commercially available since almost 2 years, the DiMAC system is still in its final testing phase. In the beginning of 2005 several tests with single and multiple camera modules as well as different lenses were performed (Lousseau, 2005). The basic concept of UltracamD and DiMAC design relies on the use of several frame based sensors combined in a multi-head camera. On the other hand new line scanners are showing up like the 3-DAS-1 scanner (Wehrli Ass.) and the Starimager (Starlabo Corp.) line scanning system which was formerly known as TLS system. The Starimager/TLS is already in use and several applications are documented (Tsuno et al, 2004), the 3-DAS-1 was presented to public in summer 2004. From recent information this system should be ready for the flight season next year, airworthiness certification is starting in summer 2005 (Wehrli, 2005). Besides this, medium or small format imagers (in some cases based on modified film cameras, i.e. analogue camera housings extended with digital sensor backs and with certain modifications for airborne photogrammetric flight conditions and later processing) can be found. The DSS (Applanix Corp.) or the DigiCAM series (IGI mbH) could be exemplarily named as representatives of this systems group. Due to their somehow limited ground coverage in comparison to the large format sensors their use as one sub-component of multi-sensor platforms, i.e. in combination with airborne laser scanners, could be advantageous. Still, the stand-alone usage might be also straightforward, namely for corridor surveys of power lines or streets, when there is no need for larger swath widths. In order to obtain largest possible flexibility concerning demands for flight block geometry both systems are equipped with integrated GPS/inertial systems to directly provide fully exterior orientation information for each individual image. In its final stage this allows for direct georeferencing of images without use of any additional ground control. In other concepts several small-format sensor are combined to a multi-head, multi-band camera platform, keeping their optically axes aligned to obtain same ground coverage. From this the main focus is laid on the acquisition of multi-spectral information instead of highest geometric resolutions (i.e. DAIS-1 (SpaceImaging), Spectra-view (Airborne Data System, Inc.)).

It has to be mentioned that in general the field of digital airborne imaging systems now is quite heterogeneous compared to the analogue world which is not only valid for the classical photogrammetric large format segment but even more when considering the small to medium format digital sensors used in stand alone or multi head configurations. Meanwhile they can be found in all kinds of different applications of airborne imaging, i.e. from standard photogrammetric mapping tasks to other applications like land use monitoring, disaster and risk assessment, forestry, traffic control, tourism, real estate search and promotion.

It is obviously very hard to follow the development and availability of new systems from new providers, nevertheless some recent and very comprehensive overviews covering the whole application segments are nicely presented in Petrie (2003, 2005a). From such compilations and the pre-ceding remarks the following major trends in digital airborne imaging can currently be observed:

- Today's world of digital airborne imaging is heterogeneous, especially when comparing the different designs of new digital systems to the classical airborne film cameras. Furthermore, digital image sensors quite often are used as one part of multi-sensor systems supplemented with other components like GPS/inertial sensors or laser scanners. This somehow makes the systems more complicated to handle.
- Many digital airborne systems are beyond their experimental stage and already used in practice worldwide. In future, a strong increase in use of new systems has to be expected, where the spectrum of applications is already becoming broader.
- The advantage of large format imaging based on high-end high-performance digital sensors is well known. Nonetheless, for smaller area projects or due to less financial conditions or risks there definitely is a market for medium to smaller format cameras to be used in a more flexible and cost effective way, where in some cases the demands on geometric accuracy are less stringent.

Although non photogrammetric (from classical point of view) digital airborne sensors will definitely play a substantial role in the future field of digital airborne imaging, it is outside the scope of this paper to comprehensively present and discuss the actual status and performance of all different kinds of digital airborne sensors that have been cited very briefly in the preceding paragraphs. For these reasons a certain focus is laid on the more restricted field of photogrammetric applications, which is mainly covered by the large format imaging sensors.

2. FROM ANALOGUE TO DIGITAL

2.1 The analogue mapping sensor world

The standard environment of analogue photogrammetric imaging and processing is well known and established for decades. Even today the majority of analogue photogrammetric images is taken by only two different mapping cameras, namely the Intergraph/ZI-Imaging RMK-Top and the Leica/LH-Systems RC30 series and their predecessors.

If one assumes that the world-wide market of airborne mapping cameras is roughly equally distributed between both large system providers (market analysis in 1998 showed, that the market share of LHS (now Leica) and Zeiss (now Intergraph/ZI-Imaging) corresponds to the relation of 60:40 (Fricker, 2005)), one should expect close to 2000 analogue cameras distributed all over the world during the years. It is hard to say, whether all of those cameras are still operational. The Zeiss RMK-A camera is available for more than 40 years now and the production of 23 x 23cm² based film camera RC8 at Wild started in 1956. Leica assumes, that about 500 analogue cameras from RC10-RC30 product series are still in regular and operational use. Assuming that a slightly lower number of Zeiss units RMK-A/TOP is still in operational practice, the today's number of analogue mapping cameras in use could be estimated as about 850 units. Nevertheless, new analogue sensors are still requested from system manufacturers even today. Intergraph/ZI-Imaging for example sells about 6-8 analogue RMK-Top cameras per year, where the number of sales is expected to decrease in future. The RC30 product from Leica is sold 8-12 times per year (Fricker, 2005). Instead of purchasing new systems the advent of a more vital second hand market for used cameras is expected (Rosengarten, 2005).

The analogue mapping cameras are very similar from their major system design concepts using large format films with standardised formats. The choice of optic, i.e. the angular field and the corresponding focal length, is dependent on the desired application and accuracy. This quasi standardisation of cameras has additionally pushed the development of appropriate scanning, measuring and data evaluation tools, which are almost independent on the imaging sensor and have been replaced as soon newer and more powerful tools became available. In typical processing environments the analogue imagery is digitised first using photogrammetric scanners and all other processing steps are done digitally, based on digital photogrammetric stereo workstations. Nevertheless, if one focuses on photogrammetric processing world-wide, analytical plotting still plays a certain role.

2.2 Market distribution of digital sensors

The already mentioned ADS40, DMC and UltracamD sensors are certainly the most relevant large format imagers for standard photogrammetric use currently. If one looks at the most recent numbers of system sales the distribution in market is like follows (Table 1), where the numbers and remarks on market estimation given below were provided by the system providers, status as of April 2005. Although the fourth system DSS cannot compete with the other three concerning image format, it is also introduced within the table as one exemplarily representative of medium format systems, which is used as stand-alone unit as well as in combination with laser scanners already pointed out before.

Product	Sold systems	phase-in
ADS40 / Leica	27	2001
DMC / Intergraph	22	2003
UltracamD / Vexcel	19	2003
DSS / Applanix	33	2002

Table 1: Distribution of digital sensors in the photogrammetric market segment (status April 2005).

As one can see, the first ADS40 phased-in market in spring 2001, less than one year after the official market introduction at the Amsterdam 2000 ISPRS congress. From that point about 26 systems were sold in total, where the majority of systems was sold starting from beginning of 2003. For DMC up to now 22 systems are sold, about 16 of them are successfully installed and used in practice. Compared to the relatively short market availability – the UltracamD system officially was presented at the ASPRS spring meeting in 2003 – the number of sales is already quite high and almost comparable to the two other competitors. This not only reflects the quality of the UltracamD product but quite clearly shows that in the years before substantial part of market development has already be done by Leica and Intergraph. Meanwhile, the potential of digital image acquisition is well known and from that there already is a higher acceptance of new systems and sensor technologies.

If one looks at the continental distribution of ADS40 and DMC systems a certain accumulation of sales can be seen in America (ADS: 14 systems, DMC: 7 systems) and Asia (ADS: 6 systems, DMC: 10 systems), whereas the number of systems sold in the European market so far is less (ADS40: 7, DMC: 5). This general distribution is slightly different for the UltracamD. Here the majority of systems is installed in Europe so far, followed by North-American and Asian continent. This distribution was somehow pushed by the system provider itself, since Vexcel as Austrian company tried to focus on system sales in Europe first

to guarantee faster service especially for the first numbers of sensors introduced in operational data acquisition (Breg, 2005).
In general, this distribution of sensors somehow might reflect a slightly more conservative tenor concerning the introduction of digital technology in operational environments in Europe. On the other hand, and this is even more important, there definitely is a higher need for (re-)mapping very large areas for large territory countries with digital large format sensor technologies, especially when national maps are not yet available nation wide for certain map scales or state wide mapping hat to be done. Using large format sensors for large projects definitely will positively influence the return of investment.
From all this, an increase in sales of new digital sensors is expected especially for the emerging Asian countries like China. System providers like Applanix roughly expect an average growth rate of approximately 40% per year (Hutton, 2005). In Figure 1 the cumulative number of ADS40 system sales is given starting from the third quarter 2002 (Fricker, 2005). The dotted line indicates the linear trend estimation for the plotted period. From this an average number of 8-9 ADS40 sales per year can be estimated. Nevertheless, the future number of system sales is expected to become equivalent to the long-term average number of analogue mapping cameras sales, which was about 12-15 units per year (Fricker, 2005).

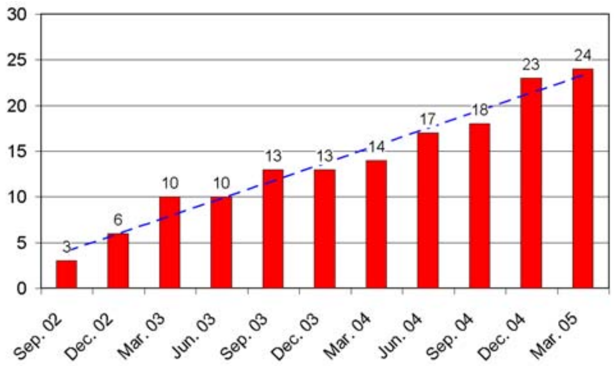

Figure 1, Number of ADS40 system sales (Fricker, 2005).

If such rate of increase is roughly used for future ADS40 market forecast about 80 ADS40 sensors will be in operational use after a five-years period. If one additionally assumes, that the digital mapping sensor market will be equally distributed between the three large-format system providers Leica, Intergraph and Vexcel roughly, more than 240 digital mapping cameras will be in world-wide use in 2010. This is close to 25% of the overall analogue/digital mapping sensor market, based on the assumption that the number of analogue sensor units used in operation remains constant.
Still, all this is very conservatively estimated. With an increased number of digital systems used, with an increased number of system providers, an increased efficiency in the digital workflows and an increased and obvious need for the replacement of old analogue cameras, the acceptance of digital technology definitely will further increase shifting the ratio analogue versus digital sensors significantly closer to the digital world.

3. EMPIRICAL CAMERA TESTS

Since the advent of digital airborne imagers and their commercial availability main attention in the photogrammetric community was laid on the analysis of the systems potential in general and compared to the former analogue mapping cameras. This is still the case – tests are done by the system vendors, in order to guarantee and validate the systems performance from empirical results, in some cases the sensors are independently analysed by organizations or universities and finally tests are done by potential customers itself before the final purchase decision is made. It has to be pointed out that in contrary to the analogue cameras not only the imaging sensor itself is evaluated but the whole processing chain has to be considered. The different system designs directly results in specific processing chains, which is totally different to the analogue world. The reason for this is quite obvious for the line scanning sensors: Due to their special image geometry, different processing steps are necessary. But even for the frame sensor based multi-head sensor configurations a certain amount of sensor specific pre-processing has to be done before large format central perspective images are available for further processing. Some more or less arbitrarily chosen empirical performance tests should briefly be covered within the following in order to reflect the actual status of digital sensors.

3.1 ADS40 Vaihingen/Enz test

A quite extensive test focussing on the geometric accuracy as well as the radiometric performance of ADS40 was done in summer 2004, as a joint project of Leica and the Institut für Photogrammtrie (ifp), Universität Stuttgart. Within this campaign the system was flown in different flying heights over the Vaihingen/Enz test range with more than 200 signalised and independently coordinated object points. Within this test not only the empirical object point determination for the standard ADS40 system installation and process flow was analysed, additionally the influence of GPS/inertial system performance on the overall geometric accuracy and the quantification and improvement of image resolution was of concern. The comprehensive analysis (on the geometric accuracy) is not yet finished, the final project report will become available in May 2005. Final results on the estimation of resolution refinement can be found in Becker et al (2005), Reulke et al (2004). Especially the influence of staggered arrays and additional image restauration methodologies is worthwhile to mention.
If one focuses on the geometrical accuracy analysis from the 1500m flying height block configuration (standard flight pattern with four long and two cross strips) the empirical accuracy obtained from independent check point analysis is given for three different control point configurations (Table 2). The processing was done using the standard ADS40 data workflow, including the ORIMA/CAP-A package for triangulation of imagery.
The GPS/inertial trajectory information, which is essential for pushbroom line scanner processing in general, was obtained from the LN200 IMU used in all standard ADS40 airborne installations. No additional self-calibration was applied, all results are based on the estimation of the inherent boresight-misalignment angles and additional block-wise GPS position and drift correction terms only, where the later six unknowns are only applicable for the 4 and 12 control point cases. The obtained statistical analysis from check point differences is very consistent and very well fits the theoretical expectations. The theoretical accuracy from normal case equation should be within 7cm and 9cm for horizontal and vertical components, respectively. This estimation is based on 3μm image point measurements accuracy. Even for the 0 GCP case the horizontal accuracy (RMS) is close to the theoretical value, the vertical component is less than factor 2 worse. This is quite satisfactory keeping in mind that for that special case the absolute accuracy of object point determination is essentially dependent on the

absolute accuracy of the GPS/inertial trajectory, which itself is based on the absolute performance of prior GPS-processing. Without using any GCP there is no way to compensate for global offsets, which might be caused by sub-optimal GPS-trajectory solutions or any systematic effects. Such trajectory offsets – if present – will directly be transformed to global shifts in object point coordinates.

# GCP / ChP	Accuracy	East [m]	North [m]	Vertical [m]
12 / 190	RMS	0.052	0.054	0.077
	Mean	0.000	-0.022	0.045
	Std.Dev.	0.052	0.050	0.063
	Max.Dev.	0.133	0.188	0.242
4 / 198	RMS	0.055	0.054	0.106
	Mean	-0.008	-0.008	0.083
	Std.Dev.	0.055	0.053	0.065
	Max.Dev.	0.145	0.191	0.295
0 / 202	RMS	0.110	0.086	0.158
	Mean	0.094	-0.064	0.142
	Std.Dev.	0.057	0.056	0.068
	Max.Dev.	0.242	0.256	0.351

Table 2: Geometric accuracy from ADS40 Vaihingen/Enz test (hg=1500m, June 26, 2005).

3.2 Investigations from national mapping agencies

Besides such vendor initiated performance studies as briefly described before, other extensive investigations have already be done under the leadership of national mapping agencies (NMAs). Some activities from the USGS (US Geological Survey) will be given in more detail in the later Section 5.2, here some of the European tests are briefly described. To the authors knowledge the following tests have been done supported by different NMAs or other official institutions. In almost all cases the direct comparison of digital sensors performance to results from analogue image data acquisition were of major concern and the analysis of operability from special requirements of NMAs. Unfortunately not from all these campaigns results are (officially) available. Nevertheless, some of these studies will briefly be presented in the following sub-sections.
Besides that, additional activities have been done in Sweden and Spain: The Landmateriät (Swedish land survey) tested the DMC within two flight campaigns (August/September 2004) in the Lund region in comparison to analogue camera data. Similarly, the ICC (Catalonian land survey) did extensive tests with DMC also, their test campaigns were done in December 2004. The first results of the tests can be found in Alamus et al (2005).

3.2.1 Finland

The Finnish Geodetic Institute (FGI) in collaboration with the Finland National Land Survey (NLS) and other partners extensively tested the performance of UltracamD by flying different systems in different test fields, i.e. the Sjökulla test range maintained by FGI. The tests were done mid of October 2004, within some of the missions analogue images were simultaneously acquired by RC20, scanned afterwards and compared to the UltracamD imagery and performance. Overall the significant higher radiometric quality of UltracamD versus scanned analogue images was proven, nevertheless comparing the geometric accuracy to the analogue performance a more differentiated rating is given. Some image deformation effects are mentioned which have to be compensated by additional parameters are documented. They are of major impact especially on the vertical accuracy. Even though the UltracamD in some cases performs worse compared to results from standard analogue cameras. More detailed results on these tests are given in Honkavaara et al (2005).

3.2.2 Austria

Another UltracamD study was initiated by Bundesamt für Eich- und Vermessungswesen (BEV) Austria in collaboration with Technical University of Graz. Again UltracamD and RC20 analogue camera were flown simultaneously and the results are compared. The tests were done in Graz, September 2004. From the very first results UltracamD performs consistently and significant better than the results from scanned analogue image blocks, where this finding relies on the analysis of theoretical accuracy of object point coordinates from error covariance matrixes (Ladstädter, 2005). The estimation of absolute accuracy from analysis of check point difference is not yet done. Additionally, the performance of automatic tie point transfer in low-contrast areas was exemplarily analysed. Within the analysed case, tie point matching performs better for UltracamD due to the lower image noise compared to scanned analogue imagery.
In addition to the UltracamD tests BEV also investigates the performance of ADS40, with special focus laid on the analysis of operability (Franzen, 2005). Two tests were done in October 2002 and October 2003 already. Within these test campaigns the high potential of digital image acquisition was proven and some more detailed remarks on the long-term archiving of digital imagery are given. The need for storing the image data for very long periods is a special requirement of NMAs since they have to guarantee for time series analysis or conservation of evidences. Nonetheless, this problem is non-specific for airborne digital imaging but digital data at all. In general, an overall positive estimation of ADS40 and digital airborne imaging is given. It is interesting to see that BEV estimated the product cycle of such high-end digital sensor to be a within a five years period. For the return of investment about 90000km² have to be acquired during this time interval. This roughly corresponds with the whole area of Austria.

3.2.3 Switzerland

The Swiss Federal Office of Topography (swisstopo) extensively tested the ADS40 for their special requirements with focus laid on operability, also. The tests were already done in July 2002 in the Thun area, covering one 1:25000 map sheet region of 210km² size. Within the analysis a very detailed estimation on the batch-processing and interactive operator times, the amount of generated data, the requirements on data storage and the need for online data availability for certain time frames is done, in addition to the usual checks of geometric and radiometric performance of the sensor itself (O'Sullivan, 2004). Such estimations are highly relevant for the later operational use of new digital systems in general. For example, for one Swiss 1:25000 map sheet the amount of generated data including raw, rectified and final orthoimageries (RGB and CIR with 0.3m resolution) is about 197Gbyte. Assuming that raw and processed data are kept online for 2 and 6 years, respectively (based on a 6 years long update cycle of 40 map sheets per year), about 25.5 Tbyte of data storage have to be provided. To guarantee reliable processing times a 1Gbyte network is needed, otherwise all the data processing has to be done locally. Nonetheless, accuracy and high automation of processing was verified and there is a significant time reduction comparing to the traditional development, scanning and triangulation of conventional analogue images. Still, some need for refinements in processing flow or data handling was mentioned also.

3.2.4 United Kingdom

Already three of the large-format digital frame cameras have come into operation in the U.K.: UltracamD with two of the commercial companies and the DMC with the Ordnance Survey of Great Britain (Petrie, 2005b). Ordnance Survey has performed tests with all three large-format sensors, with focus laid on aerial triangulation accuracies, DTM accuracies, orthoimagery specification and vector capture requirements (in positional accuracy and geometric fidelity). In general all tested systems passed the accuracy requirements. From that the final procurement was done including business requirements which throws in a multitude of other aspects helpful and relevant for such decision (Marshall, 2005).

4. STANDARDIZATION ACTIVITIES

If one should characterize the today's status in digital airborne photogrammetric imaging we could see a situation that is clearly stamped by the actual changes. As already described above a certain number of users are gaining their first experiences with digital airborne sensors, besides that quite a number of systems are in operationally use already and digital images are already provided for photogrammetric mapping tasks. On the other hand the actual knowledge on the digital sensors and their technologies is quite heterogeneous, since the design and the process flow of digital images is different to the former and well established product line. Furthermore clear guidelines for the users and standards itself are not yet available.

4.1 Standardization in Germany

From this there are several initiatives in different countries to modify the existing guidelines to take care of the new airborne digital sensors technology. In Germany for example such standards are provided by DIN (German Institute for Standardization), where the working group on "Photogrammetry and remote sensing" is currently working on the fourth part of the already existing DIN standard series 18740 "Photogrammetric products". Within the first three parts of this standard the following topics are already covered:

- Part 1 – Requirements on image flights and analogue airborne imaging (November 2003)
- Part 2 – Requirements on scanned aerial images (draft from May 2004)
- Part 3 – Requirements on orthoimagery (October 2003)

The noted dates clearly reflect current activities in this sector, all updates of already existing older versions of standards were done within last two years period. The fourth part now will cover the requirements on digital airborne imaging sensors and digital imagery itself (Dörstel et al, 2004). Since the behaviour of digital CCD-technology is quite different compared to analogue films the requirement of scanned imagery as described in the second part of DIN 18740 cannot be transferred to the digital images as provided by digital airborne sensors directly. Additionally, the geometric design of digital airborne sensors is different from their analogue sensors which increases the need for definition of such new standard. This fourth part will focus on the digital sensor itself, the requirements for image flights based on digital airborne sensors and the requirements on the obtained digital images provided by digital airborne cameras. Finally, the criterions on quality control for digital airborne images are given. Within this context additional focus has to be laid on the need for sensor (system) calibration and validation.
Compared to the traditional analogue camera calibration, which was done as a component based approach via lab calibration techniques (i.e. goniometer or multi-collimator) and is documented in the well-known calibration certificates, situation is quite different now. This is due to the complexity of digital airborne sensors and the substantial differences in their systems design, compared to analogue frame cameras as well as the obvious design differences within the different digital sensors itself. From this the component driven approaches will be substituted from more system driven concepts as they can be solved for in-situ calibration approaches. The topic of sensor calibration is discussed in Section 5.

4.2 International activities

Besides the national German standardization activities mentioned above, others can be found for example in the international framework of ISO (International Standards Organization), where a number of project teams of technical commission ISO/TC 211 "Geographic information/Geomatics" is working on the development of new standards on image and raster data for the past years. A current overview on these activities is given by Kresse (2004). Within the development of the ISO 19100 standards family, the standard of ISO 19130 "Sensor and data models for imagery and gridded data" is in its final stage already. The second committee draft is now available, the comment period will end in mid of May 2005. ISO 19130 mainly focuses on the georeferencing of airborne and satellite based images, where the different remote sensing sensors are classified by system design and the definitions of camera models are given (see ISO committee draft 19130.2 for more details).

5. 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 can be done by using the specially designed calibration facilities (i.e. multi-collimator or goniometer) to determine for example the camera distortion parameters from the obtained discrepancies between measured coordinates or angles versus their a priori known values. In addition to that, system validation is described as the process of assessing the quantity of the data products derived from system outputs. Such system validation typically is done using in-situ approaches. In future the following calibration scenario might be possible: The effort of sensor lab calibration is restricted on the calibration of radiometric properties of the sensor only, whereas the whole geometric calibration part is solved by in-situ calibration technologies.
As already motivated before, the overall workflow of digital camera calibration has to be re-designed, since 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. Apparently, the development of a digital sensor calibration workflow and the certification procedures and standards is a complex and time consuming process. From that the strong need for initiatives in this context is obvious. The different groups and their activities are shortly presented in the following. Although their work in calibration and validation is done relatively autarkic right now

(only a relatively small number of participants is included in more than one expert group), significant input and progress could already be seen. Nevertheless, potential future bundling of research and expertise might be helpful for highest progress and definition of world-wide standards and methods.

5.1 The CEOS and ISPRS calibration and validation task force

To the authors knowledge the today's main initiatives dedicated to the topics of calibration and validation of remote sensing devices in general and digital airborne cameras in particular are concentrated in North-America and Europe. One working group on "Identifying, defining and measuring radiometric and geometric calibration parameters for earth observing sensors" was established end of 2002 in the framework of ISPRS (International Society of Remote Sensing) Commission I and CEOS (Committee of Earth Observing Satellites). In December 2003 the first larger workshop on "Radiometric and geometric calibration" was organized by this group. Although ISPRS in principle is an international organisation, almost 80% (from the participants list at 2003 workshop) of the working group members are from North-America, which might be due to the origination of this task force from EROS. The final report based on the findings of the mentioned workshop was submitted to the CEOS plenary meeting and the ISPRS congress in June and July 2004, respectively. Based on this, the creation of a standardization project on "Calibration and Validation" is aspired within ISO/TC 211 (Kresse, 2004).

5.2 The USGS Digital Camera Characterization initiative

Other relevant investigations are done by USGS (US Geological Survey). Already in 2000 USGS and ASPRS (American Society of Photogrammetry and Remote Sensing) become aware of the need for appropriate calibration methods and devices for digital airborne sensors. This initiative was based on the ASPRS Camera Calibration Panel formed in fall 1998. Right now USGS is in cooperation with NASA (National Aeronautics and Space Administration) SSC (Stennis Space Centre) to support the development and implementation of characterization methods and standards for digital imagery and other imaging sensors systems (Rufe & Zanoni, 2004). Within these investigations various digital camera contractors are flying their systems across the NASA SSC test range. Using in situ calibration (validation) methodologies the different systems are investigated with respect to the system calibration parameters and the final product. From the final results of this test USGS expects general remarks on the geometric and radiometric accuracy and stability of the individual systems and their use according to mapping standards. The deployed test range for empirical analysis provides 44 geodetic targets equally distributed over the whole test area (Figure 2). These targets are added by 136 coordinated and painted man-hole covers which are distributed in the southern part of the test site only, mostly following the streets or on places. All these targets are used to independently determine the geometric performance of the (calibrated) sensor in object space. Besides that, spatial resolution and radiometric characterization patterns are provided. More details on the design of the test area can be found in Pagnutti et al (2002). In the meantime all relevant large format digital airborne cameras (ADS40, DMC, UltracamD) are flown. Additionally, other systems like DSS (results of this analysis can by found in the DSS overview presentation and other DSS related papers provided by Applanix, 2005), DAIS or satellite based IKONOS are already tested or under current investigation.

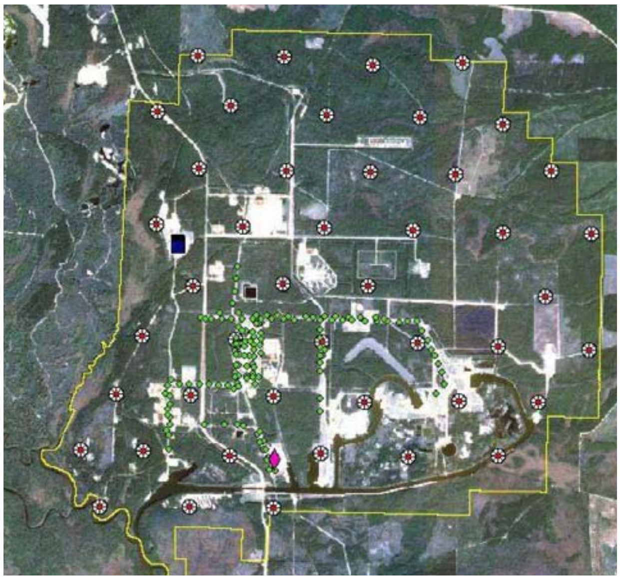

Figure 2: The NASA Stennis Space Centre test site
(© USGS, includes material © Space Imaging LLC).

Since several decades the (North-American) mapping community relies on the USGS, 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 the USGS activities in assessment of existing calibration standards and new digital camera/sensor technologies. The general strategy could be given like follows: define a certification setup first, confirm the topics to be checked and validated and finally prepare methods for quality assessment and quality control. Such topics were deeply discussed during the special session "Digital sensor calibration: research, policies and standards" organized by USGS at this years ASPRS spring meeting in Baltimore (ASPRS, 2005).

5.3 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 already 49 experts from altogether 35 different institutions from research, industry system providers and users like national mapping agencies joined the network. At the time of writing the project is just before starting-up its second phase. The time before was primarily used to establish the network itself and to prepare an extended report on the methods used for calibration of digital airborne mapping sensors. This report is amended by exemplarily attached calibration protocols as provided by the manufacturers, namely Leica, Intergraph/Z/I-Imaging and Vexcel. Project progress and general remarks on the calibration of digital sensors as performed today are given in Cramer (2004a, 2004b, 2005).

In addition to this more theoretically oriented investigations of phase 1 the second phase is focused on empirical analysis of individual flight data sets. In general the approach is quite similar to the USGS investigations, nevertheless EuroSDR will focus on a quite restricted number of test flights only, which are distributed within the network afterwards. The individual network members should then apply their software 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. Several European national mapping agencies and other private companies kindly provided access on digital test flight data sets. A promising one was acquired by TerraTec/Norway. Their support is gratefully acknowledged. Within a one and a half years period all three major digital systems (ADS40 (September 2002), DMC (October 2003), UltracamD (May 2004)) were flown on the Fredrikstad test site, which is a specially designed photogrammetric test area with sufficient number of ground control points already well-known to the EuroSDR user community from former tests (i.e. the OEEPE test on integrated sensor orientation). The flight configuration of the UltracamD flight is exemplarily given in Figure 3. This figure also indicates the distribution of geodetic targets. Almost 52 targets are (theoretically) available, not all of them could be measured in all different flight campaigns. Some more details on the UltracamD flight and the other system flight parameters are shown in Table 3.

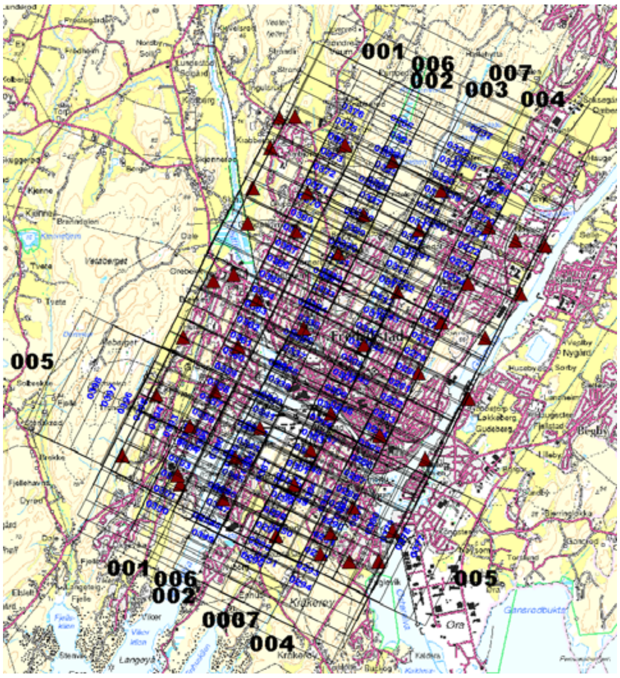

Figure 3,UltracamD block configuration at Fredrikstad test range (hg=1900m, May 4, 2004).

#	Altitude [m]	GSD [m]	# Strips long/cross	% Overlap long/cross
ADS40 test campaign (September 9, 2002)				
1	1824	0.20	5	100 / 20
2	3840	0.40	3	100 / 20
DMC test campaign (October 10, 2003)				
1	950	0.075	5	80 / 30
2	1800	0.15	3	80 / 30
UltracamD test campaign (May 4, 2004)				
1	1900	0.17	4 / 1	80 / 60
2	3800	0.34	2	80 / 60

Table 3: Basic flight parameters of Fredrikstad digital sensor flights (data provided by TerraTec/Norway).

Within all test campaigns different flying heights were realized for all systems, which is pre-condition for strong in-site system calibration and validation. GPS/inertial data were recorded throughout all flights. Such data sets provide sufficient information for testing and validation of system calibration parameters. It should be clearly pointed out again that the goal of this second phase is not to assess the different system performances against each other (although data were obtained from one test range for all three sensors), but to finally find guidelines for optimal overall sensor calibration (validation) for each type of sensor individually.

The data sets will be made available to all network members as soon as the standard quality of all flight data is checked and verified from the project pilot centre. Since the first analysis of Frederikstad flight data is not fully completed at the time of writing the paper, the project core team has not yet decided, which kind of data in detail will be provided to the network member, i.e. pan-chromatic and/or multi-spectral imagery, image (raw-)data only and/or additional image coordinate measurements, number and distribution of GCP. These decisions will be made in congruence with the system manufacturers. Nevertheless, since the second phase of this EuroSDR initiative is still in its preparation phase, as mentioned above, anyone being interested in empirical analysis of digital sensor data is cordially invited to actively participate starting from phase 2 of this project!

6. SUMMARY AND CONCLUSIONS

The paper tries to give a short insight view on the actual situation in digital photogrammetric airborne imaging. The status of testing different sensors (focused on the tests performed from national mapping authorities) is covered, than the focus is laid on the world wide activities in development of guidelines, standardization and system calibration procedures. Many of the topics could only be given briefly, nevertheless the potential of the new sensor technologies in operational environments becomes evident. Without doubt, in all cases the higher radiometric performance of digital image data acquisition is well accepted compared to the analogue scanned imagery. From several other tests the high geometric accuracy which typically fulfils all requirements could also be proven. Nevertheless, in some cases problems showed up, they sometimes are caused by hardware system errors or even more non optimally designed software for processing of the new sensors data. This was particularly the case in the first years when commercial large format digital sensors became available. Many of those problems are already cleared from system vendors, still, it seems to be a general problem, that in some cases non fully developed systems and/or software becomes commercially available due to marketing strategies and pressure from competitors. Nevertheless, with progressing time and extended experiences continuous refinement of overall systems is and will be done, definitely.

From all this background information the following general trends are quite obvious:

Digital airborne sensors are in current operational use. Close to 70 large format sensor system installations are providing data already, mostly used in high-developed or in emerging nation countries. Due to the high financial investment only a limited number of customers is able to buy such sensors. They will try to take the economic advantage using digital sensors instead of analogue image data acquisition.

The distribution of digital sensors and with that the acceptance of different ways of data processing will increase. This is

additionally pushed by future availability of generally accepted guidelines for flight configurations and data handling and even more the need for re-supplement of old and malfunctioning analogue mapping cameras. Although the estimation of potential market share and number increase systems is hard to quantify, one thing seems to be evident: Since the number of analogue mapping cameras is relatively high compared to the number of digital photogrammetric sensors, they still will play a significant role in photogrammetric applications for a certain period of time.
Besides that it is interesting to follow the future role of digital sensor systems based on smaller formats. They seem to have a nice market right now, but with an increase of applications which have less stringent demands than high photogrammetric tasks, their influence in the airborne market in general will increase.

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REFERENCES

Alamus, R., et al (2005): Validation process of the ICC digital camera, in this proceedings, 6 pages.

Applanix (2005): DSS papers and material accessible from the Internet at http://www.applanix.com/products/dss_articles.php, accessed at April 20, 2005.

ASPRS (2005): Special Session “Photogrammetry – Part 2: Digital sensor calibration, policies and standards”, organized by G. Stensaas (USGS), ASPRS Spring Meeting Baltimore, March 9, 2005.

Becker, S., Haala, N. and Reulke, R. (2005): Determination and improvement of spatial resolution for digital aerial images, in this proceedings, 6 pages.

Breg, E. (2005): Personal correspondence via email at April 14, 2005.

Cramer, M. (2004a): The EuroSDR network on digital camera calibration, Report Phase 1 (Status, Oct. 16, 2004), digitally available at http://www.ifp.uni-stuttgart.de/eurosdr/EuroSDR-Phase1-report.pdf, 53 pages.

Cramer, M. (2004b): A European Network on Camera Calibration, in Photogrammetric Engineering & Remote Sensing (PE&RS), December 2004, column on Direct Georeferencing.

Cramer, M. (2005): Digital camera calibration and validation, *GeoInformatics* 2(8), March 2005, pp. 16-19.

Dörstel, C., Reulke, R. and Schwebel, R. (2004): Berücksichtigung digitaler Kameras im neuen Normentwurf E DIN 18740-4, in Publikation der DGPF, Band 13: Vorträge Jahrestagung Halle, September 2004, pp. 235-242.

Franzen, M (2005): Erfahrungen ADS40 im BEV, internal note provided via email at April 4, 2005, 3 pages.

Fricker, P. (2005): Personal correspondence via email at April 14 and 21, 2005.

Honkavaara, E., Markelin, L., Ilves, R., Savolainen, P., Vilhomaa, J., Ahjokas, E., Jaakola, J. and Kaartinen, H. (2005): In-flight performance evaluationof digital photogrammetric sensors, in this proceedings, 5 pages.

Hutton, J. (2005): Personal correspondence via email at April 15, 2005.

Kresse, W. (2004): Committee draft der ISO 19130 “Sensor and data models for imagery and gridded data”, in Publikation der DGPF, Band 13: Vorträge Jahrestagung Halle, September 2004, pp. 251-261.

Ladstädter, R. (2005): Vexcel UltracamD vs. Analoge Luftbildkamera (RC20) – Aerotriangulation und Genauigkeitsuntersuchungen Testbefliegung Graz/Maria Trost, internal PPT-presentation (10 slides), provided by M. Gruber via email at April 11, 2005.

Lousseau, J. (2005): Personal correspondence via email at January 27, 2005.

Marshall, P. (2005): Personal correspondence via email at April 5, 2005.

O’Sullivan, L. (2004): ADS40 tests carried out by the Swiss Federal Office of Topography, internal swisstopo report, provided by email from A. Streilein at March 23, 2005.

Pagnutti, M., Holekamp, K., Ryan, R., Blonski, S., Sellers, R., Davis, B. and Zanoni, V. (2002): Measurement sets and sites commonly used for characterizations, Proceedings of ISPRS Commission I meeting, Denver, November 2002, digitally available on CD, 6 pages.

Petrie, G. (2003): Airborne digital frame cameras, *GeoInformatics* 7(6), October/November 2003, pp. 18-27.

Petrie, G. (2005a): Airborne pushbroom line scanners, *GeoInformatics* 1(8), January/February 2005, pp. 50-57.

Petrie, G. (2005b): Personal correspondence via email at March 27, 2005.

Reulke, R., Tempelmann, U., Stallmann, D., Cramer, M. and Haala, N. (2004): Improvement of spatial resolution with staggered arrays as used in the airborne optical sensor ADS40, Proceedings of ISPRS congress 2004, Istanbul, July 2004, digitally available on CD, 6 pages.

Rosengarten, H. (2005): Personal correspondence via email at April 14, 2005.

Rufe P. & Zanoni, V. (2004): Remote sensing characterization project, Digital camera product characterization, In situ test plan for aircraft flyover at Nasa Stennis Space Centre, Report provided by USGS, digitally accessible from http://calval.cr.usgs.gov/documents/stennis_in_situ_test_plan_070104.pdf, Version 0.6, Status May 2004, 34 pages, accessed at March 4, 2005.

Tsuno, K., Grün, A., Zhang, L., Murai, S. and Shibasaki, R. (2004): Starimager – a new airborne three-line scanner for large scale applications, Proceedings of ISPRS congress 2004, Istanbul, July 2004, digitally available on CD, 6 pages.

Wehrli, H. (2005): Personal correspondence via email at April 18, 2005.