Published in GeoInformatics, 2/2005, March 2005, Vol. 8, pp. 16 – 19.

EuroSDR: Digital Camera Calibration and Validation

Michael Cramer
Institut für Photogrammetrie (ifp) – Universität Stuttgart / Germany

Introduction

“Airborne imaging dominates the show” – this was the sub-title of Gordon Petrie’s report on the technical exhibition of the ISPRS 2004 Istanbul congress published in GeoInformatics October/November volume 7/2004. If one reads that article one could even add the term “digital” to the sub-title without any loss of generality, since all the different airborne systems reflected in the mentioned article were digital. Comparing the today’s situation to the last ISPRS congress, where the very first commercial digital large format airborne sensors ADS40 (Leica Geosystems) line scanner and DMC (ZI-Imaging now Intergraph) frame based camera were launched into the market, an increase in number of new digital airborne sensors (some of them already introduced into operational use) is clearly obvious from the last 4-years period. And the advent of new airborne system is still an ongoing and very viable process!

From photogrammetric point of view mainly the medium and large format systems are of interest. Besides the already fairly well introduced ADS40 and DMC systems, the Ultracam$_D$ (Vexcel) and DiMAC (DiMAC Systems) have to be mentioned as new-comers for large format multi-head frame based cameras. 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. Besides this, medium format systems (typically based on medium format analogue camera housings extended with digital sensor backs using 4k x 4k CCD arrays or higher) can be found as stand-alone systems or in combination with other airborne sensors (multi-sensor platforms) like laser scanners. The DSS camera (Applanix Corp.) based on Contax 645 film camera and the AIC camera (Rollei) using Rolleimetric housings supplemented with 14k or 22k digital backs could be seen as representatives of the first group of medium format cameras. Other companies like IGI are using of-the-shelf medium format cameras (like Kodak DCS Pro 14n or the Rollei camera) to be modified for airborne operational use (dIGIcam 14k, GigaCAM 22r). Typically these units are offered as companion units to airborne laser scanners. Still, they also can be used as stand-alone imaging sensors.

The list of digital systems mentioned so far for sure only gives a certain insight on the today’s situation in digital airborne imaging. There are several other systems (experimental or operational) available and in use without having the big market attention yet. Again, Gordon Petrie gave a very comprehensive overview on digital frame sensors available for airborne applications in GeoInformatics, October/November volume 7/2003.

The following major trends can be currently observed:

- The world of digital airborne imaging is very manifold, especially when comparing the different design of new digital systems to the classical airborne film cameras. Additionally, such digital image sensors quite often are used as 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 strongly increase in use of new systems has to be expected, where the spectrum of applications will become broader, i.e.

from standard photogrammetric mapping tasks to other applications like land use monitoring, disaster and risk assessment, forestry, tourism, real estate search and promotion to fully exploit the potential of digital airborne imaging.

- The advantages of large format image recording based on high-end high-performance digital sensors are 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.

From this background a certain need is obvious to provide and transfer fundamental knowledge on the characteristics of such digital sensor systems and their proper use in practice to the growing user community – especially as it has to be expected that many of them will be not familiar with those new digital airborne sensor technologies or not even more with airborne imaging at all.

When focussing on object reconstruction from images special attention has to be laid on the topic of camera calibration and overall system calibration. This in general is one essential necessity in the process of image data processing. Since the design of the new digital sensors is quite different compared to the analogue cameras used so far the classical methods of sensor calibration have to be extended and modified. Even more important, these new methodologies have to be transferred to the system users and additional recommendations on optimal system calibration and validation for the different system set-ups have to be specified. This was the motivation to establish a network of experts on Digital Camera Calibration in the framework of EuroSDR. So far, more then 31 different institutions from industry, research institutes and national mapping agencies already joined this initiative. It is worthwhile to mention, that besides that representatives of all major commercial camera system providers are participating and actively supporting the project in progress. Starting end of 2003 the project now is entering in its second phase where experimental data sets are analysed to finally obtain optimal approaches for overall system calibration and validation.

After a short overview on the EuroSDR organization itself the main results from phase 1 and the ongoing work within this project are presented.

The EuroSDR organization

The EuroSDR organization (European Spatial Data Research, see www.eurosdr.org) is a European user driven organization already founded in 1953 (formerly The OEEPE). Today 18 European countries are officially members of the organization, where each member state is represented by two delegates: 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.

From the very first beginning the main focus in research activities 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 inertial/GPS-based direct georeferencing. From this, the actual project on Digital Camera Calibration continuous former research projects and corresponds to the aims of organization.

The EuroSDR project on Digital Camera Calibration

The first phase lasted about one year and was mainly dedicated to start-up the project including the acquisition of individual experts to form the network. Besides that a comprehensive report was compiled documenting the different approaches for sensor calibration in general and the calibration methods for digital cameras applied from manufacturers so far. This report is already available for all persons interested in this topic and can be accessed via the project homepage http://www.ifp.uni-stuttgart.de/eurosdr/index.html→Progress & Documents. The report is mainly based on extracts from already published scientific papers amended with additional input from the system providers directly, like exemplarily provided calibration protocols for ADS40, DMC and Ultracam$_D$ systems. Additionally, it is completed with an extensive bibliography on the topic of camera calibration including many of the fundamental publications in general. It is worth mentioning here that many of these publications are available in digital PDF format. For further information please contact the EuroSDR secretariat. The main outlines from the phase 1 investigations should be recalled in the following.

Status of digital camera calibration

Camera calibration in general consists of three aspects: geometric calibration, resolution determination and radiometric calibration. In classical airborne analogue camera calibration the main focus is laid on the geometric part and the determination of optical resolution, radiometric aspects are not considered. This situation changes with the availability of digital sensors, when colour plays a major role. Since (absolute or relative) radiometric calibration is without the scope of this paper, only the standard geometric aspects are treated in the following.

Traditional calibration is done in a laboratory, using quite complex mechanical devices like multi-collimators and goniometers, where the interior camera geometry (i.e. focal length, principle point location plus lens distortion parameters) is estimated from differences between measured coordinates or angles in image space and their a priori known values. Besides that, specifications for the average resolution of optics are given. All this information is related to the individual camera body with its lens only (component only calibration) and documented in the well-known calibration certificates. Another calibration option is the in-situ calibration, namely self-calibration, test site calibration or simultaneous calibration. Within this approach the calibration parameters are resolved in the object reconstruction process itself via bundle adjustment. Although this methodology is originated from close range applications its influence in airborne applications increases especially for the calibration of more complex sensor system designs, with for example more than one optics module and combined with other sensors like GPS and inertial orientation components. In-situ calibration allows for the calibration of the overall sensor system in its true physical environment (system driven calibration), which is in clear difference to the system component only laboratory calibration.

From this, it seems to be evident that today's digital airborne camera calibration typically consists of a combination of laboratory calibration and in-situ calibration methods. The laboratory part of DMC and ADS40 geometrical calibration for example still relies on the use of traditional goniometers (moveable collimator), which are also used for calibration of the standard analogue RMKTop and RC30 airborne cameras (Figures 1 and 2). Other lab calibrations are done with fixed collimators, where the camera is mounted on a two axis rotation table to realize the different viewing angles. This collimator technique for example is used for the Starimager line scanning system and even the engineering model of ADS40 was calibrated with such device available at DLR Berlin (Figure 3). However, in all cases this more or less standard lab calibration technique provides information on the imaging component of the sensor only, which is non sufficient for the complex digital systems as already pointed out before. DMC on the one hand consists of altogether 8 individual camera heads, whose spatial relations have to be determined. On the other hand, line scanning systems have to be integrated with inertial/GPS sensors for efficient data processing. Hence, the spatial offsets and misalignments between those components and the imaging part have to be provided from calibration also. These parameters can only be resolved with in-situ calibration methodologies. Thus, in all cases additional calibration flights are necessary to finally obtain an overall system calibration including all parameters to sufficiently describe the system geometry. For ADS40 such flights are already done as part of each individual system calibration and its results are already noted in the calibration document. For other systems these parameters have to be determined from the individual user data sets.

The calibration approaches used for other digital sensors like Ultracam$_D$ and DSS are quite different. Their calibration is totally based on in-situ calibration techniques, where the laboratory part is not based on goniometers but terrestrial 3D calibration test fields instead. In case of the Ultracam$_D$ large format multi-head sensor a 3D calibration field providing a large number of targeted and coordinated points (Figure 4) is imaged from three different stations with rotated and tilted camera views. Using appropriate bundle adjustment software the calibration parameters for each individual camera head are obtained from those image blocks, typically consisting of several images to strengthen block geometry and calibration parameter determinability. Still, for both systems the lab calibration has to be completed from airborne flights in order to obtain relative orientations between the different camera heads of Ultracam$_D$ – similar to DMC – and spatial relation of the camera head to the integrated inertial/GPS system as it is used by default from DSS.

For reasons of completeness one should mention, that the virtual large format Ultracam$_D$ images are obtained after stitching of individual single head images based on their individual calibration parameters. These virtual image is theoretically distortion free, as it is the case for the DMC virtual large format images also. Since the merged large format images are standard input for later processing there is no direct link between originally determined calibration parameters of single head images and the parameters related to the later used virtual imagery.

The DiMAC sensor system calibration is exclusively based on in-situ techniques from airborne flights over signalized test areas, which is assumed to be the standard approach for other sensor using smaller to medium format sensor arrays. In contrary to the other multi-head frame based sensors DMC and Ultracam$_D$, the smaller format images from individual camera heads are not merged to large format image.

What are the major conclusions to be drawn from this brief status overview on today's applied digital sensor calibration?

- A decreased use of standard collimator based lab 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 manufacturers system calibration parameters.
- Due to the fact, that such techniques are not as common in the traditional airborne photogrammetry field, clear knowledge deficits, concerning the features and advantages of system calibration in flight, are present right now on the users' side.

Empirical investigations on in-situ calibration

The statements above basically are the motivation for the second experimentally oriented phase of the project, where real test flight data from digital systems are offered to the network members to be evaluated from their individual software processing chains and knowledge. So far, the project has access on several data sets from DMC, Ultracam_D and ADS40 systems. These data sets were kindly provided by national mapping agencies and private companies. A very promising one was acquired by TerraTec/Norway. Their support is gratefully acknowledged. Within a one and a half years period the three major digital systems (ADS40 (September 2002), DMC (October 2003), Ultracam_D (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. Different flying heights were realized with all systems, which is pre-condition for strong in-site system calibration and validation. Besides this digital image data, (reference) analogue images from standard aerial cameras are also available. GPS/inertial data were recorded throughout all flights. Such data sets provide sufficient information for testing and validating the system calibration parameters. We hope, that in addition data from other digital sensor could be made available.

The technical aspects of calibration have to be treated with different priority. At the beginning of the empirical analysis focus is laid on geometry. Later on in Phase 2 investigations concerning radiometric aspects, colour and general aspects of image quality are covered. The long-term perspective of the network activities is geared towards the development of optimal calibration setups, which is appropriate for individual sensor system designs. The goal is not to compare between individual camera systems, but to transfer such new information on calibration to a wide range of users who then can be adopted to any other digital camera of comparable system architecture. In general, experiences within this network have already resulted in the fruitful interaction between system providers and system users. Since camera calibration has a world-wide interest, the EuroSDR initiative has a close link with other calibration activities, mainly in the United States. From this point the project not only supports camera users but system providers also in designing their optimal calibration process for newly developed digital imaging systems.

Conclusions

As it was shown above, calibration and validation of new digital imaging sensors is a quite complex process, which additionally is different for each individual system design. Since the users directly are increasingly involved at least in the validation process, theory and practice of system calibration has to be communicated. This is the main reason for running this EuroSDR initiative. From this anyone being interested in analysis of digital sensor data is cordially invited to participate in Phase 2. Even more, if someone has access to flight data from other digital imaging sensors such data set possibly could also be used within the empirical testing phase. Again, please feel free to contact the author directly!

Author

Dr. Michael Cramer
Project leader EuroSDR project "Digital Camera Calibration"
Institut für Photogrammetrie (ifp), Universität Stuttgart
Geschwister-Scholl-Str. 24D, D-70174 Stuttgart / Germany
Email: michael.cramer@ifp.uni-stuttgart.de
WWW: www.ifp.uni-stuttgart.de/eurosdr

Figure 1, Gonimeter calibration of individual DMC camera head at Zeiss (© Zeiss)

Figure 2, Gonimeter calibration of ADS40 at Leica (© Leica)

Published in GeoInformatics, 2/2005, March 2005, Vol. 8, pp. 16 – 19.

Figure 3, Collimator calibration of ADS40 engineering model at DLR Berlin (© DLR)

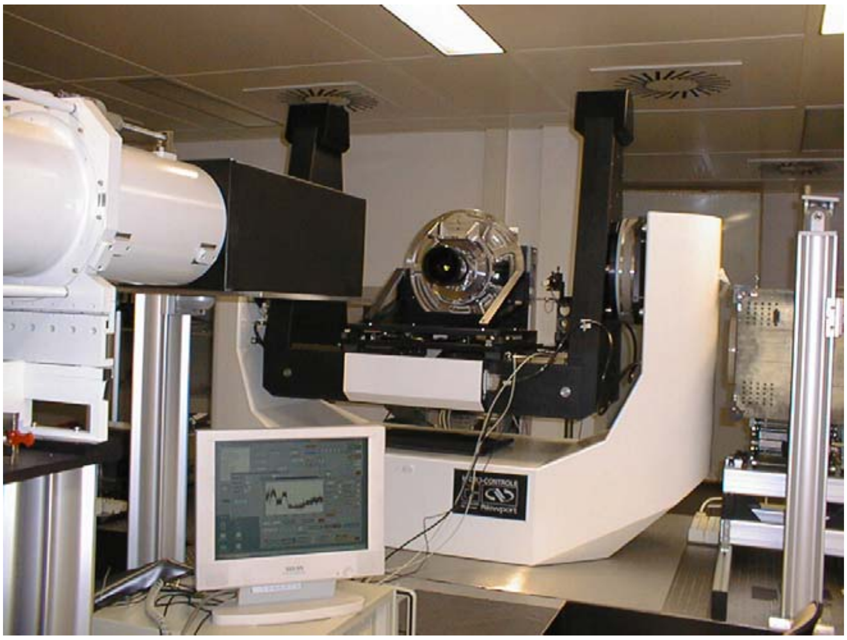

Figure 4, Terrestrial 3D calibration site used for Ultracam$_D$ lab calibration (© Vexcel)