A European Network on Digital Camera Calibration

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Background

The need of a camera calibration is a fundamental requirement in the context of photogrammetric data processing. For airborne sensors this calibration is typically realized under well controlled laboratory conditions. In this case, special calibration devices are used to determine the internal camera characteristics with sufficient accuracy. Using such calibration facilities, the distortion parameters of the lens in use, are estimated based on the computed obtained discrepancies between measured coordinates or angles and their a priori known values. In addition, the focal length and principle point coordinates are chosen to minimize the absolute amount of lens distortions and to realize a symmetric distortion pattern.

However, this classical technique changes with the increasing availability of new digital airborne imaging systems, mainly due to the following two aspects. First, comparing digital sensor systems from their system design concepts, there are large variations within the specific system realizations and in comparison with standard analogue cameras. These can be summarized as:

1. Frame sensor concepts versus line scanning approaches
2. multi-head systems versus single head sensors
3. large image format data acquisition versus medium or even small format cameras
4. panchromatic versus multi-spectral image data recording.

Table 1 summarized these design characteristical differences with respect to the currently available commercial systems. Figure 1 shows the differences in design of multi-head digital cameras compared to each other and to the standard analogue frame sensors. All of the aforementioned differences result in different calibration approaches, which have to be defined individually for each sensor type. Additionally, due to the new parallel multi-spectral imaging capability (which is one of the major selling points for the new digital sensors), calibration should not only be restricted to geometric calibration, but should also include radiometric calibration.

The second fact is mainly due to the integration of the imaging sensors with additional sensors for direct sensor trajectory determination, e.g. GPS or integrated inertial/GPS modules. The combination of digital imaging sensors with direct orientation components is straightforward, since they provide very accurate information of the sensors' movement and which can be used for fast generation of photogrammetric products such as ortho imagery. In the case of line scanning systems a tight integration with inertial/GPS sensors is mandatory for efficient image data processing. The topic of overall system calibration is then important to discuss because calibration has to cover the whole sensor system consisting of both the imaging component and the positioning component. Therefore, the more complex, extended and more general calibration procedures are needed. In this case, the aspect of in-situ calibration gains importance, since calibration should cover the whole sensor system and not only the optical part.

The Digital Camera Calibration Network

The preceding discussion defines the framework of the EuroSDR[1] initiative on "Digital Camera Calibration". Within this project a network has been established by the author who formed this network by selecting a group from experts from around the world with different areas of complementary expertise: currently more than 30 experts from the industry, universities, research institutes, and system users. Table 2 lists the members of the network who already have joined the network since September 2003.

The objective of the Digital Camera Calibration project is twofold:

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

As a result of Phase 1 a report has been compiled based on contributions from all project participants, which is helpful for digital camera system users to increase their knowledge of digital camera calibration aspects. Additionally, an extensive bibliography of all relevant publications on airborne camera calibration topics has also been compiled and is available to all interested users. The second phase focuses on the development of commonly accepted procedures for camera calibration and testing. A certain number of well-controlled test flight data sets will be provided for experimental analysis, which can be used by each network member individually. It seems to be necessary to concentrate on some of the technical aspects

[1] EuroSDR, which stands for European Spatial Data Research, is the European user driven organization already founded in 1953 (formerly The OEEPE). For details, see (www.eurosdr.org).

in a sequential order, starting with geometrical aspects and verification in a limited number of test flights by different camera producers and discussion on radiometric and image quality aspects. One aspect is the design of optimal calibration flight procedures and then to test them empirically. Another aspect is collecting a list of recommendations from the system vendors about how calibration is optimally done with their systems.

As already mentioned in the beginning of this article the standard method of camera calibration is restricted to the optical part of the camera only. This component-driven approach, typically realized by a visual goniometer technique, is sufficient as long as the system itself consists of this one lens only. On the other hand, a multi-collimator calibration is more efficient and includes not only the optical lenses but also the photographic emulsion fixed on the glass plate placed in the camera. This leads to the more general system driven view, considering not only the individual components during calibration, but also all other important parts forming the overall system. Although most of the photogrammetric system users still feel it is sufficient to have only a traditional system component calibration, the obvious need for an overall calibration has grown over the last 30 years and continues to gain in importance, especially with the advent and use of additional integrated sensors like GPS and IMU. Against this background the need for an in-situ calibration approach increases since this offers the only possibility to calibrate complex digital sensor systems consisting of several sub-components within true physical environments. The in-situ calibration methodology, originating from the close range application field, solves for the calibration parameters within the object reconstruction process. However, one should not be confused and clearly differentiates between simultaneous calibration, test site calibration, and self calibration.

In, today’s commercial digital systems, the geometric calibration is increasingly done using the in-situ calibration approach. The Z/I-Imaging DMC and Leica Geosystems ADS40 sensors both rely on a goniometer lab calibration for their individual lenses at first. Nonetheless, the DMC “platform calibration”, for example, is obtained from the mission flight imagery. Similar to that, the ADS40 lab calibration parameters are refined from specific test flights. These are performed for each ADS40 sensor before the system is delivered to the end user. Additionally, camera to the IMU spatial relation, which is an essential part of any airborne line scanning system, is determined from the calibration flights too. The calibration flights are done within a special pattern (two flight lines forming a cross, each line flown twice in bi-directional directions and at two different flying heights) in order to realize a sufficiently strong block geometry. It is worth mentioning here that this is certain evidence of exclusively obtaining ADS40 sensor calibration parameters from self calibration in the future.[MM1] The lab calibration part for the Vexcel Imaging Ultracam$_D$ large format digital sensor and the medium format DSS camera system from Applanix Corporation is similar to standard terrestrial close range camera test site calibrations. In both cases 3D terrestrial calibration fields with sufficient number of targeted and coordinated points are recorded from different stations with rotated and tilted camera views. Using appropriate bundle adjustment software the calibration parameters are obtained using least squares technique. In the case of the DSS, an initial boresight calibration is also done during the lab calibration since the IMU is a standard part of the system. On the other hand, the relative orientations between the individual camera heads of $Ultracam_D$ are estimated for control purposes to detect any tilt between the different optic modules. Since the orientation between pan-chromatic master cone and the three slave camera heads is assumed to be variable, the transformation parameters are determined for each image individually from the mission site imagery itself, quite similar to the DMC approach. This is essential for stitching the individual image patches together to obtain large format imagery from the multi-head systems DMC and $Ultracam_D$. Within this process the distortions parameters from calibration are already considered providing a (theoretically) distortion free image which is used in production then. Again, these values are verified from airborne calibration as a second step. For the DIMAC sensor from Dimac Systems, which is again a frame based sensor with a flexible combination of up to four individual camera heads, is exclusively calibrated from calibration flight data. In contrast to the DMC and $Ultracam_D$ concept, the images from the different camera heads are kept individually without merging them into a larger format image during data post-processing.

From the preceding discussion on the geometric calibration using six examples of modern airborne digital systems, the following statements could be summarized:

- System-driven calibration approaches are of increased importance.
- A decreased use of classical lab calibration seems to be evident, whereas the importance of in-situ calibration is definitely increasing.
- The acceptance environment of a combined lab and in-situ calibration has to be increased. There are clear knowledge deficits on the users’ side, when talking about a full system calibration using in-situ calibration techniques. This is basically due to the fact that these are not as common in the traditional airborne photogrammetry field. With their increasing usage, such methods will be accepted as powerful and efficient tools for overall system calibration.

All these aspects will be discussed in more detail and verified from experimental research in the ongoing project at hand. The long-term perspective of the network activities is geared towards the development of optimal calibration setup, which is appropriate for each individual sensor system design. The goal is not to compare between individual camera systems, but to distribute information to a wide range of users that can then be transferred to any new 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. It is also expected to see more and more recommendations on system calibration and optimal data processing provided by camera manufacturers. Since camera calibration has a world-wide interest, the EuroSDR initiative has a close link with other calibration activities, mainly in the United States. Other experts from this background are also cordially invited to participate in the EuroSDR network. All relevant information is available from the project website at http://www.ifp.uni-stuttgart.de/eurosdr/ .

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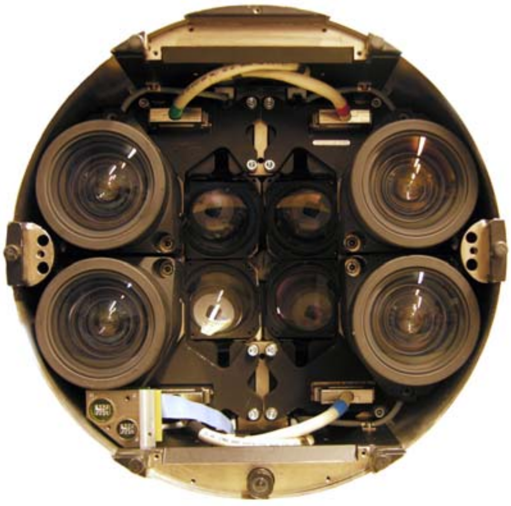
Table 1. Characteristics of modern digital airborne sensor system designs

#	System	Geometry		Sensor heads		Image format		Image recording		Inertial/GPS components	
		line	frame	single	multi	large	medium	syn-chronous	Syn-topic	optional	man-datory
1	ADS40	☑		☑		☑		☑			☑
2	DMC		☑		☑	☑		☑		☑	
3	Ultracam_D		☑		☑	☑			☑	☑	
4	DSS		☑	☑			☑	☑		☑	
5	DIMAC		☑	☑	☑		☑	☑		☑	
6	HRSC-Ax	☑		☑		☑		☑			☑
7	3-DAS-1	☑			☑	☑		☑			☑
8	Starimager	☑		☑		☑		☑			☑

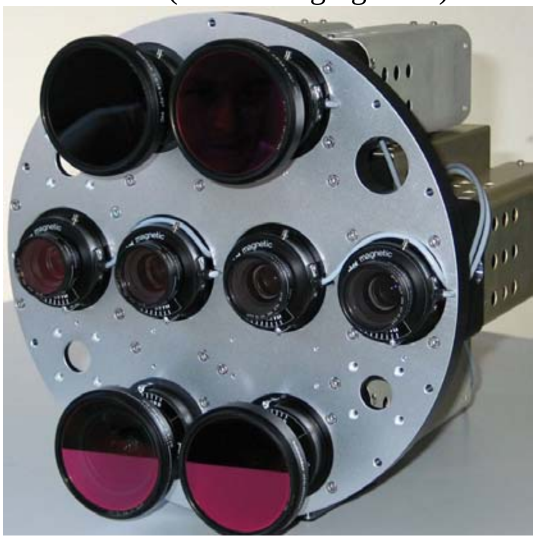
Table 2. EuroSDR Digital Camera Calibration Network members (as of September 2004)

#	Organization	Network member
System providers		
1	ADS 40, Leica Geosystems	Mr. U. Tempelmann, Mr. P. Fricker
2	DMC, Z/I-Imaging	Mr. C. Dörstel, Dr. M. Madani
3	Ultracam$_D$, Vexcel	Dr. M. Gruber
4	DIMAC, Dimac Systems	Mr. P. Louis, Mr. J. Losseau
5	DSS, Applanix Corp.	Dr. M. Mostafa
6	Starimager, Starlabo Corp.	Dr. K. Tsuno
Industry & other software developers		
7	ISTAR	Dr. P. Nonin
8	MacDonald Dettwiler	Dr. B. Ameri
9	Vito	Mr. J. Everaerts
10	Optical Metrology Centre	Dr. T. Clarke
11	GIP Engineering	Dr. E. Kruck
12	ORIMA	Dr. L. Hinsken
13	DLR Oberpfaffenhofen	Prof. M. Schroeder, Dr. P. Reinartz, Dr. R. Müller, Dr. M. Lehner
University		
14	Ohio State University	Prof. T. Schenk, Prof. D. Merchant
15	ETH Zürich	Prof. A. Grün, Mr. L. Zhang, Mrs. S. Kocaman
16	University of Glasgow	Prof. G. Petrie
17	University of Rostock	Dr. G. Grenzdörffer
18	University of Stuttgart	Dr. N. Haala, Dr. M. Cramer
19	University of Hannover	Dr. K. Jacobsen
20	Humboldt University Berlin	Prof. R. Reulke
21	University of Applied Sciences Stuttgart	Prof. E. Gülch
22	University of Applied Sciences Anhalt	Prof. H. Ziemann
23	Institute de Geomatica Castelldefels	Dr. I. Colomina
24	Agricultural University of Norway Aas	Dr. I. Maalen-Johansen
National mapping agencies & other authorities		
25	Swedish Land Survey	Mr. D. Akerman
26	Finnish Geodetic Institute	Prof. R. Kuittinen, Prof. J. Hyppä
27	British Ordnance Survey	Mr. P. Marshall
28	Swisstopo – Landestopographie	Dr. A. Streilein
29	US Geological Survey	Dr. G. Stensaas, Dr. G. Y. G. Lee
30	ICC Barcelona	Dr. J. Talaya
31	IGN France	Dr. J. Lagrange, Dr. M. Deseilligny

Figure 1. Examples of camera head designs of multi-head frame based airborne digital sensors



DMC (© Z/I-Imaging 2004)



Ultracam$_D$ (© Vexcel 2004)

DIMAC (© Dimac Systems 2003)