REQUIREMENTS FOR AN ORIENTATION AND CALIBRATION STANDARD FOR DIGITAL AERIAL CAMERAS AND RELATED SENSORS

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ABSTRACT:

Though the ISPRS has had standardization on its agenda for a long time the progress was slow and the output of completed document is still limited. The reasons are manifold: lack of awareness of standardization, necessary alignment with the standardization of geographic information done by the ISO/TC 211, emerging of new sensors while standardization work was ongoing, and the lack of technical consensus on many details such as data formats. Initiated by EuroSDR and ISPRS the EuroCOW workshop in January 2006 brought experts together who represented the leading edge of the new generation of airborne imaging sensors. This article is intended to be a starting point for the necessary discussion about an orientation and calibration standard that fulfills modern requirements. Three authors give their views on the topic and point to essential components of a standard in the future.

1. INTRODUCTION

The ISPRS has had standardization on its agenda for a long time. In earlier days standards for the calibration of aerial cameras were published. Exactly ten years ago the Working Group II/7 “Image Transfer Standards” was established. Four years later it changed its name and broadened its scope to WG II/4 “Image data standards”. Its present status is that of an ad-hoc group. At the same time the ISO (International Organization for Standardization) and the OGC (Open Geospatial Consortium) have been making their efforts. The ISO-project 19130 “Sensor data model for imagery and gridded data” started in 2001. The OGC supports the Sensor Model Language which is a component of their Sensor Web Enablement initiative.

The EuroCOW workshop held in Castelldefels, Spain, in January 2006 brought experts together who represented the leading edge of the new generation of airborne imaging sensors. Representatives of the manufacturing companies – ZI-Imaging, Leica-Geosystems, and Vexcel – as well as users and software experts were present. DMC, ADS 40, UltraCam, and airborne laser scanners were the sensors mostly addressed. None of the existing standardization documents of the ISO and the OGC was sufficiently complete enough to serve the needs discussed during the EuroCOW workshop. This lead to the idea of writing a joint paper to serve as a forum for experts to document the requirements in their field of work.

The paper combines the views of three authors. Jan Skaloud discusses the calibration of the direct georeference of sensors combined with GPS and INS (Inertial Navigation System). Ludger Hinsken reports the procedure to georeference frame and line sensors on airborne platforms when integrated systems are used. Wolfgang Kresse comments on the present document of ISO 19130 “Sensor data model for imagery and gridded data” and reports the ISO perspective.

2. OBSTACLES

This fairly large number of activities in standardization has not yet resulted in generally accepted standards. The reasons for the slow progress are manifold.

Until recently only a minority of people were really convinced of the necessity for standards that make products independent of hardware and software. There is still a lack of awareness of standardization.

While efforts towards standardization have been ongoing since 1996 a completely new generation of imaging sensors emerged from the laboratories and changed the paradigm of photogrammetry as well as the daily technical work: digital aerial cameras, airborne laser scanners, high resolution satellite imagery, and radar imagery (SAR, IfSAR).

When understanding geographic information as a specialization in computer science a model-driven approach is a must. As photogrammetry and remote sensing are a subset of geographic information they have to follow those rules. The ISO/TC 211 (Technical Committee) “Geographic information / Geomatics” is building a family of standards that are completely and consistently integrated in one single model written in UML, the Unified Modeling Language. Since the aspects of orientation and calibration as well as the data exchange formats are on a low logical level of this model the developers of the related ISO-standard had to wait for the completion of the intermediate levels. Not earlier than 2006 the ISO reference model for imagery and gridded data (ISO 19101-2) and the metadata for imagery and gridded data (ISO 19115-2) have reached a stable state that allows the development of subsequent standards such as the ISO 19130.

The top-down approach favored by the ISO forces a merger of the currently disjunctive domains such as photogrammetry, remote sensing, and military applications. As a consequence different scientific cultures have to cooperate.

Standardization of software – formats, models, parameters – is always difficult if existing products have to be integrated. Photogrammetry and remote sensing is governed by a limited number of very advanced software solutions. Any standard has to guarantee compatibility with existing software systems.

Analysis of the starting point of standardization in the different domains reveals heterogeneous perspectives towards standards: exchange formats for orientation and calibration data, quality measures, mission data, and others. A generally accepted standard requires consensus as to what purpose the standards should serve. This consensus does not yet exist yet because people have their different technical background resulting in different expectations.

3. GPS – INS – SENSOR CALIBRATION (BY JAN SKALOUD)

What is here understood by system calibration is the process of finding the relations in space (lever-arm), orientation (boresight) and time (synchronization) between the sensors. The calibration of systematic effects in the imaging/ranging sensors can be made either separately or within the same process (e.g. parameters of camera interior orientation, LiDAR range-finder offset). The concepts of state-space estimation (Kalman Filter in GPS/INS) and bundle adjustments (AT with GPS/INS data) have the ability to accommodate and estimate additional calibration parameters. However, it may cause severe correlation among the variables and hamper the reliability of the whole process. Hence, independent methods and parameter separation is recommended whenever feasible.

The related coordinate reference systems are defined as follows:

sensor frame: arbitrary definition, right-handed Cartesian system x-y-z.
gimbal frame: arbitrary definition, right handed Cartesian system x-y-z
body frame: defined by the x-y-z accelerometers of the IMU
local-level NED frame: North(x)-East(y)-Down(z) axes orientation
local-level ENU frame: East(x)-North(y)-Up(z) axes orientation

Note that the gimble frame corresponds to the sensor frame in cases when the sensor stabilization by a gimbal mechanism is not present. Also, the rotation between the sensor frame and the gimbal frame can be considered as time invariant when the gimbals are locked.

3.1 Sensor to GPS-antenna distance / lever-arm without Inertial Measurement Unit (IMU):

3 coordinates (x, y, z) in gimbal frame.

Situation:
The GPS antenna is represented by its phase-center and this point can be physically materialized (usually without difficulties). The reference frame for the antenna lever-arm measurement should be the gimbal frame.

Recommendation:
The use of tachymetry is more accurate and reliable compared to the indirect estimation as via the bundle-adjustment. However, calibration protocol using tachymetry should contain information about the "materialization" of the sensor-frame. This is perhaps less evident for line-scanners and small CCD-chips than analog frame-cameras.

Problem:
The use of sensor-stabilized mount represents a serious problem for GPS positioning if gimbals-stabilization history (orientation) is not recorded and synchronized with GPS-time, because the orientation of sensor frame with respect to the gimbal frame and thus to GPS antenna varies during the flight and so does the projection of lever-arm. This is often one of the limiting factors on GPS-derived exterior orientation parameters as demonstrated in several papers presented during EuroCOW 2006. Mitigation: manufacturers provide GPS-synchronized history of angles used in gimbals stabilization.

3.2 Sensor to GPS-antenna distance / lever-arm with IMU:

3 coordinates (x, y, z) expressed in IMU body or gimbal frame.

Situation:
The use of body frame is required for GPS/INS integration. The physical realization of the IMU-body frame is not trivial. The often used tactical-grade instruments are of a small size that makes the use of marks on the instrument's case inaccurate. Also, the accuracy of the "static" alignment (system orientation with respect to local-level frame) of such instruments may be insufficient. The needed accuracy of the body-frame realization augments proportionally to the lever-arm distance.

Recommendation:
The use of tachymetry is more accurate and reliable compared to the indirect estimation via the bundle adjustment. The reading of IMU orientation (with respect to local-level frame) should follow a "dynamic" alignment and the subsequent tachymetry measurements should be realized with respect to local-level frame so the subsequent transformation to body-frame can be performed. Alternatively, the tachymetry measurements may be taken with respect to sensor frame if the orientation between IMU-sensor (boresight) is known with a sufficient accuracy.

Problem:
The problems related to the use of sensor-stabilized mount apply also here and at same scope as discussed in Section 3.1.

3.3 Sensor to IMU orientation (mounting / boresight):

9 element matrix, Sensor to IMU-Body frame.

Situation:
The Sensor to IMU orientation can be (but does not have to be) split into two subsequent rotations: $M_s^b = \left(I + \Omega_{b*}^b\right) T_s^{b*}$ with T_s^{b*} representing the approximate axis orientation from sensor to body-frame (i.e. the refection matrix containing only "0" and "1" elements) assumed to be known *a priori* and $\left(I + \Omega_{b*}^b\right)$ being a matrix of small unknown rotations $\Omega_{b*}^b = \begin{pmatrix} 0 & -\gamma & \beta \\ \gamma & 0 & -\alpha \\ -\beta & \alpha & 0 \end{pmatrix}$, which values are to be determined by system calibration. What is referred as boresight in practice is sometimes the

skew-symmetric matrix $\left(I+\Omega_{b*}^{b}\right)$, that allows only small rotations (few degrees), sometimes the sensor to IMU rotation matrix $\left(M_{s}^{b}\right)$ that spans all possible rotations.

Recommendation:
In contrary to the lever-arm, the calibration of the boresight requires the use of an integrated sensor orientation to attain sufficient accuracy. The situation for frame-cameras is relatively well understood, although some conceptual approaches are better than the other and possibilities for improvements exist. The situation is not conceptually very different for line-scan imagery when "pushbroom" image blocks are formed and adjusted. The correct recovery of the Laser-IMU misalignment is considerably more complicated. The adopted approaches (based on physical boundaries or cross-sections, DTM/DSM (Digital Terrain Model / Digital Surface Model) gradients or signalized target points) are recognized as being sub-optimal since they are labor-intensive (i.e., they require manual procedures), non-rigorous or provide no statistical quality assurance measures. The more rigorous class of calibration procedures or strip adjustments uses the modeling of systematic errors directly in the measurement domain, yielding practical and adequate results with good de-correlation between all parameters.

3.4 Sensor to gimbal orientation:

9 element matrix, Sensor to gimbal frame.

Situation:
The platform stabilization is often exercised by a gimbal mechanism that was designed before the method of GPS(/INS) was widely accepted for direct sensor orientation. Hence, the readings of gimbal angles cannot be synchronized or even recorded together with GPS/INS measurements, which then limits their usefulness due to time varying projection of the GPS-antenna lever-arm vector.

Recommendation:
Use only platform-stabilization where the evolution of gimbal angles can be recorded and synchronized with respect to GPS time.

4. THE USE OF THE ORIENTATION PARAMETERS BY DIGITAL PHOROGRAMMETRIC WORKSTATIONS (DPW) (BY LUDGER HINSKEN)

In the ISO 19130 the exterior orientation is described as a simple transformation from object to sensor. For those systems the author is working with, namely Leica Geosystem's LPS and BAE's SOCET SET, this simple transformation is less important, although it does exist and is fully supported.

Instead a more sophisticated model is used. It consists of a chain of transformations. Typically a project has a project system which can be any map projection or geographic latitude and longitude. Additionally there is a height system independent of the planimetric system. Both systems might have different units and refer to different datums.

For triangulation purposes a 3D cartesian system, also called local space rectangular (LSR), is established. The transformation between the project system and the LSR must be known.
The exterior orientation is then described in the LSR only.
Digital workstations constantly perform the transformation-chain:
Project -> LSR -> Ideal Sensor -> Physical Sensor

A clear definition of the used coordinate systems is absolutely essential for combined adjustment of photogrammetry, GPS and IMU data.

With respect to the internal sensor parameters it is always important to define how the corrections must be applied. In practical work this is causing big problems. Certain calibration values are meant to be applied to measured image points, whereas others are meant to be applied to projected points.

Problems caused by this difference are becoming more evident as certain modern sensors do have larger distortion values.

5. ISO-STANDARD FOR THE SENSOR ORIENTATION (BY WOLFGANG KRESSE)

The ISO 19130 "Sensor data model for imagery and gridded data" standardizes the orientation parameters of photogrammetric and remote sensing sensors. Since the definitions of the attributes of radar sensors had not been supplied before the due date the standard was officially deleted in March 2006 after the five-year period had expired. However, it is most probable that the main chapters of the standard will be the basis for a new standard in the future.

The basic structure of the ISO 19130 is well accepted in the project team. The standard is written in UML. This UML-model is a part of the overall UML-model of all ISO 19100 standards made by the ISO/TC 211.

The most general class of ISO 19130 is SD_GeolocationInformation. This class is a specialization of geographic metadata for the georeference of imagery. To be precise in UML terms: The class SD_GeolocationInformation aggregates to MI_Georeferenceable. MI stands for Metadata of Imagery.

According to ISO 19130, geographic imagery may be referenced by five methods. The two most important methods use a functional fit approach or a sensor model.

The functional fit approach establishes a mathematical relation between image and object space. It distinguishes between polynomials and ratios of polynomials.

The sensor model falls apart into a location model, platform parameters, optics, a correction model, and imagery parameters. The location model covers position, attitude, velocity, and acceleration of a platform. The location model holds the classical exterior orientation and further parameters used in some special applications. The optics model and the correction model contain the interior orientation of a camera (ISO 19130, 2005).

This component-approach does not limit the application of the standard to a few existing types of sensors only. Today, many users demand standardized models that are applicable to a large number sensors. For the new digital large format multi-head sensors the appropriate sensor parameters are thus the camera interior orientation (c', x_0', y_0'), pixel size (x, y), number of pixels (rows, cols) and the look-up table of corrections (Honkavaara, 2006).

In addition users demand further important parameters to be standardized within the ISO 19130 or its successor. Quality indicators should be included in the standard. For instance the standard deviation of the distortion or the exterior orientation is missing. Also the correlations between the parameters would be advantageous, even though these are not actively used at the moment. However, this information can be used to predict the attainable geometric accuracy. The existing ISO 19130 is limited to a geometric model. The radiometric model and the MTF/PSF (Modulation Transfer Function / Point Spread Function) could also be advantageous for many users (Honkavaara, 2006).

Being well aware of further changes to model of ISO 19130 a prototype XML-model of the existing ISO 19130 is being developed in Neubrandenburg. This model shall demonstrate the integration of standardized parameters into the practical workflow.

6. CONCLUSIONS

This article is intended to be a starting point for the necessary discussion about an orientation and calibration standard. The authors' views give a glimpse of the range of the topic.

In principle the resulting standard could be a technical specification of the ISPRS or of the ISO. However, an "official" ISO-document is preferable.

The ISO 19101-2 (reference model) and the ISO 19115-2 (metadata) are almost completed. The future of the ISO 19130 (sensor model) is unclear. A clarification can be expected at the ISO/TC 211 meeting in May 2006. Probably the ISO 19130 will be downgraded to a "Technical Specification" as this would allow for an easier updating procedure. Three procedures are currently possible:

1.) Formal reintroduction of the unchanged document
2.) Removal of some unnecessary chapters and reintroduction of the remaining document
3.) Integration of the new sensors following a complete rearrangement of the document

The discussions within the ISPRS and the EuroSDR will play an important role in shaping the future of the standard.

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