DRIVING TOWARD A WORLDWIDE ACCEPTANCE PROCEDURE FOR DIGITAL AIRBORNE SENSORS

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ABSTRACT:

The U.S. Geological Survey (USGS), with the cooperation of 14 other Federal agencies, has proposed a quality assurance plan for acquiring digital imagery in the United States. This plan is a result of cooperative work with sensor manufacturers, data providers, and the American Society for Photogrammetry and Remote Sensing (ASPRS). The plan identifies four key components affecting quality when acquiring digital imagery. The four components are 1) sensor type certification, 2) data provider certification, 3) contracting guidelines for procuring digital imagery, and 4) quality assessment guidelines. The implementation details in each component are still being developed and will be further refined; however, the sensor type certification component is the most mature and four key digital aerial sensors systems have completed certification. The sensor type certification process is being further refined[1] through the lessons learned from the initial certifications and certification documentation has been updated. Currently, the sensor type certification approval is being considered as a requirement for procurements for use by officials in the United States. One primary concern is that manufacturers are generally required to perform some sort of acceptance test with each of their prospective buyers, and there is a different process used by each country for procurement and acceptance. Even though the USGS is informally discussing the possibility of a reciprocal sensor type certification process with European Spatial Data Research (EuroSDR), Australia, and Canada, there is no commonly accepted procedure that is universally used by all countries. In fact, many countries (e.g., Japan, China, and Russia) have purchased digital sensors and they each have independent acceptance processes. This paper describes the need to establish a process for certifying the acceptance of digital sensors on a worldwide basis.

1. INTRODUCTION

The U.S. Geological Survey (USGS), in conjunction with its partners, has been working to establish a quality assurance process for digital aerial imagery in the United States to supplement the long-term film camera calibration process that has been used as a requirement in the majority of image acquisition contracts. This process involves four major components and is still under development. The most mature component, sensor type certification, is being refined from lessons learned from the initial phase and is the focus of this paper.

2. AERIAL MAPPING CAMERA CALIBRATION IN THE UNITED STATES

2.1 Background

Since 1973, the USGS Optical Science Laboratory (OSL) in Reston, Virginia, has been responsible for calibrating analog film cameras for the aerial mapping community (Tayman 1974). Over the years, the laboratory has gained national recognition for providing this essential service. Today's digital technology offers the aerial mapping community a choice of using film cameras or digital cameras/sensors. The USGS continues to calibrate film cameras and is researching and developing processes for assessing and calibrating digital sensors (Lee 2004).

2.1.1 Analog Laboratory Calibration

The OSL employs an operational-type photographic method using multi-collimators and Brown's calibration concepts with the "Simultaneous Multiframe Analytical Calibration" computer program (Light 1992) for the determination of lens and camera constants of aerial mapping camera systems. The USGS Report of Calibration provides the camera calibration parameters (interior orientation parameters and distortion coefficients) necessary to create higher-order products from aerial film images. Without the calibration parameters contained in the report, the film images could not used in traditional photogrammetric production systems. Thus, it was necessary that the USGS Report of Calibration be delivered with the film images (Tayman 1984). This report has become a de facto standard and is used as a requirement throughout the mapping community for acquiring film-based imagery. Additional information about the OSL and film camera calibration specifications is available on the Web (OSL 2003).

[1] One refinement made is the name "sensor type certification". Initially this was referred to as "manufacturer certification," which caused confusion as to what exactly was being certified. The name now used, "sensor type certification," more clearly and accurately describes what it being certified: sensors of a certain type/model.

2.1.2 Digital Camera Calibration

In 2000, a panel of experts commissioned by the USGS and the American Society of Photogrammetry and Remote Sensing (ASPRS) concluded that digital sensor calibration and associated processes were inherently governmental and recognized the need for a new capability to calibrate digital cameras (ASPRS 2000). The panel recommended that the USGS establish a digital camera calibration capability and develop guidelines to satisfy the growing national need for a quality acquisition process.

Based on the panel's recommendations, the USGS installed a digital camera calibration facility at its Earth Resources Observation and Science (EROS) Center in Sioux Falls, South Dakota, to research small to medium format digital cameras via the use of a control point cage and an automated software program called "Australis" (Fraser 2001). The processes, hardware, and software related to small and medium format camera system stability, including laboratory and *in situ* calibration, are currently being researched by USGS (Stensaas 2007).

3. THE USGS PLAN FOR QUALITY ASSURANCE OF DIGITAL AERIAL IMAGERY

3.1 Background

Further following the recommendations from the ASPRS Camera Calibration Panel, USGS established the Inter-Agency Digital Image Working Group (IADIWG) to address the needs of the federal consumers of aerial digital imagery and support development of a digital camera calibration capability and quality assurance plan. The IADIWG now consists of 14 federal government agencies and represents the largest purchasers of image data in the United States.

With the increasing availability and continued growth of digital sensors in the aerial mapping environment, the USGS is working to understand the many differences between analog and digital camera systems and their effect on products. It is clear that all the digital imagery sensors we have seen have their unique design and require customized calibration methods. Further, these sensors are often integrated with other support systems, such as global pointing system (GPS) and inertial measurement unit (IMU) equipment to form a complete data collection system. Hence, complete calibration approaches are important due to the complexity of digital sensor systems consisting of several components.

In 2005, the USGS and the IADIWG held a workshop consisting of sensor manufacturers, data providers, and end-users to help address issues when contracting for digital imagery. This workshop led to the development of an initial quality assurance plan for digital aerial imagery acquisitions, which looks at the quality process for the complete system through quality assessment of the entire process—a full systems approach. As a result, the proposed quality assurance plan was developed and reviewed in consultation with major Federal agencies, industry, and academia, and the USGS and its partners are working to enhance and establish common procedures and guidelines to support quality imagery acquisition needs. The plan was implemented with understanding that each component within the plan would be revised based on lessons learned in the initial implementation phase.

3.2 USGS Quality Assurance Plan for Digital Imagery

The USGS Quality Plan (RST 2007) addresses the procurement and generation of digital image data in two domains, data procurement and data generation. The Quality Plan addresses the following four elements within data production and procurement areas: 1) defining the contract requirements and data specifications, 2) defining a process and the criteria to validate that the deliverables meet the terms of the contract, 3) manufactures have produced adequate systems, both hardware and software, which can perform the necessary primary data acquisition, and 4) data Producers have integrated these systems into their production environments and have produced the required data products. By focusing on the processes involved in procuring and generating digital aerial data, the plan seeks to assure quality at each major step and place the responsibility for maintaining quality with those most directly able to affect it. The following subsections address each of the four distinct elements.

3.2.1 Contracting Guidelines for Digital Aerial Imagery

The first component of the USGS Quality Plan is the contracting guidelines and stems from the fact that the first step in digital aerial imaging is the identification of a need by a customer. Digital aerial imaging presents new capabilities and some limitations, as well as many new terms and concepts in the lexicon of aerial imaging. Differences in terminology and expectations have given rise to numerous misunderstandings and problems in contracting for digital imagery and have hindered procurement of digital aerial products.

To help alleviate these issues and to promote common usage of terms and expectations, the USGS, in conjunction with its partners in the IADIWG, has developed Contracting Guidelines for Digital Aerial Imaging. The Contracting Guidelines for Digital Aerial Imaging are based on the experiences of the largest purchasers and providers of digital products and will be updated as needed to reflect the evolving industry and new capabilities as they become available. In addition, a Web-based tool is being developed to help end users or contracting officials to generate portions of the statement of work and specifications for procuring digital aerial products.

Finally, it is recognized that users need to understand image quality and the effects of system and environmental issues on image quality. Therefore, another Web-based tool is being developed to assist users in visualizing and evaluating quality levels of imagery due to changing ground sample distance, geometry, spatial, spectral, and radiometric parameters. This tool will help the user to determine appropriate image specification requirements.

3.2.2 Sensor Type Certification

The second component of the USGS Quality Assurance Plan is the "type certification" of digital aerial sensors for their suitability to high-quality aerial imaging needs. A team of USGS and partner members will visit the manufacturer of a digital aerial sensor system and learn the design, development, and testing of that sensor as well as the manufacturer's intended operational constraints and required support needed to ensure that the data generated by the system is of reliable quality. Included in this process is a total review of the manufacturer's recommended calibration, operation, and maintenance requirements for the system after sale.

It should be noted that "type certification" is intended to ensure that the sensor systems made by the manufacturer have been designed to reliably, repeatedly, and routinely deliver an output product of consistent quality. The certification will provide customers and users of digital imagery a verification of manufacturer specifications and claims. This type certification does not imply that each separate sensor system within the certification type class will deliver identical data characteristics. Rather, the USGS Sensor Type Certification simply endorses that a particular "type" of system, when operated in accordance with the manufacturer's parameters, has a high likelihood of reliably producing products that meet the claims of the manufacturer for that system.

The USGS has completed four sensor type certifications with digital aerial sensor system manufacturers (Applanix, Intergraph, Leica, and Microsoft Vexcel). The initial certification effort focused on the major manufacturers of digital aerial sensors currently in use. This effort was undertaken with the support and cooperation of the major manufacturers to help further develop and refine the standards and methodology proposed by the USGS in this process. At this time, the certification process is on a cost-share basis with the manufacturers paying a fee to cover some of the expenses. Dr. Michael Cramer of EuroSDR has been following the USGS plan and has participated in two of the sensor type certification efforts and has provided comments to the USGS plan (Cramer 2007).

3.2.3 Data Provider Certification

The third component of the USGS Quality Assurance Plan involves the data providers—a term used to describe those who use the digital aerial systems described in the previous section and process its output into the final image product for the end user. A data provider is viewed as one entity, although in practice the work involved may be split among several firms. For example, a data provider may contract out portions of the flying or the data processing and product generation to other subcontractors and combine the work of others into the final product. For the purposes of the USGS Quality Assurance Plan, the data provider is assumed to be the firm that has the contractual relationship with the contracting customer. As such, they have the responsibility to ensure that all subcontractors and business partners meet the requirements of the data provider certification.

The USGS Quality Assurance Plan will offer certification of data providers. During the certification process, the USGS will inspect the data provider's process from mission planning and flying, down to product generation and final delivery. Of primary concern to the USGS is that the data provider have a well documented quality plan governing all operations from data collection to product delivery and, more importantly, follow the plan. This certification assures the contracting officer that this firm has a high likelihood of delivering consistent, high-quality data. The data provider certification component is made up of two important pieces: 1) evaluating the process that a provider uses to ensure a high-quality, consistent product, and 2) evaluating whether the provider can use the process to produce products of a designated quality level.

The USGS has established a team to define and test the data provider certification component of the quality plan. The data provider certification team is currently working to establish the evaluation criteria and is evaluating the implementation of this portion of the plan with data providers. The USGS is also working with partners to establish additional test ranges strategically located throughout the United States.

3.2.4 Acceptance Guidelines for Digital Aerial Data

The final component of the USGS Quality Assurance Plan deals with the question of determining whether the data delivered by a data provider meets the quality specifications in the contract. A USGS Image Quality team has been formed to define uniform quality assurance methods and quality control measures to monitor the quality of products. This will also aid smaller contracting offices lacking imagery expertise on their staffs in identifying concerns related to systems and operators. The implementation and utilization of a performance database by all contracting offices will enhance the performance and quality of the data providers and their data deliveries. This database and Web-based visualization tools will allow contracting officers and their technical staff to easily evaluate quality metrics on past Government task orders. To this end, the USGS and its IADIWG partners are developing standard methods and metrics for use in measuring digital aerial data product quality. At this time, draft plans for the data provider certification process are being reviewed, and the recommended quality acceptance guidelines and practices are being compiled.

4. LESSONS LEARNED DURING INITIAL PHASE

4.1 Lessons Learned During Sensor Type Certification

There is general agreement in the geospatial community that an independent certification process for sensors used in data acquisition tasks is in the best interest of the remote sensing community. The independent certification process will facilitate more rapid acceptance of new technologies and be helpful to both professional and novice users of the resulting products and services using remote sensing technologies.

The first notable lesson from the initial sensor type certification was from reviewing the materials provided by manufacturers and the need to understand their definition of sensor calibration terminology. Moreover, if the calibration and certification report is going to be useful, there was a need for consistency in the definition of these terms. Of course, this has been an issue to the remote sensing community for decades (Trinder 2004).

Second, since there are design differences between manufacturers, it is difficult to establish a list of required information that would be appropriate for all types of sensors. It is also difficult to communicate the level of detail in the information being requested to meaningfully document the calibration process in a certification report. There needs to be common type certification terms and processes so that common certifications can be made.

While the certification team signed nondisclosure agreements with each of the manufacturers for the information provided prior to the certification inspection phase, the manufacturer generally marks everything as propriety information, although much of the information is not really propriety because the information is published in their sales literature or in their user manuals. It is very difficult to document the inspection findings in a certification report without the manufacturer's careful review. It is also a difficult task to record and document specific question and answer exchanges throughout the on-site factory certification phase. Ample time must be allocated for the certification team to digest and to fully understand the particular process being discussed. The manufacturer also needs enough time to respond to questions for a successful and thorough inspection and certification process.

Finally, while there is a clear need for a sensor type certification process, it is time consuming and costly for all parties. The manufacturer must clearly be responsive to all potential customers. However, without a standardized certification process that is accepted on both a national and international basis, the manufacturer must go through multiple processes to satisfy everyone. This is a huge burden to the manufacturers. Time and cost savings for both the certifying organization and the manufacturer would be realized if a standardized type certification approach was used and accepted worldwide.

4.2 Need for National Acceptance and Implementation of USGS Guidelines

In the past, the USGS performed all phases of the map production with in-house personnel with the exception of image acquisition, which was contracted to the private sector. Since proper camera calibration was critical to the remainder of the photogrammetric production process, the USGS imposed camera calibration requirements into its contract. Government agencies at all levels have since used the USGS calibration requirements in their contracts, and the current calibration requirements for analog camera became the de facto standard in the United States. It should be noted that the USGS never had authority to impose camera calibration requirements on other government agencies. However, since the USGS requirements became the de facto standard for North America, the USGS continued its camera calibration functions for the past three decades.

Today, agencies at all levels of government are contracting for their own products and services needs. These agencies all have their own contracting regulations and practices and are not bound by those used or recommended by USGS. Since USGS is not a regulatory agency, it can only recommend any guidelines it proposes and must educate other agencies on the merits of using best practices to ensure the quality of geospatial products. Organizations and agencies must develop and gain acceptance on new guidelines for emerging technologies by educating their constituents.

4.3 Guidelines Needed for Other Sensors

The USGS and its IADIWG partner agencies have been developing a quality assurance plan that focuses on digital imagery. Similar guidelines are also critically needed for Light Detection and Ranging (LiDAR), Synthetic Aperture Radar (SAR), and Interferometric Synthetic Aperture Radar (IFSAR), sensors that are already being widely used as single sensors or as integrated systems. It is important to establish a general governance model and best practices guidelines that can apply to all remote sensing technologies in the future.

5. CURRENT INTERNATIONAL COLLABORATION EFFORTS

The USGS and other countries and international organizations, such as EuroSDR (Cramer 2007a), Canada (Habib 2007), and others, have been researching and comparing calibration methods in the laboratory and in an *in situ* environment for Large Format Digital Cameras (LDFC), Large Format Analog Cameras (LFAC), and Medium Format Digital Cameras (MFDC). There is a strong need to collaborate and continue to test digital systems in the laboratory and in the field to evaluate standard procedures and processes for using calibration software in conjunction with quality guidelines.

It is well known that professional analog cameras, which have been designed specifically for photogrammetric purposes, possess strong structural relationships between the focal plane and the elements of the lens system. Medium format digital cameras, however, are not manufactured specifically for the purpose of photogrammetry, and thus have not been built to be as stable as traditional mapping cameras. Research has proven that their stability requires thorough analysis over time. If a camera is stable, then the derived Interior Orientation Parameters (IOP) should not vary over time (Habib 2006). USGS is continuing to work camera calibration and stability assessment processes and software with Canada British Columbia Base Mapping and Geomatic Services (BMGS) and the University of Calgary Digital Photogrammetry Research Group (DPRG) (Quackenbush 2007). The USGS and BMGS are testing digital camera systems and are working with the DPRG group to influence the calibration toolset that will work directly with accurate quality assurance processes defined within future guidelines and standards. Once clearly defined standards are developed and accepted, the accuracy of the final product can be evaluated thus ensuring high quality work, customer satisfaction, and offering well-founded encouragement for the use of digital imaging systems in current and emerging markets (Habib 2007). The EuroSDR is also working to understand medium format camera stability and calibration that will allow collaborative efforts to happen in the future (Grenzdörffer 2007).

The USGS has been using *in situ* system/product characterization of digital systems over test ranges to evaluate accuracy of the sensor system. Many of the LFDCs used in USGS contracts have been tested over common test ranges and the USGS is continuing to test the accuracy of these systems. The USGS and its partners, in conjunction with Canada BMGS and the University of Calgary, are also currently assessing calibration software using aerial imagery over designed camera calibration control point ranges to work toward an accurate and usable calibration tool for the community.

Additional ranges are being designed and will be available for testing in the United States. However, for the benefit of the manufacturer, data provider, and user, there is a strong need for worldwide, standardized calibration/validation ranges and associated range certification procedures. The establishment of worldwide, common test ranges should be considered an important international collaborative effort in support of manufacturer and data provider system calibration.

There is also a strong need for additional work related to spatial and radiometric accuracy and consistency assessment of digital sensors. The need to better understand and provide characterization methodologies to assess the digital sensor's ability to discriminate image content across spectral bands, spatially, and radiometrically, will be very important in the future. USGS and EuroSDR projects are working to improve knowledge on radiometric aspects of digital photogrammetric cameras and are analyzing the benefit of radiometric calibration in support of new applications (Honkavaara 2007). Collaborative efforts are required in this area to allow the development of additional standards and processes for spatial and radiometric calibration and assessment.

The USGS is very interested in establishing common guidelines and standards across the digital imaging arena, especially with respect to establishing similar processes and reciprocity related to digital imaging system certification and calibration requirements. The USGS has been working directly with the Canada BMGS, EuroSDR, and the Australia Intergovernmental Committee on Surveying & Mapping (ICSM) to reduce duplication of effort by utilizing partner expertise and to establish common requirements and processes (Christopherson 2007, Cramer 2007b, Duncan 2007).

6. CONCLUSIONS AND FUTURE COLLABORATION

The USGS sensor type certification team has learned from the initial certification reviews that many countries and organizations (e.g., EuroSDR, Japan, Russia, China, and others) are requesting similar activities related to system certification, but there is not a standard process to allow completion of the effort acceptable to all countries and organizations. The USGS is interested in working internationally to standardize processes and guidelines and share ideas and knowledge related to digital sensors. Having similar sensor type certification processes and other quality processes would be a huge benefit to the manufacturers and data providers, as well as the end users. National working groups, such as IADIWG, EuroSDR, and Canada BMGS, should be extended to an international working group that includes all countries working with digital imagery. An international group of this type would help standardization of digital imagery quality processes and efforts and help work toward future needs and processes in this rapidly changing environment. It is recommended that an international digital imagery working group be established to foster collaboration, promote commonality, and reduce duplication of effort.

A worldwide sensor type certification process would be beneficial to all those involved in the data acquisition and production process. Ultimately, it would be beneficial to the end user because such a process would ensure a quality product for remote sensing applications. Currently each country, agency, procurement authority, or user must establish their own criteria for sensor performance acceptance to make a purchase. This is inefficient, time consuming, and delays acceptance of new technologies. If one were to examine all the performance testing that has been conducted to date, one would find a high degree of similarity. The ISPRS, with its history, expertise, and infrastructure, is best positioned to develop and foster worldwide acceptance of a standard certification process for remote sensing technologies.

The use of remote sensing technologies is certainly global, and the reciprocal acceptance of another organization's sensor certification is feasible if a worldwide standard can be established. Manufacturers are selling their technologies worldwide, data providers are working globally, and remote sensing technologies have been used for Earth observing communities since its inception. It is recommended that the ISPRS Commission I establish a process to work toward a worldwide standard methodology for calibration and certification.

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