U.S. Geological Survey Digital Aerial Mapping Camera Certification and Quality Assurance Plan for Digital Imagery

GREGORY L. STENSAAS, Sioux Falls

ABSTRACT

The United States Geological Survey (USGS) has been characterizing and calibrating aerial and satellite sensors for many years. This paper will describe the USGS calibration and characterization processes and activities with respect to digital aerial mapping cameras. The paper also describes its Quality Assurance Plan for digital aerial imagery. By focusing on four distinct processes involved in procuring and generating digital aerial data, the plan is designed to ensure quality at each major step of the acquisition process and places the responsibility for maintaining quality with those most directly able to affect it. The USGS and its partner agencies encourages the use of the processes and guidelines outlined in the Quality Assurance Plan in hopes to help in the image acquisition and procurement process to ensure that the needs of providers and consumers of aerial data are met. The paper concludes with an outlook of future digital camera calibration research and development, and programmatic discussion related to collaborations and partnerships.

1. AERIAL MAPPING CAMERA CALIBRATION IN THE UNITED STATES

1.1. Background

Fig. 1: USGS Optical Science Labratory

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).

1.2. Methods of Camera Calibration

Basically, the purpose of traditional camera calibration is to be able to reconstruct the precise geometry of the bundle of rays that entered the camera at the instant of exposure by using the two-dimensional coordinate measurements of points on the resulting image. The solution to this problem is best performed mathematically using analytical models for radial and decentering distortion introduced directly into the well known photogrammetric projective equations. There are three methods for camera/sensor geometric calibration being used today: laboratory calibration using precision calibration instruments; digital sensor calibration via laboratory methods; and *in situ* (in-flight) calibration. The following sub-sections discuss USGS activities in each of these areas.

1.2.1. Analog Laboratory Calibration

In 1992, the USGS OSL implemented Brown's calibration concepts with the "Simultaneous Multiframe Analytical Calibration" computer program (Light 1992). The OSL employs an operational-type photographic method using multi-collimators for the determination of lens and camera constants of aerial mapping camera systems, conducted in a controlled, repeatable test environment. With this method, a series of optical collimators focused at infinity and equipped with reticules containing a center cross and image resolution targets, are affixed to supporting frames, and oriented toward a common camera station.

After glass plates are exposed with collimator and fiducials marks, measured on a comparator, and the resultant data reduced, and a Report of Calibration is issued by the OSL. 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 calibration report be delivered with the film images (Tayman 1984). Additional information about the OSL and camera calibration specifications is available at http://edclxs22.cr.usgs.gov/osl/index.html.

1.2.2. Digital Camera Laboratory Calibration

In the year 2000, a panel of experts commissioned by the USGS and the American Society of Photogrammetry and Remote Sensing (ASPRS) suggested 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 the USGS acquire a digital camera calibration capability to satisfy the growing national need. A design study on digital camera calibration sponsored by the USGS provided for a digital camera calibration facility to be installed at the USGS Center for Earth Resources Observation and Science (EROS), Sioux Falls, South Dakota.

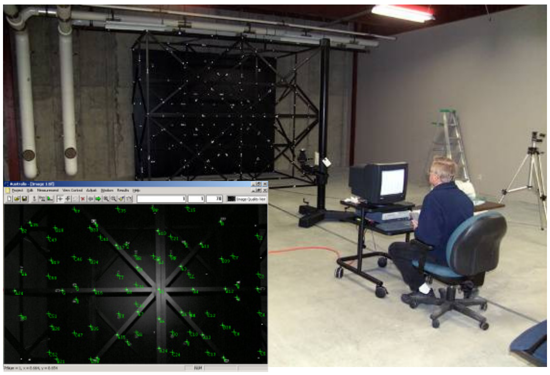

Fig. 2: USGS Digital Camera Calibration Cage

The EROS calibration facility supports small to medium format digital cameras via the use of a control point cage and an automated software program called "Australis" (Fraser 2001). Dr. Clive Fraser utilized Brown's developments and an automated measurement and a least squares data reduction process to produce Australis. This software reduced the labor-intensive task of measuring x, y-coordinates on the images used for calibration. The Australis software, used in concert with the image measurements from nine or more images taken of a control point cage, solves the exterior orientation of all the images while simultaneously determining the camera's interior orientation, lens distortion, and sensor non-orthogonality.

The current digital camera calibration laboratory cannot support calibration of large format systems, especially multi-sensor and scanning systems. The processes and methods proposed for understanding the quality of these systems and their data will be discussed in later paragraphs.

1.2.3. System Calibration Process

Now with the increasing availability and anticipated continued growth of digital sensors in the aerial mapping environment, USGS is establishing processes that can be used for the many different digital imaging devices used in the mapping world. Digital sensor calibration has been done for many years; however, the calibration of particular systems was usually performed by complete characterization of the system and the sensor. The premise that the USGS is currently working with is, “How do you come up with appropriate guidelines for calibration of digital imaging systems to meet all requirements of so many different systems being used for so many different purposes?”

With that in mind, the USGS is working to understand the many differences between analog and digital camera system parameters and their effect on products. Digital sensor systems have several aspects to consider; such as, frame sensor concepts versus line scanning approaches, multi-head systems versus single-head sensors, large image format data acquisition versus medium or even small format cameras, pan-chromatic and/or multi-spectral image data recording. These differences can result in different calibration approaches, which have to be treated individually for each sensor type.

Another significant difference between digital sensors and analog systems is the integration of the imaging sensors with an integrated global positioning system (GPS) and inertial measurement unit (IMU). The combination of digital imaging sensors with direct orientation components is straightforward, since they provide very accurate information on the sensors’ movements. This information can be used for fast generation of photogrammetric products, like orthoimagery. In the case of line scanning systems, accurate position data is mandatory to allow for efficient image data processing. Hence, calibration has to cover the entire sensor system consisting of an imaging component and additional components, such as GPS and IMU sensors. Also, the microclimate aspects of pressure, temperature, and wind; and platform effects; such as vibration, optics, and mounting, need to be addressed. Additionally, due to the new parallel multi-spectral imaging capability of digital sensors, calibration should not be restricted to only the geospatial aspects but must also include the radiometric aspect. The radiometric capability of satellite digital sensors has been very important in the remote sensing community and may now extend and grow in aerial imaging community.

Complete system calibration approaches are gaining importance due to the complexity of digital sensor systems consisting of several sub-components. The community recognizes that cameras have evolved beyond film to digital technology which includes GPS and IMU sub-systems needed to create and establish image reference; therefore, the new digital sensors require that a total system calibration approach be used.

The trend noticed in the data acquisition community is a wider use of *in situ* calibration (i.e., self calibration based on distinct calibration flights) in conjunction with laboratory calibration measurements. The user community’s acceptance of such a combined laboratory and *in situ* calibration methods is currently low and has to be increased. This low acceptance is caused by the understandable tendency to apply analog camera concepts to digital imaging systems. In the future, these combined methods will be accepted as powerful and efficient tools for overall system calibration. Since the calibration approach for large format, multiple sensor systems is a designed approach by the manufacturer and in conjunction with processes used during operation, the USGS has developed a plan for the Quality Assurance of Digital Aerial Imagery that looks at the quality process for the system through quality assessment of the data; a full systems approach.

1.3. Digital Camera Research and Colaboration

The USGS has been researching and comparing calibration methods in the laboratory and in an *in situ* environment for Large Format Digital Cameras (LDFC), Large Format Analog Camera (LFAC), and Medium Format Digital Cameras (MFDC) with respect to comparability to film, sensor/product characterization, camera calibration, stability analysis, environmental effect analysis, achievable accuracy, and *in situ* calibration and stability assessment. The USGS has tested over 30 camera systems and multiple lenses in the laboratory and continues to partner and collaborate to better understand technology and relate it to science applications. The USGS continues 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.

1.4. Using *In situ* Camera Calibration

The United States Geological Survey (USGS) recognizes the need to calibrate cameras in a manner that accounts for the camera's operational environment (i.e., *in situ* calibration). In addition, the advancement of airborne sensors associated with the metric camera makes it necessary to collect calibration data of the camera and of the relationships between the added sensors, both in terms of spatial orientation and position. To accomplish this in a practical manner, data for calibration is be collected under circumstances in which all airborne sensors are employed simultaneously and within a range of altitude and platform speed intended for operational use. Photogrammetrically, the computation associated with this form of calibration has been termed "Bundle Block Adjustment with Self-Calibration" (BASC) (Merchant 2004). The prime purpose of this software is for measuring imagery and computing the calibration solution for both digital and film-based aerial cameras. This software provides the tools and a practical understanding for establishing an *in situ* approach to camera system calibration including added airborne sensors.

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).

Based on the University of Calgary Digital Photogrammetry Research Group (DPRG) camera calibration and stability work, the BASC software package is currently being upgraded by USGS and Canada British Columbia Base Mapping and Geomatic Services (BMGS) through the University of Calgary DPRG to provide an enhanced, user-friendly, upgrade to include both point and linear base tools, such as a Multiple Sensor Advance Triangulation tool, a new mensuration tool, and camera stability software module. The upgraded BASC software will utilize allow of two sets of IOP of the same camera that have been derived from different calibration sessions to assess their equivalence and determine camera stability. The linear based tools will provide users the ability to setup a simple calibration test field without incurring large expenses, as well as reduces the required number of point features necessary for *in-situ* or laboratory calibration. The software allows for the automated extraction of image points and line features will greatly aid in the efficiency and ease of the overall calibration process, and thus encourage companies and manufacturers to perform reliable camera calibrations and ensure stability over time.

The USGS is currently using this software via aerial mapping flights over design camera calibration control point ranges at the USGS Center for EROS in Sioux Falls, SD and the Ohio Department of Transportation range in Madison, Ohio. The software is being used to study *in situ* calibration and is being Beta tested for proper analysis and usability. Additional *in situ* ranges are being designed and will be available for testing in the United States later this year.

Methods for the determination of camera stability in addition to the procedures for camera calibration and validation are being worked via initiatives undertaken by the British Columbia BMGS and the USGS via collaboration with the University of Calgary DPRG. The USGS is very interested in a continued relationship with Canada and BMGS. The standards and specifications being compiled through this joint effort can serve as a reference for the mapping industry, for the purpose of regulating the product quality attained through the use of digital cameras in airborne mapping, and will serve as a guide for newcomers to the industry. This joint effort will produce definite standards and specifications for MFDC calibration and stability analysis, in addition to outlining achievable accuracies for various integrations of sensor data and ground control for airborne mapping. The USGS and BMGS are continuing to test digital 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 accepted, the accuracy of the final product will be definite, 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 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 of requirements for the manufacturers and data providers. See links to these partners in the references below.

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

2.1. Background

The USGS, as directed by the ASPRS Camera Calibration Panel, developed processes and guidelines will assure that high-quality digital aerial imagery can be produced and procured. A four-part process plan has been developed and reviewed in consultation with major federal agencies, industry, and academia. In order to address the needs of the federal consumers of aerial digital imagery and support development of the plan, the USGS established the Inter-Agency Digital Image Working Group (IADIWG) to help address issues when contracting for digital imagery. The IADIWG consists of fourteen federal government agencies and represent the largest purchasers of data in the nation. 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 USGS and its partner agencies hope to encourage the use of digital aerial imaging systems to meet the needs of providers and consumers of aerial data.

2.2. USGS Quality Assurance Plan for Digital Imagery Data

The USGS Quality Plan (web reference) addresses the procurement and generation of digital image data in two domains, data procurement and data generation. The Quality Plan outlines four distinct elements in these domains as follows:

Data Procurement:

Defining the contract requirements and data specifications.

Defining a process and the criteria to validate that the deliverables meet the terms of the contract.

Data Production:

Manufactures have produced adequate systems, both hardware and software, which can perform the necessary primary data acquisition.

Data Producers have integrated these systems into their production environments and have produced the required data products.

The next sub-sections describe how the USGS addresses quality assurance in each of the four individual parts.

2.2.1. Contracting Guidelines for Digital Aerial Imagery

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 of 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 is being developed. This tool will help the user to determine appropriate image specification requirements.

2.2.2. Manufacturer Certification

The second step in the process in 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 Manufacturers Certification simply endorses that particular "type" 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. At this point, the USGS has not attempted to judge the application capability of systems but has left the application mix of capabilities, usability, and price for the market to decide. However, based on discussions of need from the community, USGS recognizes that an understanding of application-based capabilities may be required and the USGS is interested in working with the community and partners to help establish this understanding.

As of this writing, the USGS has worked on four manufacturer certification efforts with digital aerial sensor system manufacturers (Applanix, Intergraph, Leica, and Microsoft Vexcel). The initial effort was focused on the major manufacturers of digital aerial sensors in use. This effort is undertaken with the support and cooperation of the major manufacturers to help further develop and refine the standards and methodology used by the USGS in this process. At this time, the certification is being done 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 manufacturer certifications efforts, and has provided comments to the USGS team (Cramer 2007).

2.2.3. Data Provider Certification

The third part of the USGS 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 product for the customer. A Data Provider can be 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 the requirements of the Data Providers certification are met by all subcontractors and business partners.

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 has a well-documented and has followed quality plan governing all operations from data collection to product delivery. This certification ensures 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: evaluating the process that a provider uses to ensure a quality, consistent product, and evaluating whether the provider can use the process to produce products of a designated quality level.

The USGS has established a Data Provider Certification team to evaluate the processes used and the imagery taken over designated test ranges. The Data Provider Certification team is currently working to establish the evaluation criteria and will evaluate the implementation of this portion of the plan with five data providers. The USGS is also working with partners to establish additional *in situ* test ranges, strategically located, throughout in the United States.

2.2.4. Acceptance Guidelines for Digital Aerial Data

The final portion of the USGS Quality Assurance Plan deals with the question of determining whether or not the data delivered a data provider meets the quality specifications in the contract. An 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 be a big benefit for "smaller contracting offices without 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. 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, final drafts of the plans for the data provider certification process are being reviewed, and the recommended quality acceptance guidelines and practices are being compiled.

3. FUTURE VIEW AND OUTLOOK

The USGS has been researching digital imaging sensor capabilities via the laboratory and the field for many years. This effort has allowed us to follow the growth in the digital sensor market and to understand the ability of the digital system to meet science applications needs. New digital imaging technologies, strong growth in the use of digital imaging sensors, and the community-wide push for applications will to allow this market to continue to explode in the Geographic Information System (GIS) and Remote Sensing areas.

The USGS has been using *in situ* system/product characterization of digital systems over defined test ranges to evaluate prescribed accuracy of the sensor system. Many of the LFDCs used in USGS contracts have been tested and the USGS is continuing to test the accuracy of these systems. There is also a strong need for additional work related to spatial and radiometric accuracy and consistency 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. The USGS is working to establish test methods for assessing these areas in the near future and will be looking for partners in this area.

The *in situ* characterization and calibration process is a great methodology for assessing system accuracy and learning about stability of systems. However, the USGS realized that digital system characterization and *in situ* calibration work did not account for the full process of creating quality image products. In order to assure consistent, quality imagery, the USGS need a way to understand the capability of the system, the user of the system, imagery created by the system, and the quality processes associated with image delivery. The USGS recognizes that there are numerous data providers, using a wide variety of sensor systems, providing geospatial products to the user community under different contract specifications and requirements. Further, the USGS also recognizes that simply implementing capabilities to calibrate digital sensor systems does not ensure the overall quality of geospatial products.

In order to meet the broad needs of the federal consumers of aerial imagery, the USGS established the Inter-Agency Digital Image Working Group (IADIWG) to deal with a broader issue of quality when contracting for digital imagery products. The IADIWG consists of fourteen federal government agencies and represent the largest purchasers of data in the America. This group helped establish a quality assurance plan for digital imagery and meets on a regular basis to address digital imagery technology issues, interoperability, information and knowledge, and enhanced quality assurance methods.

USGS manufacturer certification team has learned from the first four manufacturer certifications that many countries; such as, Japan, Russia, China, and others, are requesting similar activates related to system certification. The USGS is interested in working internationally to standardize processes and guidelines, and share ideas and knowledge related to digital sensors. The advantage of having similar manufacturer type certification processes and other quality processes is a huge benefit to the manufacturers and providers, as well as the consumers. An effort similar to the IADIWG could be beneficial to all digital images users worldwide. 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.

The USGS Land Remote Sensing Program, the National Geospatial Information Program Office, the IADIWG, and associated partners and collaborators will continue to establish processes and techniques to allow the enhanced use and confidence in digital imaging systems. The USGS will continue supporting and training partners and users on contracting and technical aspects of digital imaging systems. The USGS is always open to suggestions and partnerships related to enhancing the ability of remote sensing to address societal needs. Please contact us with suggestions, partnership and training ideas, questions, or comments.

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