TRADITIONAL AERIAL FILM CAMERA VS. DIGITAL CAMERA

Statewide Mapping Advisory Committee
Working Group for Orthophotography Planning

Introduction

Large Format Digital Camera Technology arrived in the market in 2001 and took over the large scale aerial imagery producing world. This whirlwind of new technologies took everyone in need of aerial imagery by surprise, especially those who didn't need it often. It is now in the last five years that this technology is being vastly used by more local and state entities. The current North Carolina Land Record Specifications [1] were created for and are related to aerial film collection. This paper will attempt to bring meaning to the differences outlined in the North Carolina Land Record Specifications [1] between the aerial film camera collection and digital camera collection. For the purposes of this paper the term "digital camera" refers to large format digital camera sensors. This paper was never intended to explain the mathematics of the topics listed below. There are several links to other resources that have detailed explanations of the mathematics behind the film and digital camera.

Film vs. Digital

There are fundamental differences between Digital Orthophotography produced from aerial photography acquired with a film camera and a digital camera. The main difference seems simple enough. In order to produce a digital aerial photograph, the film camera collects film. The film must be developed and the developed film products must be scanned to produce a digital aerial photograph. The scanned image is the digital aerial photograph. In comparison the digital camera collects a digital aerial photograph at the time of acquisition. This means that for the digital camera there is no film, there are no negatives, there are no diapositives, there are no contact prints, there is no need for a scanning device and scanning resolution is not applicable. None of these products or processes is available or necessary with the digital camera.

The elimination of the film development and the scanning process has some advantages in production scheduling for digital orthophotography production. Over time the process of developing film has become a highly specialized service particularly for large aerial photography projects. There are two major reasons for this. One is the chemicals used to develop film. The second is the specialized training in the film development process. Because of this film development is a technical service that is typically outsourced to specialty companies and the lead-time must be added to the turn around time for film based orthophotography projects.

The second production scheduling difference is the elimination of the scanning process. Scanning has to be done in a clean room environment to eliminate artifacts in the scanning process. Because of this, scanning can be done in house by the vendor if the facility is available or outsourced if not. Clean room environments must be a

requirement for scanned products. The turn around time for this process has to be included for film based orthophotography projects.
Finally, the film used in the cameras is a specialized product; because of the evolution of digital camera technology it will become increasingly difficult and more expensive to purchase film. This will become more apparent in specialized film products like color infrared. While it is true that we are moving to a new "digital age", there are core IT (Information Technology) issues related to digital camera technologies. Raw digital data files are large files and the process of downloading and verification is a time consuming process. These processes are typically done in-house which eliminates outsourcing certain processes. In addition, there is no historical process flow because this process is relatively new. This should be discussed at the time of aerial acquisition planning.

Camera Calibration

Historically, any type of aerial acquisition planning includes accuracy requirements. These accuracy requirements are necessary to determine what terrain surface model is needed to produce orthophotography, topography and other planimetric products. This is a fundamental requirement of any aerial acquisition regardless of what camera (or sensor) is used. The final project accuracy (this is not pixel resolution) needs to be determined at the onset of a project.
This paper is not going to get into specific mathematics for film base aerial cameras and acquisition; however, all film cameras are built and based upon the same mathematical formulas. In other words, *"field area cameras for many years have been based on consistent square formats, focal lengths and angles of field" (Characteristics Of New Generation Of Digital Aerial Cameras)* [2]. In addition, because of this consistency all film cameras can be calibrated by the same methods. 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)*[3]. A current calibration report is typically a required deliverable for any aerial mapping project. One of the contingent points of digital cameras is that there is no specified means of calibration. The sensor geometry is unique to each type (sometimes even model) of digital camera. Each digital camera manufacturer has a unique design. Therefore, there is no means of doing a single or series of camera calibrations as is done for the film cameras. Currently vendors send the digital cameras back to the manufacturer where it is tested, serviced, and certified to be as accurate as when created. There is an exciting new option in which calibrations sites are set up to verify the accuracy of digital cameras. The USGS is also thinking about using these sites for film cameras to test in situ calibration *(USGS/OSU Progress with Digital Camera in situ Calibration Methods)*[4]

Pixel Resolution, Ground Sample Distance, Photo Scale and Accuracy

The next major difference between film cameras and digital cameras is related to pixel resolution. Again, the film camera collects film, the film must be developed, the developed film product must be scanned to produce a digital image (digital aerial photograph). Pixel resolution is directly related to this digital image. In the film products the scanning process turns the film image into a digital image comprised of many pixels.   In comparison, digital cameras collect the digital image; the pixels are produced at the time of acquisition.   This is important to understand during the project planning process.   Pixel resolution is not an accuracy statement. Pixel resolution is the size of the final pixel. Ground Sample Distance (GSD) is the corresponding distance on the ground that is within the pixel. For example a 1 foot pixel resolution means that every pixel in a digital image is one foot on the ground. It does not matter if it is a digital image collected from a digital camera or a film product scanned to a digital image. It also does not mean that the measured coordinate of that 1 foot in the digital image is the same as the coordinate of that corresponding point on the ground. You must state the pixel resolution requirement and also the accuracy requirement of that pixel to the corresponding "real world point". This can be confusing in the "digital" world because in the traditional "film" world there was photo scale. "*Photo Scale is the ratio of a distance on an aerial photograph to that same distance on the ground in the real world*". *(Scale and Area Measurement)*[5] Because digital images are not photos there is no photo scale. This is a simplification but, photo scale contributed to the determination of the accuracy of the final pixel to the real world corresponding location. It is important to determine in project planning the final pixel resolution, the corresponding GSD and the accuracy requirement. It is important not to substitute the term pixel resolution for accuracy.

Scanning Devices and Scanning Resolution

Scanning is directly related to film camera technology. The film camera has changed very little over the years; one of the technological advances that have occurred is related to the scanning devices. Like most technologies, scanning devices have become more powerful and more accurate.

"The device used for scanning shall be a precision instrument designed and manufactured for use on aerial film and/or diapositives with an aperture which can produce a scanning resolution of at least 9.5 microns (approximately 2600 dots per inch), geometric accuracy of less than 5 microns RMSE, and a capability of resolving 256 levels of gray and 256 the levels each of red, green and blue bands."(North Carolina Land Records Standards) [1]

Now remember that the pixels are produced in the scanning process. The scanning process takes the film product and converts it into a digital form that can be recognized by a computer.   This digital form is a collection of pixels that make up the image. The scanning process uses the measurement term (or unit of length) "micron". A micron is one-millionth of a meter or 39 millionths of an inch (.000039). The size of the pixels that make up the image is called "pixel size" and is usually expressed in microns, a pixel size of 50 means that each pixel in the image is 50 microns wide. The number of pixels per inch of the image is commonly called DPI, which stands for Dots per Inch. This measurement term is a carry over from printing technologies where an image was created by putting dots on the paper. Remember the dot matrix printer? The measurement means the higher the DPI, the higher the quality and the larger the file size. The file size is larger because there are more pixels per inch in the image. Another way to express this is the smaller the pixel size the more pixels it takes to fill an inch of the image. (There are many scanning devices that can produce a scanning resolution less than 9.5 microns, 7 microns is not uncommon. With any scanning resolution less than 9.5 microns the vendor should have a history of working with this scanning resolution.

The ability to scan at smaller resolutions meant that the flying height could change. Because of this there was a period before digital camera technology where it became more common that film camera specifications changed to adjust to newer technology in scanners. The mathematical calculations related to the actual film camera did not change but these “super” scanners allowed the plane to fly higher to produce the same pixel resolution, which reduces flight line miles, which reduces cost, or allows production of smaller pixel resolutions at the same flying height. The only reason this is discussed in this paper is because there was a period of time where high resolution imagery acquisition (less than .5 feet) collected by a digital camera was impacted by this final pixel size requirement and the horizontal accuracy requirements. Because there was no intermediary process with the digital camera to produce pixels, the image acquisition process could be a problem. In other words, there were restrictive flight acquisition requirements to collect these high resolution images and it was could be problematic and expensive. Recent changes in technology have adapted to these issues, but should be discussed in project planning when the final product requirements are pixel resolutions are below .5 feet. (*What Scale is my scan? And other common questions, Keystone Aerial Surveys*) [6]

One advantage of these higher resolutions is that the smaller the pixel resolution the more detail the image has and as a final digital product the closer the user can “zoom in” to see details. Pixel resolution became very important to the users. If you need very detailed final orthophotography you need to fly low enough for the camera to “see” the details. For example, if the end user needs to “see” manhole covers in the final digital orthophotography, the project has to be flown so the camera can “see” the manhole covers and the manhole cover shows up in the original digital image and by default the details of the manhole cover are visible in the final digital orthophoto image. Be specific about what you expect in the final product.

In comparison, the digital camera collects the digital aerial photograph at the time of acquisition. The final orthophoto pixel resolution is directly related to the pixel resolution acquired at the time of flight acquisition. There are no negatives, no diapositives and no scanning process. There are no secondary processes that impact the pixel resolution of the aerial photograph. If the final orthophoto pixel resolution is .25 feet you have to acquire the imagery to support a .25 feet pixel resolution. The same truth applies as with the film camera. If you need very detailed final orthophotos you need to fly low enough for the camera to “see” the details. If the end user needs to “see” manhole covers in the final digital orthophoto, the project has to be flown so the camera can “see” the manhole covers and the manhole cover shows up in the digital image. Be specific about what you expect in the final product.

It is important that during the project planning process for any aerial acquisition that several things are considered. The current or future need for topography and 3d planimetric products should be discussed. The accuracy requirements for these products are much more stringent than for orthophotography. Is there a necessity either short term or long term, for stereo pairs? The North Carolina Land Records standards for film acquisition are 60% overlap and 30% sidelap and this provides for stereo coverage. (*North Carolina Land Records Standards*) [1] Data Acquisition for digital orthophotography may not be sufficient to produce stereo pairs. This is no reflective on data providers. This needs to be clearly specified in project planning and discussed up front. Stereo Pairs can be produced from aerial photography acquired with a digital camera but they are secondary products and not a standard deliverable. Digital orthophotos can be used to "heads up digitize" planimetric features. These are 2D products with no vertical attributes. Stereo pairs are used to produce 3D compilation products.

Ground Survey, Global Positioning Systems and Inertial Measurement Units

Digital aerial photography is not the same as a Digital Orthophoto.
"A digital orthophoto is a digital image that has the properties of an orthographic projection. It is created from perspective aerial photography by differential rectification so that image displacement caused by camera tilt and relief terrain are removed. This process requires, as input, ground control points acquired from ground survey ,and airborne Global Positioning System and Inertial Measurement Units (IMU). It also requires aerial triangulation and a digital elevation model (DEM)."(*North Carolina Land Records Standards*)[1]
Orthophotography are photos where all the misalignment has been corrected and the photos are tied to each other in the proper geographic location. Orthographic projection means that even though the image is a two-dimensional object with no elevation (z value) it has been corrected to a three-dimensional plane or surface. It is a very complicated process that is very simple conceptually. The camera takes pictures, the camera is in an airplane, the GPS tells the airplane where it is located, and the IMU tells the plane if it is tilted in the air. Through the magic of computers and synchronized clocks the picture (aerial photograph) knows when it was taken, what picture is next to it, where it was located when it was taken and if it was horizontal straight. This is called direct referencing. Traditionally direct referencing was an indirect process and achieved during the aerial triangulation process. Aerial triangulation is the mathematical process to determine the position and orientation of each photograph at the moment of acquisition. It is an indirect process that occurs after the film is developed and the images scanned. These scanned images are just pictures, they have no location information. Aerial triangulation is a complicated process but the end result is that the scanned image has location information.

Another significant difference between digital cameras and film cameras is the integration of the imaging sensors with an integrated GPS and IMU in the digital camera. This allows directly measured position and orientation of aerial images or to aid other orientation methods (*System Calibration of Aerial Camera/GPS/IMU Systems – Procedures and Experiences Jens Kremer.)* [7] All this means is that the image has location information inherent at the time of acquisition. Because this is a direct process it can reduce the amount of ground control necessary and also time during the aerial triangulation process. This does not eliminate the need for surveyed ground control or aerial triangulation.

The other outcome of this integration in the digital sensors means that every pixel collected has location information at the time of acquisition. Every pixel has a coordinate. This means that a terrain surface can be produced. This is not a ground surface model. It is usually referred to as a Digital Surface Model and represents the canopy of landscape. It can be used in the ortho rectification process. *(Dense Digital Surface Model and TrueOrtho image allow supporting versatile and Innovative applications)*[8]

Digital Camera Information and Resources

There are four major large format digital cameras utilized today. These are the Leica ADS40 2nd generation, Z/I Imaging DMC, Ultracam-X, and DiMac.

The Leica ADS40 2nd Generation Sensor is a line-scanning sensor that collects images in a 12,000 pixel-wide swath. This camera can simultaneously collect panchromatic, color and color-infrared stereo imagery, collecting all multi-spectral bands simultaneously at the same high resolution. Providing 5-band, co-registered and equal resolution imagery from data acquisition.
http://www.leica-geosystems.com/corporate/en/ndef/lgs_57627.htm

The Z/I Imaging DMC or Digital Mapping Camera System incorporates frame sensors rigidly mounted giving stable internal geometry. 4 high resolution panchromatic camera heads and 4 multi-spectral camera heads.   The camera was designed to perform under diverse light conditions with a wide range of exposure times and utilizes electronic Forward Motion Compensation (FMC)
http://foto.hut.fi/opetus/350/k03/luento7/DMC.pdf

The Vexcel Ultracam-x is which collects a 14,430 pixel-wide swath. The vexcel collects panchromatic and multi-spectral separately (9 pan and 4 color arrays).
http://www.dcviews.com/press/pdffiles/Vexcel-Ultracam-x.pdf

DiMAC- Large format frame based digital camera which collects a 10,500 pixel wide swath.   Its modular design allows combining 1, 2, 3 or 4 camera modules together (true-color and IR) and producing 1.2.3 or 4 individual images simultaneously. The DiMAC also incorporates forward motion compensation
http://www.dimacsystems.com/pdf/dimac_technical_specifications.pdf

Other References:

1. North Carolina Land Records Standards,
http://www.ncgicc.com/Portals/3/documents/orthostand.pdf

2. Characteristics Of New Generation Of Digital Aerial Cameras, The Future Of Digital Images In Photogrammetry, By John Trinder
http://aerialservicesinc.com/news/archives/articles/0607_digitalcameras.html

3. USGS/ Optical Science Lab (OSL)
http://edclxs22.cr.usgs.gov/osl/index.html

4. USGS/OSU Progress with Digital Camera *in situ Calibration Methods,* D. C. Merchant[a,]*, A. Schenk[a], A. Habib[b], T. Yoon[a]
http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VF4-4K7FJC0-1&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=d155fe0e0422066716a8ad3565da6211

5. Scale and Area Measurement,
http://www.geog.ucsb.edu/~jeff/115a/lectures/scale_and_area_measurement.html

6. What Scale is my scan? And other common questions, Keystone Aerial Surveys
http://www.keystoneaerialsurveys.com/faqs.html#scaleofscan

7. System Calibration of Aerial Camera/GPS/IMU Systems –Procedures and Experiences; Jens Kremer .
http://www.isprs.org/commission1/euroCOW06/euroCOW06_files/papers/Kremer_EuroCOW_06.doc

8. Dense Digital Surface Model and TrueOrtho image allow supporting versatile and Innovative applications; Myriam Chikhi, Frank Bignon
http://www.aars-acrs.org/acrs/proceeding/ACRS2006/Papers/H-1_H1.pdf

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