ITT

Aerial Photography Field Office—National Agriculture Imagery Program (NAIP) Suggested Best Practices – Final Report

CDRL A006
SUBMITTED UNDER GSA Contract Number GS-23F-0284M, SIN 871_2

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February 1, 2007

Executive Summary

ITT Space Systems Division (ITT) has completed an initial effort to identify opportunities for improving image quality delivered to APFO by vendors and providing recommendations of best practices to achieve those goals. These recommendations are geared towards the National Agriculture Imagery Program (NAIP) however they are pertinent to other enterprise production efforts, such as the National Resources Inventory, or any program that might replace NAIP.

The recommendations are based on a combination of observations from the FSA User Study and vendor visits completed for this effort. These recommendations are not requirements for specific procedures, but are intended to outline good image processing practice that will produce more consistent and desired image quality results. The main emphasis is on encouraging vendors to process imagery as components of a whole rather than optimizing each individual tile in a mosaic. This report includes sections for collection, processing, and characterizing imagery as well as supplying supporting processes such as metadata, QA/QC processes and workstation calibration.

Methods for calculating metrics to characterize several image attributes are also given as well as suggested minimum and target values. The contrast, color balance, and individual channel clipping metrics are recommended to be used during all phases of image processing. The sharpness, noise, saturation and overall clipping metrics are more suitable to be used as final image compliance measures.

1 Introduction

ITT Space Systems Division (ITT) has completed an initial effort to identify opportunities for improving image quality delivered to APFO by vendors and providing recommendations of best practices to achieve those goals. These recommendations are geared towards the National Agriculture Imagery Program (NAIP) however they are pertinent to other enterprise production efforts, such as the National Resources Inventory, or any program that might replace NAIP.

ITT began with an assessment of user sensitivity associated with typical products used by FSA field offices, and then, in the context of user priorities and feedback based on product variations, meet with a representative subset of vendors. Given the significant production volume and tight collection timeframes associated with the NAIP, the observations from the end user perspective were then integrated with the observations of how the imagery was produced to identify practices, processes, and metrics that should aid in achieving optimal imagery.

The initial phase of the contract (the FSA User Sensitivity Study), documented that USDA end users of NAIP imagery are sensitive to image quality and that degraded image quality impacts their ability to discern CLU boundaries. For example, imagery that was low contrast caused fatigue and was prone to inaccuracy as the definition of fields was less clear. Also, the study documented that users desired consistent and sufficiently saturated color reproduction to aid in the determination of crop type for compliance issues.

Tone and color is influenced by every step in the imaging chain. At a high level, the imaging chain consists of capture, processing, and display. The User Sensitivity study focused on the display step, however, visits to several vendors allowed observation of practices used to capture and process NAIP imagery. This report describes recommendations of practices that may be implemented by the vendor to more consistently deliver imagery of the desired tonal and color characteristics both for NAIP and any subsequent programs.

The following sections describe recommendations for handling and processing imagery to help ensure that an optimal product is delivered. These recommendations are not requirements for specific procedures, but are intended to outline good image processing practice that will produce more consistent and desired image quality results. Section two describes the auxiliary information or metadata that will aid in tracking image quality issues and enhance the overall applicability of the imagery. Sections three through five describe collection recommendations, characterization , and processing recommendations, respectively. Sections six through eight detail considerations for image delivery, viewing environment, and storage.

2 Image Metadata

2.1 Job Tracking

For any vendor, there are two primary forms of metadata: the overall job tracking system and the data referenced. The vendor job tracking system is in effect, an all-inclusive database yielding information regarding collection, manipulation, processing, and archive/storage parameters about image data. The customer (APFO) metadata is a subset of this job tracking system. It is the main connector between the two parties, vendor and customer.

Job tracking may be the most essential part of image processing and data retention. Metadata, when recorded accurately, allows the re-creation of any dataset without storing any unnecessary, intermediary processing files. Only raw, or native, data and records determining how the end product or customer deliverable was built are required. This includes but is not limited to: aircraft, sensor, and collection parameters, processing parameters for developing data (film and digital), image corrections, orthorectification, orthomosaicking, image compression, QA/QC, data archiving, data delivery, project management, staff at each step, and other pertinent information.

2.2 Product Metadata

The metadata, or data about data, is sent with the deliverable to the customer, and is a subset of the complete vendor job tracking dataset. It is the vendor’s best tool to demonstrate product(s) meeting customer requirements. It does not contain proprietary vendor information, but allows traceability between the product and raw data. This section is specific to DOQQ imagery, and much of the suggested information can be accommodated in GeoTIFF fields.

Having high-quality metadata facilitates any needed discussions between customer and vendor, demonstrates that the product meets or exceeds contract requirements, allows rapid discrepancy remediation, maintains accountability, and allows both the customer and vendor to compare and contrast data and costs across jobs, contract, and time.

Customer (APFO) metadata for each data delivery should include camera/sensor certification reference and collection settings, collections dates, flight collection conditions, and information regarding processing systems or imaging chain. A more detailed description of the categories listed is given below.

2.2.1 Camera/Sensor Specifications:

The camera/sensor specifications should be included with metadata sent to the customer as provided to the vendor from the OEM. The manufacturer hardware specifications should include all information regarding the sensor, such as the lens, lens filter(s), sensor array, shutter assembly, and other. This varies by sensor type as film and digital imaging systems are very different. Systems vary not only by type, film or digital, but by manufacturer, make and model.

The possession of this information allows feedback from the APFO to the vendor if any recurring problems are found within the imagery that may be attributed to the sensor, aircraft or data collections. The ability to trace and aid in the identification of sensor issues can reduce costs associated with reprocessing data, and may eliminate unnecessary reflights. This may also release the vendor from liability if an error or problem can be traced back to the sensor manufacturer, if multiple systems of the same make and model are exhibiting the same problem.

The vendor should provide proof that the sensor system is capable of collecting geometrically and radiometrically accurate imagery. The vendor should supply calibration certification, maintenance certification, and all supporting documentation to the APFO. This gives confirmation that system and preventive tasks have been completed for all aerial imaging sensors, to encompass the duration of USDA image collects. As part of the metadata, the vendor should include the date of the latest certification as well as accuracy results.

2.2.2 Date of collect

Flight conditions such as weather and camera settings vary from day to day and collect to collect. Geographically adjacent images may be noticeably different; combining multi-date data may introduce real or perceived visual artifacts to imagery. This may include stretched or compressed dynamic ranges, clipping, haze, very rapid or distinct changes in any of the above listed items that appear to be field boundaries. Ideally a CCM is comprised of only one flight.

Recording the date of collect is significant to FSA agents. This effort facilitates such tasks as crop identification, crop yield, legal and other related issues. This information could be embedded into the GeoTIFF tags of individual DOQQs, packed into a database file, or listed in a text file shipped with the package of deliverables.

Using this information will help FSA agents determine that what they are seeing in any given a situation is related to differing collection parameters versus a real linear field boundary, road, or other ground feature. Having this data also allows the user to trace back to the vendor. The vendor is then able to answer any specific questions about what happened the day of collect.

2.2.3 Flight Collection Conditions

Metadata should also include specific information about the flight collect including flight conditions, flight crew, camera settings and sensor data regarding each individual image collected per CCM and DOQQ. This is important for APFO QA/QC personnel and end users to understand the relationship between flight collects, changing flight conditions, and resultant imagery without attributing these differences to actual ground data.

A data report regarding the collect should include specifics for the below listed items:

Flight Conditions: Air temperature, relative humidity, percent cloud cover and type of clouds, time of day, light intensity (#fL or cd/m^2 and degrees Kelvin)

Flight Crew: To include all members; Pilot, Navigator, sensor operator, and others on board.

Camera Settings: Focal length, exposure, aperture, shutter speed, ISO, exposure compensation, and other

Images: the unique image ID or name, collection date(s), image format and naming, the time of capture, altitude of the aircraft above sea level, height of the aircraft above the ellipsoid, photo-event stations, flight paths, roll (tilt), pitch, heading, latitude, longitude, UTM zone, exposure, aperture, f-stop, ISO, lens, and other. The vendor need only report those pieces that correlate to the end product. For example, the end user does not need to know the roll of the aircraft for frames not compiled in the end product dataset.

2.2.4 Image Processing

There are two types of processing that occur post-collection; processing to give correct radiometric response (e.g. tone and color) and geometric processing.

While no specific metadata must be supplied with the delivered imagery, well documented processes should be in place to ensure consistent and repeatable results. Software versions and processing parameters should be included as part of the job tracking information.

3 Image Collection

3.1 Camera Certification Requirements

Tests and certifications should be performed to manufacturers' standards and requirements by an approved subject matter expert. Procedures and parameters are unique to manufacturer since hardware varies from manufacturer to manufacturer and sensor to sensor.

The camera certification should be detailed only to the extent necessary to demonstrate that the camera is proven to operate to manufactures specifications, and meets the USDA APFO NAIP contract requirements. Certification documentation should include at a minimum: agency information, date of certification, an outline of procedures completed, and results generated for geometric and radiometric calibrations.

Geometric testing should include all the following that is applicable to the sensor type: calibrated focal length, lens distortion parameters, the principal point offsets (Xpp, Ypp), boresight angle values (tx, ty, tz), lever arm values (lx, ly, lz), image size and pixel size (microns), and other. Camera boresighting should also be performed to manufacturer's specs, on an as needed basis and documentation sent along with camera certification.

Radiometric calibration parameters and files should also be provided to the APFO. These should include performance metrics for the sensor across the measurable spectrum for each band, (R, G, B, NIR, IR, other).

A film and digital cameras should be calibrated no less than once every three years, and once a year, respectively. (This is due to the behavioral characteristics of the focal plane array and possible CCD degradation.)

3.2 Standard Collection Methods

It is crucial that vendors follow consistent practices when collecting image data. They must always adhere to contract guidelines, and notify the contracting agency immediately if an issue arises.

A lack of consistency in collection methodologies becomes apparent in imagery. Any change in collection methods such as collecting at a different bit depth, the use of a different lens filter, collecting outside of a typical flight window (time of day), or other change compounds the effects of these visual differences and compromise the integrity of the image data. All should remain constant; do not alter collection parameters or change methods during flight. Any deviations required by extenuating circumstances should be recorded in the metadata.

Prior to data acquisition, the mission should be well thought-out and planned. A plan should clearly indicate data collection parameters to be used including the following:

Flying Height: the flying height of the platform should be that so images are captured on a 1:1 ratio, where one pixel equals one ground resolution unit as defined by the contract (1m or 2m). This ensures images are captured at the resolution needed for processing and delivery to the customer.
Flight Path: Standard practice indicates that flight lines be arranged in parallel lines in the North to South directions to minimize the effects of shadows over the duration of the flight, as sun angle is constantly changing. This may not always maximize the efficiency of the aircraft, however imagery will be more consistent and require less processing.
Frame rate: The frame rate, or the rate at which the camera captures images, should be set so that images are recorded with the needed overlap and sidelap for stereo imagery. Having multiple images at each point ensures that the most nadir pixel will be chosen during the orthorectification process, eliminating any effects of platform movement such as roll, pitch, or yaw. Five images should be available for every pixel recorded in the survey area.
Forward Overlap: 55 – 65% of overlap should be collected for stereo images or 20 – 30% overlap for mosaics. There should be half of a frame's length (50%) between the center of one frame to the center of the next frame.
Sidelap: Sidelap is the overlap between images of adjacent flight lines. This overlap should be 15 - 45%, averaging 20 – 30% over the entire flight line. This ensures, due to any variance in flight path, turbulence or other, that no ground coverage is missed for any reason.
Crabbing /Drift - The horizontal displacement of the aircraft about an azimuthal axis is referred to as crab or drift. It should not affect more than 10% of the image width for any three consecutive photos.
Roll or Tilt – The rotation of the aircraft about the lateral axis of the wings. Roll should be less than +/- 3 degrees from perpendicular for orthophotos, and average less than +/- 1 degree across the entire flight.

3.3 Flying conditions

Imagery should be captured only when the ground is free from clouds, cloud shadows, high overcast clouds causing low illumination, haze, fog, smoke, dust, excessive waters due to rain, or other environmental factors causing non-manmade obstruction of the ground surface.

Light conditions should be such that collected images are free from smear, blur, or noise. This can be conquered by flying at the right latitude at the right time of year and the right time of day, free from clouds, rain, smoke, and other.

Cloud cover – Images must be delivered with less than 10% cloud cover. They should be collected only when the atmosphere is free from clouds and when the ground is free from cloud shadows. However as this is not always possible given constraints, it is again recommended to use a light meter and ensure there is enough light to capture an image free from smear, blur, or noise.

Sun angle – The intensity of the light and the angle of the sun at a particular time of day is dependant upon the time of year (season) and latitude. The intensity of light at a given time of day increases with proximity to the equator, and timeliness to the summer solstice.
The angle of the sun above the horizon is very important when capturing images; too high or too low of a sun angle will lead to shadows in your images. Often image detail is lost because shadows cannot be seen through. To eliminate shadows, images should be captured when the sun has a minimum angle of 30 degrees or more above the horizon, 40 – 60 degrees is preferred. Twelve noon is the optimal time; but two hours before and after local noon provides the best collection window. Collect imagery from 10 am to 2pm, Local Standard Time. Standard practice also indicates that flight lines be arranged in the North to South directions to minimize the effects of shadows over the duration of the flight, as sun angle is constantly changing.

3.4 Camera Settings

The camera should be set according to the lighting conditions of the day as to prevent pixel smear, sensor blooming, and under/over exposure. Always use a light meter to assess current lighting conditions and set the camera appropriately. Blur and smear are visible when an image is overexposed, or when there is not enough light in a short enough time to expose the film or CCD.

It is not recommended to use automatic exposure controls. A camera's automatic exposure can have adverse affects often seen in imagery. Affects visible in imagery can appear from rapidly changing atmospheric conditions. The effect of auto-exposure can be clearly seen over sandy soils, older tarmac, lighter colored rooftops and other light, near white objects.

A filter may be needed depending on the system used and the atmospheric conditions of the day. Filters are used to prevent vignetting or lens falloff, and minimize the effects of haze. They are generally specific to camera, film type, and lighting conditions. Check with camera, sensor, and film manufacturers' as needed.

4 Image Characterization

In order to ensure that the processing procedures discussed in Section 4 are producing imagery consistent with the optimum characteristics identified by the FSA User Study, methods are needed to quantify image quality attributes. Recommendations for quantifying several image quality attributes are given in the following sections. A summary of the attribute and suggested range is given below:

Attribute	**Minimum**	**Target**
Clipping	< 2	< 1
Contrast	> 120	> 150
Saturation	0.06 < X < 0.12	0.08-0.10
Sharpness	>0.5	>0.8
Noise	< 12	< 10

The contrast, color balance, and individual channel clipping metrics are recommended to be used during all phases of image processing. The sharpness, noise, saturation and overall clipping metrics are more suitable to be used as final image compliance measures.

4.1 Clipping

Clipping is defined as the presence of pixels exhibiting the minimum or maximum digital count in an image's dynamic range. If an image contains many pixels that are clipped, potential detail about the imaged scene may be lost. As such, USDA users may have trouble determining line boundaries from imagery that is severely clipped. It should be noted that a small amount of clipping may be acceptable if the pixels that are saturated are in unimportant parts of the image. A good guideline to use during image processing is to ensure that the percentage of pixels in the first or last histogram bin be less than 1% of the total. A metric that more closely relates to the visual loss of information caused by clipping is given below.

The process to find the clipping metric *CLM(f)* of the input image *f(x,y)* is found in Figure 4.1.1.

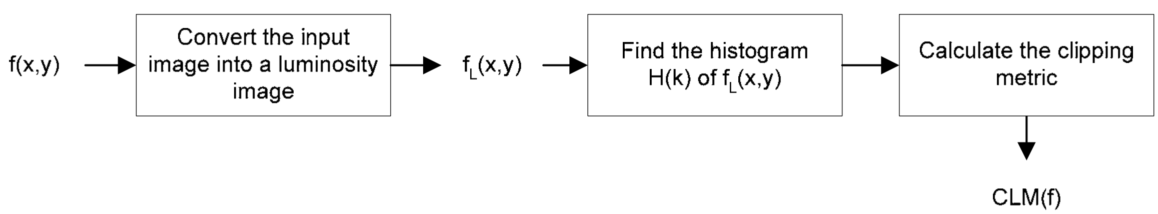

Figure 4.1.1. Clipping metric

The first step in calculating the contrast of a color image is to form its luminosity image using Equation 1. The luminosity image is a one-band image that provides an estimation of how an end-user would perceive the lightness in a color image.

$$L = \lfloor (0.30 * R) + (0.59 * G) + (0.11 * B) \rfloor \qquad (1)$$

L represents the luminosity pixel while R, *G*, and *B* represent the red, green, and blue component of a pixel in the input color image, respectively. The second step in finding the clipping metric is the determination of the luminosity image's histogram *H(k)* where *k* represents an arbitrary digital count and *H(k)* represents the number of pixels within the luminosity image with said digital count. To find the clipping metric *CLM(f)*, one must add the values in the first five and last five bins of the histogram. Once that summation has been made, the CLM can be found as the result divided by the total number of pixels within the image, formed as a percentage. According to the FSA User Study, USDA users prefer imagery that has a CLM of less than two.

Imagery that is clipped can arise through a number of processes. Most often, an image becomes clipped if an over-aggressive contrast enhancement process is employed during the image processing phase of the end product creation.

4.2 Contrast

The contrast of an image is a measure of the difference in how the darkest and the brightest pixels in an image appear to the end-user. If an image has high contrast, it will appear vibrant and contain a great amount of information about the scene imaged. If an image is low in contrast, there is less distinction between imaged features and as such, an FSA user would have to work hard to discern line boundaries.

To measure the contrast of an image, a process suggested by Figure 4.2.1 is employed.

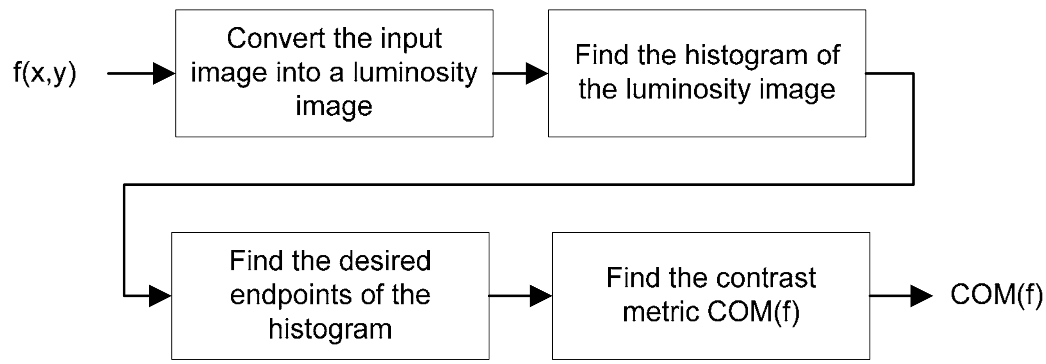

Figure 4.2.1. Contrast metric

The first step in calculating the contrast of a color image is to form its luminosity image using Equation 1 in section 4.1. The second step in finding the contrast metric is the determination of the luminosity image's histogram *H(k)* where *k* represents an arbitrary digital count and *H(k)* represents the number of pixels within the luminosity image with said digital count. Once the histogram has been found, the cumulative histogram function can be found by performing a running sum of H(k) and dividing each bin by the total number of pixels within the image, resulting in a function that varies in value from zero to one. To find the contrast metric COM(f), one must locate the grayscales values k_{min} and k_{max} that correspond to a cumulative histogram function value of 0.01 and 0.99, respectively. If the bins within the cumulative function do not have the exact values desired, the grayscale values with the closest value to the desired value should be selected. Finally, the contrast metric can be calculated using Equation 3.

$$COM(f) = k_{\max} - k_{\min} \tag{3}$$

According to the FSA User Study, USDA users prefer imagery that has a COM of greater than 120.

Many different processes can affect the measured contrast of an image. First and foremost, any contrast enhancement routine in place as part of the end product creation process will increase the measured contrast. By properly balancing the tone of an image, contrast can be increased. If the imaged scene is captured on a sunny day, the measured contrast will be much greater than an image captured on an overcast day.

4.3 Saturation

Saturation of a pixel is defined as the quantity of color contained within said pixel. If a pixel is under-saturated, it will be bereft of color and will make crop identification difficult. On the other hand, if a pixel is over-saturated, the colors present within the image will seem artificial and will also make crop identification difficult.

To find a quantitative metric for the saturation present within a color image, a color space transform is employed. The layout of the metric calculation can be seen in Figure 4.3.1.

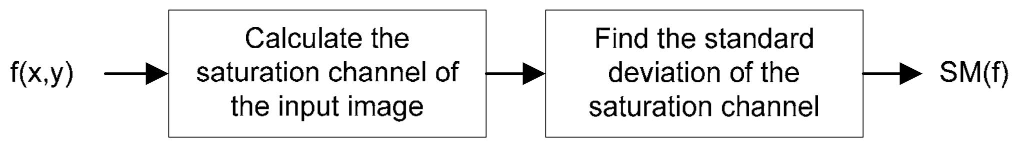

Figure 4.3.1 – Saturation metric

First, a saturation value is calculated for all the pixels of the input color image using the saturation component of HSV-color space given by Equation 4. A more complete explanation of HSV conversion can be found in Smith.

$$S = (\max(R,G,B)-\min(R,G,B))/\max(R,G,B) \quad (4)$$

Where R, G, and B are the red green and blue channel digital count values and “max” and “min” are the maximum and minimum for the triad.

Once the input image has been converted, the standard deviation of the saturation channel is found. This value represents the saturation metric *SM(f)*. According to the FSA User Study, USDA users prefer imagery that has a SM that is between 0.4 and 1.

There are some processes that may affect the measured saturation within an image. If an image is not properly color balanced, the color shift present in the image may increase the overall saturation. Also, a color image must have a controlled contrast enhancement process employed to ensure that the addition of contrast is not traded for the creation of an artificial image.

4.4 Sharpness

Excellent sharpness increases detail, edge definition, and is necessary for high quality exploitation. The result will be better CLU information for the USDA offices. Improved sharpness will also provide more information on the image such as land boundaries, structure detail, crop type, etc.

Sharpness is monitored using measurements of the Relative Edge Response (RER) of distinct edges. A graphical depiction of the RER measurement process is provided in

Figure 4.4.1 and a more detailed discussion of the steps needed can be found in Leachtenauer, et. al. A perfect edge yields an RER value of infinity.

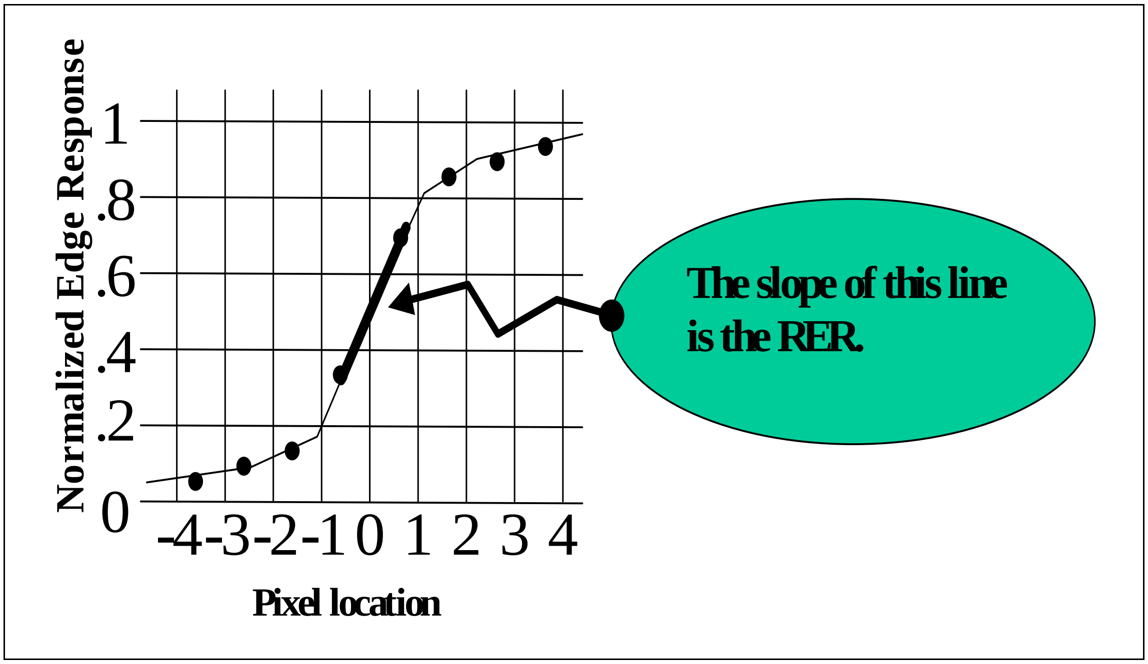

Figure 4.4.1. Relative edge response (RER)

Sharpness in monitored images should have a relative edge response (RER) within designated range achieved in the FSA User Study which is greater than 0.50 based on user feedback. RER data is preferred above 0.80 to give the best possible CLU information.

Factors which can influence the sharpness of an image are:

- Atmospheric degradations for different ranges
- Variations between along-track and cross-track measurements due to forward motion of the aircraft.
- Variations along the focal plane.

4.5 Noise

Noise is defined as non-imagewise variations in intensity and can have an effect on the interpretation of an image. Noise is classified as two types, random noise and fixed pattern noise. Random noise has no visual pattern and often has a Gaussian distribution. Fixed pattern noise has a structured, often predictable, appearance. For comparable levels of noise, fixed pattern noise will have a greater visual impact on image than that of random noise.

The Signal to Noise Ratio (SNR) of an image is usually defined as the ratio of the mean pixel value to the standard deviation of the pixel values. Imagery with a low standard deviation (STD) appears less noisy than imagery with a high STD. According to results from the FSA User Study, the Standard deviation of the data for all channels should be less than 12 to give the best possible CLU information. Images with standard deviation metrics higher than 12 were deemed unusable by FSA users.

Noise can be minimized in imagery using the following practices:

- Take imagery close to peak times with maximum light and optimum exposure settings.
- Keep camera lenses clean from any debris and have optics equipment cleaned regularly. Monitor vibrations to any equipment used during pre or post image capture.
- If using film as a medium, keep stored in a cold location if possible, have exposed film processed quickly to avoid UV radiation effects on the imagery. Old film can also introduce grain, which causes noise.

5 Image Processing

This section covers the various steps used in preparing an image as a DOQQ or a CCM for both film and digital origination. The processes used in all steps should be well documented. All monitors used for proofing should be calibrated on a routine schedule. All software used, including vendor proprietary software, should be under version control. The recommendation for a basic flow is as follows:

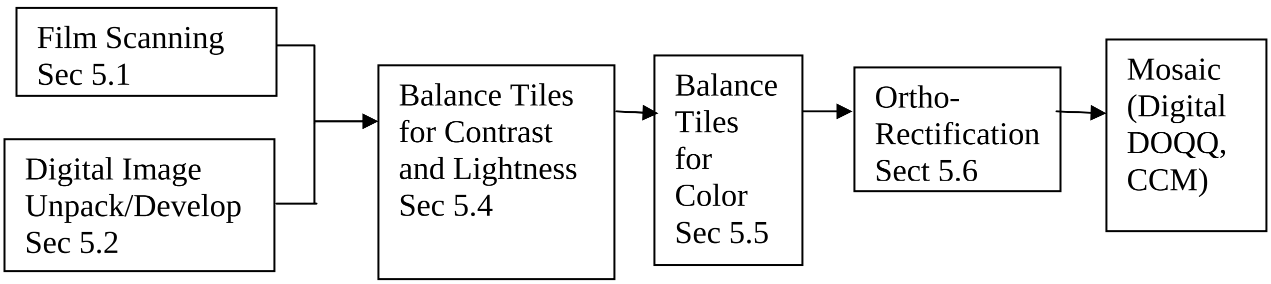

Figure 5.1 Suggested Image Processing flow

5.1 Film Scanning

For film origination, it is necessary to digitize the image for further processing. The first step in the process is to adjust the scanner settings so that a full histogram of the image is obtained. The scanner settings should be adjusted on a per collect basis, not an image-by-image basis. On days where the collection conditions varied considerably from the start to finish or an emulsion change was made, it might be prudent to treat the single collect as multiple collects. Images collected under similar conditions would then be grouped together for processing as a single collect.

5.1.1 Dynamic Range Adjust (DRA), Tonal and Color Rendering

Either a process control strip or a representative image that covers the full dynamic range can be used for a collect to determine the necessary scan settings. These settings should ensure that the full histogram is obtained for each color channel with roughly a 5% margin in terms of digital counts should be left on the bright (high count) side and roughly 5-10% on the dark (low count) side of the histogram to allow for further processing. Once selected, these settings should then be used for all images in a given collect.

As well as setting the overall range of the histogram, the histogram also must be centered so that the peaks of the color channels are ±15% of the middle digital count value (e.g. 2048 ±307 for 12-bit imagery). This ensures that the overall lightness of the image is optimized. The exact placement and shape of the histogram for a given color record can vary considerably depending on scene content, so there should not be any attempt to force the peak of the three channels to a common spot. In order to achieve a more centered histogram, a shaping function or LUT may be applied. An “S” shaped function is preferred over a gamma function, preferably one that was built for the film product type being used.

It is sometimes necessary to correct for overall color balance shifts in the scan due to film characteristics or for differences in contrast in individual color channels that can cause color shifts that vary from dark to light. Again, adjustments should be made to a representative image that covers the full dynamic range for a given collect and then the same levels applied across all other images in that set. A recommended sequence for doing this initial balance can be found in section 5.5.

Optimizing each image before a scan is not recommended. In any given collect there can be areas of mostly high or low reflectance that may be over adjusted in further processing if optimized individually at this point. It is important that the film be scanned and saved at the maximum bit depth allowed by the scanner in order to ensure that information is not lost in the tonal and color balance steps due to quantization. The scan resolution should be appropriate for the GSD of the final product.

5.2 Digital Camera Image Unpack/Develop

Digital camera systems collect imagery in a raw format. Many systems pack this data in a way such that data storage is maximized; often this means images are received at the vendor worksite in a non-human readable format. They may need to be unpacked or developed, and converted into a three or four band image (R, G, B, and NIR). There are many different techniques for doing this and corrections to imagery vary due to the sensor characteristics and the conditions at time of collect.

It is imperative to maintain the bit depth of the imagery through the processing chain. Data reduction at any step throughout the collection and processing chain may cause unwanted loss of information due to quantization or shifting of the histogram. Image bit depth should be held constant from time of collect until time of delivery; such that if an image is captured at 12 bit, it is unpacked, tonally and color adjusted, and orthorectified to12 bit. The reduction to 8 bit occurs only in the final mosaicking step.

5.2.1 Color Record Registration

Mis-registration is the misalignment of color channels in an image, or the visual separation of red, green, and blue bands. This affect can be best seen most easily in midtone linear features such as roads and is illustrated in Figure 5.2.1.1

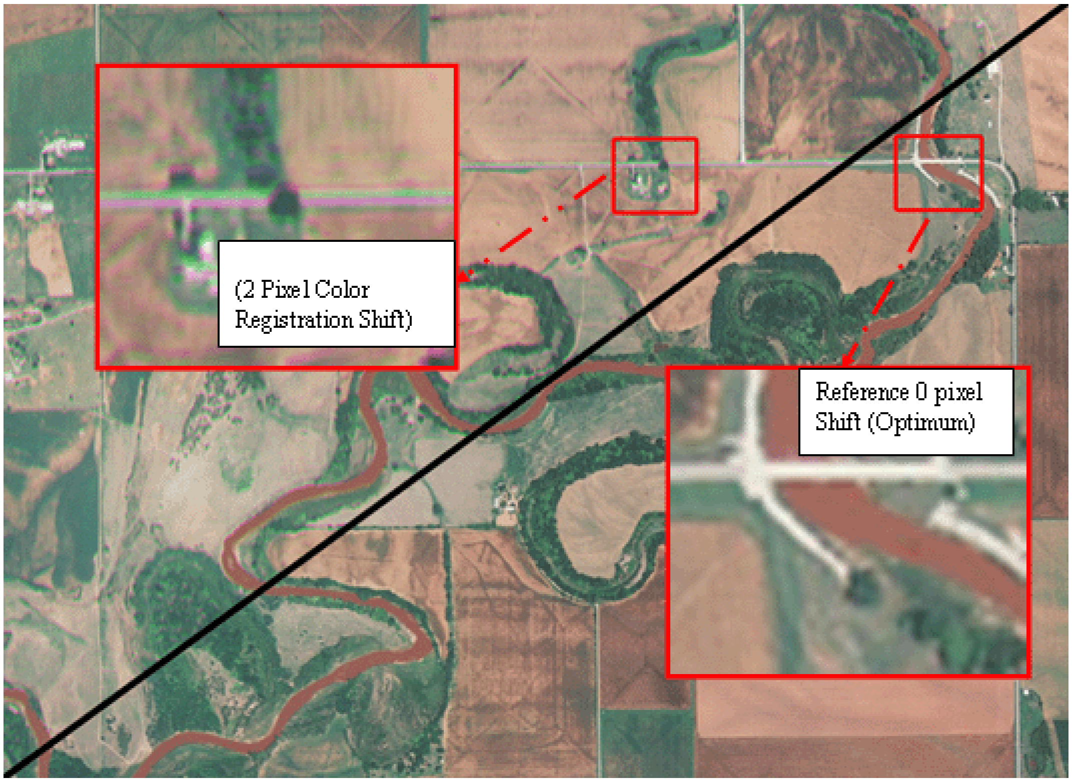

Figure 5.2.1.1. Illustration of Color registration shift versus an Optimum image

Some digital aerial sensors, such as the Leica ADS40, collect the same ground area at slightly shifted times depending on the channel. The channels must be registered as part of the ground processing chain. Mis-registration can occur as part of the processing, or the sensor may be out of calibration.

Mis-registration should not exceed 1 pixel. Each pixel in an image should be referenced to the same R, G, and B channel value. This can be measured by zooming into a portion of the image that contains a clear edge. Any misalignment is seen and measured easily. The pixel coordinate of the edge should be determined for each channel and the difference should be no greater than one between any two channels.

5.2.2 Image Corrections

All processes used for correction should be well documented such that they are repeatable, and allow images to be produced in as true a representation of ground cover at the time of collect as possible. This repeatability and consistency allows the job tracking to function as the link between data collect and final product without having to store multiple copies of data such as, raw, intermediary processing files, orthophotos, orthomosaics, compressed imagery and final product data.

The following image corrections should ideally be performed in the order listed.

5.2.2.1 Lens Falloff

Similar objects within an image should not have major variations in tone from the center of the image to the corners. However, due to lens optics and sensor characteristics this behavior is frequently present. Most camera manufacturers provide software to correct for this artifact. This correction should be applied before any other processing steps. Figures 5.2.2.1.1 and 5.2.2.1.2 illustrate the effects of lens falloff in a flat field and a scene.

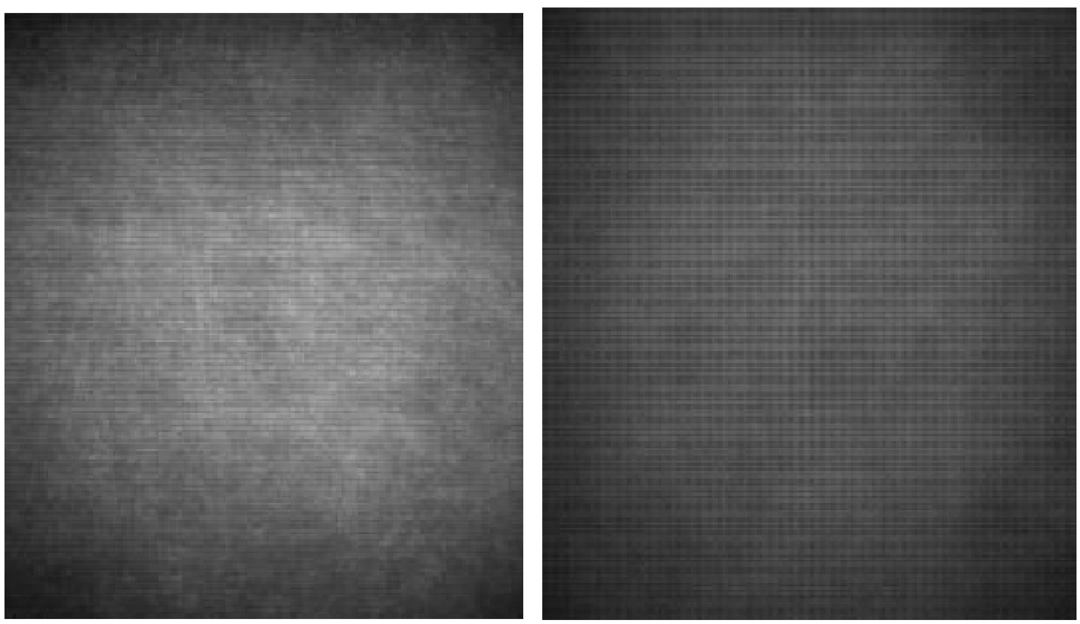

Figure 5.2.2.1.1. Lens falloff image

Figure 5.2.21.2. Raw Image (L) and Lens Falloff Corrected (R)

5.2.2.2 Dynamic Range Adjust (DRA), Tonal and Color Rendering

A DRA is a stretch of the histogram to ensure that the full range of available digital counts is used to display the imagery. It is recommended that this initial process be done strictly on the basis of histogram statistics and not by visual matching. Both linear adjustments and non-linear adjustments to correct for the camera response can be applied at this point. The exact nature of the adjustment is dependent on the sensor system used. Many manufacturers supply tools to do this step automatically. However the adjustment is achieved, the histogram of all the images in a given collect should meet the criteria given below.

The target range for the stretch should be determined by taking histogram statistics from all images within the collect (defined as the same day and collection conditions), or from a representative image that contains objects covering the full dynamic range of an area. Roughly a 5% margin in terms of digital counts should be left on the bright (high count) side and roughly 5-10% on the dark (low count) side of the histogram to allow for further processing.

In addition to setting the overall range of the histogram, it should be centered so that the peaks of the color channels are ±15% of the middle digital count value (e.g. 2048 ± 307 for 12-bit imagery). This ensures that the overall lightness of the image is optimized.

The exact placement and shape of the histogram for a given color record can vary considerably depending on scene content. Therefore, there should not be an attempt to force the peak of the three channels to a common spot. In order to achieve a more centered histogram, a shaping function or LUT may be applied. Using a calibrated monitor, images should appear neither too dark nor too bright. Dodging corrections can also be applied if needed. Dodging corrections are local changes within an image to brightness and contrast to gain a more uniform visual appearance.

5.3 Reference Selection and Use

In order to aid in tonal and color balancing processes, a reference image is a useful tool. A reference can come for an external source, such as APFO, or simply be an ideal image tile from a collect. External references are useful in gauging overall contrast and approximate color for ground and vegetation. Ideally, a timely reference should be available for each regional environmental type (e.g. Pacific forest, northwest state desert, southwest state desert, northeastern state forest). All external references should be selected by APFO to meet the contrast, clipping, saturation and color balance criteria outlined in Section 4.

To ensure consistency within a digital DOQQ or CCM, a reference for a given collect can also be chosen that meets the contrast, clipping, and color balance criteria outlined in Section 4. Every tile in the collect can be adjusted relative to that reference and the collect references can be adjusted so they are as consistent as possible with each other and the external reference.

5.4 Balancing Tiles for Contrast and Lightness

Once all component tile images have been either scanned or digitally developed, the next part of the process is to ensure good tonal characteristics across all tiles that will go into the final product. The FSA User Study indicated good dynamic range and contrast, without clipping, are very important to quickly and effectively determine boundary areas for compliance. By optimizing each tile before orthorectification and mosaicking, a more consistent and optimal end product will be obtained. At this point, a reference image might be helpful. Details regarding selection of a reference are given in Section 5.3.

The recommended process for balancing tiles for contrast and lightness across different collection events is similar to that recommended for balancing within a collect. First, a representative image is chosen that represents the whole dynamic range of the expected end mosaic. Statistics are computed using all the tiles to aid in this selection. These tiles are then optimized for contrast (as given by the metric in section 4.2) with care being taken that the endpoint clipping (the counts in the first or last bin/total number of counts) on any single color channel not exceed 1%. All other tiles are then matched to these images such that they are visually consistent within a mosaic.

It is very important that the monitors used for this step have a known and calibrated response so that accurate judgments can be made as to the apparent contrast of an image. This process is an iterative process with color balancing steps to ensure the best overall quality.

5.5 Balancing Tiles for Color

Color balance refers to the natural look of colors within an image without the dominance of any individual color. The presence of such a dominating color within the entire image is called a color shift. In imagery without a color shift, objects such as lush grass appear green while a freshly paved asphalt road is black or gray. Color balance is important because it affects many FSA and other end user imagery duties. A properly balanced image lends itself to crop identification; true colors lead to more certainty in crop type. Color shifts can be perceived as a loss of contrast, making it hard for FSA users to properly determine crop boundaries. Overall, the presence of a color shift is distracting to end users, forcing them to spend more time completing their duties. Examples of an unbalanced and balanced image are shown in Figure 5.4.1.

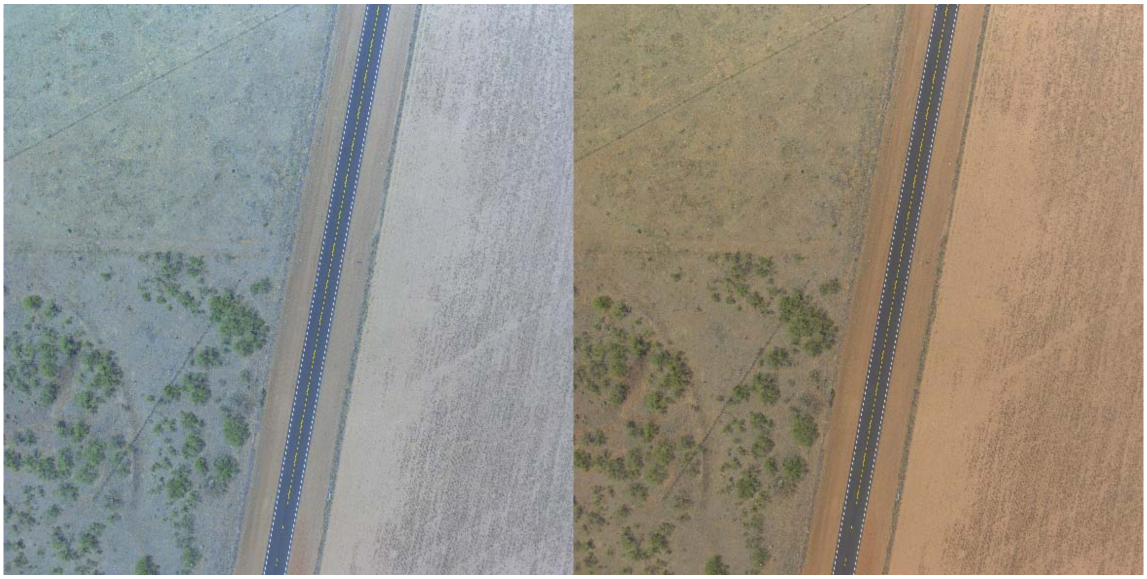

Figure 5.4.1. Color shifted (L) and Color Balanced Image (R)

Before checking the color balance within an image, it is important to confirm that the image is tonally balanced. The overall balance of an image can be visually checked against a reference, but numeric verification should also be performed to ensure that neutrality is met. It is very important that color balance judgments be made only under proper lighting conditions on display systems that are calibrated and have the correct tone scale (see Section 7).

A simple process may be used to confirm the color balance of an image. First, a nearly neutral object is selected within the imaged scene. For example, nearly neutral objects may include certain paved roads or building tops. If there are no natural neutrals in a scene, then another image in the same collect can be used to determine the needed color shift to apply. Once a nearly neutral object is identified, pixels representative of the object are selected and their associated RGB pixel values (digital counts) are examined. If the difference between the minimum and maximum digital counts in the triplet is less than 2% (5 counts for an 8 –bit image), one can consider the image balanced. The difference between triplets across an image (within the same object type or cover type) or between two tiles that will be part of a mosaic should be 4% or less (10 counts for an 8-bit image). If this is not the case, steps should be taken to equalize the values.

One method for balancing the color of an image is adding the necessary color to the image. For example, if the RGB triplet for a representative pixel is [180, 181, 152], one must add blue to each pixel within the image. Many commercial off-the-shelf products contain color balance functions to change the color balance of an image. This process should be completed for a dark (shadow) and light (highlight) neutral area also.

Many factors can influence the color balance of an image. For film, improper selection of the film type for the illumination of the scene, haze, and emulsion to emulsion variability can cause color shifts. For a digital capture system, an improper calibration of the CCD sensor can introduce a color shift. For both systems, capturing imagery outside the prescribed mid-day window or weather effects can introduce a noticeable color shift.

5.6 Orthorectification and Orthomosaicking

Orthorectification is the process of correcting a photograph for the rotations around the axis of the camera (X, Y, Z, or Omega, Phi, Kappa), aberrations of the lens, and removing the effects of relief displacement. This process places the elements of the image that are at ground level in their true ground position while providing uniform scale in all directions. True orthophotos will correct for effects of building lean and other artifacts by shifting objects located above the earths surface to their true physical location corresponding to the base of the building or other.

Mathematically, rectification is the process of projecting an image onto an ellipsoid of the earth.

Absolute geometric accuracy is the average Euclidean distance between the physical surveyed location of an identifiable ground location and its apparent or visible location in the imagery. To achieve the best possible accuracy to which a system is capable, imagery should be collected, processed and delivered in the same bit-depth and output resolution or Ground Sample distance (GSD). In this manner, the true (absolute) or apparent (relative) accuracy is maintained as much as possible, and not intentionally manipulated, throughout the processing stream.

The creation of down sampled or resampled, interpolated, or highly sharpened data is not recommended as accuracy (relative and absolute) of data may be reduced. However, introduced constraints may make it necessary to collect at varying resolutions and resample. In this case, linear and nearest neighbor interpolation methods should not be used. Though bicubic methods give satisfactory results in most cases, LaGrange is preferred. Both Lagrange and bicubic use 4x4 neighbors for interpolation, but the LaGrange polynomial method is faster. Interpolation should not be completed for any greater than a 2x change in resolution (e.g. 1 meter GSD to 2 meter GSD).

The accuracy of the output orthoimage is heavily dependent upon the accuracy of the orientation data and the Digital Elevation Model (DEM) used, and cannot improve upon the errors in these models.

Image processing should be done following the guidelines given in Sections 4.1-4.4 prior to running the imagery through orthorectification tools such as Inpho Orthomaster, BAE Socet Set, Leica Photogrammetry Suite, Z/I ImageStation, and other vendor proprietary tools, etc. The contractor should record all processing steps and software used including version number.

Some processes that help ensure optimum orthorectification and high quality images:

- Mosaic only those images obtained from a single flight collect as much as possible.
- Output image resolution should equal input resolution
- Images should have 50% or greater forward and 30% overlap as mentioned in section to remove distortion affects such as building lean.
- Use digital terrain or digital elevation models such as DSM's or DEM's to aid in properly mapping coordinates. A flat earth model does not correctly geolocate each pixel in an image. This is clearly seen in areas with topographic relief
- The best quality obtainable DTM should be used. As terrain relief increases, the density of postings should also increase.
- High quality Digital Surface Models (DSM's) should be used for man made objects Buildings, bridges, etc. where possible.
- Only use bicubic or Lagrange 4x4 neighbor interpolation.
- The Geoid used in converting GPS-derived ellipsoid heights to orthometric heights should be the most current version.
- Use the closet proximity base station for precise CORS/IGS orbit ephemeris for GPS processing. May need to use multiple base stations depending on distance or area covered.
- Use the most rigorous orthorectification model; such as one that selects the most nadir pixels instead of most nadir image chips.

5.6.1 Orthomosaic Tiles

There are many options available for mosaicking. If a batch mode is chosen, extra care should be taken that all of the tiles are consistent for tonal and color balance as per Sections 5.3-5.4. Otherwise, adjacent tiles may be driven to a common and less optimum middle point.

Small adjustments can be made to the tiles before mosaicking to optimize contrast and color uniformity. However, care should be taken that the proper reference point be chosen for automatic optimization. The proper reference being defined as a tile with contrast, clipping, and color balance attributes within the suggested guidelines (see Section 4).

If the above practices are followed, large nonuniformities in the resulting mosaic between tile areas should not be evident. As a goal, the variation in an area of similar type (e.g. roads, buildings, same crop field) should not vary more than 10% in average digital count or 4% in the difference between each of the three channels (see color balance Section 5.5). Overall, the finished mosaic should meet the criteria given at the beginning of section 4. If the resulting product does not meet these criteria, then non-compliant tiles can be redone to be more consistent.

5.7 Compression

The final step in the image processing chain is the compression of the processed image data into its final delivery format. A vendor may choose to employ compression to reduce the overall file size of the end product to fit more data onto the media of choice. It is important to note that compression should be the final step in the image processing process; it should not be compressed during the collection and previous phases of the image processing chain.

To compress the image, a codec (encoder/decoder) must be selected that is visually lossless. Visually lossless is defined as the point at which the compressed image and the non-compressed original image are just noticeably different but not different enough to cause a preference for either image with respect to image quality or usability. As such, codecs that perform lossless or lossy but visually lossless compression on the image data may be used. Such codecs include MrSID, JPEG/JPEG2000, and enhanced wavelet compression (ECW).

5.8 QA/QC Practices

Proper quality assurance practices should be performed between each step of the processing chain. This will ensure any errors found will be corrected before data is transformed and help to correct any improper processing steps before additional data is processed with these same parameters.

All processes should be well documented such that every step of the imaging chain is consistent and repeatable, independent of data set and operator. A QA/QC process should at minimum include:

- Camera certification and maintenance
- Image collection procedures
- Data handling procedures
- Image processing standard operating procedures
- Softcopy display set up, calibration and maintenance procedures
- Image verification procedures

6 Image Delivery

When the product is ready for delivery to the end user, scrutiny must be placed on the contents of the final package. At the very least, an image delivery package should consist of the imagery collected, the metadata associated with the imagery collection and processing, and monitor certification(s). The package should also be free of any commercial form of data compression, such as ZIP or RAR. This definition does not include any image compression methods such as JPEG or MrSID.

Once the package has been formed, the delivery media must be selected. Before selecting the media type, the vendor should be assured that the end user is able to access the media type on their information systems, whether it is optical (recordable but not rewritable compact discs or Digital Versatile Discs) or magnetic (tape or hard drive). Care must be taken when optical media is selected. First, the vendor should use archival-quality media. Second, when copying the product to the media, a write speed should be selected that is slightly below the maximum speed capable for the optical drive and media selected. This will help prevent write errors. Moreover, the media should have its session closed to prevent further addition of data and ensure compatibility across information systems. Finally, the media should be marked only with labels specifically designed for placement on optical media. The use of other types of labels may cause read failures in an end user's optical drives.

Once the delivery media has been selected, the product must be sent to the end user. The vendor should be assured that the product will be delivered safely and that a chain of custody exists. When using a network to deliver the product to the end user, a method such as Secure FTP should be implemented where the actual data is encrypted and a log file that contains the end user's FTP server responses indicating successful transfer of files can be kept. When the product has been copied to some form of physical media, the vendor should be assured that the carrier used to transfer the media is reliable and that some form of delivery confirmation exists with their service.

7 Viewing Environment

The softcopy display used for viewing the imagery during the various processing steps is a critical component in the image chain. The perceived color and contrast of an image are highly dependent on both the intrinsic response of the display and the viewing conditions surrounding the display. For instance, if a monitor is set to a blue-ish color temperature (9300K) and in an environment with bright overhead lights, then any image will be perceived as being washed out and blue-ish compared to an image viewed at 6500K monitor color temperature and more optimum image viewing conditions. If such a monitor was used for visual adjustments to an external reference, then images received by APFO could be yellow and higher contrast than the optimum. In order to assure that the image manipulation and QC/QA processes produce consistent imagery with APFO expectations, monitor calibration and viewing conditions need to be consistent between the APFO and the vendor.

7.1 Monitor Calibrations

Monitors that will be used for image evaluation should be calibrated to a Gamma 2.0 curve at a color temperature of 6500K. Minimum luminance should be between 0.1-0.15 fL and maximum luminance between 25-40 fL. This tone scale is the default response for many CRT monitors, but not for many LCD monitors, though a "sRGB" mode will approximate this behavior. Calibration software that will achieve these criteria is available from several external vendors. In addition, a monitor calibration should be verified at least once a month and a full calibration performed at least once a quarter. Tracking and trending information regarding monitor performance should be included in QC documentation.

Alternative tone scales to a simple Gamma relationship such as the DICOM aim (see References) used by the medical community would provide some additional capability for gaining information from imagery, but would require the implementation of a comprehensive calibration and maintenance program across vendors, APFO, and end users.

7.2 Viewing Conditions

The viewing environment for the evaluation and processing of imagery should be such that there is no overhead lighting that will cause glare on the monitor screen and that shades or blinds be used on all windows near viewing screens. Most of the ambient light should come from lighting behind or beside the monitor. The ambient lighting should be similar to the intensity of the monitor screen (5-24 lux) and the color temperature of the ambient should be close to 6500K. Fluorescent tubes that match these criteria are available from several manufacturers. In areas that are dual use, such as scanning and image processing, auxiliary lighting can be used when higher ambients are needed, but should be turned off when image evaluation is being done. In order to avoid color adaptation effects, the environment immediately around the softcopy display should be as neutral as possible; gray walls and furniture are preferred.

8 Data Storage and Retention

All data should be stored and archived based on contract guidelines. At minimum the following types of data should be retained:

- Metadata – As per Section 2. Includes collection parameters such as weather conditions, pilot, altitude, camera, flying height, frame rate, overlap, side lap, latitude/longitude, time of event capture, film type (if applicable), equipment report.
- Original Raw image data – Raw native imagery, GeoTIFF.
- Orthomosaic tiles built or DOQQ's, etc. This can also be a clustered into a full County Mosaic.

8.1 Storage

- Digital data should be stored on negotiated media; Portable Hard Drives, secure FTP, DVD+/-R, DVD-ROM, CD-R, CD-ROM, or DLT.
- All digital media should be readable by both Windows and UNIX systems.
- All digital media should contain finalized closed sessions, no multi-session discs.
- All digital media should be properly labeled in standard cases (no slim-line or non-standard cases accepted
- Film should be stored in air and light tight containers that are approved for film storage.

8.2 Retention

The contractor / vendor shall maintain all data until the USDA office acknowledges receipt, and acceptance. Received data must meet contract specifications. Product data should be maintained for the projected lifetime of the imagery.

9 References

A. R. Smith, "Color Gamut Transform Pairs," Computer Graphics **12**, 12-19 (1978)

J. C. Leachtenauer, W. Malila, J. Irvine, L. Colburn, and N. Salvaggio, “General Image-Quality Equation: GIQE” , Appl. Opt. **36**, 8322-8328 (1997)

Digital Imaging and Communications in Medicine (DICOM) Standard, “Part 14: Grayscale Standard Display Function”, PS 3.14-2007, National Electrical Manufacturers Association (2007)

10 Glossary

Aerotriangulation	A photogrammetric method of intensifying a ground control network. Involves measuring all known points along with additional points marked on the photography. Positions of the unknowns are computed treating all the photographs as one large block.
Analytical Stereoplotter	A photogrammetric instrument which uses electronics, motors, and lenses to view two overlapping aerial photos in 3-D. The stereoplotter corrects for distortions caused by rotations in the camera and relief displacement. This allows the operator to view the stereo model in a binocular viewing system and make measurements based on the ground coordinate system.
CCD	A Charge Coupled Device is a type of digital sensor technology used in cameras. A CCD consists of a solid state array of photodiodes that each store an electric charge corresponding to the level of light. Each photodiode corresponds to a pixel in a digital image.
CCM	A Compressed County Mosaic is a NAIP product that consists of all DOQQ's necessary to cover a given county. It is delivered in a 15:1 MrSid compressed format.
Clipping	Presence of pixels exhibiting the minimum or maximum digital count in an image's dynamic range. Important detail can be lost with severely clipped imagery on the high or low ends of a scene.
Contour	Lines of equal elevation traced on a map to graphically display the shape of the ground. Formerly traced by the technician using a stereo instrument, most contours are now generated from a digital terrain model.
Cumulative Histogram	A cumulative histogram is a mapping that counts the cumulative number of observations in all of the bins up to the specified bin. That is, the cumulative histogram H_k of a histogram h_k is defined as: $$H_k = \sum_{k'=1}^{k} h_{k'}$$
DEM	Digital Elevation Model, one of many names used to describe a file describing terrain shape in 3-D. Usually used to describe a raster file created for further processing, less rigorous than a DSM and can not be used for contour models however can be used for orthorectification.
Digital Count	Digital count is the total number of pixels occurring in an image for each possible data value.
Distortion	Anything that moves an object from it's true position in an aerial photo. Can be caused by the rotation of the camera about the XYZ

	axis, elevations changes, and even the distance away from the center of the photo.
Dodging, Digital	The selective shading or masking of a portion of a photograph during copying to soften the contrast. Automatic dodging selectively varies the illumination over the photograph in proportion to the average density of each area on the photograph.
DOQQ	A Digital Ortho Quarter Quad is a digital version of an orthorectified quarter quandrant defined as 3.75 x 3.75 minute area in the UTM, NAD 83 coordinate system plus a 300 meter buffer on all four sides.
DSM	Digital Surface Model, one of many names used to describe a file describing terrain shape.
DTM	Digital Terrain Model, one of many names used to describe a file describing terrain shape, typically in 3-d terms. Usually used to describe the raw data as collected by field or photogrammetric methods. Typically digitized as a combination of breaklines and random (or grid) spot readings, typically used for orthorectification.
Georeference	The process of adding a real world coordinate system to a digital image. Accomplished in varying ways by viewing, CAD, or GIS systems.
GIS	Geographic Information System, a system of data and software used to store, manipulate, and analyze geographic data.
Histogram	In a more general mathematical sense, a histogram is simply a mapping that counts the number of observations that fall into various disjoint categories (known as *bins*), whereas the graph of a histogram is merely one way to represent a histogram. Thus, if we let N be the total number of observations and n be the total number of bins, the histogram h_k meets the following conditions: $$N = \sum_{k=1}^{n} h_k$$ where k is an index over the bins.
LaGrange	Interpolation method, Lagrange polynomial function, 4 x 4 neighbours, similar quality as bicubic but faster.
JPEG	Popular format of raster file, very efficient but lossy compression make it more suitable for snapshots than precision aerial photographs.
LIDAR	A form of airborne radar used to collect terrain data.
Metadata	Formal documentation describing the characteristics of a specific geospatial data set, usually consisting of flight conditions, hardware, and image collection data.
Mis-registration	Is the actual and apparent misalignment of color channels in an image or the visual separation of red, green and blue bands. This affect can be best seen most easily in midtone linear features such as roads.

Mosaic / Image Tile	A process of combining multiple photographs by cutting them so as to hide the cuts and pasting them together in one large photo. What was once nearly an art-form has been moved to the computer as photos are merged digitally.
MrSid	Popular format of raster file using a very efficient though not lossless compression technique developed for aerial imagery by LizardTech and International Land Systems.
Noise / Graininess	The impression of non-uniformity in the image which is produced on the consciousness of an observer by the granular structure. It is most noticeable in areas of uniform density of middle values. It becomes less apparent in light and in dark areas and in areas that contain considerable detail. Noise / Graininess is subjective in nature and can be measured as Standard Deviation..
Orthorectification	The process of correcting a photograph for the rotations around the X, Y, and Z axis of the camera, and the removing the effects of relief displacement. This process places the elements of the photograph which are at ground level in their true ground position.
Orthophoto	A photograph either digital or hardcopy that has undergone the orthorectification process.
Pixel	Term used for the Row / Column units that make up a raster file or digital image.
Quantization	To reduce the number of colors or shades of gray in an image, with the goal being to reduce file size while maintaining image quality. Also used to display images with more colors than are available on the display device.
Radiometric Correction	Image correction based on equalization of global statistical functions such as histogram, mean, standard deviation, etc. in overlapping regions of imagery in mosaics.
Raster	Computer files made up of rows and columns of values. These values are usually greyscale or colors stored in such a way that when they are read by a viewing program they form a digital photograph.
Relief displacement	The distortion caused in an aerial photograph caused by objects being displaced away from the center as their elevation changes.
Sharpness / RER	Measured detail and edge definition in an image(Relative Edge response), typically described by using MTF (modulation transfer function) data.
Stereomodel	Two overlapping aerial photographs viewed in 3-D. The basis for all measurements made by photogrammetric methods.
TIFF	Popular format of raster file when used for aerial photos it is delivered uncompressed and georeferenced with a world file. Because it is uncompressed it is as perfect a copy of the original photo as is possible.

Tonal Scale	The range of grays or densities of an image.
Vector	Computer files made up of lines and points, which are digitized in a known coordinate system. Entities usually have multiple attributes

Aerial Photography Field Office— Scaled Variations Artifact Book

CDRL A002
SUBMITTED UNDER GSA Contract Number GS-23F-0284M, SIN 871_2

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February 1, 2007

Engineered for life

Noise

σ for [R,G,B]=[12.12,12.15,11.90]

Noise

σ for [R,G,B]=[2.57,2.97,2.38] **(Target)**

σ for [R,G,B]=[6.41,6.67,6.46]

σ for [R,G,B]=[12.12,12.15,11.90]

σ for [R,G,B]=[18.41,18.58,18.63]

ITT

Sharpness

RER = 0.343

Sharpness

RER = 0.910 **(Target)**

RER = 0.518

RER = 0.343

RER = 0.251

Shadow Clipping

2.19% clipped pixels

Shadow Clipping

0% clipped pixels **(Target)**

1.14% clipped pixels

2.19% clipped pixels

3.18% clipped pixels

Highlight Clipping

2.04% clipped pixels

Highlight Clipping

0% clipped pixels **(Target)**

0.95% clipped pixels

2.04% clipped pixels

2.92% clipped pixels

Overall Clipping

2.29% clipped pixels

Overall Clipping

0% clipped pixels **(Target)**

1.28% clipped pixels

2.29% clipped pixels

3.14% clipped pixels

Low Contrast

Contrast = 113

Low Contrast

Contrast = 164

Contrast = 143

Contrast = 113

Contrast = 79

High Contrast

Contrast = 188

High Contrast

Contrast = 164

Contrast = 169 **(Target)**

Contrast = 188

Contrast = 204

Low Saturation

Saturation = 0.07

Low Saturation

Saturation = 0.09 **(Target)**

Saturation = 0.07

Saturation = 0.04

High Saturation

Saturation = 0.11

High Saturation

Saturation = 0.09 **(Target)**

Saturation = 0.11

Saturation = 0.15

ITT

Color Channel Registration

2 pixel shift in the green channel

Color Channel Registration

0 pixel shift in the green channel **(Target)**

1 pixel shift in the green channel

2 pixel shift in the green channel

3 pixel shift in the green channel

ITT