The Photographic Composition and Display of Multiband Pixels

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Abstract

The impending commercial availability of hyperspectral data acquired by imaging satellites coupled with the limitations of color monitors and standard photographic processing compels a reexamination of the photographic composition and display of multiband pixels. Full-color satellite photographs are the end product of a synergistic series of electronic, sensitometric, and color-additive events. Taken collectively, the color signatures generated by those events create the images from which inferences are drawn about the changing nature of the earth's surface. Examined separately, the multiband pixels whose color signatures are the building blocks of the image are found to be influenced by a host of variables that threaten their integrity as legitimate data points. This paper traces the acquisition and subsequent hardcopy display of the color signatures of pixels composited from three bands of remotely sensed data having a radiometric resolution of 256 levels. Attention is directed to the inadequacies of commercial photographic processing and electronic displays to accomodate the full color palette of satellite remote sensing imagery. Emphasis is placed on the conversion of digital data to the accurate retention of densities in black-and-white film separations and their function as filters that regulate the exposure of color film during the composition of multiband pixels.

Introduction

The preparation of photographic hardcopy from the imaging data transmitted from satellites offers the end user at least three options: (1) using "state-of-the-art" printing technology, write a 3-band composited image directly to a positive print at a predetermined scale, (2) using color film recorders, write a selection of three bands of data directly to a color negative from which positive prints can be produced at a variety of scales, and (3) write each band of data to a separate black-and-white positive, register the separations and prepare a composited color negative by additive filtration and controlled exposures. The first and second options reduce the production time from data ingestion to final print, assure the retention of spatial resolution, and truncate the color palette essential to the retention of the system's radiometric resolution. The third option is the focus of this paper which treats the individual composited pixel as a data point whose authenticity requires the retention of original radiometric values throughout the hardcopy production process.

Validation of that authenticity enables the assignment of ground truth to the pixel footprint whose positional accuracy is achieved by GPS. Because the potential for the analysis and interpretation of satellite imagery requires the reliable display of spatial and radiometric resolution, this paper concludes with an overview of display technologies that includes color monitors and full-color photographic hardcopy.

Band Selection

The final rendition of any satellite multiband image is a function of specific bands of data selected for their known detection characteristics and the primary color through which each band of data is translated as a component in a full-color display. Standard practice is to match three bands of data to the three primary colors, -- blue, green, and red – from which all colors are derived. The practice of blending more than three bands of data in a single image by sharing partial exposures of a primary color may support a specific objective for interpreters but generally is achieved at the expense of the broader interpretive value of the image. The fact that multiband data is color composited for the retrieval of information not directly related to the spatial resolution of the imaging system underscores the importance of preserving the radiometric values that compose the database for any single band.

Most satellite images are "painted" in broad brush strokes that significantly delimit the value of individual pixels whose color signatures have been lost or distorted by production expediency. The broad area coverage provided by such images is displayed without critical regard for the radiometric resolution that resides with each pixel in the image. The benefits of knowledgable band selection by qualified image analysts and photo interpreters is enhanced when the full dimensions of the imaging database is preserved in the digital-to-analog conversion taken one band at a time. Sacrificing expediency for labor intensive and time consuming production is justified only when the outcome of that additional effort is the extraction of information not otherwise available. Remote sensing is, by purpose and design, an information gathering technology.[1]

Care must be taken that the original intent is not lost in the rush to a rapid turnaround in the production lab.

Registration Crosshairs

Accurate registration of three film separations and the validation of color signatures requires the positioning of crosshairs in each corner of the separation outside of the image area. These crosshairs must occupy precisely the same position in each of the separations. The intersection of the crosshairs must be a single pixel, but to make it easier to find the crosshair during the registration process each arm of the crosshair may be expanded to make it visible to the unaided eye.

The objective of multiband composition from B&W film separations is to preserve the radiometric authenticity of the individual pixels whose color signatures create the satellite image. The significance of that color signature increases with improvements in the spatial resolution of the system because the digital value of the pixel within each band is an average of all the reflected and emitted energy detected by the satellite. As the area covered by each pixel decreases, there is a corresponding decrease in the area of the terrain and the variations of energy that contribute to that average. With every refinement in the spatial resolution of satellite digital images there is a corresponding increase in the quality of the information that resides in the radiometric resolution taken one color signature at a time.

The integrity of a composited pixel is based on the area of the pixel sharing the exposure of all three primary colors compared to the area of the single band pixel measured at the crosshair. Both areas can be measured by appropriate scales in the optical field of sufficiently strong magnifiers. If the area of the composited pixel is at least 51% of the area of a single band pixel, the validity of the color signature is established. Because registration can shift across the face of the image, measurements of the area of the pixel should be taken at each corner of the color negative and reported accordingly. The average values of the four color pixels matter little. Critical image interpretation depends more on the validity of the color signature within a quadrant of the image. If only one quadrant meets the standard for pixel validation, that one quadrant may include the area of interest to the interpreter.

B&W Film and Chemistry

Nearly all imaging satellites are designed with a radiometric resolution of 256 values (0-255). Theoretically, all B&W films have the capability to hold a range of 256 densities which suggests that matching the imaging data from a satellite to the dynamic range of film is readily achievable by any photographic laboratory.[2] In practice, however, the combination of film and chemistry selected by any one lab is but one element in the calibration of the laboratories entire sequence of image processing. There are a seemingly infinite number of film and chemistry combinations, but only systematic testing will identify the one best combination for production of film separations.

The B&W films used commercially for general photography are processed to a range of values significantly less than what is required for satellite imaging. Even though a general scene might have a luminanace range of 2000 between the deepest shadows and brightest highlights, the pictorial representation of that scene will compress that range to a gray scale of approximately 32 values or five f-stops. Good B&W photography is an abstraction that plays to the psychological response of the viewer. An absolutely faithful reproduction of the original scene is not the objective of the pictorialist. Any attempt to backfit the range of values delivered by an imaging satellite into the standard laboratory procedures of a commercial photo lab will result in a significant loss of imaging data from the end product and a distortion of the small percentage of values that survive.

Preliminary screening of film based on emulsion characteristics must consider the requirements for successful extended range processing and registration. The sensitometric response curves of film include a toe, straight-line, and shoulder traced from the first measureable density above the level of base-plus-fog. Achieving the objective of an extended straight-line portion of the curve that will accomodate 256 discrete density levels, a limitation of the chemical fog associated with extended range processing, and the retention of high resolution and minimal granularity contradicts the normal relationships of film speed, resolution, contrast, and latitude. Generally speaking,

SLOWER EMULSIONS HAVE	FASTER EMULSIONS HAVE
Finer Grain	Coarser Grain
Higher Contrast	Lower Contrast
Higher Resolution	Lower Resolution
Less Latitude	Greater Latitude

Ideally, B&W film separations prepared for the production of multiband satellite images would have an emulsion that combines the highest resolution and finest granularity with the greater latitude and lower contrast that meets the requirement for an extended sensitometric straight-line capable of holding 256 densities. Combine a film speed suited to the extremely short exposure times of film recorders so that the reciprocity limit of the film remains within reach of the calibrated chemistry, processing time, temperature and agitation frequency, would define an emulsion whose characteristics have yet to be published.

The calibration of any laboratory to the production of film separations represents a compromise of all the factors that influence the end product. The effectiveness of that compromise is reflected in the full-color end product and the extent to which the signatures of individual pixels can be validated by objective measurement.

Extended range processing should not be confused with the processing procedures that push or extend the effective speed of the film. The objective of the former is to extend the straight-line portion of the sensitometric curve while preserving the intrinsic resolution of the film Push processing is intended to elevate the density range of the negative exposed at several f/stops below its ISO rating. In order to produce a printable negative, chemistry and processing procedures are used that increase granularity and reduce resolution which contradict the objective of extended range processing.

The oldest maxim in photography may be to, "expose for the shadows and develop for the highlights." Exposure times and intensities delivered by film recorders do not allow for any lab procedure that fails to preserve the lowest densities dictated by the radiometric range of 256 values. A digital input value of "1" must yield a measureable density in the separation positive above base-plus-fog. In this case, "exposing for the shadows" is governed by the film recorder, and the density producing energy of the chemical developer must be capable of generating that first significant density. If the extended range processing formula cannot generate that density level, calibration has not been achieved and the dimensions of the color palette will be correspondingly diminished.

Laboratory calibration includes the film recorder and adjustments to its light output in response to the digital values it receives from the database of the image. Adjustments are in the form of algorithms that modify light output to extend the straight-line portion of the curve. If the lower digital values produce densities clustered in the toe, the algorithm is written to 'pull" that portion of the curve into the straight line. If the higher vales are clustered in the shoulder of the curve, the algorithm is adjusted to increase the separation of densities so that the straight line is extended. These lookup tables (LUTs) should be used only after the collective options within the darkroom have been exhausted. Film recorders offering higher light output significantly increase the probability of adequate exposure to the lower digital values. Evenly separated densities at the low end of the scale is the first order of business. The 'highlights" frequently are controlled by reductions in processing time. Because all LUTs are specific to the calibration of individual film recorders with a specific laboratory, the development of effective algorithms are evolutionary and depend upon the reliability of the lab to generate consistent density steps from their film and chemistry combinations.

Archival Washing and Drying

A silver-based image achieves archival permanence by the removal of residual chemistry from the emulsion. Extended film washing times can be substantially reduced by the use of commercial hypo-removing products. Because satellite image film separations are end products as well as pieces in the production puzzle of a color composited negative, archival processing should be a standard practice.

The drying of film separations directly influences the eventual registration and preservation of individual pixels in the first generation color image. Each separation is unique to the band data that produced it. While similar to each of the other bands in terms of the geospatial footprint, a film separation has its own distribution and concentration of the black metallic silver that creates its densities. That distribution of silver can influence the shrinkage of the emulsion during drying. Because no two separations contain the same amount or distribution of silver, variations in the shrinkage of the emulsion directly affects the registration of one separation with another.

Shrinkage is held to a minimum when saturated emulsions are allowed to dry at room temperature. The forced hot air drying provided by film drying cabinets can cause uneven shrinkage and a curl of the film base which further discourages accurate registration. Allowing the separations to dry in a flat position on screens is preferable to suspending the separation from a corner of the image. Even if the gravitational pull on silver suspended in the saturated emulsion is undetectable, the tendency of the suspended film is to produce a curl of the base around the vertical line from the point of suspension. Curl in the film base seriously impairs the successful positioning of one separation over another during registration.

Registration

Successively punch registering three film separations with micrometric precision necessitates consideration of several factors that influence the process. The film punch hardware designed for graphics production was marginally acceptable when the spatial resolution of the satellite image was 79 meters and the spot size of the film recorder was 50 microns. Five meter data written through a spot size of 12.5 microns requires punch pins of one-sixteenth inch to reduce slippage between separations. Film thickness is also a factor. The thicker the film base the greater the resistance to the penetration of the punch pins with a corresponding increase in the probability of slippage.

Positioning separation #2 over separation #1 is accomplished under magnification at each corner sufficient to clearly define the perfect alignment of the intersection of the crosshairs. If the magnification is too great, the depth-of-field may not allow both crosshairs to be brought into acceptable focus at the same time. Thickness of the film base is also a factor here because it determines the separation of the crosshairs under magnification. When the best possible alignment of the separations has been achieved, both films are punched and separation #2 is replaced by separation #3 while separation #1 remains secured to the film punch base. The process of alignment is repeated after which all three separations are cross-checked to insure that the registration has been successful.

Color Composition

Satellite-based film separations are B&W positive images composed of pixels with densities equivalent to the digital values that determined their exposure by a film recorder. If calibration of the film, chemistry, and processing procedure was conducted properly, the density of each pixel in each separation will function as a neutral density filter to regulate the additive exposure of the color negative.

A principal advantage of compositing the color negative from successive exposures through separations is the ability to maintain exposure times within the reciprocity limits of the color negative material.[3] Color film recorders expose each pixel at approximately four ten-millionths of a second which is close to 1/4000th of the exposure color film requires to faithfully and predictably record an image. The deficiency is not overcome by what amounts to push-processing in the chemistry of a production processor. Best practice among commercial laboratories that processed satellite images like general photography resulted in a loss of 92% of the satellite's color palette.[4]

There are several combinations of red, green, and blue filters used for making color separations in the graphics industry. Designed for the isolation of primary colors in a full-color image, they serve equally well for the introduction of colors during the composition of a color negative from B&W separations. Two combinations of Kodak Wratten Filters used effectively in the production of satellite images are:

29 Red	25 Red
61 Green	58 Green
47 Blue	47B Blue.[5]

Filter selection and proper exposure times are part of the calibration procedure that assures high quality images.

Photographic technologists tasked with the preparation of color negatives from B&W separations tend to develop their own routines for the shuffling of color negative stock, film separations matched to appropriate filters, cover sheets for vacuum frames, and the exposure times established by preliminary testing. Accurate color compositing requires a neutral light source to avoid introducing any shift in the color balance during the sequential exposures. Cold light works well if the intensity is adequate to the exposure requirement, but nearly any neutral light source will serve if it meets the compositing requirement.

Color Film Processing

The inability of commercial photo labs to process satellite image film separations without essential calibration does not extend to the processing of the composited color negatives prepared from those separations. Commercial color labs survive in a highly competitive business environement when they meet the needs of demanding professional photographers working with large format equipment. If the satellite imaging lab cannot justify a quality controlled E6 line because of limited production, they are advised to work with a local lab serving the professional photographic community. Turnaround times may be no longer than a few hours and should be factored into the announced delivery time to the end user.

Display Technologies

Electronic display technology refers to the full range of color monitors including LCD, RGB, CRT, and the Wide Gamut RGBs coming off the drawing boards. Most of these are delivered in screen sizes from 13" to 21" and are viewed as tabletop displays supporting a variety of computer configurations. Image analysts working with satellite imagery may never see a hardcopy of the scenes they work with depending, instead, on the range of colors delivered by their particular screen. The consistency of colors varies from screen to screen according to the age of the monitor, the operating temperatures, and the quality of the phosphors.

The range of colors that can be perceived by human vision significantly exceeds the color range delivered by the best of electronic monitors.[6] For most work this presents no problem. Like the film designed for general photography, color monitors are designed to meet the requirements of general color graphics including the creative talents of professional artists. For satellite imagery with a palette of over 16 million colors, the problem lies with the color shortfall of electronic displays. Measured against the area of the CIE chart showing the range of human color perception, electronic monitors achieve the following:

LCD ------------------------ 24%

RGB ------------------------- 27%

CRT ------------------------- 34%

WGRGB -------------------- 59%

The color palette of satellite imagery approximates the dimensions of human color perception. When a satellite image is color composited from film separations to preserve the radiometric resolution delivered by the satellite, that resolution is never displayed by electronic monitors.

Photographic hardcopy can be prepared as a paper print or a transparency from the first generation color negative. Prints predominate for their convenience of usage and generally lower cost. Maximum resolution is delivered by the transparency which is the product of choice for the more demanding interpretive tasks. Light transmitted through a film base will discriminate subtleties that cannot be detected by light that travels first through the emulsion of the paper print, is reflected from the white paper base, and then passes back through the emulsion of the print to the viewers eye with greatly diminished intensity.

The highest quality satellite image in terms of spatial and radiometric resolution that can be prepared for visual interpretation will be the end product of B&W film separations prepared by custom calibrated photolabs.

Conclusion

Hyperspectral, multispectral, and panchromatic imaging data delivered by an increasing number of imaging satellites represents an enormous amount of raw data available to the end user. Allowing for the screening of that data to narrow the selection to potentially useful scenes, the cost of data acquisition, processing, and assessment constitutes a major investment that deserves a comparable effort in the translation of the imaging data to the best possible end product.

This paper has revisited the steps and procedures practiced by photographic laboratories first involved with the production of large scale satellite images. Over the past 25 years, the quality of satellite imaging data has steadily improved along with the reduction in time and effort required to convert that data into usable imagery. Much of that reduction in labor has been in the form of printing technologies that bypass darkrooms and chemistry to deliver scaled photomaps of unquestionable value. The value of those images lies primarily with shortened production times, the retention of spatial resolution, and cartographic scaling.

Given the potential for reliable information retrieval from the radiometric resolution of imaging satellites, there is a powerful argument to be advanced in favor of the resurrection and refinement of earlier photographic darkroom procedures. Mutterings have been heard within the remote sensing community that photography, if not dead, is essentially obsolete. This paper responds by outlining the unique advantages to be gained by applications of photographic technology to the composition and display of satellite imagery.

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