Validation of Multiband Color Signatures

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Abstract

The practice of remote sensing by the acquisition of imagery from space has promised more than it has delivered.[1] Photographic interpreters schooled in the techniques of information extraction from panchromatic and color infrared single frames and stereo pairs were, in the absence of an established reference for multiband color signatures, relegated to inferential analysis of false-color satellite imagery composited from the digital data of several spectral bands. A principal roadblock to the reliable interpretation of space photography lies with the fickle nature of the color signatures which, pixel by pixel, create the satellite-based digital image. This paper presents one approach to the validation of those color signatures that offers the potential for the evolutionary development of a reference library for multiband interpretation. A solution to the problems associated with the conversion of digital imaging data to analog silver halide hardcopy, the registration of black-and-white film separations, and the introduction of color by additive filtration are presented as prerequisites to the validation of spatial resolution and color signatures in a multiband color composited film negative. Practical color signature validation enables the reliable interpretation of multiband imagery regardless of bandwidth and frequency.

Introduction

Full-color satellite photographs are digital images composed of millions of pixels derived from the remotely sensed reflected and emitted energy within three spectral bands. Depending on the specifications of the imaging system carried on the satellite, the *radiometric resolution* is the numerical range of values by which the level of detected energy may be expressed as a *digital number* (DN). The radiometric resolution of Landsat and SPOT is 256. For Space Imaging's IKONOS satellite, the radiometric resolution is 2048. Within any one band - or frequency - of the electromagnetic spectrum, the DN for a pixel represents the intensity level of energy detected by the on-board sensors. As shown in Figure 1, the *color signature* of any pixel within the satellite photograph is determined by the combinations of DNs for a selection of three bands of imaging data and the assignment of an additive primary color - blue, green, or red - to each of the bands. The dimensions of the color palette for a digital imaging system is the cube of its radiometric resolution. For Landsat and Spot the color palette represents 16,777,216 discrete color signatures.[2]

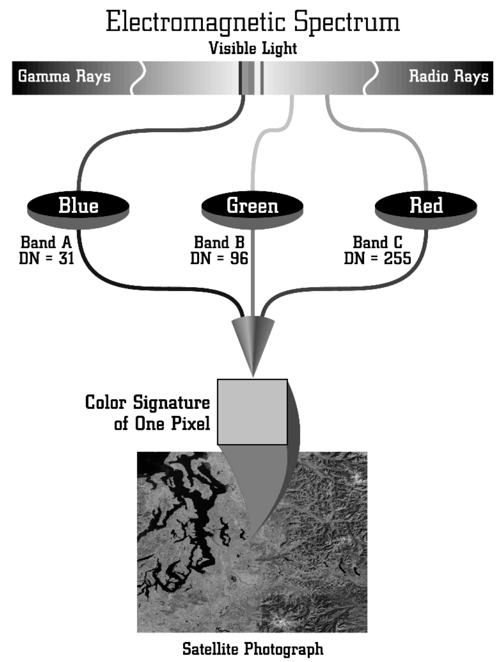

Figure 1. Color signature derivation. Color signatures can be validated when their radiometric integrity is preserved during the digital-to-analog conversion. The DNs assigned to the levels of detected energy must govern the color composition of individual pixels within the photographic hardcopy.

The *spatial resolution* of a digital imaging system is the target area footprint of a single pixel. The ability to discriminate and identify smaller and smaller features in the imaging field is a common objective for the design of most imaging systems. Over the past 30 years, the spatial resolution of commercial imaging satellites has improved from the 79 meters of the first Landsat to the one-meter resolution of the IKONOS panchromatic band. Licensing for half-meter data has been approved. Because the validation of multiband color signatures covers spatial as well as radiometric resolution, provision must be made for the impact of registration procedures on both conditions. Image analysts requiring confirmation of the reliability of imaging data for both types of resolution obligates the production laboratories to report color signature factors (SF) and effective spatial resolution (ER) so that the quadrants of the end product may be treated as an authentic display of the information gathered by the imaging satellite.

Radiometric Accuracy

General photography is characterized by the color and black-and-white pictures that fill our family albums. Black-and-white photographs are panchromatic images whose single band origins encompass the visible blue, green, and red frequencies of the electromagnetic spectrum. Color photographs are multiband records in which each of the primary colors is captured by a separate layer of the color film emulsion. A seemingly infinite mix of red, green, and blue light combinations reflected from the original scene is reproduced as the color photograph. If the photograph matches our recall of the scene when the picture was taken we judge the color rendition to be accurate. Fine art black-and-white photography is considered accurate if the final print displays the shadows and highlights visualized by the photographer when the film was exposed. In either case, discussions or thoughts about radiometric accuracy probably were not a factor.

Space photography is accurate when two essential criteria have been met in the production of the end product. Satellite imagery is acquired as a function of remote sensing and is intended to gather information. The success of the remote sensing effort is measured by the accuracy of the information acquired regardless of the analytical methodology employed in its application. A principal value of satellite remote sensing is the ability to create images from frequencies beyond the range of photographic film. Most satellite photographs are false-color images generated by the assignment of an additive primary color to data captured in bands outside of the visible spectrum. The resulting color rendition is unrelated to the reality of the visual display at the time the scene was recorded. The accuracy of a true or false-color satellite photograph resides in (1) the *retention of the radiometric values* within each band recorded by the satellite and, (2) the *successful registration* of multiband pixels that will ensure the display of a first generation color image which accepts the potential pallete of multiband imagery. *Validation of multiband color signatures* is achieved by the *objective measurement* of both criteria.

A single-band satellite image displays radiometric accuracy when the monochromatic densities of individual pixels match the DNs which they represent. If the radiometric resolution of a satellite imaging system is 256, a test pattern of densities should display an evenly stepped progression of densities from 0 - 255. When the display is a black-and-white film transparency, there is a requirement that the straight-line portion of the film's sensitometric curve accommodates the imaging system's radiometric resolution. Any extension of radiometric values into the toe or shoulder of the sensitometric curve represents a compression of high or low radiometric values which distorts the original data delivered by the satellite. As shown in Figure 2, matching the straight-line of the curve to the radiometric resolution of the imaging system assures the evenly stepped distribution of radiometric values displayed as densities in a positive film separation.

Production of separate black-and-white film records for each band selected for color composition enables the densitometry that satisfies the first criterion for color signature validation. Depending on the calibration procedures of individual production laboratories, varying combinations of film recorders, film, chemistry and processing procedures will generate different sensitometric curves for film separations. However, all such curves must include a straight-line portion that matches the radiometric range of the satellites's imaging system.

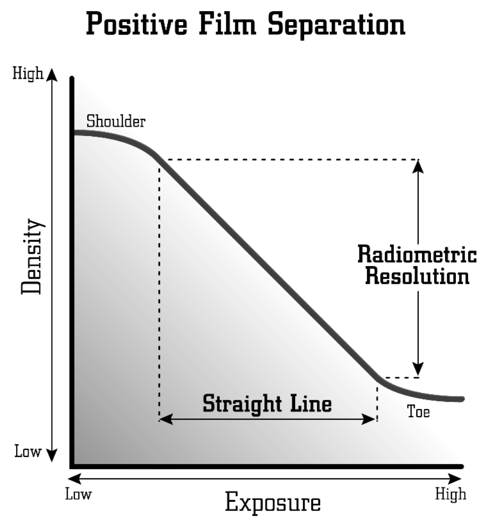

Figure 2. Requisite sensitometry. Fitting the radiometric resolution of the imaging system into the range of densities in the straight-line portion of a film separation's sensitometric curve assures an even and equitable progression of density steps that regulate color exposure.

Multiband Registration

The production of film separations that establish the retention of radiometric values obligates the successful registration of those separations to ensure the production of valid color signatures. Crosshairs positioned in each corner of the separation outside of the image area occupy precisely the same digital address among all three film records. In the maximum density field of the film positive surrounding the image, the intersection of each minimum density crosshair is occupied by a single pixel. Depending on the spot size of the film recorder that translates the digital values of the imaging database to the analog values within the film emulsion, the resolution of that crosshair will impact directly the resultant resolution of the corresponding crosshair in the color negative. High levels of granularity[3] in black-and-white film separations work against the measurement of color pixels in composited negatives.

Under high magnification, the precise edge of the pixel in the color negative is softened by any misregistration of the film separations. Additionally, the granularity of the color emulsion contributes its own softening effect to the definition of pixel boundaries.

Successful registration of all three film separations assures the measureable resolution of the pixels in the crosshairs of the color negative. Perfect registration is demonstrated when the dimensions of the pixels in the positive film separations matches the dimensions of the pixels in the color negative. As shown in Figure 3, multiband registration requires acceptable registration at each corner of the image. In practice, some variance can be expected in the measurement ratios of positives and negatives among the four corners, but validation data is reported for each corner which eliminates assumptions of validity across the quadrants of the image.

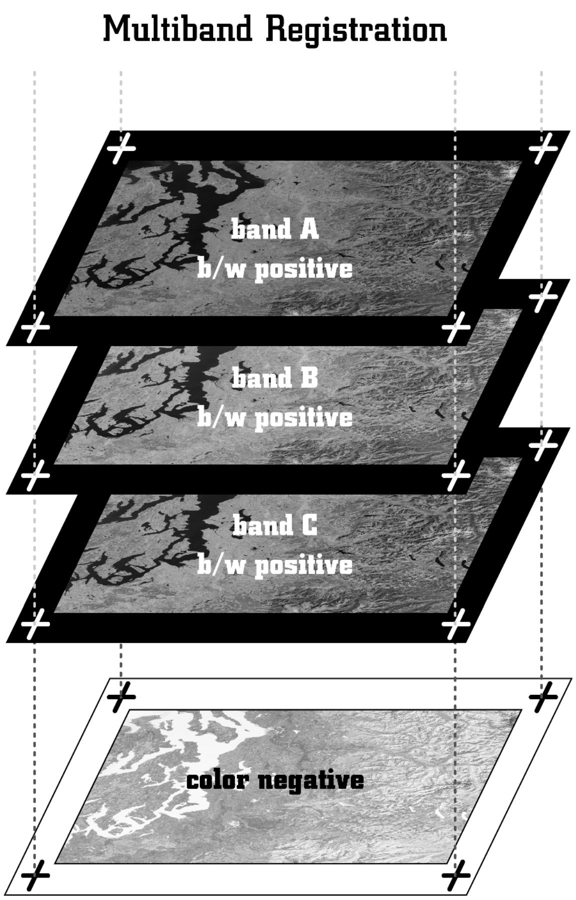

Figure 3. Multiband registration. The crosshairs in each corner of the film separations occupy the same pixel address among all three black-and-white positive records. Their accurage registration assures a controlled composite in the first generation color negative.

Perfect registration means that the bilateral dimensions of a pixel in the film separation are the same as the bilateral dimensions of that pixel in the color negative. Given the range of influential variables that work against that probability, perfection must yield to excellence defined as a color pixel whose area is greater than 50% of the area of that pixel in a contributing separation. Acceptable area ratios of color to black-and-white pixels will range upwards from .51 : 1.00. When these color negatives are printed to a positive image, the dominating color of each pixel will be governed by the retained DNs which function as regulating neutral density filters in each pixel of the film separations. Images that fail to achieve acceptable ratios in each quadrant may still be useful for critical analysis if a particular area of interest lies within a quadrant whose corner registration passed muster. If a set of film separations fail to achieve acceptable registration, reruns of the multiband data may overcome fleeting problems in the performance of the film recorder, processing of the film, or errors in the punch registration exercise. Because the imaging data has been geometrically and radiometrically corrected by the time it is translated to film, identifying the source of registration errors is substantially simplified.

Comparative measurements of the pixels in the Black-and-white film separations and the color negative is done under magnification appropriate to the spot size of the film recorder. The dimensions of the pixel at the intersection of a crosshair in a positive separation is the standard against which the dimensions of the corresponding pixel in the crosshair of the color negative are measured. Reticles in the optical field of view of the microscope are selected according to the measurement required. As shown in Figure 4, registration is 100% when the biaxial dimensions of pixels in the positive and negative are equal.

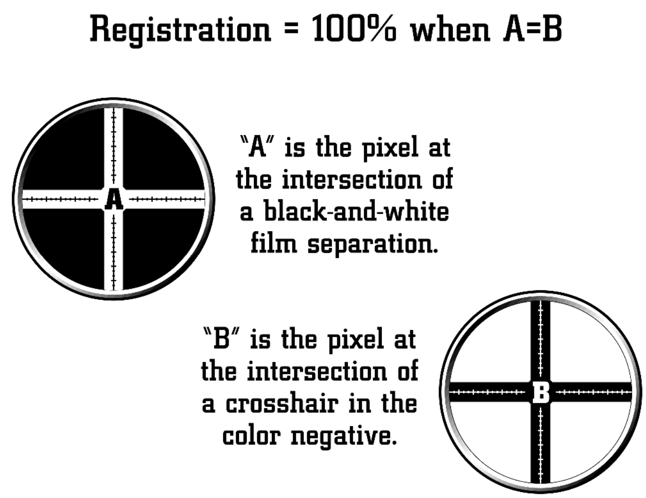

Figure 4. Comparative pixel measurements. The functional integrity of a color signature is based on the comparative measurements of the biaxial dimensions of a pixel in a film separation with a corresponding pixel in the color negative. That pixel is located at the intersection of the crosshairs in each corner of the positive and negative.

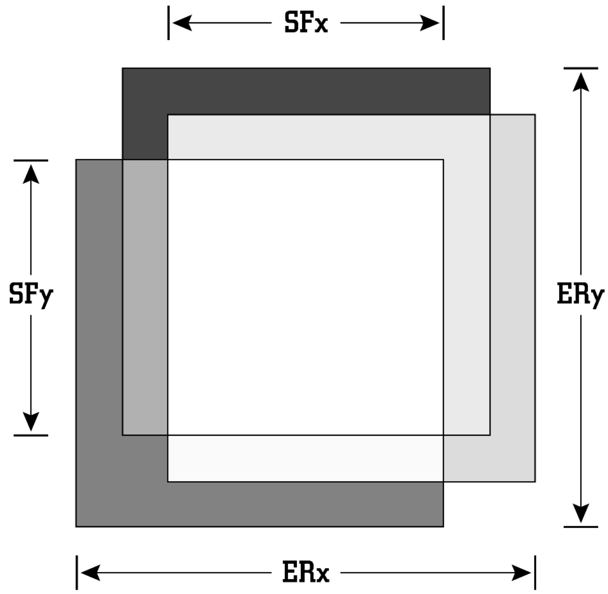

Figure 5. A white pixel with SF .64 / ER 120%. When registration is perfect, the signature factor will have a value of 1.00 and the effective spatial resolution will equal the design specifications of the imaging system. Gathering accurate information is the objective of remote sensing and image analysts must know that the color signatures which form the image are valid expressions of energy detected by the sensors.

There is a low probability of achieving perfect registration at each corner of the negative. The distribution of black metallic silver within film positives varies with the particular band and can influence the migration of silver grains while the film is drying. Shrinkage of the emulsion also varies among positive separations and is likely to detract from the perfect alignment of all three bands. Knowing the extent of misregistration and being able to account for it by objectvie measurement is the principal challenge of color signature validation. While the standard for acceptable validation is to have the area of the color pixel exceed 50% of its black-and-white counterpart, that threshold is commonly exceeded in practice. Figure 5 shows a diagrammatic white pixel which occurs when the contributing DNs of three bands were at the very top of the imaging system's radiometric resolution scale. For Landsat or SPOT, that means that a DN value of 255 was detected for each band resulting in an area of minimum film density in the positive separation which, in turn, allowed for the maximum exposure of the color negative to each of the additive primary light sources. As shown in figure 5, the slight misregistration has resulted in a measured signature factor (SF) of .64 which tells the image analyst that the area of essential overlap of the three bands is within the region of acceptable criticality. Misregistration detracts from the designed spatial resolution of the imaging system and will correlate inversely with the decline of the signature factor. In Figure 5, the effective spatial resolution (ER) has risen to 120% of the imaging system's design specification.

Summary

The purpose of acquiring photography from space is to expand our knowledge about the earth and its atmosphere. Commercial imaging satellites have operated for nearly thirty years and, during that time, have delivered records of energy recorded within visible and non-visible bands composited into color photographs and interpreted by scientists in dozens of traditional and emerging dsiciplines. Missing from the practice has been an established methodology for validating the color signatures of pixels that are the building blocks of the final image. Improvement in the spatial resolution of imaging satellites has reduced the area of the pixels footprint averaged by the on-board sensors with a corresponding increase in the significance of the radiometric resolution assigned to that pixel Multiband records of that radiometry acquire meaningful significance when the color signatures of their imagery are linked to specific features in the area of coverage. Validation of those color signatures lends credence to the practice of ground truthing and permits the extrapolation of a color pixel's composited DNs to other sites within the dimensions of an image.

This paper has described a methodology for the validation of multiband color signatures based on the objective measurement of two elements in the production of a satellite-based digital image: (1) The retention of radiometric values is determined by the densitometry of the straight-line portion of a positive film separation's sensitometric curve and, (2) The successful registration of film separations is established by the comparative measurement of the biaxial dimensions of color and black-and-white pixels. This validation methodology bypasses the loss of original imaging data that occurs when writing directly to color film and provides single-band archival records that contribute without variance to other renditions.

References

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Biography

Jerry Noss has conducted research on the calibration of photographic systems, managed a commercial photographic laboratory for the production of satellite imagery, and explored the independent variables that influence the retention of digital imaging data in the production of color photographs. He taught photo-analysis and developed a research laboratory for the University of Maryland where he received his Ph.D. He is an educational technologist for Autometric, Incorporated, a business unit of The Boeing Company.