N78-14592

DIGITAL COLOR ANALYSIS OF COLOR-RATIO COMPOSITE LANDSAT SCENES

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ABSTRACT

A method is presented that can be used to calculate approximate Munsell coordinates of the colors produced by making a color composite from three registered images. Applied to the Landsat MSS data of the Goldfield, Nevada, area, this method permits precise and quantitative definition of the limonitic areas originally observed in a Landsat color ratio composite. In addition, areas of transported limonite can be discriminated from the limonite in the hydrothermally altered areas of the Goldfield mining district. From the analysis, the numerical distinction between limonitic and non-limonitic ground is generally less than 3% using the Landsat bands and as much as 8% in ratios of Landsat MSS. bands.

1. INTRODUCTION

In the past, discrimination of altered ground in mineral areas has been achieved using diazo color composites of Landsat ratio images (Rowan and others, 1974). Such discrimination relies on subjective recognition of particular colors in the color ratio composites and is strongly affected by variability in diazo film processing. A digital technique has been developed by which the digital ratios values can be numerically transformed from the three axes of an orthogonal coordinate system to a cylindrical coordinate system that approximates the Munsell color space (Strandberg, 1968). The colors that would result in a color-compositing process, such as the diazo process or a color additive process, thus can be precisely and quantitatively defined in terms of Munsell color coordinates.

This technique is illustrated by use of the color-ratio composite of the Goldfield, Nevada, area presented by Rowan and others (1974). The reader is assumed to be familiar with that report, and details of the compositing and geologic analysis are not repeated here.

2. METHOD

The geometric relationships involved in the transformations from an orthogonal coordinate system to cylindrical coordinate system approximating the Munsell coordinate system are shown in Figure 1. The Munsell coordinate system is a coordinate system that uses dimensions related to the psychological aspects of color (Strandberg, 1968). The three Munsell coordinates are hue, saturation, and value. Hue is basically the color such as red, green, brown, yellow, etc. Saturation is a measure of the purity, the higher the saturation the greater the purity for a given hue and value. The value is a measure of the brightness of the color, the greater the value, the brighter the color. With these three variables any color, as seen by a human observer, can be uniquely defined.

The equations used for the transform from the additive primary colors to Munsell coordinates are given in Table 1. The inverse equations, Munsell coordinates to additive primary colors, are given in Table 2. These transforms assume a color-additive process with the additive primaries, blue, green, and red. The diazo process uses a color subtractive process. The relationship between color subtractive and color additive processes is shown in Table 3. If the relationships outlined in Table 3 are used, the same color composite will be derived with ideal color subtractive or color additive techniques. With the equations in Table 1, the colors that would be seen in the color-ratio compositing process can now be calculated. Briefly, the color-ratio-composite process as used by Rowan and others (1974) is as follows. The ratios of Landsat bands 4 divided by 5 (designated 4/5), 5 divided by 6 (designated 5/6), and 6 divided by 7 (designated 6/7) are formed. Then these ratios are linearly rescaled to the integers 0 to 255 which is the full range of gray levels of the film. Finally, positive black and white images on film (a high ratio has a low density on these images) are formed and these images are copied onto the appropriate color diazo film. The 4/5 image is cyan, the 5/6 image is yellow, and the 6/7 image is magenta. These color-coded ratios images are composited to form a color-ratio composite in which all colors are possible. The numerical analog using the equations in Table 1 and the relationships in Table 3 are as follows. The 4/5 ratio value is the red value, the 5/6 ratio value is the blue value, and the 6/7 ratio value is green. Then entering the calculated ratios into the transforms in Table 1, hue, saturation, and value are calculated. The blue, green, and red colors are centered at hue 0°, 120°, and 240°, respectively. The intermediate colors blue-green and yellow are centered at hues of 60° and 180°, respectively.

Now the reason that this precise transform gives an approximation of the Munsell coordinate system is apparent. The boundaries between these colors are not precisely defined. Therefore, a subjective decision has to be made with regard to what the individual interpreter considers the boundary. However, as a guide line, the divisions between the colors are approximately half-way between the pure hues. Furthermore, if in the color-composite image an observer recognizes the color as distinct, then the saturation must be high and the value moderate. Value can also be estimated by inspections of color composite images. Lack of definition of the colors in this numerical transform is not really a limitation, since any decision that is made is well defined, repeatable, and uniform for the whole data set. Thus, the decision can be exhaustively tested to see if it is acceptable and can be modified until an acceptable decision is derived.

As the transforms can be used both ways, additive primaries to Munsell and Munsell to additive primaries, a very powerful image enhancement technique is also available. Individual colors of a color composite image can be isolated or very subtle color variations can be enhanced for better visual interpretation of images. These operations can be performed by transforming from additive primaries to Munsell and then manipulating the desired color aspects. For example, the saturation may be increased for one set of hues that are critical to identify; thus making it easier to recognize those hues. Then the Munsell coordinates may be transformed back to the additive primary values and a new enhanced color composite image can be formed. A specific application of this concept will be discussed in the next section.

3. APPLICATION

Once a color-ratio composite is made with the diazo process, two basic problems are encountered. The first problem is that the recognition of colors is a subjective process and is greatly affected by surrounding colors. Associated with this problem is the fact that the diazo process is not exactly repeatable. The second problem is that by using the diazo process, digital ratios produced in a well controlled numerical process have been transformed into a less-well controlled analog product. Thus, questions concerning the numerical aspects such as what are the ratios that produce green on the color-ratio composite are very difficult to answer. The advantage of the color-ratio-composite process is that the human mind can be applied to interpret an image so that image factors such as texture, shape, and association can be taken advantage of. Therefore, more than just the spectral aspects of the problem can contribute to the analysis. Thus, the method presented in the previous section is not really a substitute for the color-ratio-compositing process but is another tool to further the analysis of the color-ratio-composites. In the rest of this paper I will present examples of the application of this method to the two problems mentioned above.

The first problem is recognition of a specific color. For the color-ratio-composite image of the Goldfield, Nevada area, Rowan and others (1974) state that there is excellent coincidence between the limonitic areas such as the Goldfield mining district and the green color seen in the image. However, upon detailed inspection of these areas, I have found that it is not a straightforward matter to outline and map these green areas. Conversion to Munsell coordinates is a method to do this mapping of green areas in a well defined and repeatable fashion.

Figures 2 through 5 show images that were formed in producing the map in Figure 6 of the green areas of the color-ratio-composite images, that is the limonitic areas. These figures all cover the same area discussed by Rowan and others (1974). Figure 2 shows in black those pixels with the hues 87 to 132, the green hues. These exact numbers are image dependent. At first inspection there appear to be too many, but detailed inspection of the color-ratio-composite image shows there are indeed green pixels in all of these areas. However, there are differences in distribution of the green pixels. In the Goldfield area, the green pixels are concentrated whereas on the pediments the green pixels are scattered. This distribution is consistent with differences expected in limonite occurrence, comparing an area containing abundant iron sulfides and oxide minerals due to intense hydrothermal alteration and an area of minor scattered iron staining on a colluvium-covered pediment. The exact hue interval was selected by inspection so as to include all areas selected by Rowan and others (1974).

To further refine Figure 2, the saturation was considered next. On inspection of the Goldfield color-ratio-composite image, the greens are seen to be very distinct, easily recognized greens. Therefore, the greens of interest have a high saturation. Figure 3 shows in black those pixels with the green hues selected in Figure 2 that have a high saturation. The number of pixels selected has been greatly reduced and most of the areas of concentrated pixels are the limonitic altered areas selected by Rowan and others (1974).

Now the problem of noise in the Landsat data and the problem of individual isolated pixels is apparent in Figure 3. There is a conspicuous six-line stripping in this figure that is related to the miscalibration of the six detectors on the Landsat multispectral scanner. One solution is to filter every sixth line to subdue this stripping. Figure 4 shows the result. The second problem--isolated pixels--is only a problem in the sense that I am not interested in a limonitic area of only one isolated pixel. Figure 5 is the result of removing all selected pixels from Figure 4 that have no immediately adjacent neighbors.

Finally, color coding Figure 5 and registering this image onto an image of Landsat band 5, a map (Figure 6) is produced showing in red those pixels that were green and relatively concentrated in the color-ratio-composite image. Specifically, this is a map of those pixels with high saturation and green hues after corrected for a sixth-line stripping and removal of isolated pixels. The limonitic areas selected by Rowan and others (1974, figure 18) are seen as concentrations of red.

Now that the green pixels have been located and defined numerically, the question of what numbers in the three ratios combined to produce green in the diazo composite, can be answered. Table 4 presents the statistics of the Landsat bands and ratios of various colors or areas of interest that were defined by the process discussed above. These precise numbers are of course dependent upon the atmospheric conditions and the calibration of the satellite at the time the data were acquired. However, from work in other areas it appears that these numbers are approximately the same from area to area.

From inspection of Table 4 a further application of this methodology is suggested. There is a very small numerical difference between the green areas of the Goldfield mining district and the green areas on the pediments. Can this difference be seen in an image? Figure 7 shows an approach to this question. Figure 7a is band 5 of the area around the Goldfield district and extends south to the Cuprite district. Figure 7b is an attempt to take advantage of this very small difference between the greens at Goldfield and on the pediments. It involves the following steps: (1) transform the ratios to Munsell coordinates, (2) in the hue dimension, linearly translate the green, yellow, and brown hues to occupy all possible hues and make all other hues zero, (3) increase the contrast in the saturation and value dimensions, and (4) transform these enhanced Munsell coordinates back to additive primary colors, ratios in this case, and form an enhanced color-ratio composite. Figure 7b shows the variation of the green, yellow, and browns of the original color-ratio-composite image as variation of all hues except blue, a hue of zero. The limonitic areas at Goldfield and Cuprite are both distinct. The non-limonitic area at Cuprite is also anomalous. Furthermore, as hoped, the areas of transported limonite on the fans are partially distinct from the limonitic areas at Goldfield and Cuprite. A possible explanation of why these differences are seen does not require the transported limonite on the pediments to have different spectral properties than the limonite at Goldfield. This difference could be simply related to the distribution or concentration of limonite within the 80 meter resolution cell of Landsat, a mixture problem.

4. CONCLUSION

The application of the equations in Tables 1 and 2 has allowed a significant improvement in the analysis and understanding of color-ratio-composite images. This method provides a numerical method that is analogous to the color compositing procedure and complements that procedure. The information derived from this analysis is suggesting many further avenues of research. However, the application of this technique is not limited to analysis of color-ratio composites; it could be applied to the analysis of any color image.

5. ACKNOWLEDGMENT

I would like to acknowledge the help of Don L. Sawatzky in deriving the equations used in this analysis.

6. REFERENCES CITED

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Strandberg, C. H., 1968, The language of color, in Smith, J. T., Jr., and Anson, Abraham, 1968, Manual of color aerial photography, first edition: Fall Church, Virginia, American Society of Photogrammetry, p. 3-24.

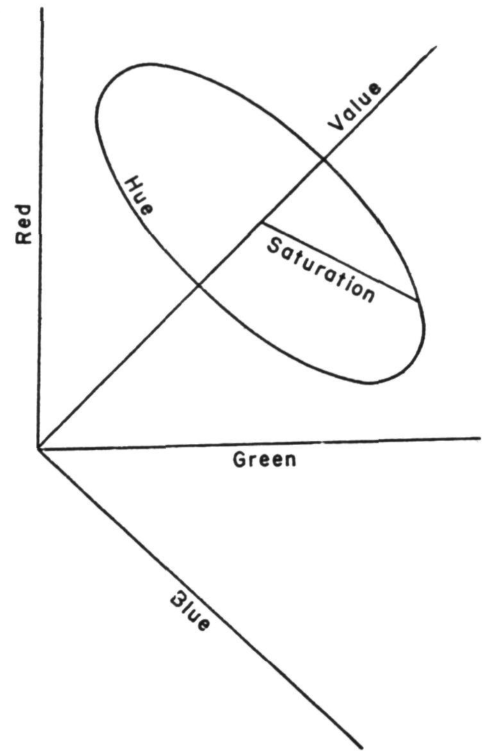

FIGURE 1: GEOMETRIC RELATIONSHIP BETWEEN THE ORTHOGONAL COORDINATE SYSTEM OF THE ADDITIVE PRIMARY COLORS AND THE CYLINDRICAL COORDINATE SYSTEM THAT APPROXIMATES THE MUNSELL SYSTEM. The cylindrical system is oriented such that the angle between the value axis and all additive-primary-color axes is the same. The saturation axis is normal to the value axis, and the hue is the azimuth of the saturation axis measured in a plane normal to the value axis. In the cylindrical coordinate system the azimuth of the blue axis is arbitrarily taken as the zero azimuth; thus, the green axis has a hue of 120 and the red axis has a hue of 240.

FIGURE 2: THIS IMAGE SHOWS IN BLACK THOSE PIXELS THAT HAVE GREEN HUES. This image, and Figures 3 through 5, was formed so that adjacent pixels would overlap on exposure; thus increasing the print density where there are adjacent selected green pixels. This was done to emphasize areas of concentrations of pixels such as the Goldfield mining district.

FIGURE 3: THIS IMAGE SHOWS ONLY THOSE PIXELS IN FIGURE 2 THAT HAVE HIGH SATURATION.

FIGURE 4: THIS IMAGE IS THE RESULT OF MAKING A CORRECTION FOR THE SIX-LINE STRIPPING OF FIGURE 3.

FIGURE 5: THIS IMAGE IS THE RESULT OF REMOVING ISOLATED PIXELS FROM FIGURE 4.

FIGURE 6: THIS IMAGE IS FIGURE 5 CODED IN MAGENTA AND REGISTERED ON LANDSAT BAND 5. The red areas are areas where there are concentrations of limonite at the surface. This image numerically reproduces in red the green areas in Rowan and others (1974, figure 18).

FIGURE 7a: LANDSAT BAND 5 OF THE GOLDFIELD MINING DISTRICT. This is the same area as in Figure 7b.

FIGURE 7b: AN ENHANCED VERSION OF THE COLOR RATIO COMPOSITE SHOWING THE VARIATIONS OF GREEN, YELLOW, AND BROWN OF THE ORIGINAL AS ALL COLORS EXCEPT BLUE. Notice that the transported limonite southeast of Goldfield is distinct from Goldfield.

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

Figure 6

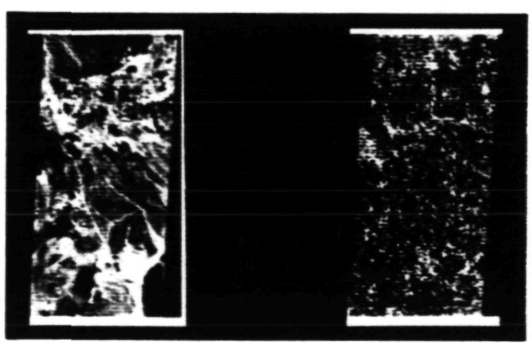

Figure 7a Figure 7b

Table I: Transformation of the Additive Primary Colors to Munsell Coordinates. In the example being considered, the blue ratio value is from the 5/6 ratio (Landsat band 5 divided by 6), the green ratio value is from the 6/7 ratio, and the red ratio value is from the 4/5 ratio.

B = blue ratio value
G = green ratio value
R = red ratio value

$K2 = \frac{\sqrt{2}}{2}$, $K3 = \frac{\sqrt{3}}{3}$, $K6 = \frac{\sqrt{6}}{6}$, $K7 = \frac{\sqrt{6}}{3}$

$B1 = (K7 \times B) - (K6 \times R) - (K6 \times G)$
$X1 = (K2 \times G) - (K2 \times R)$

if $B1 = 0$, Hue = neutral, i.e., $B = G = R$

$B1 \neq 0$, Hue = $\arctan \frac{X1}{B1}$

Saturation = $(B1^2 + X1^2)^{\frac{1}{2}}$

Value = $K3 \times (B + G + R)$

Table II: Transformation of the Munsell Coordinates to Additive Primary Colors. The constants are the same as Table I.

H = hue
S = saturation
V = value

$B1 = S \times \cos(H)$
$X1 = V \times \sin(H)$

Blue = $(K7 \times B1) + (K3 \times V)$
Green = $(K2 \times X1) + (K3 \times V) - (K6 \times B1)$
Red = $(K3 \times V) - (K2 \times X1) - (K6 \times B1)$

Table III. Relationship Between Images Used in Color-subractive and Color-additive Processes.
In order to obtain the same color-composite image, the equivalent images and primary colors are as listed below.

Color Subtractive		Color Additive	
Image	Primary Colors	Primary Colors	Image
Positive, large value is bright	Cyan	Red	Negative, large value is dark
	Yellow	Blue	
	Magenta	Green	

Table IV: Mean Values and Typical Standard Deviations for Selected Colors of Interest.

The pixels in bands 4, 5, and 6 were multiplied by 2 to put the data in the 0 to 255 range, and the pixels in band 7 were multipled by 4 to get them in the 0 to 255 range. The average ratios were calculated by recalculating the ratios from the bands, not by ratios of the average values of the band. Only typical standard deviations are given because there was very little variation between bands and ratio.

	Whole Scene	Mud Lake	Vegetation (red)	Goldfield (green)	Limonite Pediment (green)	Brown Areas
Sample Size	236,334	5,000	10,000	6,791	3,010	1,748
Band 4	83.2	183.3	47.3	85.1	89.2	87.7
Band 5	90.1	202.4	42.4	93.8	98.8	99.1
Band 6	83.0	175.9	51.9	85.7	90.4	94.9
Band 7	70.7	139.8	53.1	70.4	76.0	83.2
Typical standard deviation for bands	33	15	12	12	10	17
4/5 ratio	0.981	0.907	1.163	0.914	0.906	0.891
5/6 ratio	1.091	1.151	0.813	1.098	1.093	1.047
6/7 ratio	1.178	1.259	0.985	1.218	1.191	1.143
Typical standard deviation for bands	1.00	0.04	0.13	0.06	0.05	0.06