The Use of Intensity-Hue-Saturation Transformation for Producing Color Shaded-Relief Images

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Abstract

We present a novel technique for combining color information from one raster dataset with intensity information from another by using an intensity-hue-saturation (IHS) transformation. This technique, which we refer to as intensity adjustment, is related to IHS transformation methods (e.g., intensity substitution) that have recently been used to combine remotely sensed multispectral images with achromatic images of higher spatial resolution. Our intensity-adjustment method is not appropriate for merging multispectral and achromatic images whose intensity information is mostly redundant, but our technique is more effective than the intensity-substitution method in merging databases whose intensities are nonredundant, such as a color thematic map and a shaded-relief base image.

Introduction

The basic concept for transformation of a digital elevation image into a shaded-relief image was first explained by Batson *et al.* (1975). Since that time most image-processing software systems have incorporated this basic technique and expanded on it so that three-dimensional renditions of a digital elevation image can be produced in which different visual effects are achieved by varying the values of such parameters as surface/sun orientation, sun-elevation angle, and vertical exaggeration. We have taken another step in this process by developing an algorithm to combine a color-coded digital image with a digital shaded-relief image. This technique preserves both the distinct colors in the thematic image and the three-dimensional brightness information of the shaded-relief base image. The method was designed to convey instantly the spatial relation between topography and an ancillary thematic image (a map) of a particular attribute of a geographic region. Examples of such images that would complement a three-dimensional topographic image are those showing magnetics, gravity, elemental or mineral composition, geology, population density, landslide or earthquake risk, surface-water quality, and a Landsat ratio. The uses for this algorithm are limited only by one's imagination.

Background

Two of the more common ways to represent color are (1) designation of the digital numbers (DNs) of the three primary colors (red, green, and blue — RGB), which are used to produce color images on color monitors and photowrite scanning systems, and (2) designation of intensity, hue, and saturation (IHS), which are used to define color mathematically in cylindrical or spherical coordinate systems. An advantage of considering color in terms of IHS over that of RGB is that the manner and effects of combining two data sets can be evaluated and adjusted mathematically to arrive more easily at a desired color product.

One application of the IHS system has been in merging high-resolution achromatic image data with lower resolution color image data. The modified color image shows the spatial detail of the achromatic data while maintaining much of the spectral content of the original color data (Cliche *et al.*, 1985; Welch and Ehlers, 1987; Carper *et al.*, 1990). This digital merger is accomplished by calculating a pixel's IHS values from its RGB values (Plate 1a), substituting for that intensity value the intensity of the corresponding pixel in the achromatic image (Plate 1b), and then recalculating the pixel's new RGB values from its modified IHS values (Plate 1c). To merge digitally two images that have different pixel resolutions, it is first necessary to register the data geometrically; such registration procedures have been discussed by Chavez (1986).

The image-merging methods reviewed and evaluated by Carper *et al.* (1990) work best when the achromatic data are redundant with the color data, i.e., when the wavelength region represented by the achromatic data closely approximates the wavelength range represented by the color data. In this situation the intensities of the achromatic image and the RGB image are very similar when expressed as normalized intensities based on their maximum DN range. If one of the RGB image files is not redundant with the achromatic image file, as when SPOT panchromatic data (0.51 to 0.70 μm) are merged with SPOT XS1 (0.50 to 0.59 μm), XS2 (0.61 to 0.68 μm), and XS3 (0.79 to 0.89 μm) data, then the substitution intensity needs to be calculated as a weighted average of the achromatic data and the nonredundant (XS3) band data (Carper *et al.*, 1990). This problem is magnified when all three color image files are not redundant with the achromatic image base (e.g., merging a color-coded thematic map with a shaded-relief base image; Plates 2a, 2b, and 2c). In this paper we describe a method to digitally merge color-coded thematic images with a shaded-relief base image; this method retains, as much as possible, both the colors of the thematic image and the three-dimensional aspect of the shaded-relief base image.

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Photogrammetric Engineering & Remote Sensing,
Vol. 60, No. 11, November 1994, pp. 1369–1374.

0099-1112/94/6011-1369$3.00/0

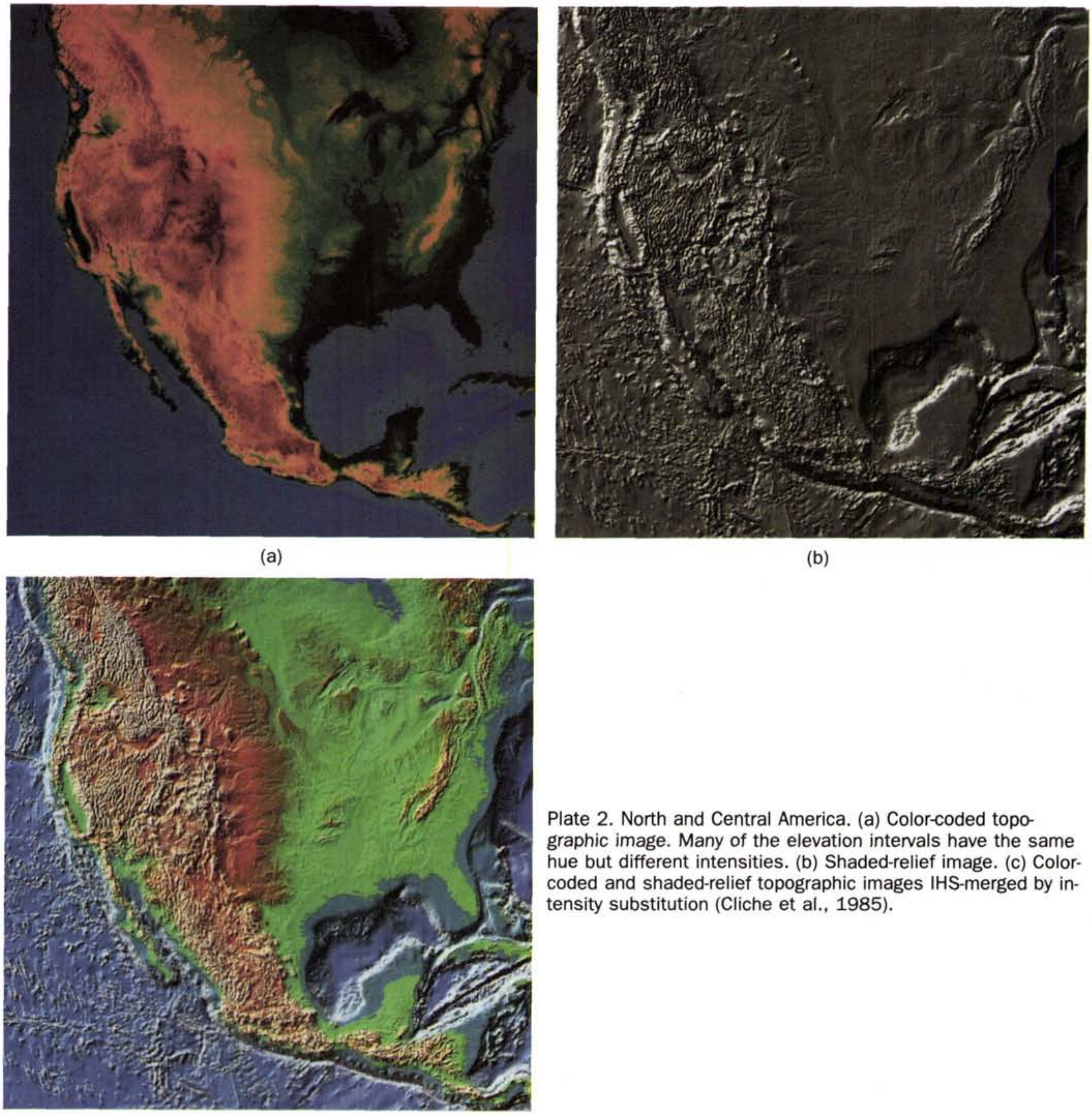
(a)

(c)

Plate 1. An agricultural and suburban area near Phoenix, Arizona. *(a) Landsat TM false-color composite image (30-m resolution)* of TM bands 1 (displayed in blue), 3 (displayed in red), and 4 (displayed in green). (b) SPOT panchromatic image (10-m resolution; copyright SPOT data CNES). (c) Landsat TM and SPOT panchromatic images IHS-merged by intensity substitution (Cliche et al., 1985).

IHS Transformation

The concept of intensity, hue, and saturation was reviewed by Carper *et al.* (1990), and the geometric transformation of a pixel from RGB coordinates to IHS coordinates was described by Siegal and Gillespie (1980, pp. 203-205). There are different mathematical representations of this transformation, depending on the primary color used as the reference point for hue and on the manner in which intensity is calculated. We have chosen blue as our reference point for the IHS coordinate system (Figure 1), and we represent a pixel's intensity as the sum of its RGB DNs. The following equations relate a pixel's RGB DNs to IHS values in cylindrical coordinates along the achromatic axis:



(a)

(b)

(c)

Plate 2. North and Central America. (a) Color-coded topographic image. Many of the elevation intervals have the same hue but different intensities. (b) Shaded-relief image. (c) Color-coded and shaded-relief topographic images IHS-merged by intensity substitution (Cliche et al., 1985).

$$I = (DN_R + DN_G + DN_B) \tag{1}$$

$$H = \tan^{-1}\left[\frac{(DN_G - DN_R)\sqrt{3}}{(2DN_B - DN_G - DN_R)}\right] \tag{2}$$

$$S = \left[\left(DN_B - \frac{I}{3}\right)^2 + \left(DN_G - \frac{I}{3}\right)^2 + \left(DN_R - \frac{I}{3}\right)^2\right]^{1/2} \tag{3}$$

Conversely, the following equations relate a pixel's IHS values to RGB DNs:

$$R = \frac{I}{3} - \frac{S\cos(H)}{\sqrt{6}} - \frac{S\sin(H)}{\sqrt{2}} \tag{4}$$

$$G = \frac{I}{3} - \frac{S\cos(H)}{\sqrt{6}} + \frac{S\sin(H)}{\sqrt{2}} \tag{5}$$

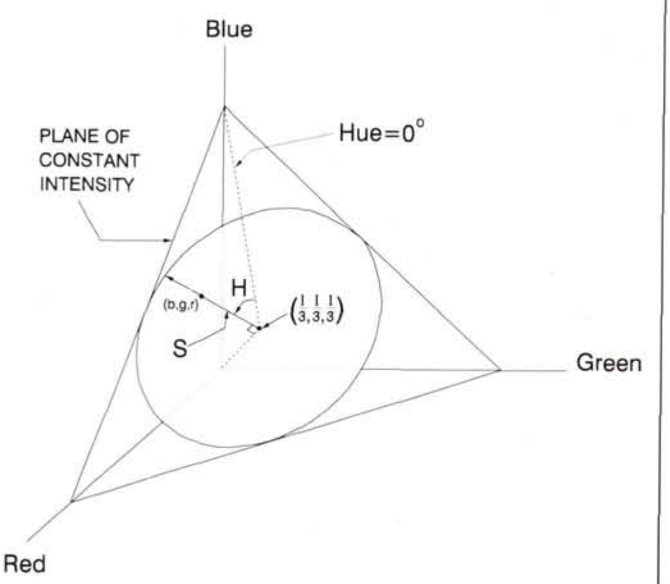


Figure 1. RGB and IHS coordinate system (adapted from Siegal and Gillespie (1980)).

$$B = \frac{I}{3} + \frac{S\sqrt{6}\cos(H)}{3} \tag{6}$$

The intensities of a shaded-relief image and a color-coded thematic image are generally not redundant, so that application of an intensity substitution method (e.g., Cliche *et al.*, 1985) to these data will produce intensities noticeably different from those in the original color image (Plates 2a, 2b, and 2c). To maintain most of the intensities of the original color thematic image during the process of combining the shaded-relief base with the color thematic data, the intensities of the color data should be adjusted toward, rather than substituted for, the intensities of the shaded-relief image.

We accomplish this intensity adjustment, for each pixel, by the following procedure:

Step 1. Convert the RGB DNs to IHS values.

Step 2. Convert the color intensity value (I_{orig}) to normalized intensity (i_{in}) by dividing I_{orig} by 765, which is the maximum intensity value that can be obtained by summing the RGB DNs. We likewise convert the shaded-relief DN to a normalized intensity (i_{base}) by dividing its DN by 255.

Step 3. Establish a piecewise linear relation between the normalized intensities of the input color (i_{in}) and the desired output color (i_{out}). This transformation is tied to the pixel's i_{base} value: it will generate an i_{out} value equal to i_{base} when i_{in} is 0.5. The $i_{in}-i_{out}$ transformation is also defined so i_{in} of 0 and 1 remain unchanged. This intensity transformation or adjustment can be expressed mathematically as follows:

$$i_{out} = \begin{cases} i_{base} - 2i_{in}, & i_{in} < 0.5 \\ (1 - i_{base})\, 2i_{in} + 2i_{base} - 1, & i_{in} > 0.5 \end{cases} \tag{7}$$

Step 4. Calculate a new normalized color intensity (i_{out}) based on i_{in} and i_{base} and using Equation 7. If i_{base} is lower than 0.5, i_{out} will be less than i_{in}. Conversely, if i_{base} is greater than 0.5, i_{out} will be greater than i_{in}. If i_{base} equals 0.5, i_{out} will equal i_{in}.

Step 5. Calculate a new color-intensity value (I_{final}) by multiplying the new normalized intensity (i_{out}) by 765.

Step 6. *During this procedure we preserve the original ratio of* $S_{orig}/S_{max}(I_{orig})$, where S_{orig} is the original saturation value and $S_{max}(I)$ is the maximum possible saturation value for a given intensity, by determining $S_{max}(I_{final})$ and multiplying it by $S_{orig}/S_{max}(I_{orig})$ *to determine the new saturation value.*

Step 7. Calculate the pixel's new RGB values by using its new intensity and saturation values and its original hue value from the color image.

Step 8. This procedure can result in RGB DNs that are less than 0 or greater than 255. We therefore check these two conditions for each of the RGB DNs consecutively, and we adjust the RGB DNs so that their values are within the range of 0 and 255 (see Appendix).

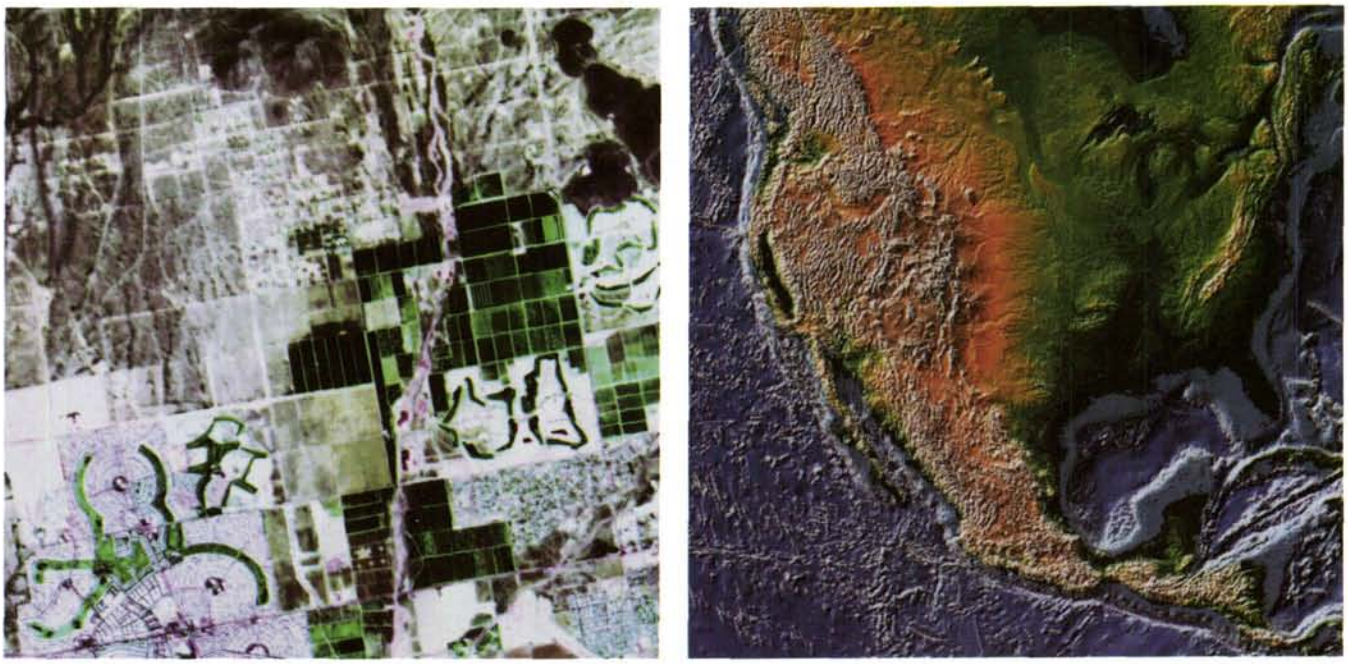
Results

Our intensity-adjustment method was applied to two different types of data. The first application involved redundant achromatic (SPOT panchromatic) and color (SPOT multispectral) data (Plate 3a); the second application involved nonredundant *achromatic shaded-relief and color-coded elevation* data (Plate 3b). In the first application the intensity-substitution method (Plate 1c) produced a color image superior to that of the intensity-adjustment method (Plate 3a). Thus, the intensity-substitution method should be used with redundant data. However, in the second application, which involved nonredundant data, the intensity-adjustment method (Plate 3b) produced a color image superior to that of the intensity-substitution method (Plate 2c). Thus, our intensity-adjustment method should be used with nonredundant data. However, redundancy of the achromatic and chromatic data is not the only issue.

In deciding between intensity substitution and intensity adjustment for image merging, one must also consider the frequency distribution (histogram) of the intensity modulation in the achromatic image. The visual cortex in the human eye consists of two cell types (magnocellular genticulate and parvocellular genticulate); the magnocellular cells are most sensitive to intensity, whereas the parvocellular cells are most sensitive to color information (Livingstone and Hubel, 1988). These different cell responses cause these two types of information to follow different signal-processing paths: the color information is processed at lower resolution than the intensity information. (This is why a black-and-white photograph appears to have more clarity than a color photograph.) Thus, if the intensities of the achromatic image are concentrated at either the low or high end of the intensity range, or at both ends, as in the case of suburban areas, the intensity-substitution method is better, because it transfers more of the intensity information of the high-resolution achromatic image to the merged color image, to which the eye is more sensitive anyway. On the other hand, if the intensities of the achromatic image are concentrated at the middle of the intensity range, as in the case of a continental shaded-relief map, the intensity-adjustment method is preferable, because it will better retain the intensities of the color image.

Acknowledgments

The authors are grateful to Alex Acosta and Randolph Kirk for their thoughtful reviews. This research was supported as



(a) (b)

Plate 3. Examples of IHS-merged data using our intensity adjustment method on (a) Landsat TM (Plate 1a) and SPOT panchromatic (Plate 1b) data, and on (b) color-coded (Plate 2a) and shaded-relief (Plate 2b) topographic images.

part of various contracts from NASA's Solar System Exploration Division.

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(Received 28 December 1992; accepted 8 April 1993; revised 20 April 1993)

Appendix

Our intensity-adjustment technique may result in RGB DNs (in step 7) that are less than 0 or greater than 255. The following mathematical sequence is used to ensure that the final RGB DNs are within the range of 0 and 255. The symbol I that is used in these equations represents I_{final}.

if $R < 0$, set $R = 0$

$$B = I - G$$

if $G < 0$, set $G = 0$

$$R = I - B$$

if $B < 0$, set $B = 0$

$$G = I - R$$

if $R > 255$, set $R = 255$

$$B = I - G - 255$$

if $G > 255$, set $G = 255$

$$R = I - B - 255$$

if $B > 255$, set $B = 255$

$$G = I - R - 255$$

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Kathleen Edwards received her B.S. in Math at Northern Arizona University in 1969. She has worked at the U.S. Geological Survey since 1964. Since 1975 she has worked as a programmer, creating software for digital cartography of the Earth and planets using spacecraft data. The specialized techniques that she has pioneered include the geometric control and reprojection of spacecraft images, mapping of irregular objects (small satellites and asteroids), and the automatic generation of shaded relief maps from digital topographic data. Ms. Edwards has participated in numerous planetary missions, including Viking, Voyager, and Galileo. In 1989 she coordinated the production of a global digital image mosaic (DIM) of Mars from over 4500 Viking Orbiter images, and helped to create a high-resolution color DIM of Neptune's satellite Triton in real time during the Voyager 2 encounter.

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