ECEN457 & ECEN657 Digital Image Processing

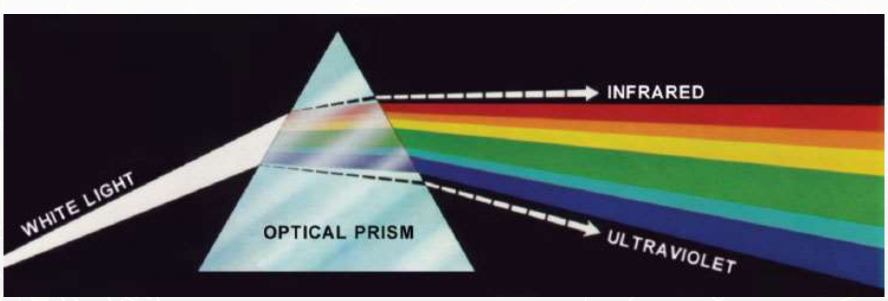
Chapter 7: Color Image Processing

Dr. Jung H. Kim

Department of Electrical & Computer Engineering
North Carolina A&T State University

Color Fundamentals

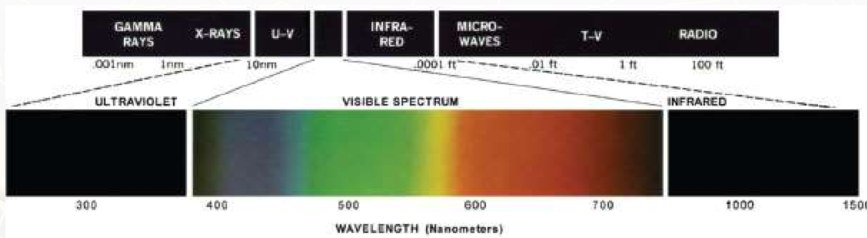
Figure 7.1: Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lighting Division.)



2

Color Fundamentals

Figure 7.2: Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lighting Division.)



3

Color Fundamentals

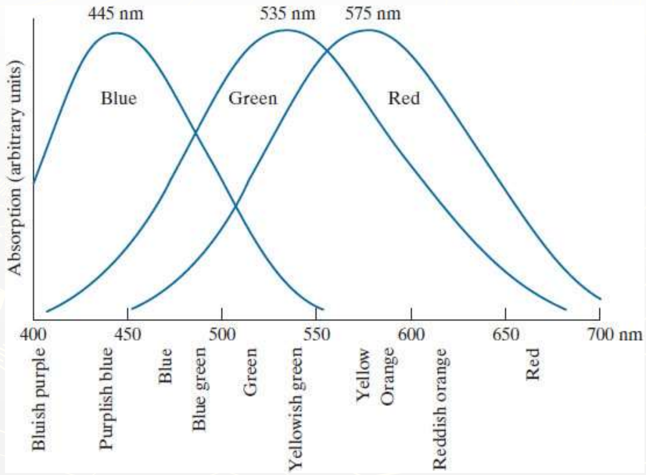
- 6 to 7 million cones in the human eye can be divided into three principal sensing categories, corresponding roughly to red, green, and blue.

  65%: red 33%: green 2%: blue (blue cones are the most sensitive)

4

Color Fundamentals

Figure 7.3: Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.



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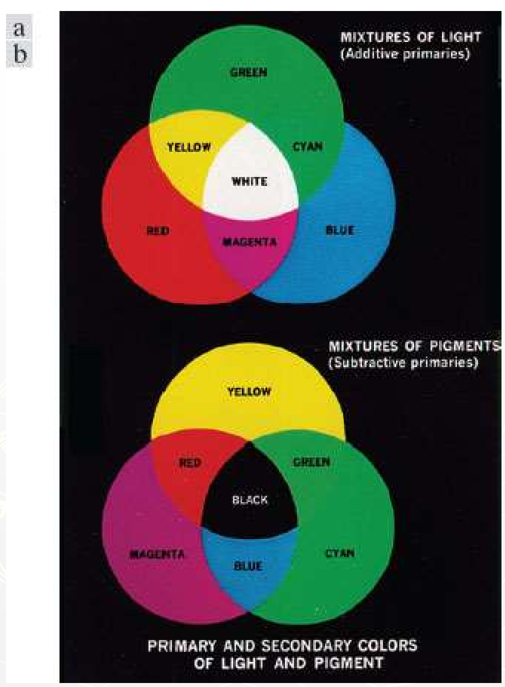


Figure 7.4: Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lighting Division.)

6

Color Fundamentals

- The characteristics generally used to distinguish one color from another are brightness, hue, and saturation

brightness: the achromatic notion of intensity.

hue: dominant wavelength in a mixture of light waves, represents dominant color as perceived by an observer.

saturation: relative purity or the amount of white light mixed with its hue.

7

Color Fundamentals

- Tri-stimulus

Red, green, and blue are denoted X, Y, and Z, respectively. A color is defined by its trichromatic coefficients, defined as

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$

8

CIE Chromaticity Diagram

It shows color composition as a function of x (red) and y (green)

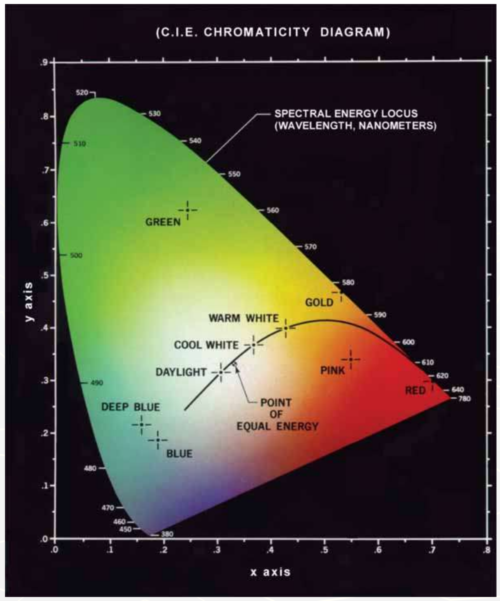


Figure 7.5: The C I E chromaticity diagram. (Courtesy of the General Electric Co., Lighting Division.)

9

Color Models

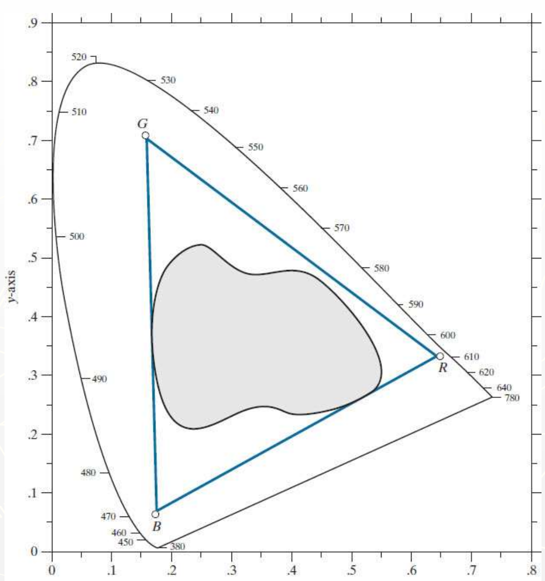


Figure 7.6: Illustrative color gamut of color monitors (triangle) and color printing devices (shaded region).

10

RGB Color Model

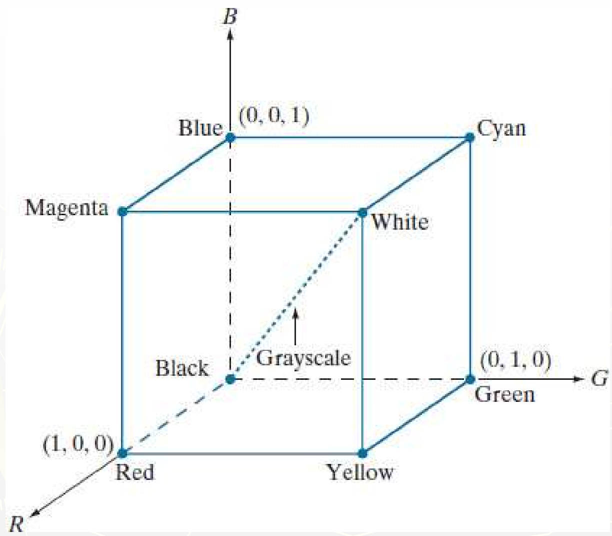


Figure 7.7: Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

11

RGB Color Model

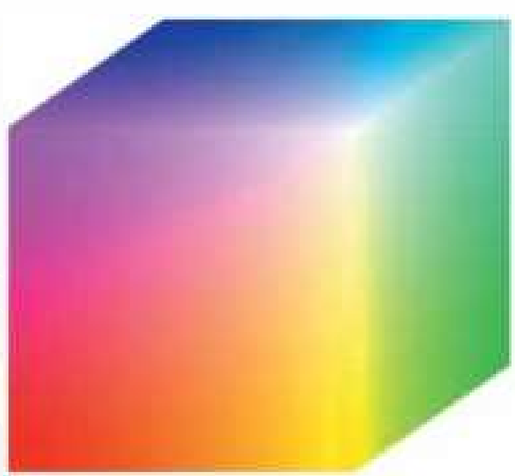


Figure 7.8:

A 24-bit RGB color cube.

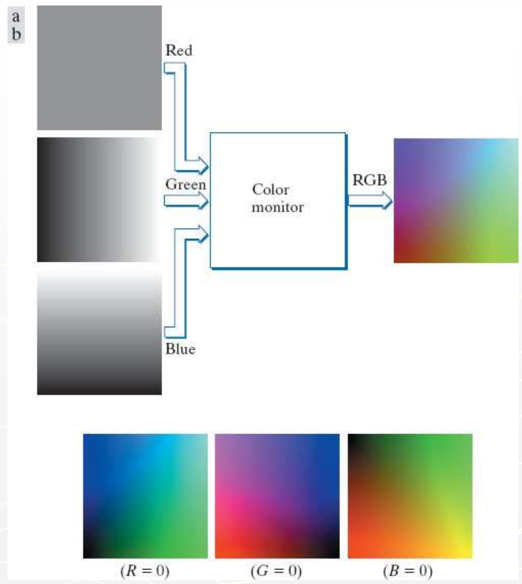
Pixel depth

The total number of colors in a 24-bit RGB image is $(2^8)^3$ = 16,777,216

12

CMY and CMYK Color Model

Figure 7.9: (a) Generating the RGB image of the cross-sectional color plane (127, G, B). (b) The three hidden surface planes in the color cube of Fig. 7.8.



13

The CMY and CMYK Color Models

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Equal amounts of the pigment primaries, cyan, magenta, and yellow should produce black. In practice, combining these colors for printing produces a muddy-looking black.

To produce true black, the predominant color in printing, the fourth color, black, is added, giving rise to the CMYK color model.

14

CMY vs. CMYK

The image above, separated for printing with process cyan, magenta, and yellow inks.

The same image, this time separated with maximum black, to minimize colored-inks use.

http://en.wikipedia.org/wiki/CMYK

15

HIS Color Model

brightness: the achromatic notion of **intensity**.

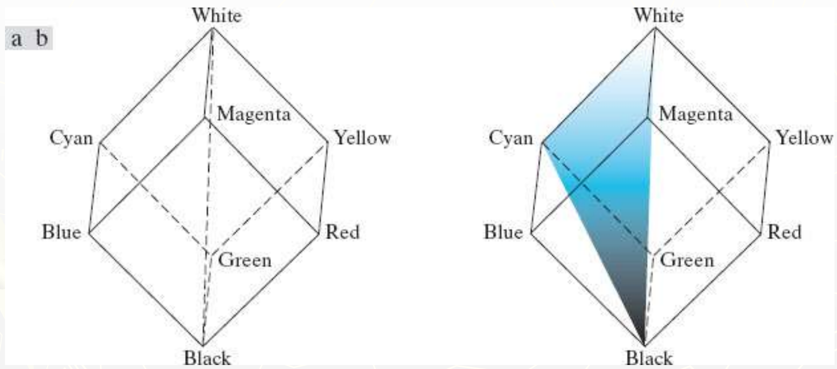
hue: dominant wavelength in a mixture of light waves, represents dominant color as perceived by an observer.

saturation: relative purity or the amount of white light mixed with its hue.

16

HIS Color Model

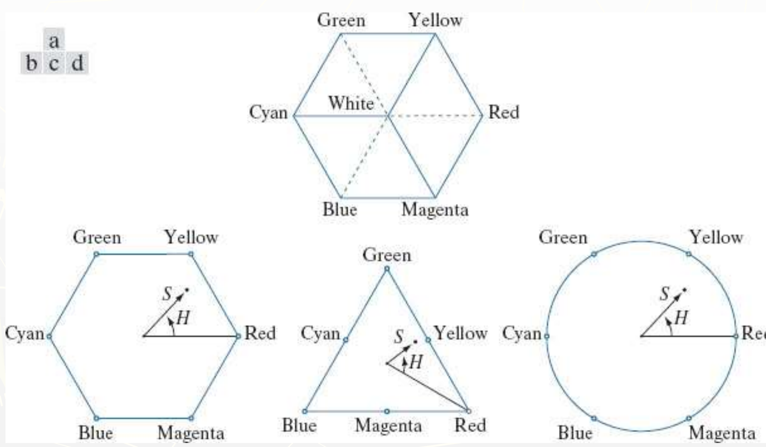
Figure 7.10: Conceptual relationships between the RGB and HSI color models.



17

HIS Color Model

Figure 7.11: Hue and saturation in the HSI color model. The dot is any color point. The angle from the red axis gives the hue. The length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.



18

HIS Color Model

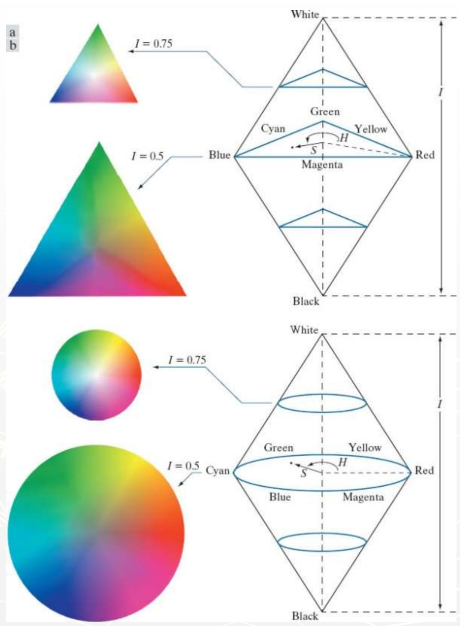


Figure 7.12: The HSI color model based on (a) triangular, and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.

19

Converting Colors from RGB to HSI

- Given an image in RGB color format, the H component of each RGB pixel is obtained using the equation

$$H = \begin{cases} \theta & \text{if } B \leq G \\ 360 - \theta & \text{if } B > G \end{cases}$$

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}} \right\}$$

20

Converting Colors from RGB to HSI

- Given an image in RGB color format, the saturation component is given by

$$S = 1 - \frac{3}{(R+G+B)}\left[\min(R,G,B)\right]$$

21

Converting Colors from RGB to HSI

- Given an image in RGB color format, the intensity component is given by

$$I = \frac{1}{3}\left(R+G+B\right)$$

22

Converting Colors from HSI to RGB

- RG sector $(0^\circ \leq H < 120^\circ)$

$$B = I(1 - S)$$

$$R = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right]$$

and

$$G = 3I - (R + B)$$

23

Converting Colors from HSI to RGB

- RG sector $(120^\circ \leq H < 240^\circ)$

$$H = H - 120^\circ$$

$$R = I(1 - S)$$

$$G = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right]$$

and

$$B = 3I - (R + G)$$

24

Converting Colors from HSI to RGB

- RG sector $(240^\circ \le H \le 360^\circ)$

$$H = H - 240^\circ$$

$$G = I(1 - S)$$

$$B = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right]$$

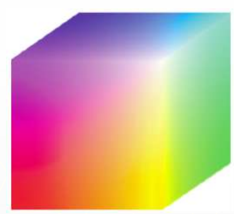
and

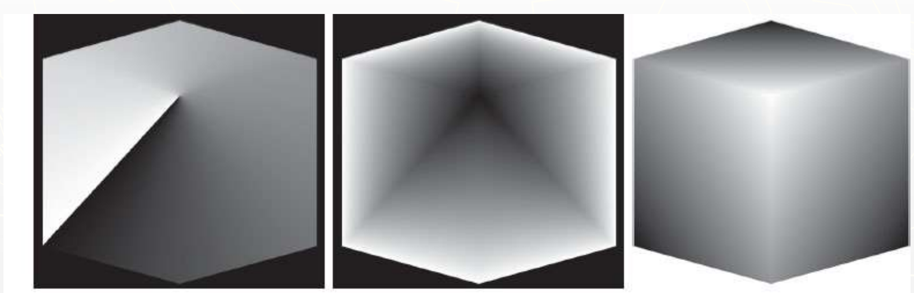
$$R = 3I - (G + B)$$

25

Converting Colors from HSI to RGB

Figure 7.13: HSI components of the image in Fig. 7.8: (a) hue, (b) saturation, and (c) intensity images.



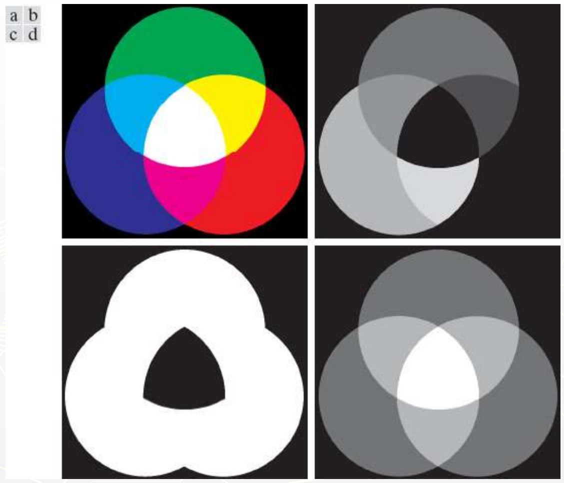


a b c

26

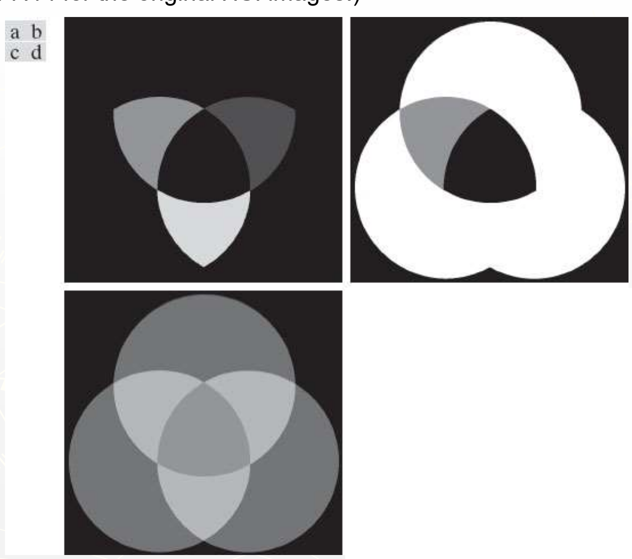
Manipulating HSI Component Images

Figure 7.14: (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.



Manipulating HSI Component Images

Figure 7.15: (a)-(c) Modified HSI component images. (d) Resulting RGB image. (See Fig. 7.14 for the original HSI images.)



Pseudocolor Image Processing

- The process of assigning colors to gray values based on a specified criterion.
- Intensity Slicing
- $f(x,y) = I_k$, let $f(x,y) = c_k$ where c_k is the color associated with the k-th intensity interval I_k, defined by the planes at $l = k - 1$ and $l = k$.

29

Intensity Slicing and Color Coding

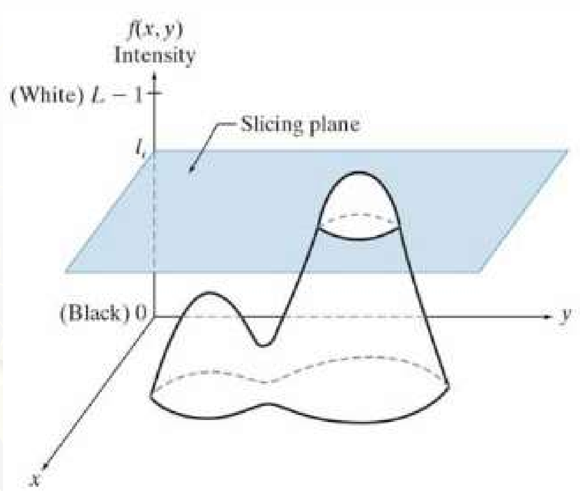
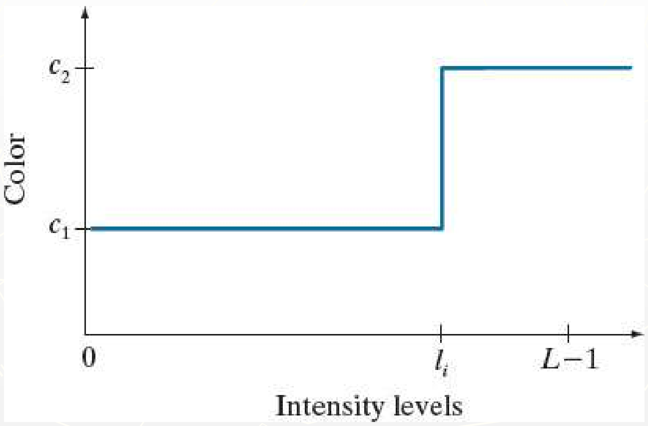


Figure 7.16: Graphical interpretation of the intensity slicing technique.

30

Intensity Slicing and Color Coding

Figure 7.17: An alternative representation of the intensity slicing technique.

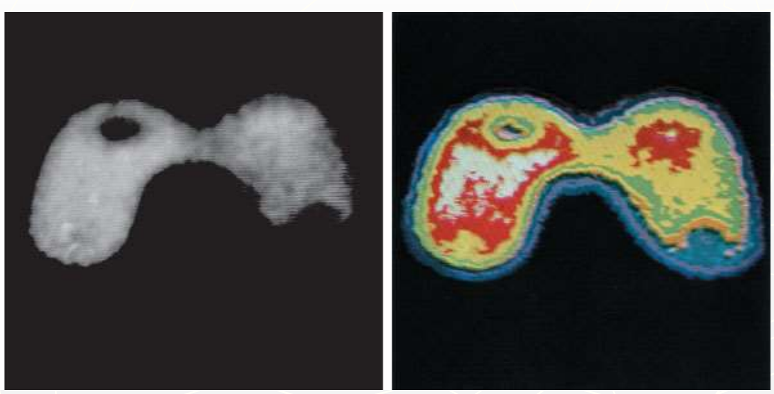


31

Intensity Slicing and Color Coding

Figure 7.18: (a) Grayscale image of the Picker Thyroid Phantom. (b) Result of intensity slicing using eight colors. (Courtesy of Dr. J. L. Blankenship, Oak Ridge National Laboratory.)

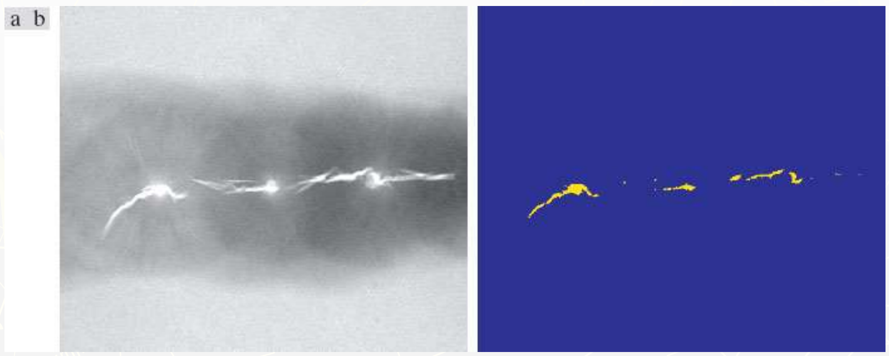
a b



32

Intensity Slicing and Color Coding

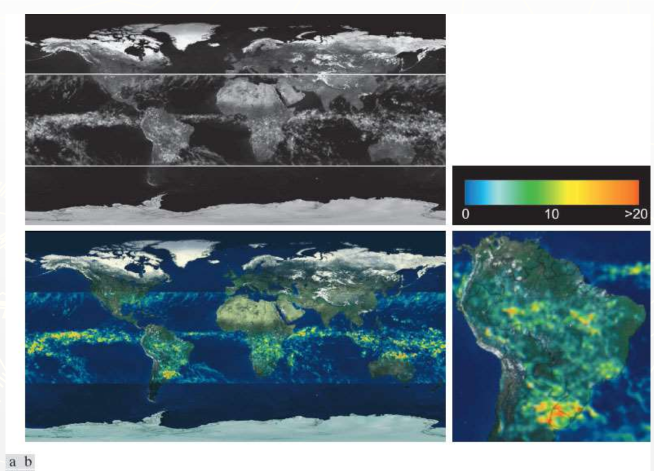
Figure 7.19: (a) X-ray image of a weld. (b) Result of color coding. (Original image courtesy of X-T E K Systems, Ltd.)



33

Intensity Slicing and Color Coding

Figure 7.20: (a) Grayscale image in which intensity (in the horizontal band shown) corresponds to average monthly rainfall. (b) Colors assigned to intensity values. (c) Color-coded image. (d) Zoom of the South American region. (Courtesy of NASA.)

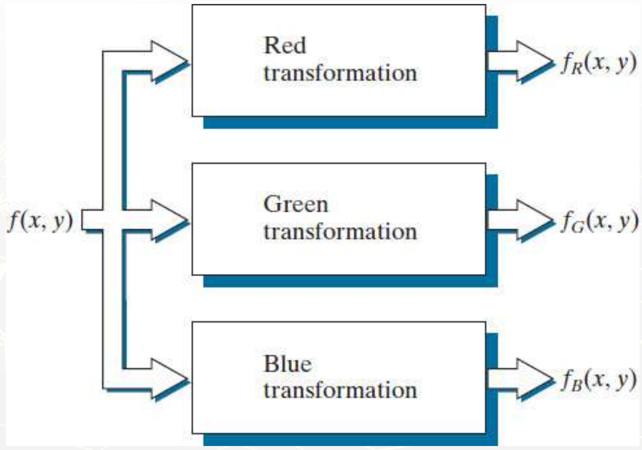


34

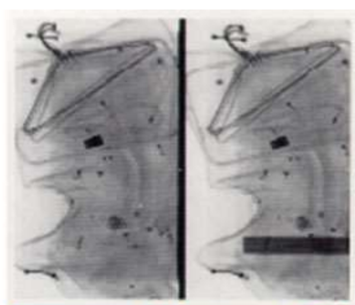
Pseudocolor Image Processing

- Intensity to Color Transformation

Figure 7.21: Functional block diagram for pseudocolor image processing. Images f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.



35



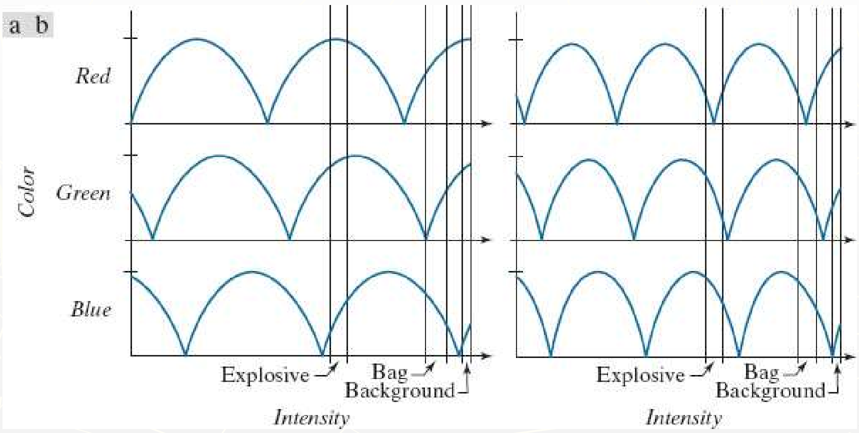
The images are obtained from an airport X-ray scanning system.
The left contains ordinary articles and the right contains the same articles as well as a block of simulated plastic explosives.

Figure 7.22: Pseudocolor enhancement by using the gray level to color transformations in Fig. 7.23. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)

36

Pseudocolor Image Processing

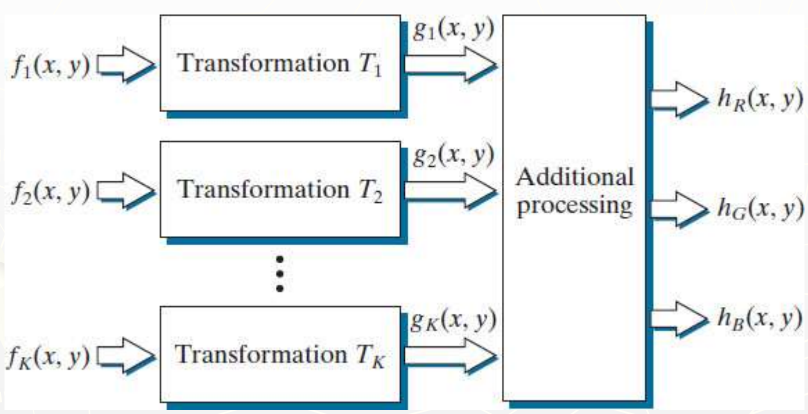
Figure 7.23: Transformation functions used to obtain the pseudocolor images in Fig. 7.22.



37

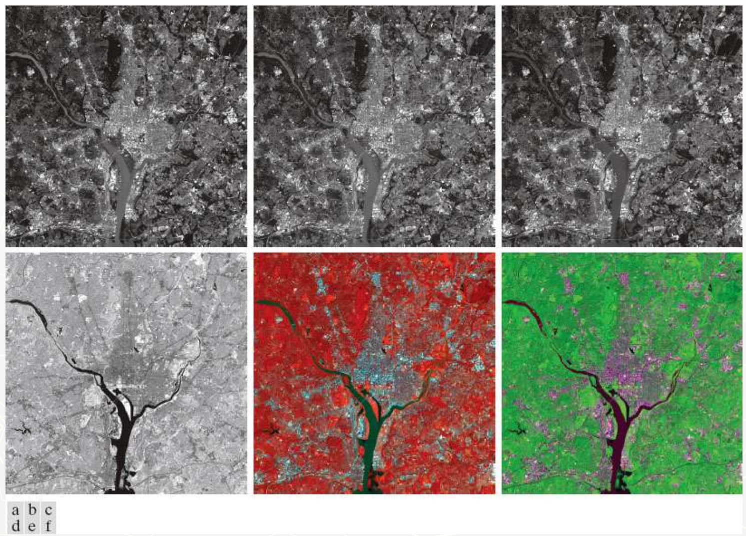
Pseudocolor Image Processing

Figure 7.24: A pseudocolor coding approach using multiple grayscale images. The inputs are grayscale images. The outputs are the three components of an RGB composite image.



38

Figure 7.25: (a)–(d) Red (R), green (G), blue (B), and near-infrared (IR) components of a LANDSAT multispectral image of the Washington, D.C. area. (e) RGB color composite image obtained using the IR, G, and B component images. (f) RGB color composite image obtained using the R, IR, and B component images. (Original multispectral images courtesy of NASA.)



Pseudocolor by combining several of the sensor images from the Galileo spacecraft, some of which are in spectral regions not visible to the eye.

Bright red depicts materials newly ejected from an active volcano on Io, and the surrounding yellow materials are older sulfur deposits.

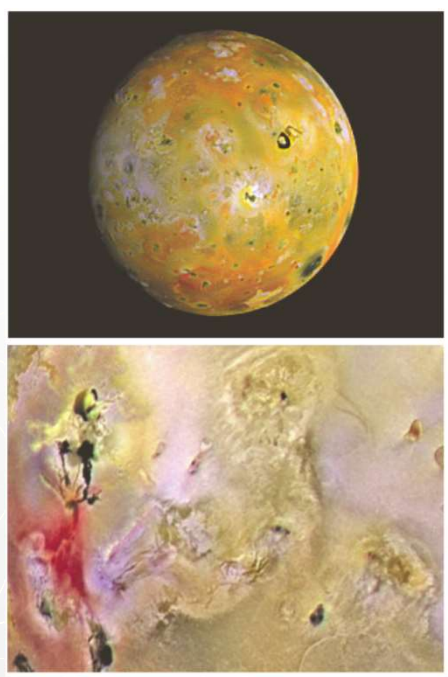


Figure 7.26: (a) Pseudocolor rendition of Jupiter Moon Io. (b) A close-up. (Courtesy of NASA.)

Basics of Full-Color Image Processing

Let c represent an arbitrary vector in RGB color space:

$$c = \begin{bmatrix} c_R \\ c_G \\ c_B \end{bmatrix} = \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

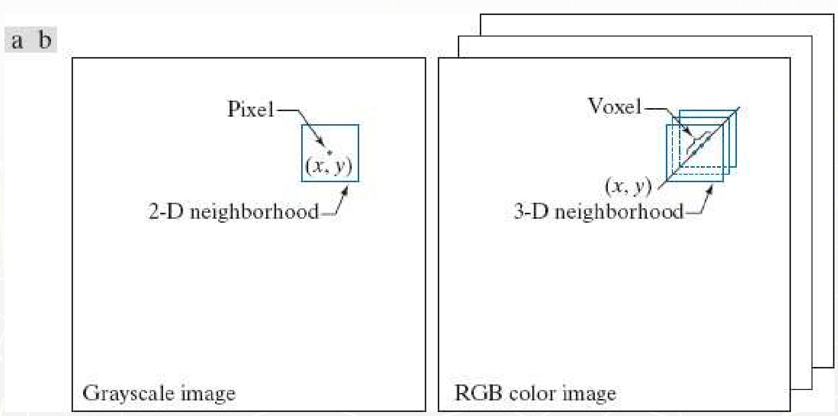
At coordinates (x, y),

$$c(x,y) = \begin{bmatrix} c_R(x,y) \\ c_G(x,y) \\ c_B(x,y) \end{bmatrix} = \begin{bmatrix} R(x,y) \\ G(x,y) \\ B(x,y) \end{bmatrix}$$

41

Basics of Full-Color Image Processing

Figure 7.27: Spatial neighborhoods for grayscale and RGB color images. Observe in (b) that a single pair of spatial coordinates, (x,y), addresses the same spatial location in all three images.



42

Color Transformations

$$g(x,y) = T\left[f(x,y)\right]$$

$$s_i = T_i(r_1, r_2, \ldots, r_n), \qquad i = 1, 2, \ldots, n.$$

In the HSI color space, we need to modify only the intensity component image. If $s_1 = r_1$, $s_2 = r_2$, and $s_3 = kr_3$ where k is a constant value in the range [0, 1], then T_1 and T_2 are identity transformation, and T_3 is a constant transformation.

However, in the RGB color space, we need to modify all three components by the same constant transformation:

$s_i = kr_i$ for $i = 1,2,3$

43

Figure 7.28: A full-color image and its various color-space components. (Original image courtesy of MedData Interactive.)

44

Color Transformations

The CMY space requires a similar set of linear transformations:

$$s_i = kr_i \qquad \text{for } i = 1,2,3$$

Similarly, the transformations required to change the intensity of the CMYK image is given by:

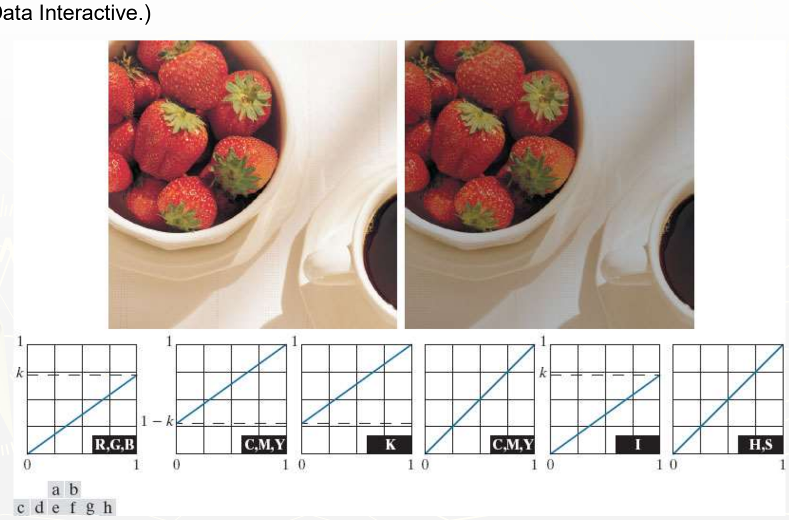
$$s_i = \begin{cases} r_i & i = 1,2,3 \\ kr_i + (1-k) & i = 4 \end{cases}$$

Thus, we only change the fourth (K) component.

45

$$g(x, y) = kf(x, y)$$

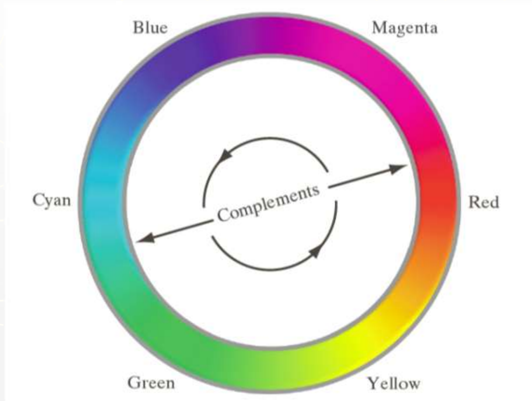
Figure 7.29: Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting k = 0.7). (c) The required RGB mapping function. (d)–(e) The required CMYK mapping functions. (f) The required CMY mapping function. (g)–(h) The required HSI mapping functions. (Original image courtesy of MedData Interactive.)



46

Color Complements

Figure 7.30: Color complements on the color circle.



Color Complements

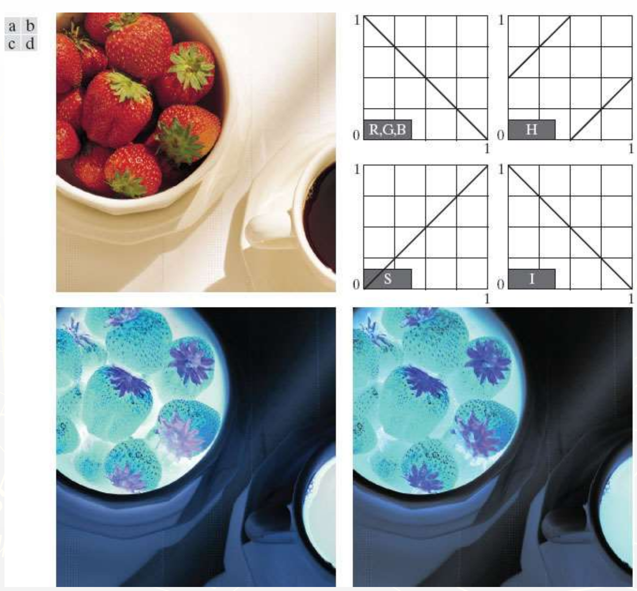


Figure 7.31: Color complement transformations. (a) Original image. (b) Complement transformation functions. (c) Complement of (a) based on the RGB mapping functions. (d) An approximation of the RGB complement using HSI transformations.

Color slicing

- Highlighting a specific range of colors in an image

If the colors of interest are enclosed by a cube of width W and centered at a protypical color with components $(a_1, a_2, \ldots, a_n)$, the necessary set of transformations is

$$s_i = \begin{cases} 0.5 & \text{if } \left[|r_j - a_j| > W/2 \right]_{\text{any } 1 \le j \le n} \\ r_i & \text{otherwise} \end{cases}$$

Where $i = 1,2, \ldots, n$

49

Color slicing

If a sphere is used to specify the colors of interest, R_0 is the radius of the enclosing of its center.
The transformations is

$$s_i = \begin{cases} 0.5 & \text{if } \sum_{j=1}^{n} \left(r_j - a_j \right)^2 > R_0^2 \\ r_i & \text{otherwise} \end{cases}$$

Where $i = 1,2, \ldots, n$

50

Color slicing

Figure 7.32: Color-slicing transformations that detect (a) reds within an RGB cube of width W = 0.2549 centered at (0.6863, 0.1608, 0.1922), and (b) reds within an RGB sphere of radius 0.1765 centered at the same point. Pixels outside the cube and sphere were replaced by color (0.5, 0.5, 0.5).

51

Tone and Color Corrections

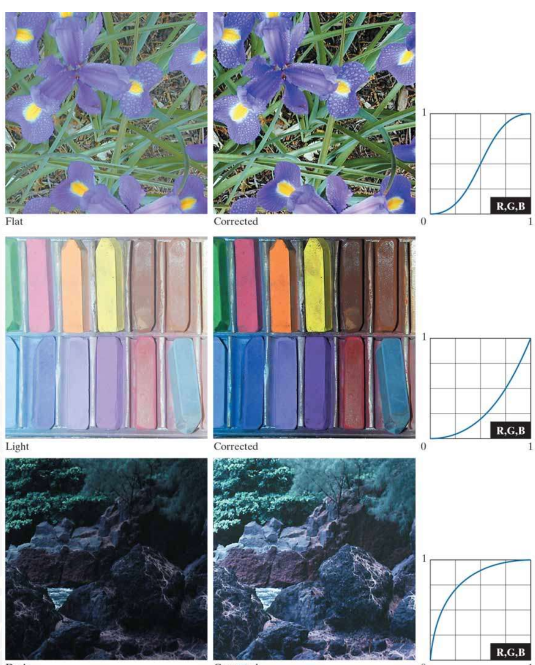


Figure 7.33: Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not always alter the image hues significantly.

52

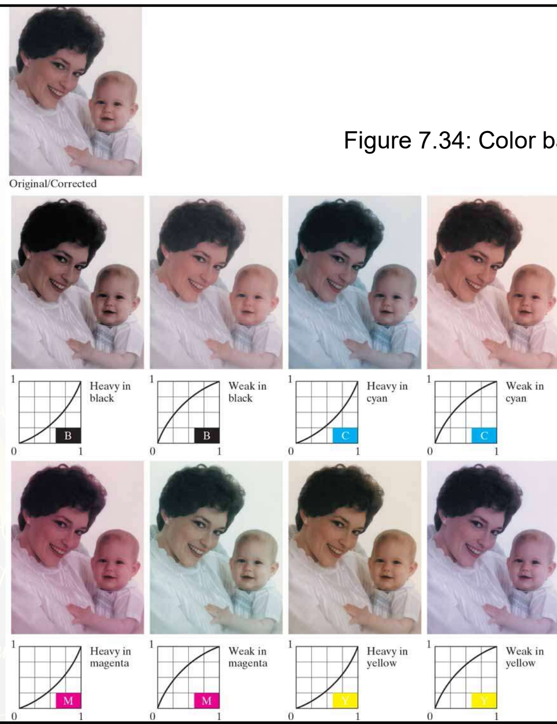


Figure 7.34: Color balancing a C M Y K image.

53

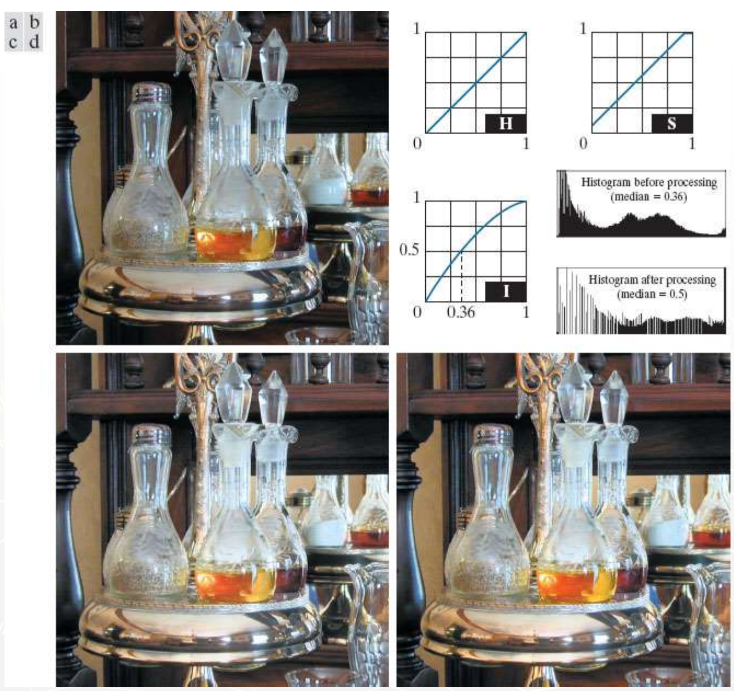


Figure 7.35: Histogram equalization (followed by saturation adjustment) in the HSI color space.

54

Color Image Smoothing

Let S_{xy} denote the set of coordinates defining a neighborhood centered at (x, y) in an RGB color image. The average of the RGB component vectors in this neighborhood is

$$\bar{c}(x,y) = \frac{1}{K}\sum_{(s,t)\in S_{xy}} c(s,t) = \begin{bmatrix} \frac{1}{K}\sum_{(s,t)\in S_{xy}} R(s,t) \\ \frac{1}{K}\sum_{(s,t)\in S_{xy}} G(s,t) \\ \frac{1}{K}\sum_{(s,t)\in S_{xy}} B(s,t) \end{bmatrix}$$

55

Figure 7.36: (a) RGB image. (b) Red component image. (c)Green component. (d) Blue component.

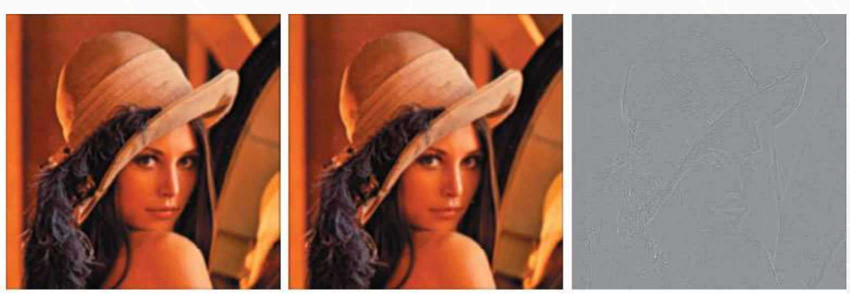
56

Figure 7.37: HSI components of the RGB color image in Fig. 7.36(a). (a) Hue. (b) Saturation. (c) Intensity.

a b c

Color Image Smoothing

Figure 7.38: Image smoothing with a 5x5 averaging kernel. (a) Result of processing each RGB component image. (b) Result of processing the intensity component of the HSI image and converting to RGB. (c) Difference between the two results.



a b c

Color Image Sharpening

The Laplacian of vector c is

$$\nabla^2\left[c(x,y)\right]=\begin{bmatrix}\nabla^2 R(x,y)\\ \nabla^2 G(x,y)\\ \nabla^2 B(x,y)\end{bmatrix}$$

59

Color Image Sharpening

Figure 7.39: Image sharpening using the Laplacian. (a) Result of processing each RGB channel. (b) Result of processing the HSI intensity component and converting to RGB. (c) Difference between the two results.

a b c

60

Image Segmentation Based on Color:

Segmentation in HIS Color Space

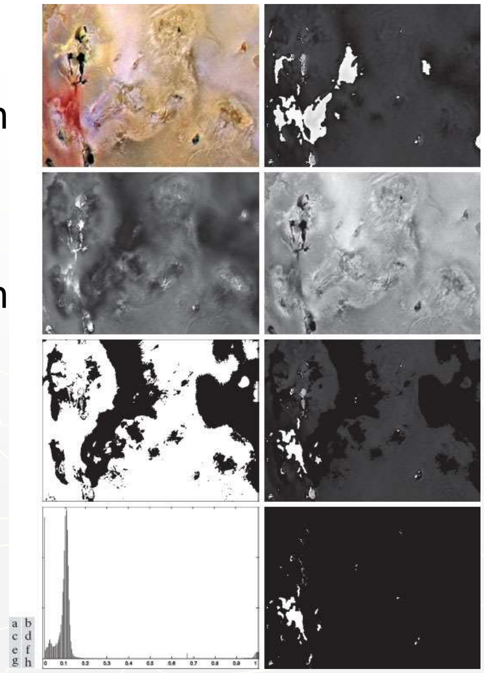


Figure 7.40: Image segmentation in HSI space. (a) Original. (b) Hue. (c) Saturation. (d) Intensity. (e) Binary saturation mask (black = 0). (f) Product of (b) and (e). (g) Histogram of (f). (h) Segmentation of red components from (a).

61

Segmentation in RGB Vector Space

Let the average color of interest is denoted by the RGB vector a. Let z denote an arbitrary point in RGB space.

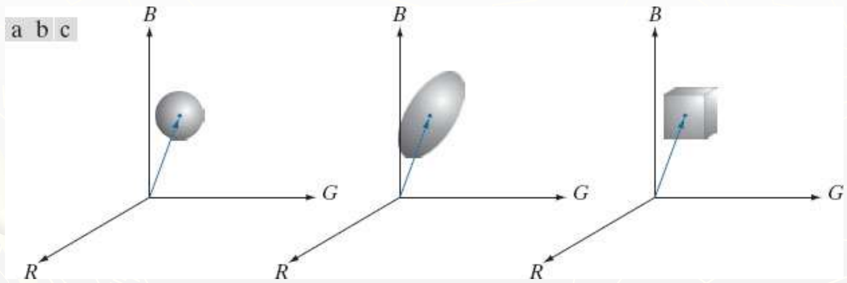
$$D(z,a) = \|z-a\| = \left[(z-a)^T (z-a)\right]^{1/2}$$

$$= \left[(z_R - a_R)^2 + (z_G - a_G)^2 + (z_B - a_B)^2\right]^{1/2}$$

62

Segmentation in RGB Vector Space

Figure 7.41: Three approaches for enclosing data regions for RGB vector segmentation.



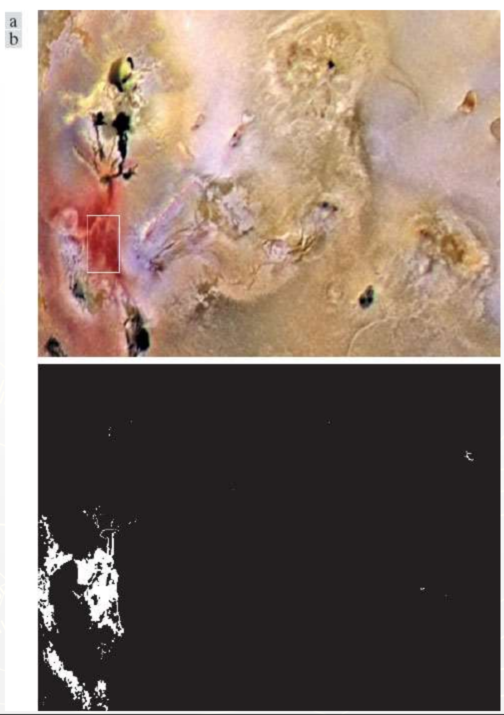


Figure 7.42: Segmentation in RGB space. (a) Original image with colors of interest shown enclosed by a rectangle. (b) Result of segmentation in RGB vector space. Compare with Fig. 7.40(h).

Color Edge Detection (1)

Let r, g, and b be unit vectors along the R, G, and B axis of RGB color space, and define vectors

$$\mathrm{u} = \frac{\partial R}{\partial x}\mathrm{r} + \frac{\partial G}{\partial x}\mathrm{g} + \frac{\partial B}{\partial x}\mathrm{b}$$

and

$$\mathrm{v} = \frac{\partial R}{\partial y}\mathrm{r} + \frac{\partial G}{\partial y}\mathrm{g} + \frac{\partial B}{\partial y}\mathrm{b}$$

4/3/2018 65

Color Edge Detection (2)

$$g_{xx} = \mathbf{u}^T\mathbf{u} = \left|\frac{\partial R}{\partial x}\right|^2 + \left|\frac{\partial G}{\partial x}\right|^2 + \left|\frac{\partial B}{\partial x}\right|^2$$

$$g_{yy} = \mathbf{v}^T\mathbf{v} = \left|\frac{\partial R}{\partial y}\right|^2 + \left|\frac{\partial G}{\partial y}\right|^2 + \left|\frac{\partial B}{\partial y}\right|^2$$

and

$$g_{xy} = \mathbf{u}^T\mathbf{v} = \frac{\partial R}{\partial x}\frac{\partial R}{\partial y} + \frac{\partial G}{\partial x}\frac{\partial G}{\partial y} + \frac{\partial B}{\partial x}\frac{\partial B}{\partial y}$$

66

Color Edge Detection (3)

The direction of maximum rate of change of c(x, y) is given by the angle

$$\theta(x,y)=\frac{1}{2}\tan^{-1}\left[\frac{2g_{xy}}{g_{xx}-g_{yy}}\right]$$

The value of the rate of change at (x, y) in the direction of $\theta(x, y)$, is given by

$$F_\theta(x,y)=\left\{\frac{1}{2}\left[\left(g_{xx}+g_{yy}\right)+\left(g_{xx}-g_{yy}\right)\cos 2\theta(x,y)+2g_{xy}\sin 2\theta(x,y)\right]\right\}^{1/2}$$

67

Figure 7.44: (a) RGB image. (b) Gradient computed in RGB color vector space. (c) Gradient image formed by the elementwise sum of three individual gradient images, each computed using the Sobel operators. (d) Difference between (b) and (c).

68

Color Edge Detection

Figure 7.45: Component gradient images of the color image in Fig. 7.44. (a) Red component, (b) green component, and (c) blue component. These three images were added and scaled to produce the image in Fig. 7.44(c).

69

Noise in Color Images

Figure 7.46: (a)–(c) Red, green, and blue 8-bit component images corrupted by additive Gaussian noise of mean 0 and standard deviation of 28 intensity levels. (d) Resulting RGB image. [Compare (d) with Fig. 7.44(a).]

70

Noise in Color Images

Figure 7.47: HSI components of the noisy color image in Fig. 7.46(d). (a) Hue. (b) Saturation. (c) Intensity.

Noise in Color Images

Figure 7.48: (a) RGB image with green plane corrupted by salt-and-pepper noise. (b) Hue component of HSI image. (c) Saturation component. (d) Intensity component.