Chapter 6
Color Image Processing

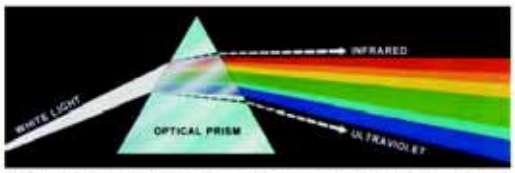


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

The light shines in the darkness, but the darkness has not understood it.

John 1:5

For a long time I limited myself to one color - as a form of discipline.

Pablo Picasso

Digital Image Processing, 2nd ed.
www.imageprocessingbook.com

Chapter 6
Color Image Processing

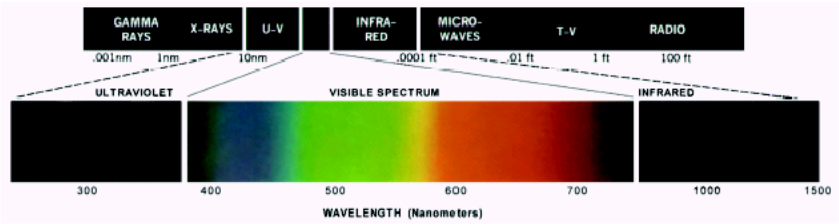


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Color Fundamentals

Chapter 6
Color Image Processing

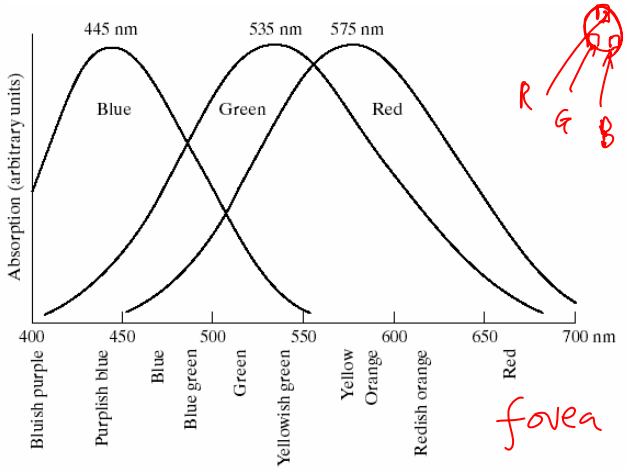
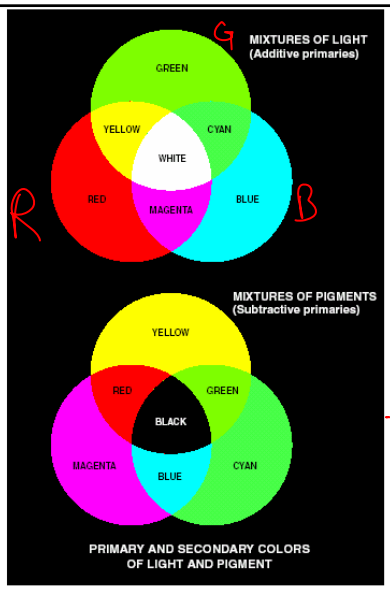


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

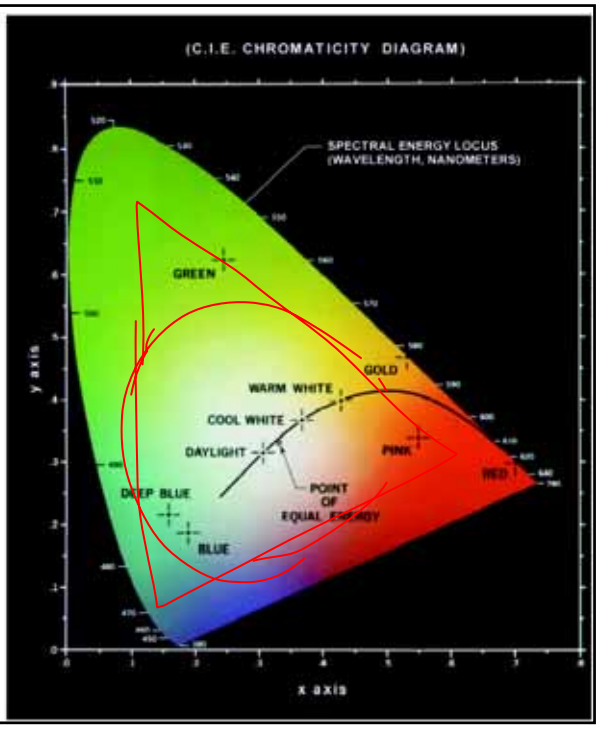


Primary and secondary colors of lights and pigments

a
b

FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)



Chromaticity diagram

Chapter 6
Color Image Processing

Color gamut of color monitors (triangle) & color printing devices (irregular region)

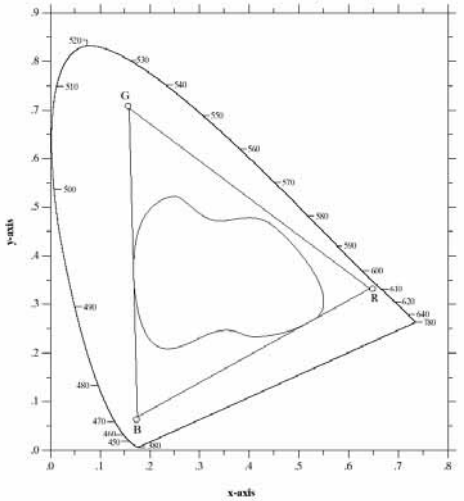


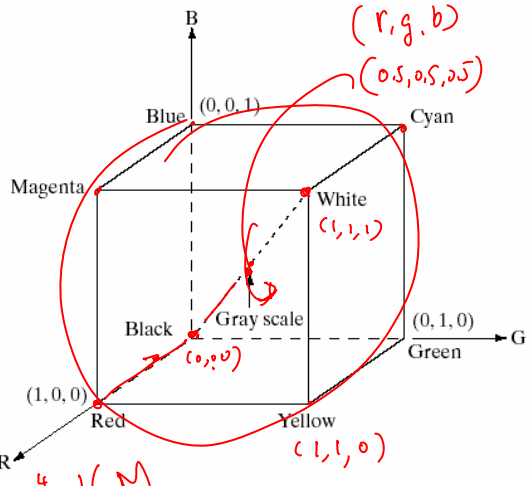
FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

Chapter 6
Color Image Processing

Digital Image Processing, 2nd ed.
www.imageprocessingbook.com
Chapter 6
Color Image Processing

Color Models

FIGURE 6.7
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).



The RGB Color Model

Chapter 6
Color Image Processing

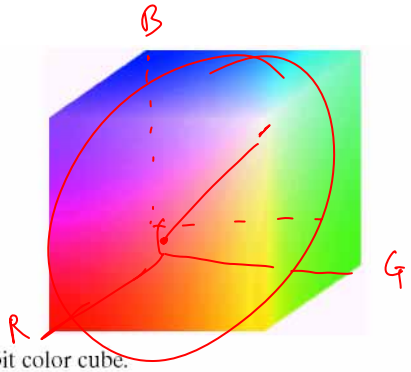


FIGURE 6.8 RGB 24-bit color cube.

The RGB Color Model

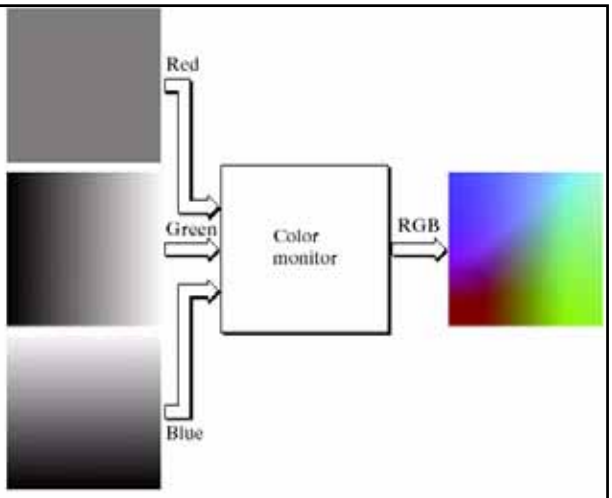
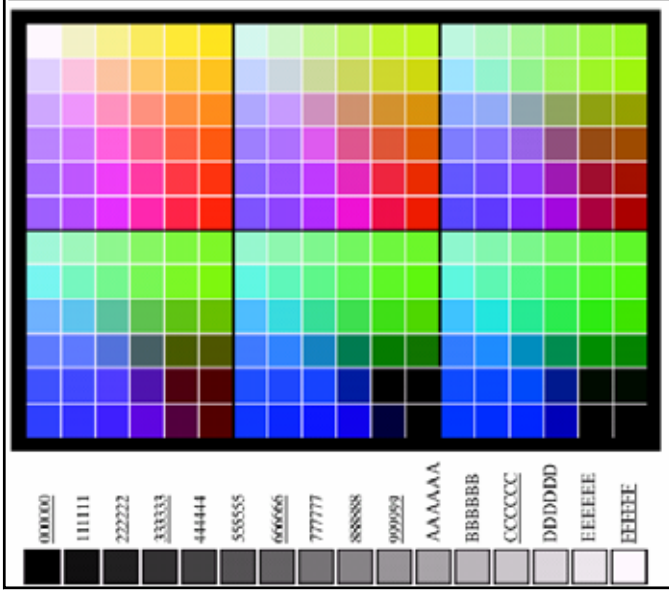


FIGURE 6.9
(a) Generating the RGB image of the cross-sectional color plane (127, *G*, *B*).
(b) The three hidden surface planes in the color cube of Fig. 6.8.

The RGB Color Model

Number System	Color Equivalents					
Hex	00	33	66	99	CC	FF
Decimal	0	51	102	153	204	255

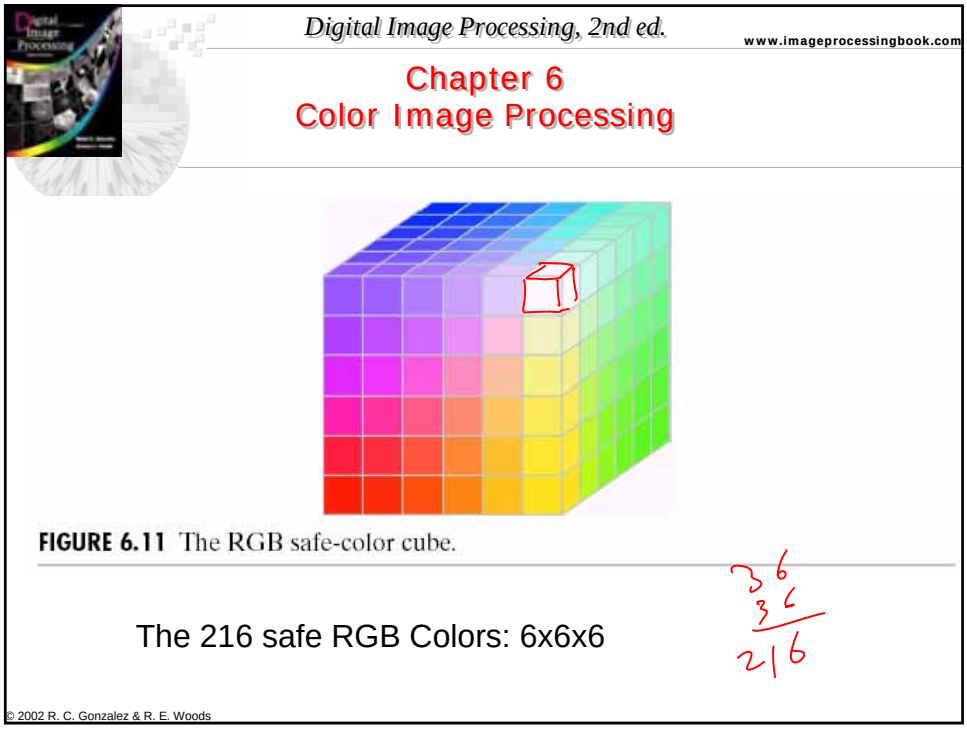
TABLE 6.1
Valid values of each RGB component in a safe color.



a
b

FIGURE 6.10
(a) The 216 safe RGB colors. (b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

The 216 safe RGB Colors



Chapter 6
Color Image Processing

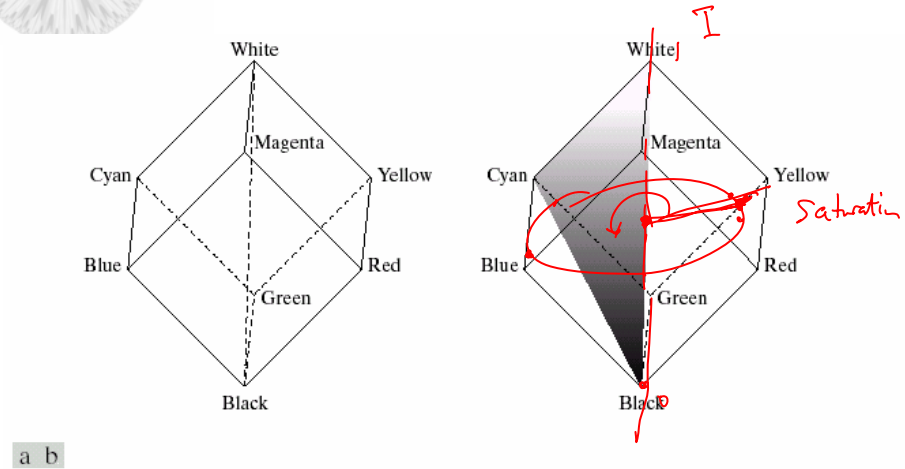
The CMY and CMYK Color Models
Cyan, Magenta, Yellow, blacK

Light reflected from a surface coated with pure

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \underbrace{\begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}}_{\text{Doesn't contain}} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

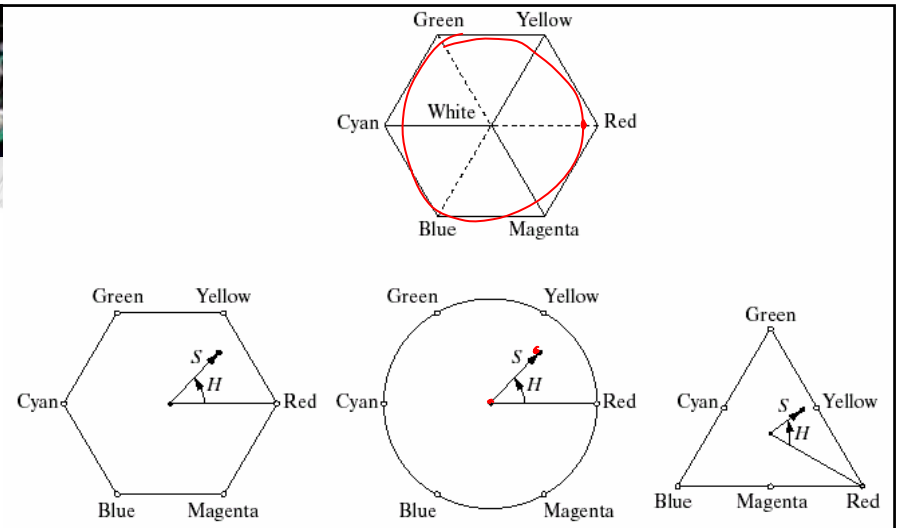
Chapter 6
Color Image Processing

The HSI Color Model



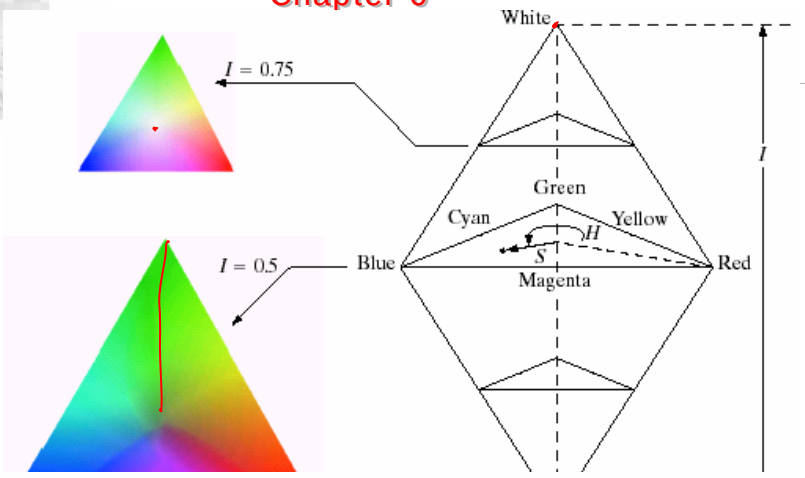
a b

FIGURE 6.12 Conceptual relationships between the RGB and HSI color models.



a
b c d

FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and 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.



a
b

FIGURE 6.14 The HSI color model based on (a) triangular and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.

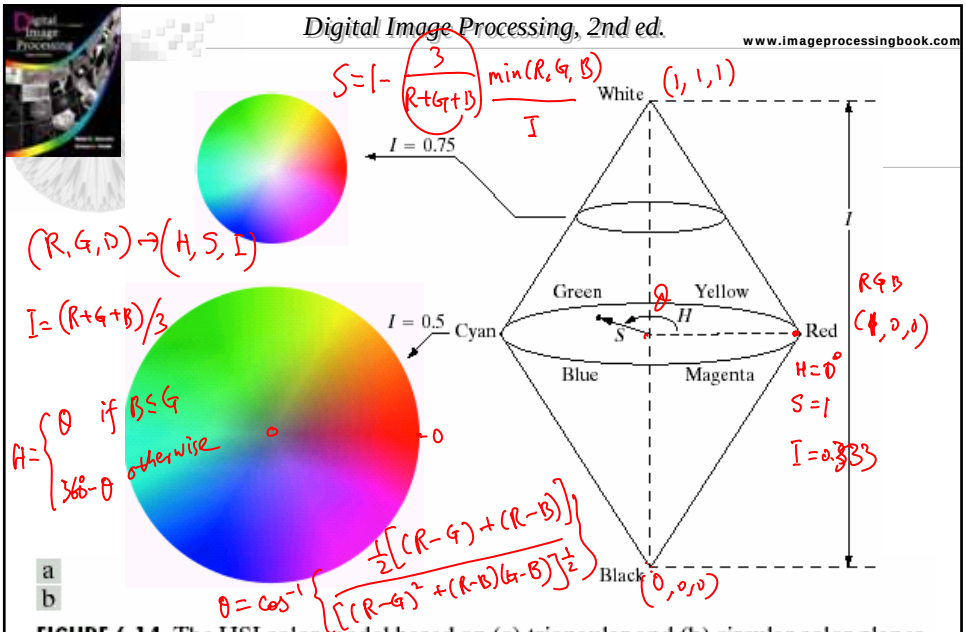


FIGURE 6.14 The HSI color model based on (a) triangular and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.

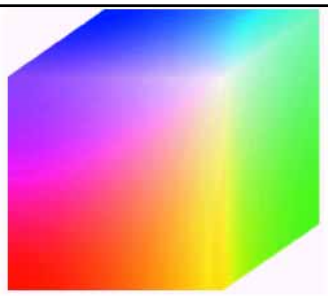
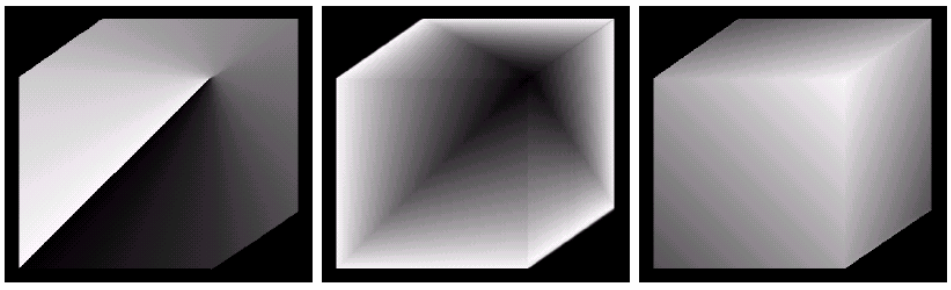
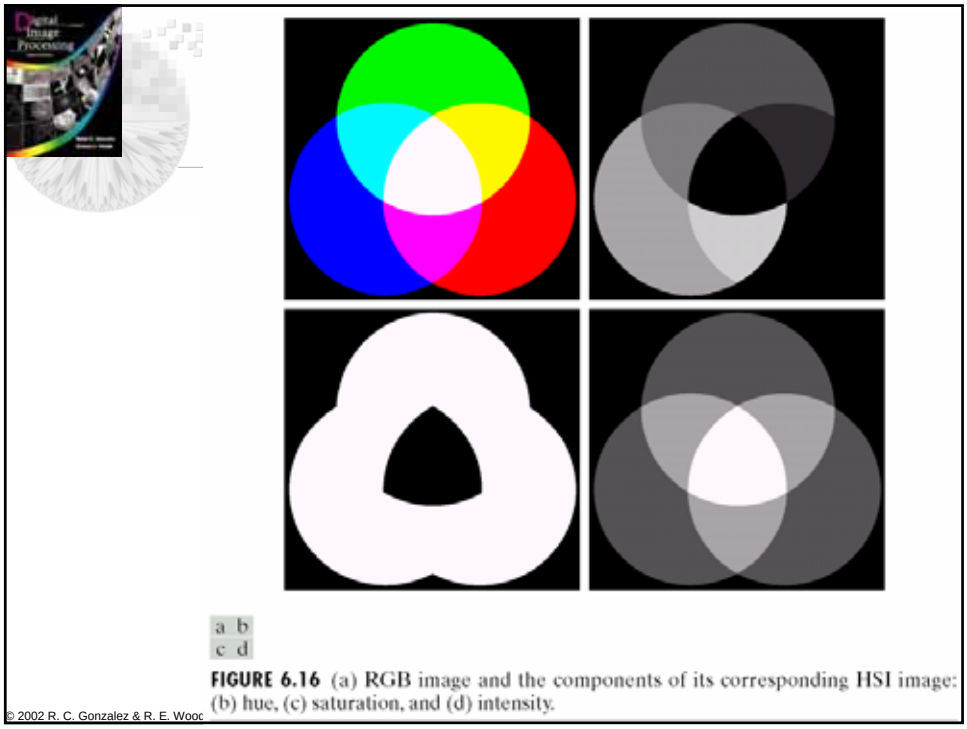


FIGURE 6.8 RGB 24-bit color cube.



a b c

FIGURE 6.15 HSI components of the image in Fig. 6.8. (a) Hue, (b) saturation, and (c) intensity images.



a b
c d

FIGURE 6.16 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.

Chapter 6
Color Image Processing

Chapter 6
Color Image Processing

Intensity Slicing

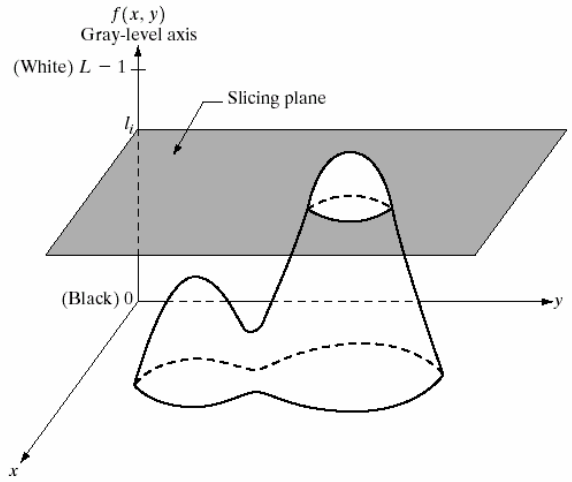


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

Digital Image Processing, 2nd ed.
www.imageprocessingbook.com

Chapter 6
Color Image Processing

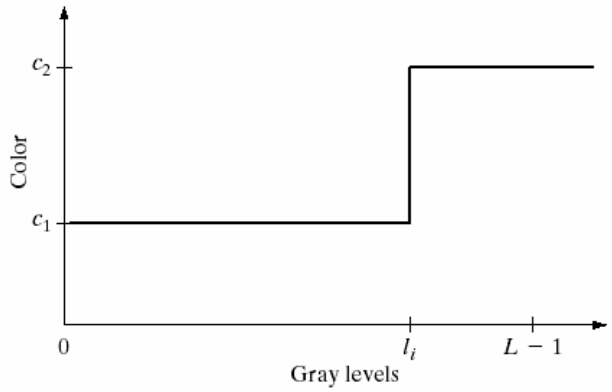
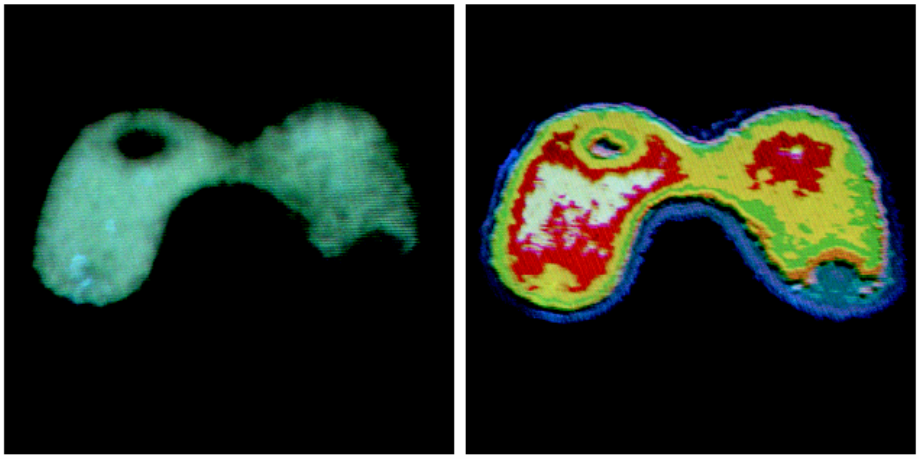


FIGURE 6.19 An alternative representation of the intensity-slicing technique.

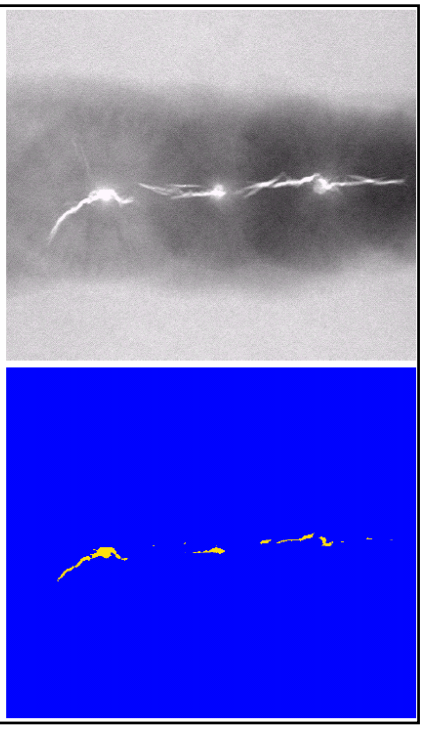


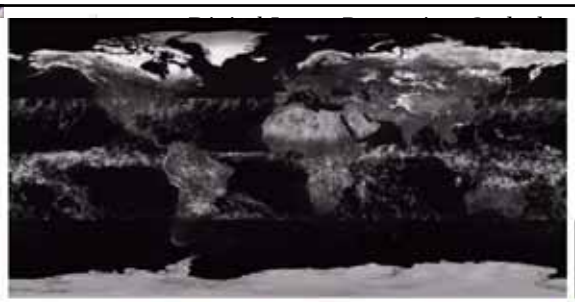
a b

FIGURE 6.20 (a) Monochrome image of the Picker Thyroid Phantom. (b) Result of density slicing into eight colors. (Courtesy of Dr. J. L. Blankenship, Instrumentation and Controls Division, Oak Ridge National Laboratory.)

a
b

FIGURE 6.21
(a) Monochrome X-ray image of a weld. (b) Result of color coding. (Original image courtesy of X-TEK Systems, Ltd.)





a b
c d

FIGURE 6.22 (a) Gray-scale image in which intensity (in the lighter horizontal band shown) corresponds to average monthly rainfall. (b) Colors assigned to intensity values. (c) Color-coded image. (d) Zoom of the South America region. (Courtesy of NASA.)

Chapter 6
Color Image Processing

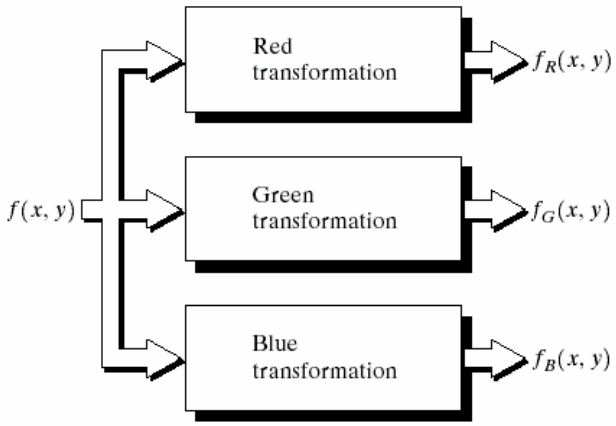
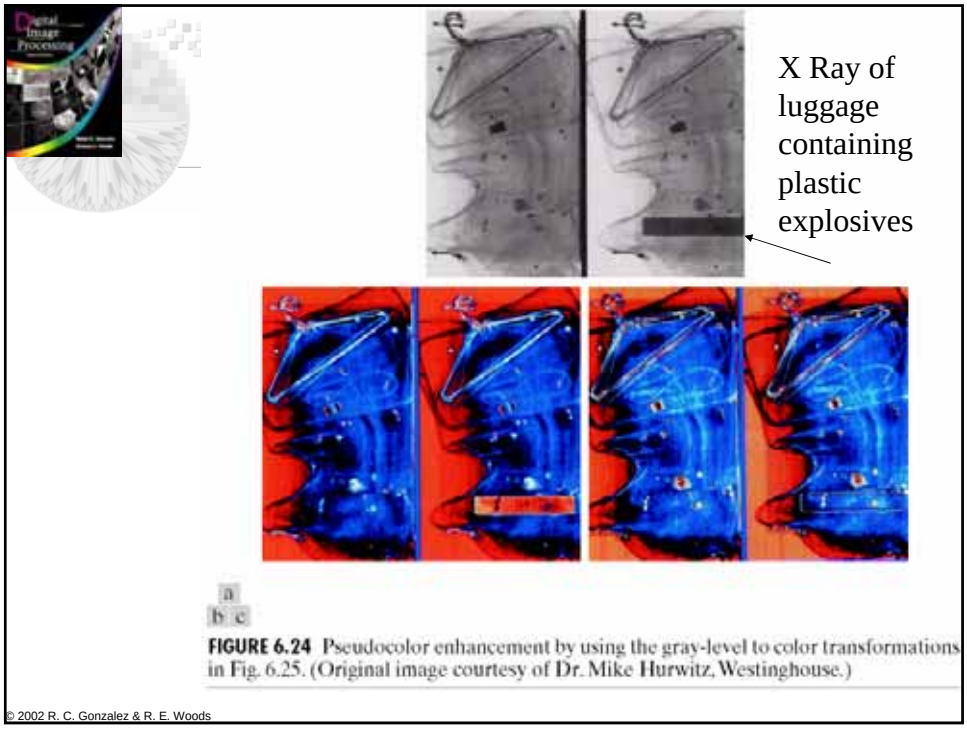


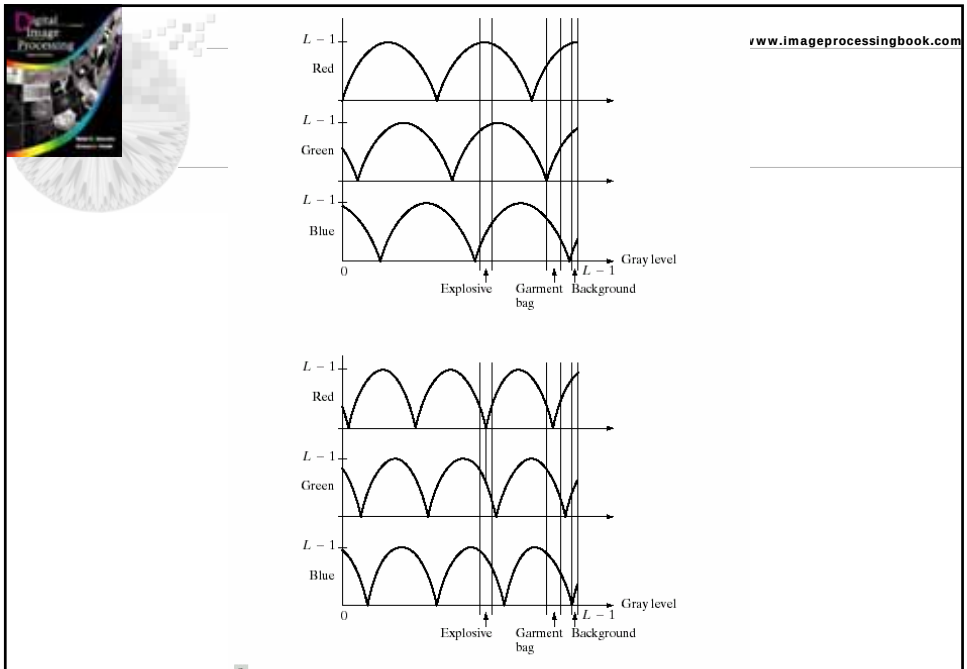
FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

Gray Level to Color Transformations



a
b c

FIGURE 6.24 Pseudocolor enhancement by using the gray-level to color transformations in Fig. 6.25. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)



a
b

FIGURE 6.25 Transformation functions used to obtain the images in Fig. 6.24.

Chapter 6
Color Image Processing

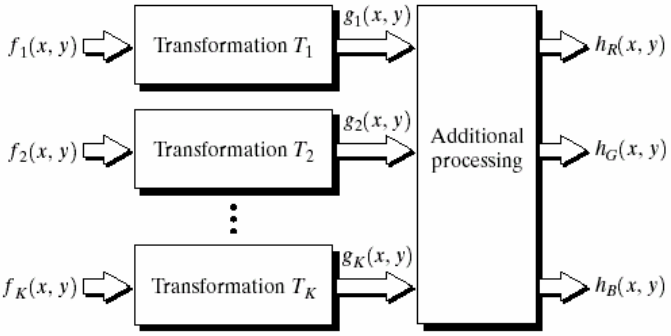
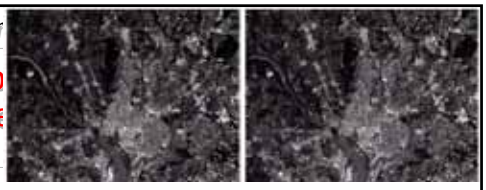


FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.

Multispectral to Color Transformations

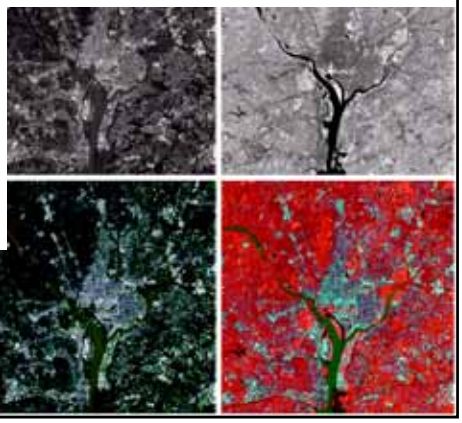
Chap
Color Image



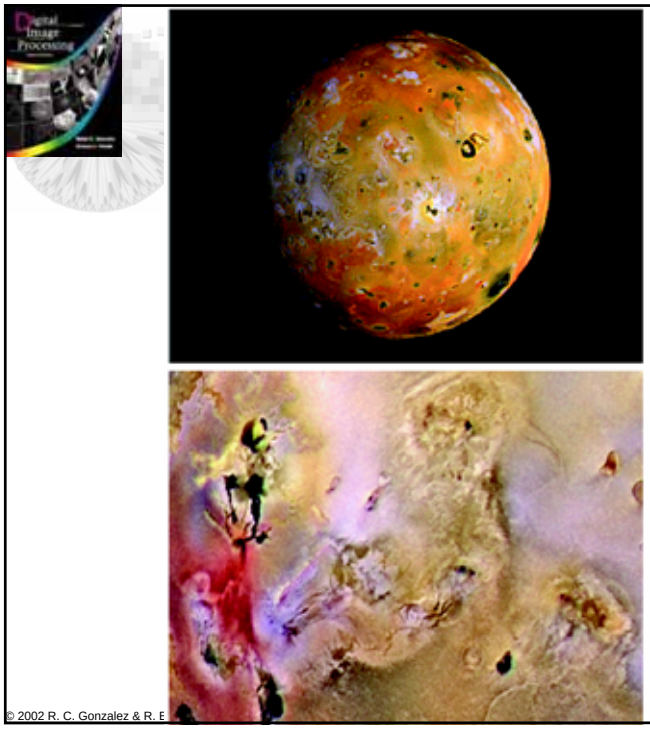
a b
c d
e f

FIGURE 6.27 (a)–(d) Images in bands 1–4 in Fig. 1.10 (see Table 1.1). (e) Color composite image obtained by treating (a), (b), and (c) as the red, green, blue components of an RGB image. (f) Image obtained in the same manner, but using in the red channel the near-infrared image in (d). (Original multispectral images courtesy of NASA.)

Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping



Washington DC & part of the Potomac River



a
b

FIGURE 6.28
(a) Pseudocolor rendition of Jupiter Moon Io. (b) A close-up. (Courtesy of NASA.)

ngbook.com

Colors show chemical compositions or surface reflectance

Digital Image Processing, 2nd ed.

www.imageprocessingbook.com

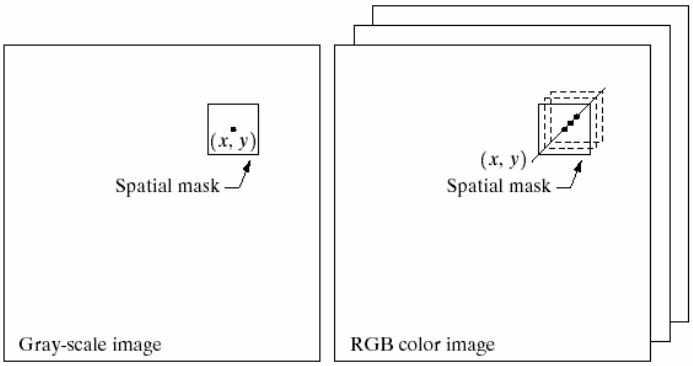
Chapter 6
Color Image Processing

Chapter 6
Color Image Processing

Formulation

a b

FIGURE 6.29
Spatial masks for gray-scale and RGB color images.



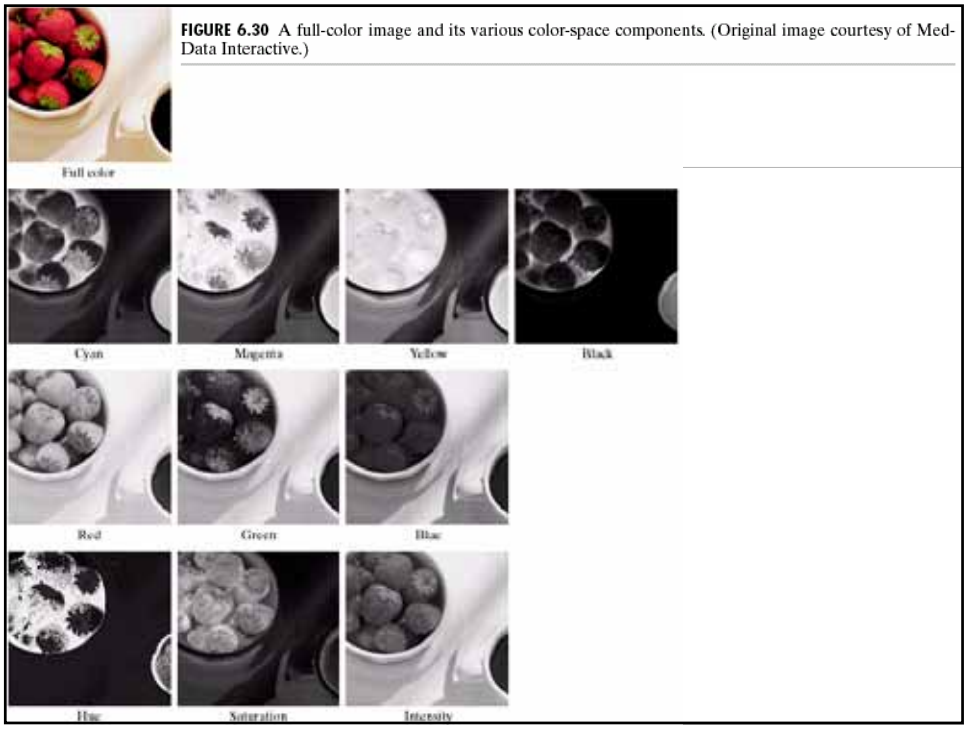
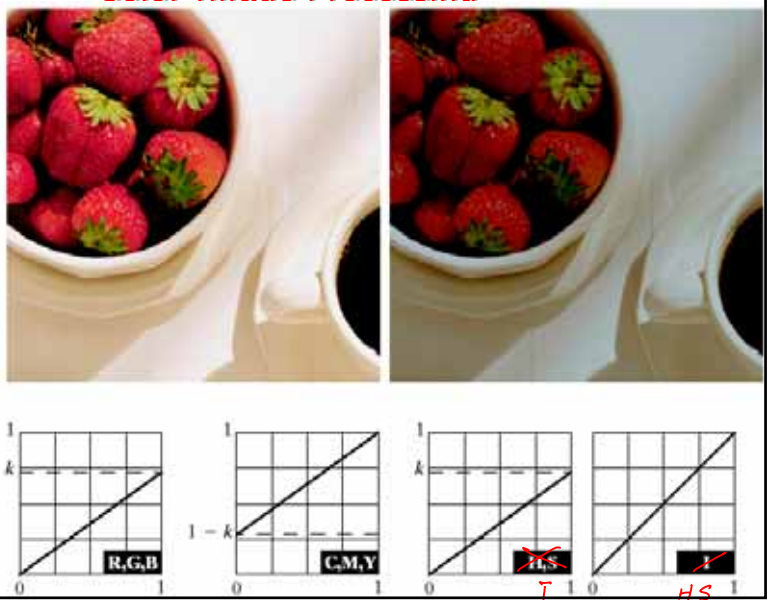


FIGURE 6.30 A full-color image and its various color-space components. (Original image courtesy of MedData Interactive.)

Chapter 6
Color Image Processing

a b
c d e

FIGURE 6.31
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)–(e) The required RGB, CMY, and HSI transformation functions. (Original image courtesy of MedData Interactive.)



Digital Image Processing, 2nd ed.
www.imageprocessingbook.com

Chapter 6
Color Image Processing

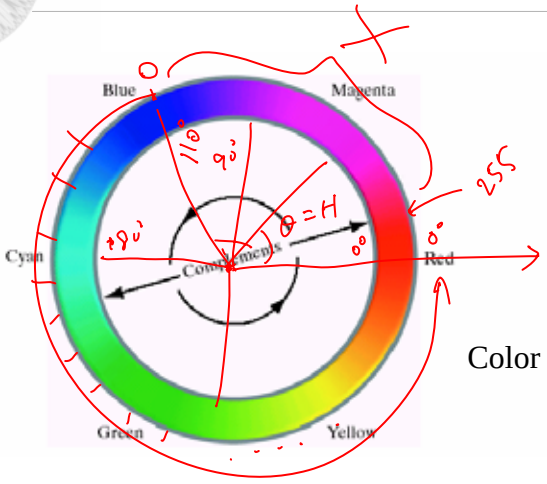
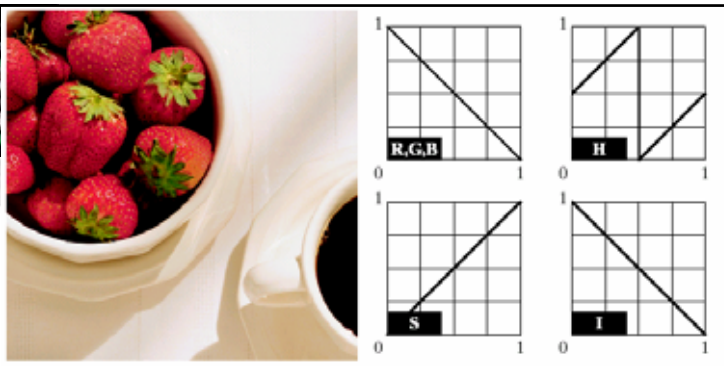


FIGURE 6.32
Complements on the color circle.

Color Complements

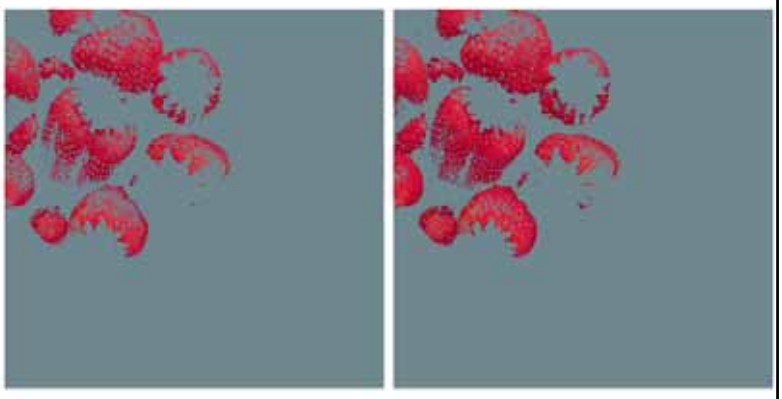


a b
c d

FIGURE 6.33 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.

Chapter 6
Color Image Processing

Color Slicing

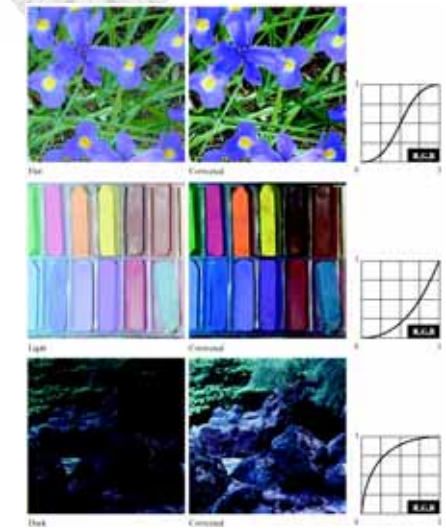


a b

FIGURE 6.34 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).

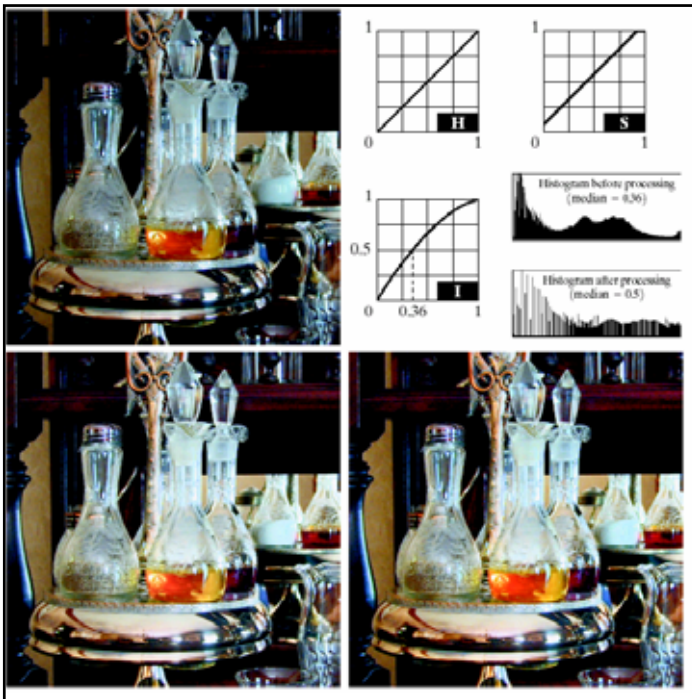
Chapter 6

FIGURE 6.35 Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not alter the image hues.



Tone and Color Corrections

FIGURE 6.36 Color balancing corrections for CMYK color images.



a b
c d

ssingbook.com

FIGURE 6.37 Histogram equalization (followed by saturation adjustment) in the HSI color space.

Histogram Processing In HSI

Chapter 6
Color Image Processing

Chapter 6
Color Image Processing

a b
c d

FIGURE 6.38
(a) RGB image.
(b) Red component image.
(c) Green component.
(d) Blue component.

Digital Image Processing, 2nd ed.
www.imageprocessingbook.com

Chapter 6
Color Image Processing

a b c

FIGURE 6.39 HSI components of the RGB color image in Fig. 6.38(a). (a) Hue. (b) Saturation. (c) Intensity.

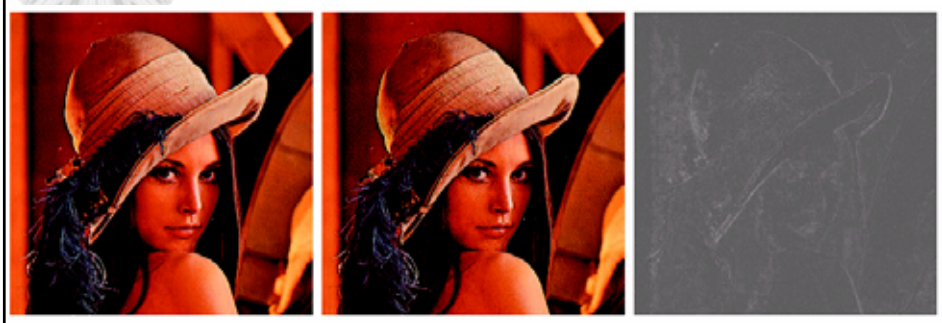
Chapter 6
Color Image Processing

a b c

FIGURE 6.40 Image smoothing with a 5 × 5 averaging mask. (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.

Digital Image Processing, 2nd ed.
www.imageprocessingbook.com

Chapter 6
Color Image Processing



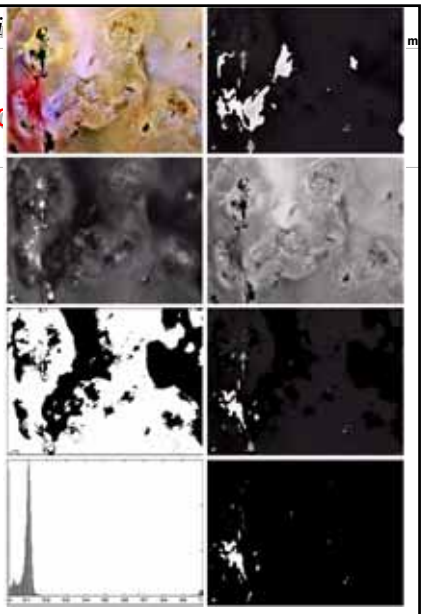
a b c

FIGURE 6.41 Image sharpening with the Laplacian. (a) Result of processing each RGB channel. (b) Result of processing the intensity component and converting to RGB. (c) Difference between the two results.

Chapter 6
Color Image Processing

Chapter
Color Image Pro

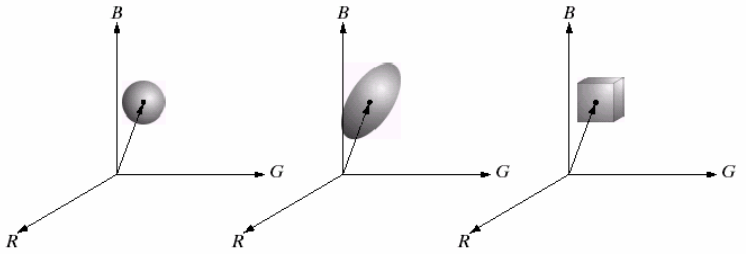
Segmentation in HSI Color Space



a b c d e f g h

FIGURE 6.42 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 in (a).

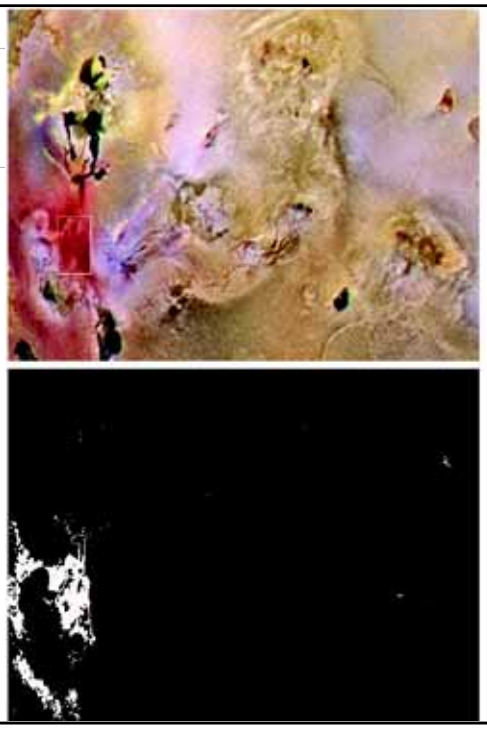
Chapter 6
Color Image Processing



a b c

FIGURE 6.43
Three approaches for enclosing data regions for RGB vector segmentation.

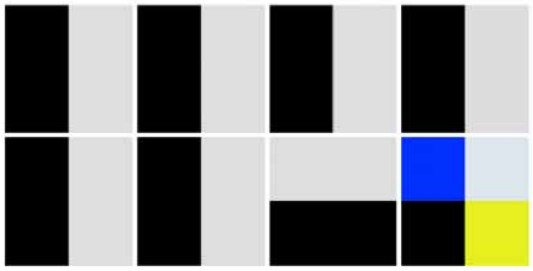
Segmentation in RGB Vector Space



a
b

FIGURE 6.44
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. 6.42(h).

Chapter 6
Color Image Processing



a b c d
e f g h

FIGURE 6.45 (a)–(c) *R*, *G*, and *B* component images and (d) resulting RGB color image. (f)–(g) *R*, *G*, and *B* component images and (h) resulting RGB color image.

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

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

$$g_{xx} = u^T u$$

$$g_{yy} = v^T v$$

$$g_{xy} = u^T v$$

$$\theta = \frac{1}{2}\tan^{-1}\frac{2g_{xy}}{g_{xx} - g_{yy}}$$

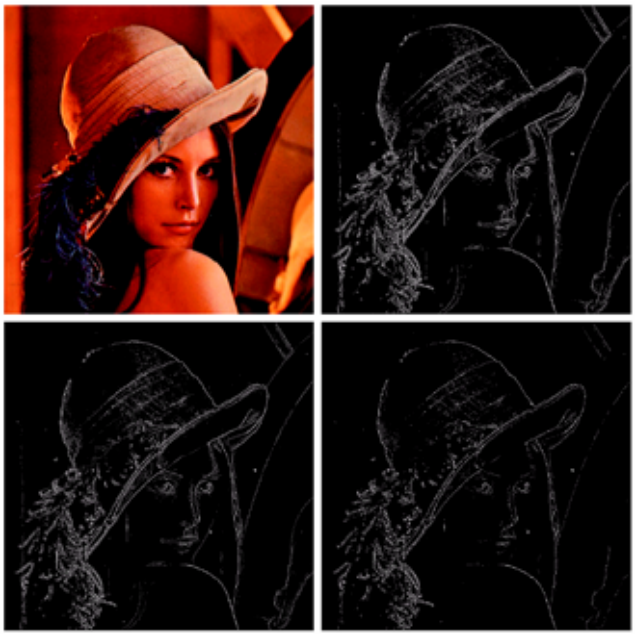
Color Edge Detection

The whole is NOT equal to the sum of its parts.

Digital Image Processing, 2nd ed.
www.imageprocessingbook.com

a b
c d

FIGURE 6.46
(a) RGB image.
(b) Gradient computed in RGB color vector space.
(c) Gradients computed on a per-image basis and then added.
(d) Difference between (b) and (c).



© 2002 R. C. Gonzalez & R. E. Woods

Chapter 6
Color Image Processing

a b c

FIGURE 6.47 Component gradient images of the color image in Fig. 6.46. (a) Red component, (b) green component, and (c) blue component. These three images were added and scaled to produce the image in Fig. 6.46(c).

a b
c d

FIGURE 6.48
(a)–(c) Red, green, and blue component images corrupted by additive Gaussian noise of mean 0 and variance 800. (d) Resulting RGB image. [Compare (d) with Fig. 6.46(a).]

Noise in Color Images

a b c

FIGURE 6.39 HSI components of the RGB color image in Fig. 6.38(a). (a) Hue. (b) Saturation. (c) Intensity.

a b c

FIGURE 6.49 HSI components of the noisy color image in Fig. 6.48(d). (a) Hue. (b) Saturation. (c) Intensity.

a b
c d

FIGURE 6.50
(a) RGB image with green plane corrupted by salt-and-pepper noise. (b) Hue component of HSI image. (c) Saturation component. (d) Intensity component.