Digital Image Processing, 2nd ed.

www.imageprocessingbook.com

Chapter 6
Color Image Processing

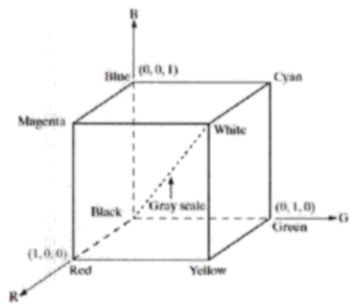


FIGURE 6.7 Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

diagonal has equal amounts of R, G, B so it is gray.

RGB color model

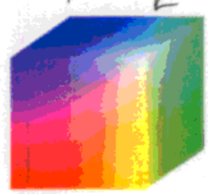
depth is the number of bits used in total

For example, 8-bit RGB is $8 \times 3 = 24$ bit depth.

Three most common color models

- RGB – color monitors
- CMY or CMYK – color printing
- HSI – decouples color and gray scale.

Chapter 6
Color Image Processing

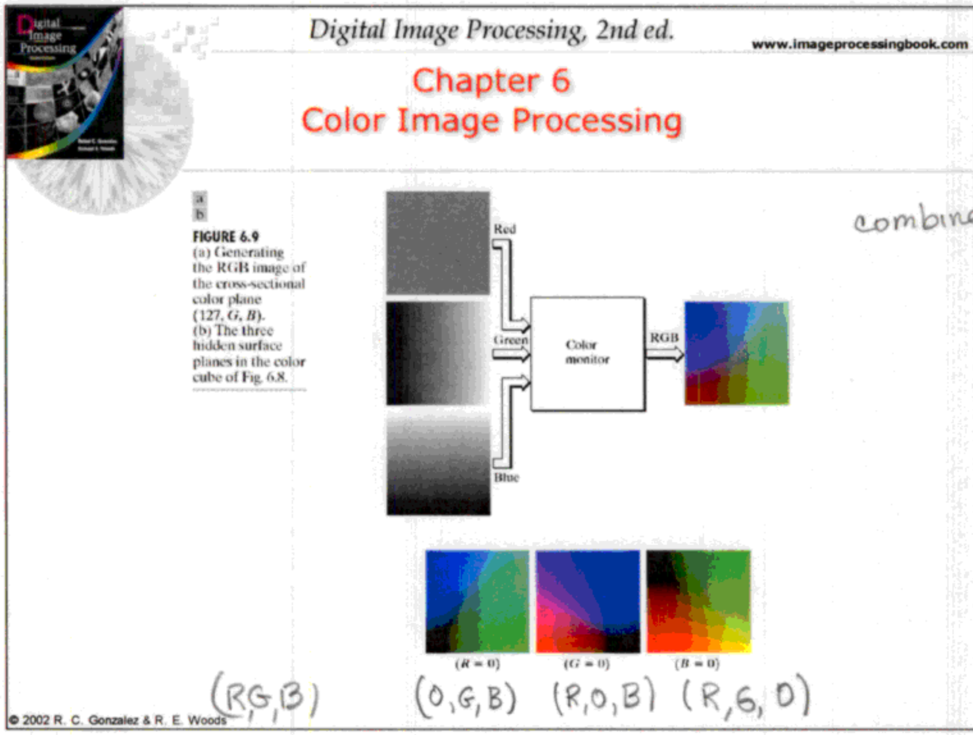


top surface is (R,G,255)

can be represented as [0,255] or [0,1]

FIGURE 6.8 RGB 24-bit color cube.

bottom surface is (R,G,0)



combine color planes into color image

(R,G,B) (0,G,B) (R,0,B) (R,G,0)

back planes looking inside out

Cameras do this in reverse by having separate filters and sensors for R, G, and B. Each resulting image is monochrome.

Digital Image Processing, 2nd ed.

www.imageprocessingbook.com

Chapter 6
Color Image Processing

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

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

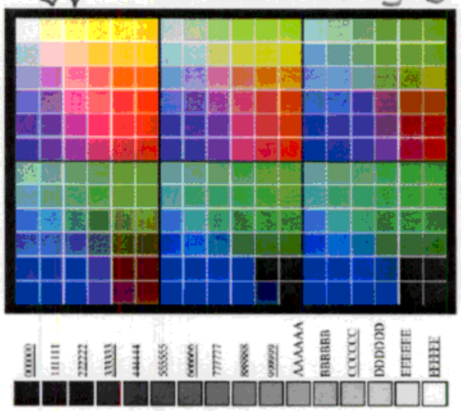
FF FF 99
FF FF CC
FF FF FF →
FF CC FF →
FF 99 FF →

→ decreasing B

decreasing G ↓

Red:

$FF	$CC	$99
$66	$33	$00



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).

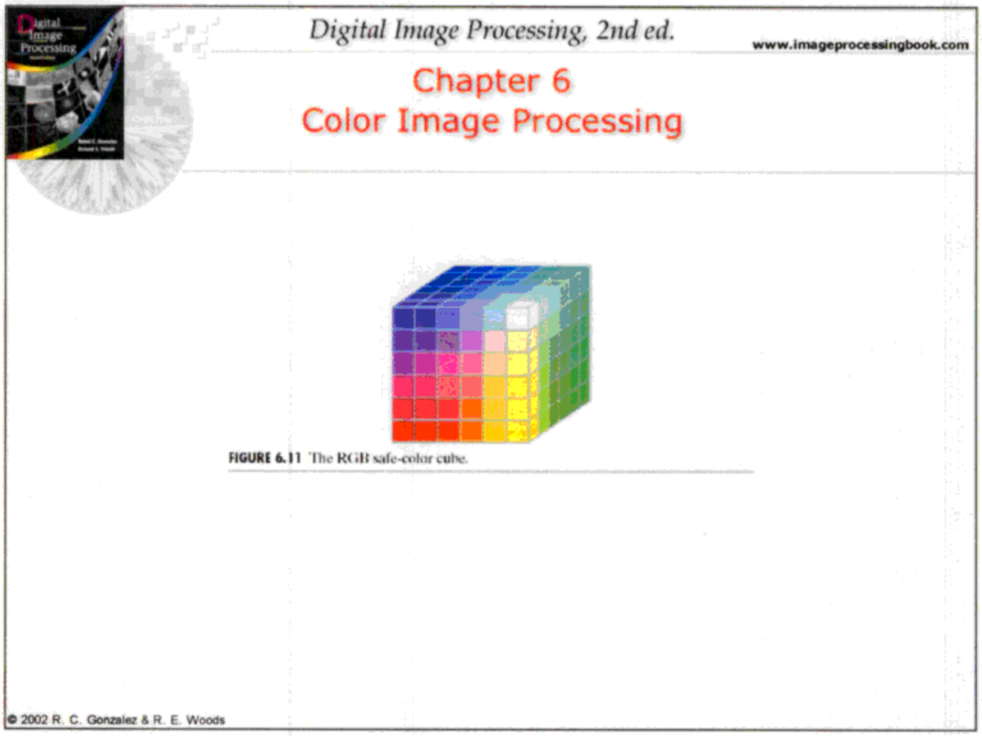
includes Internet "safe" colors

Many systems in use today restrict themselves to 256 colors for simplicity and speed of generation.

Of The only 216 Internet "safe" colors are reliably reproduced by the software.

(R, G, B)
↑
each value can only be $00, $33, $66, $99, $CC or $FF in hexadecimal

Older software could not produce even 256 colors.

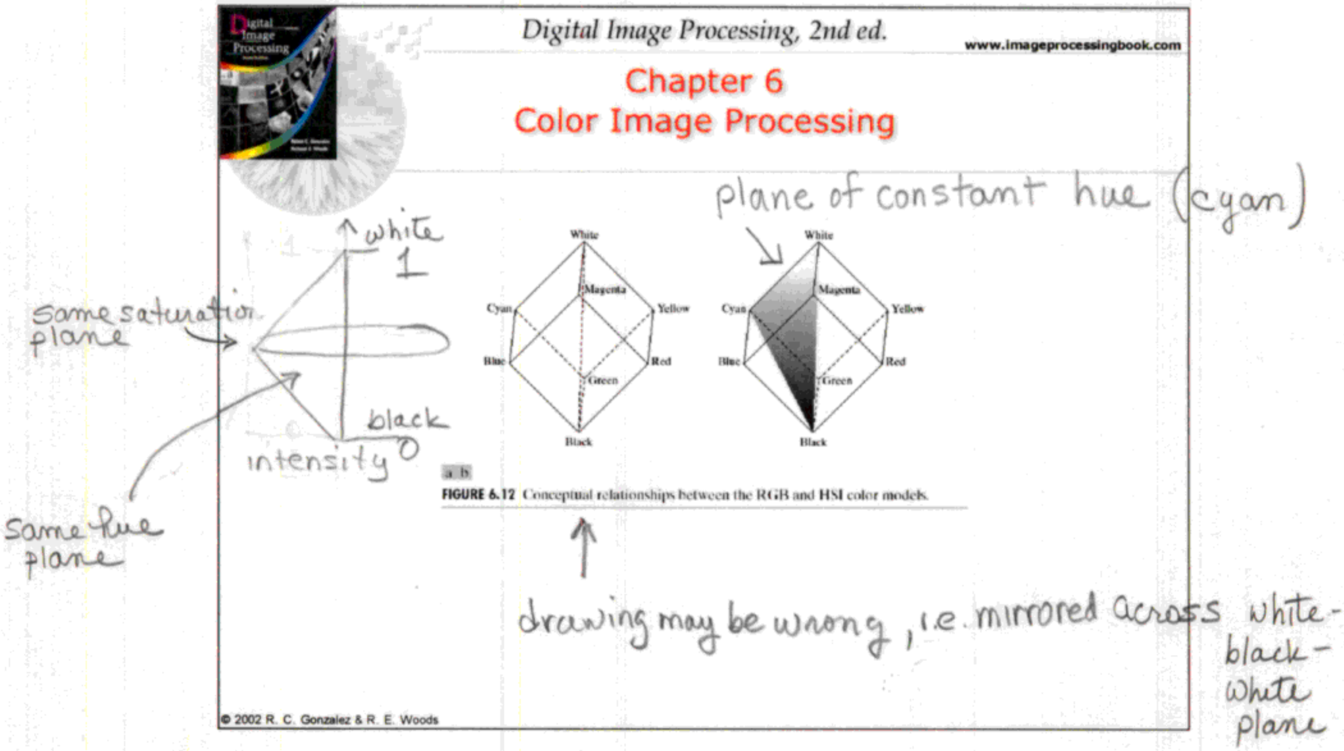


"safe" colors are only on the surfaces (faces).
No interior colors are "safe".

Color printers & copiers convert RGB to CMY

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

To get a good black on color printers we add "black" as a fourth color. Black is <u>very</u> difficult to produce by adding CMY pigments



Although RGB is good for generating colors it is not good for describing colors as humans interpret them.

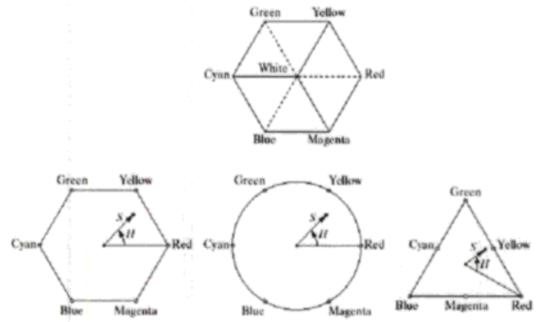
H - hue
S - saturation } color information decoupled from intensity
I - intensity } gray scale image

For an RGB color cube the intensity I is the diagonal from (0,0,0) black to (1,1,1) white. The intensity of any RGB color is its projection onto this intensity diagonal.

The plane perpendicular to the gray diagonal in the RGB cube will contain all colors of the same saturation since white does not change.

The plane defined by the gray diagonal and the cube boundaries will contain all colors of the same hue.

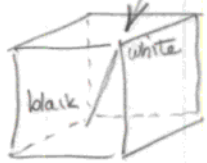
Chapter 6
Color Image Processing



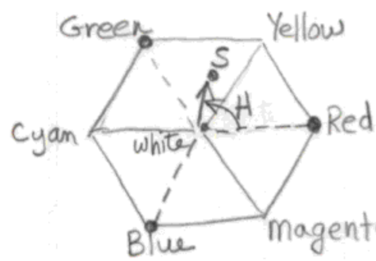
a
b c d

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.

looking at diagonal perpendicular planes are hexagonal.



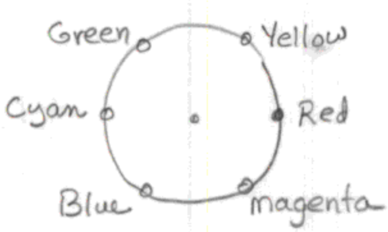
looking along axis

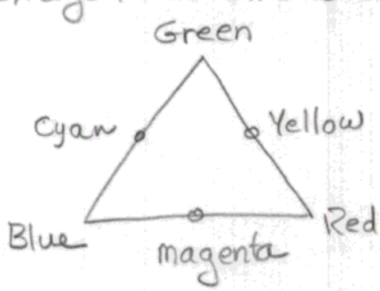


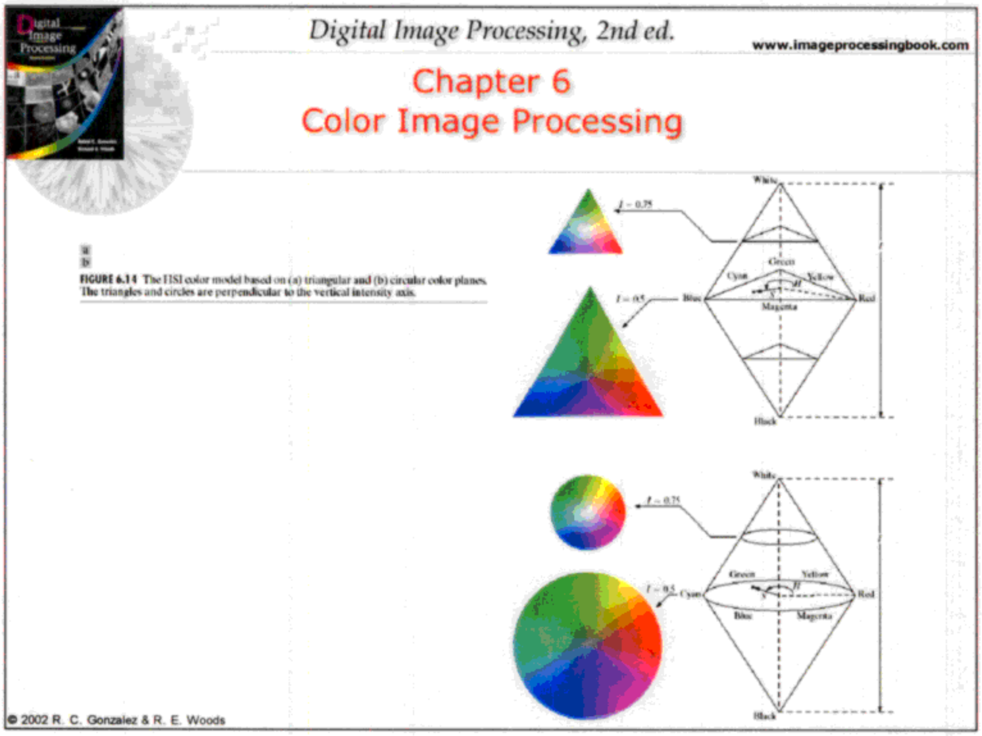
(is both 0 and 1 in terms of hue)

The hue of any point in each plane is it's angle from a reference point usually red.
The saturation is the distance from the origin.

Various simplifications of this hexagon are circles and triangles.







↑ This is the gray diagonal, i.e. the intensity axis.

From Figure 6.13 we can use trigonometry to derive the relationships between RGB and an HSI point.

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

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

saturation $$S = 1 - \frac{3}{R+G+B}\min(R,G,B)$$

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

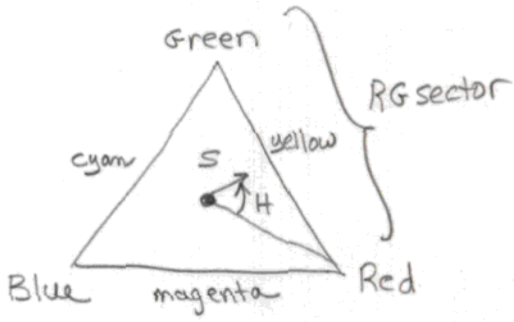
See book's web site for derivation

Converting colors from HSI to RGB

Multiply H by 360° to convert it back to an angle. H is usually normalized to [0,1].

RG Sector ($0° \le H \le 120°$)

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



GB sector ($120° \le H \le 240°$)

compute $H = H - 120°$
$$R = I(1-S)$$
$$G = I\left[1 + \frac{S\cos H}{\cos(60° - H)}\right]$$
$$B = 1 - (R+G)$$

BR Sector ($240° \le H \le 360°$)

compute $H = H - 240°$
$$G = I(1-S)$$
$$B = I\left[1 + \frac{S\cos H}{\cos(60° - H)}\right]$$
$$R = 1 - (G+B)$$

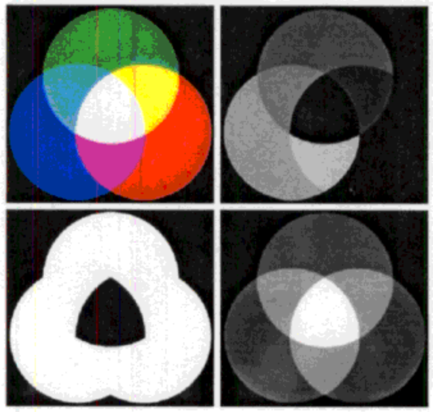
Chapter 6
Color Image Processing

Primary-secondary colors

H component (angles)

black and white have zero hue

red is 0° or black

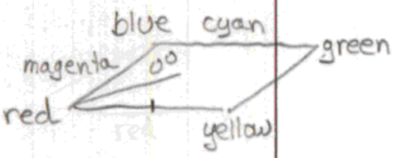


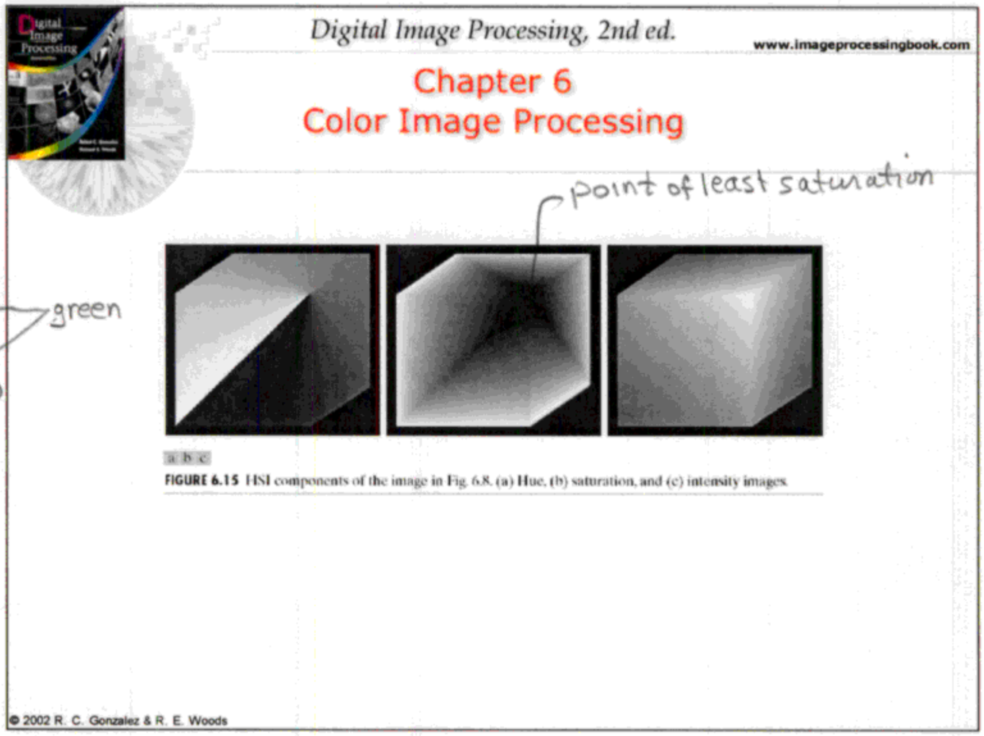
S component [0,255]

colors are fully saturated (on surface of RGB cube)

I component average intensities

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

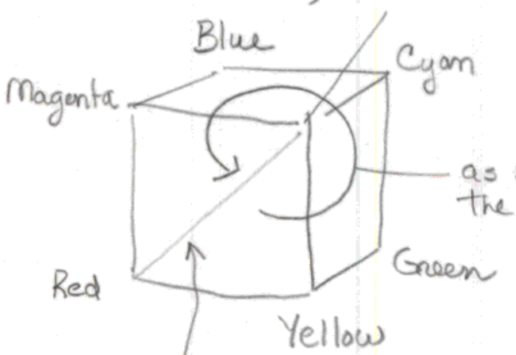




discontinuity because H is going from 1 (bright) to 0 (dark)

shows decreasing value, i.e. less saturation as you approach white

$I = \frac{1}{3}(R+G+B)$ is just average of R,G,B values



as seen looking back along the gray axis we have a discontinuity from 1 to zero along the red-white line.

this is the H=0 plane where H switches from 0°(black) to 360° (white)

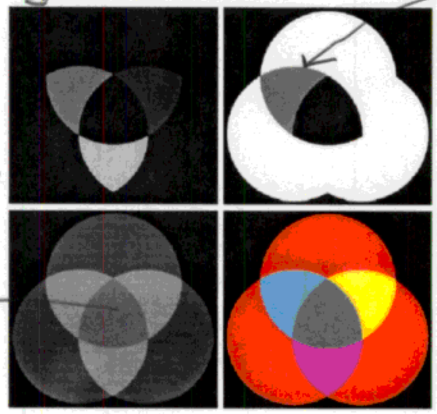
Chapter 6
Color Image Processing

green

H: change blue and green to 0, i.e., red.

blue

S: reduce cyan saturation by 50%



I: reduce intensity of white by 50%

Transformed color image
B,G become red
cyan looks washed out
white is now 50% gray

a b
c d

FIGURE 6.17 (a)–(c) Modified HSI component images. (d) Resulting RGB image. (See Fig. 6.16 for the original HSI images.)

To change color in HSI simply change the hue value and convert back to RGB without changing S and I.

To change saturation modify only S.

Chapter 6
Color Image Processing

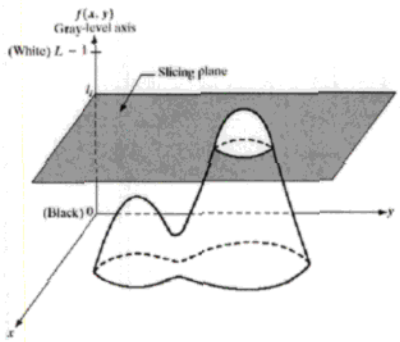


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

↑ if gray > l_i color A

↓ if gray < l_i color B.

pseudo color (false color) – assign colors to gray values using some criterion
– used a lot in data visualization

↓ false since these are not real color

Chapter 6
Color Image Processing

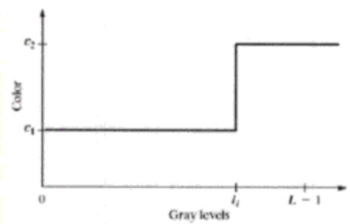
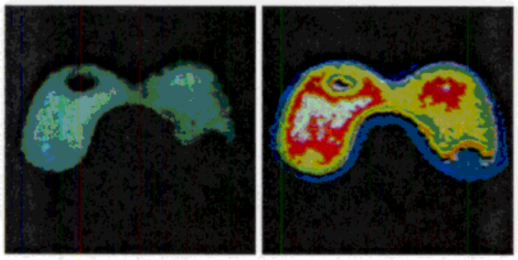


FIGURE 6.19 An alternative representation of the intensity-slicing technique.

Simply another way of describing what is done in Figure 6-18.

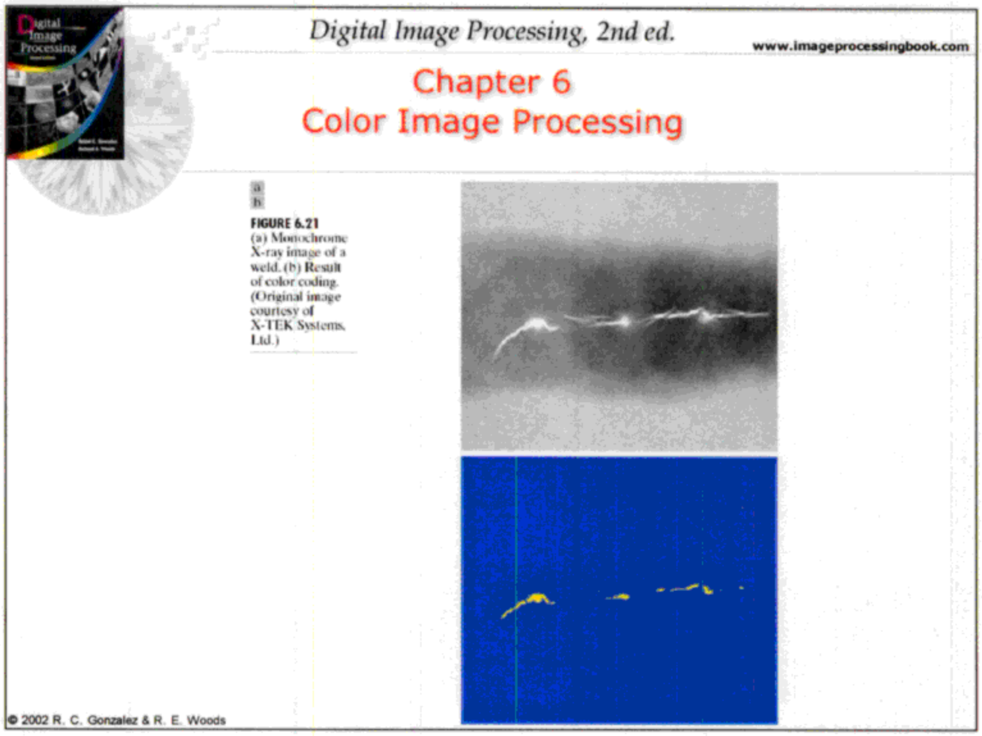
Chapter 6
Color Image Processing



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.)

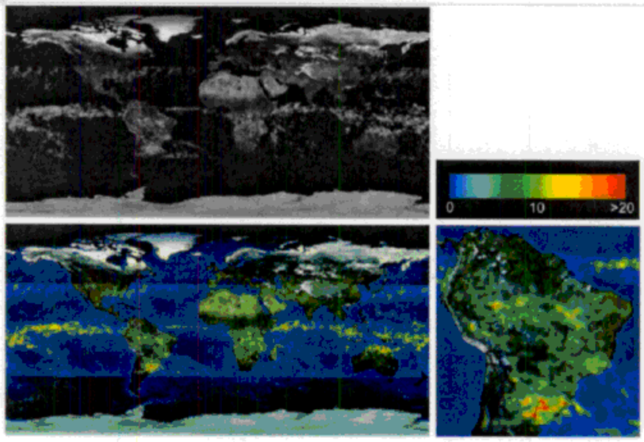
intensity slicing with multiple color slices



Simple application in X-ray analysis.
Cracks allow full X-ray intensity through metal.
Image simply codes 255 as yellow and all others as blue for inspection.

Chapter 6
Color Image Processing

intensity values correspond to rainfall →



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.)

Combine signals from (Tropical Rainfall Measuring Mission satellite)
- precipitation radar
- microwave imager
- visible/IR scanner.

to estimate average monthly rainfall.

Difficult to see patterns in grayscale. Much easier to see in pseudocolor.

Chapter 6
Color Image Processing

single gray scale input image

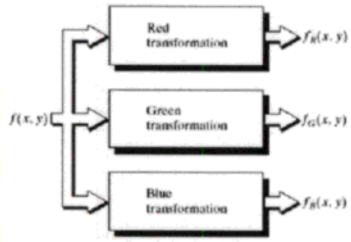
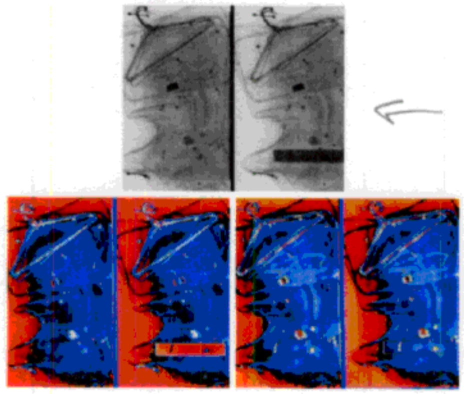


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

We can use simultaneous non-linear transforms to drive a color camera.

Chapter 6
Color Image Processing



← two images both gray scale.

Notice how explosives show up differently.

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.)

transform 6.25(a) transform 6.25(b)

2 different transforms.

Chapter 6
Color Image Processing

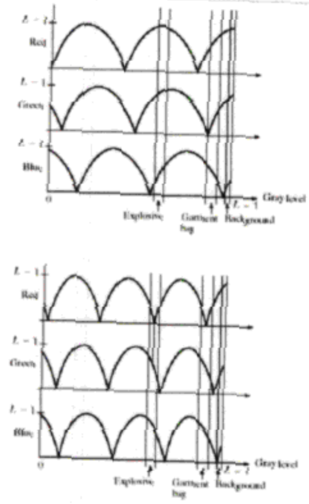
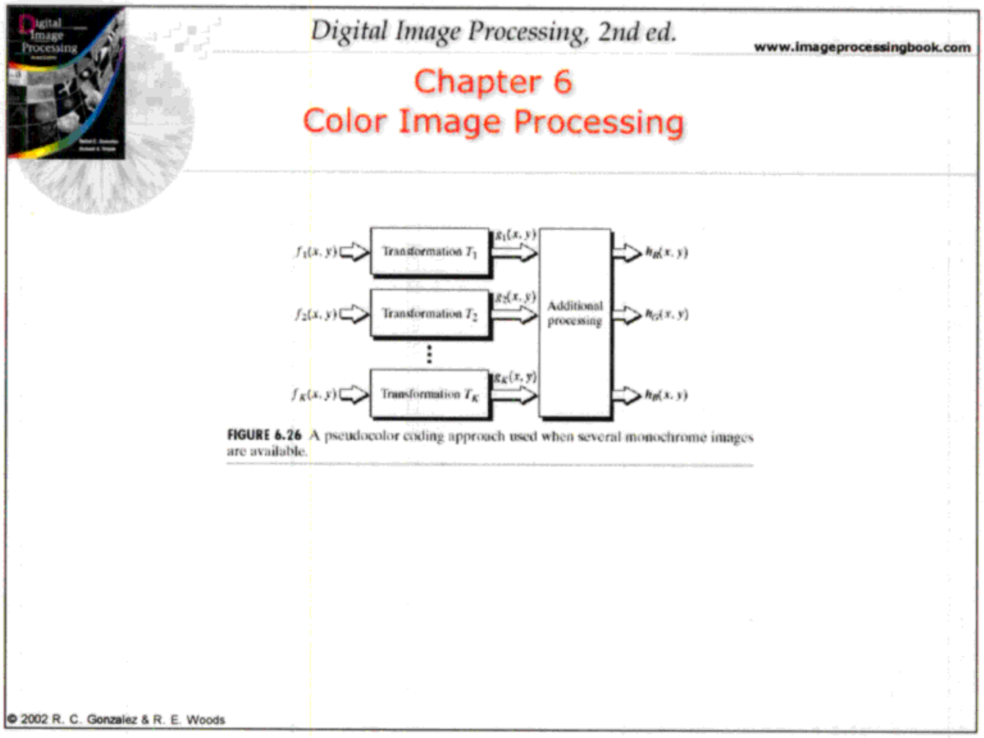


FIGURE 6.25 Transformation functions used to obtain the images in Fig. 6.24.

L = # of gray levels

transformations used
to make explosives in 6.24 visible.



more sophisticated color transformations can be used to combine grayscale images from different sensors as an example.

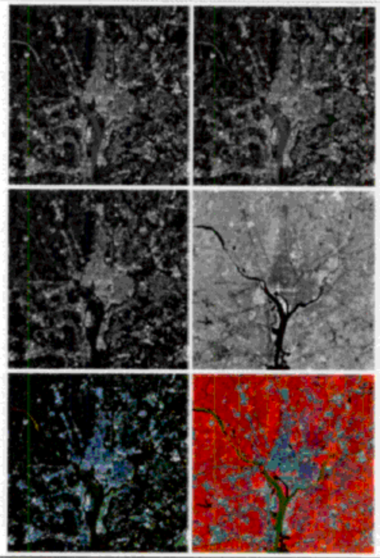
Digital Image Processing, 2nd ed.

www.imageprocessingbook.com

Chapter 6
Color Image Processing

visible red

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.)



green

blue

near-infrared

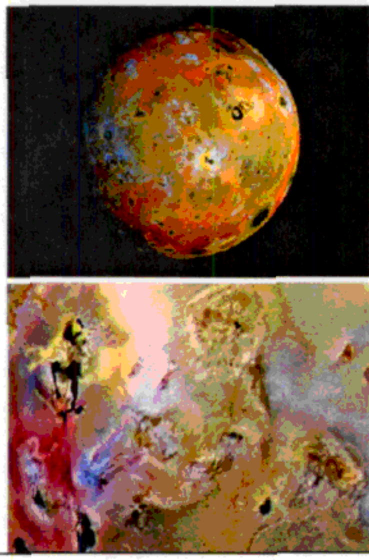
visible R – G – B image →

near infrared – G – B image

↑ used visible red for R

↑ used near infrared for R.

Chapter 6
Color Image Processing



a
b

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

used a variety of different wavelengths

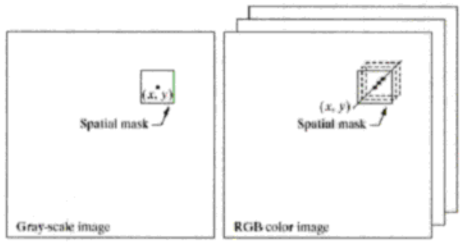
The newly ejected material is red (different material)

The older material is yellow. (sulfur)

Chapter 6
Color Image Processing

a b

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



for neighborhood averaging operations are equivalent

sum and divide all pixels in neighborhood

sum and divide all the vectors in the neighborhood to get the same result as averaging each color component and combining

full-color image processing

- process each component image separately and combine to form a composite image
- process color vectors (pixels) directly.

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

← just intensity

hue is difficult to interpret since its undefined for white, black and gray

strawberries are highly saturated

color transformations

$$s_i = T_i(r_1, r_2, \ldots, r_n) \qquad i = 1, \ldots, n = \text{\# of color components}$$

s_i: new color components

$r_1, r_2, \ldots, r_n$: color components, i.e., R, G, B

T_i = set of color transformations

There are different costs associated with image processing in the different color spaces

For example, to do intensity modification $g(x,y) = k\, f(x,y) \quad 0 < k \le 1$

in HSI color space $\quad s_3 = k r_3$

$\qquad s_1 = r_1 , \quad s_2 = r_2$

in RGB color space $\quad s_i = k r_i , \quad i = 1, 2, 3$

in CMY color space $\quad s_i = k r_i + (1 - k) , \quad i = 1, 2, 3$

We didn't show it but $I = \frac{1}{3}\left[3 - (c + m + y)\right] = 1 - \frac{1}{3}(c + m + y)$ which is why this formula looks a little odd.

RGB space:

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

to modify intensity

$$I' = \frac{1}{3}(kR+kG+kB)$$

$$= \frac{k}{3}(R+G+B) = kI$$

CMY space

$$I = \frac{1}{3}(1-C+1-m+1-Y)$$

$$I = \frac{1}{3}(3-C-m-Y) = 1-\frac{1}{3}(C+m+Y)$$

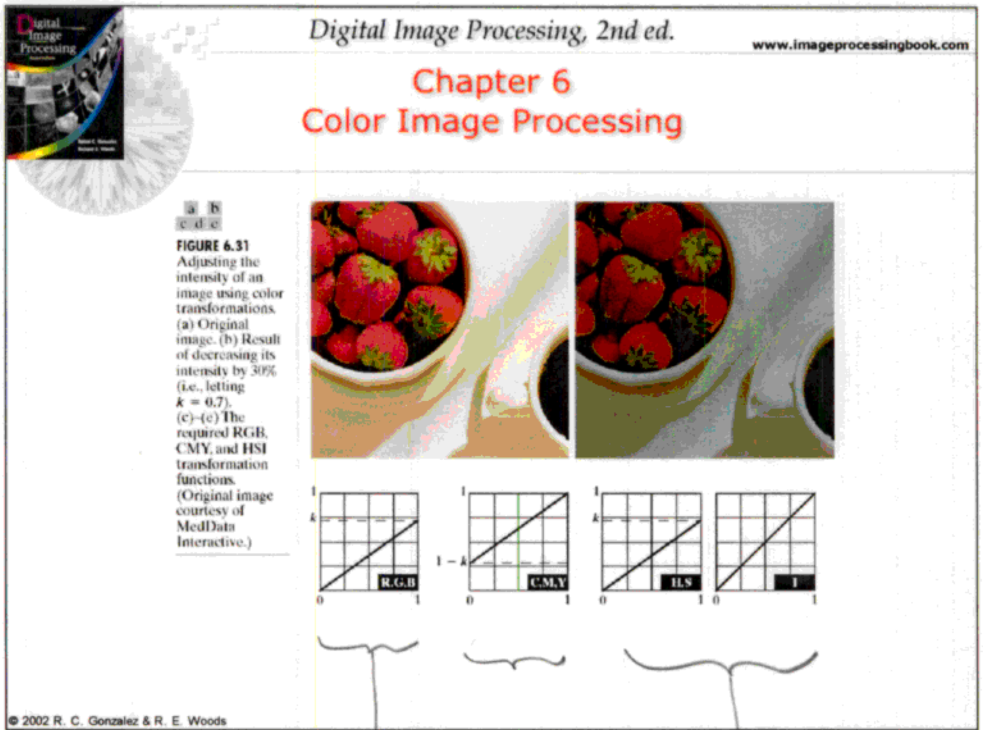
let $C' = kC+(1-k)$

$$I' = 1-\frac{1}{3}\left[kC+(1-k)+km+(1-k)+kY+(1-k)\right]$$

$$= 1-\frac{1}{3}\left[k(C+m+Y)+3(1-k)\right]$$

$$= 1-\frac{k}{3}(C+m+Y)-(1-k)]$$

$$= k\left[1-\frac{1}{3}(C+m+Y)\right] = kI$$

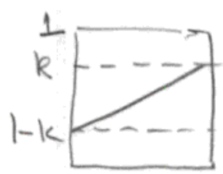


Scale each component in RGB

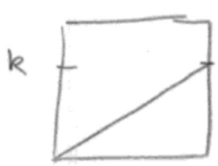
Since $C = 1 - R$, etc. This is simply a linear transformation.

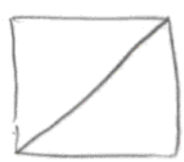
these are reversed
I is decreased
H, S remain the same.

lots of errors in figure



CMY





I H, S