COLOR IMAGE PROCESSING

Digital Image Processing

Preview

Preview

Light

Light is fundamental for *color vision*

Unless there is a source of light, there is nothing to see!

What do we see?

We do not see objects, but the light that has been *reflected by* or *transmitted through* the objects

Light and EM waves

Light is an electromagnetic wave

If its wavelength is comprised between 400 and 700 nm (*visible spectrum*), the wave can be detected by the human eye and is called *monochromatic light*

Physical properties of light

This distribution may indicate:

1) a dominant wavelength (or frequency) which is the color of the light (*hue*),
2) brightness (luminance), intensity of the light (*value*),
3) purity (*saturation*), which describes the degree of vividness.

Spectrum of White Light

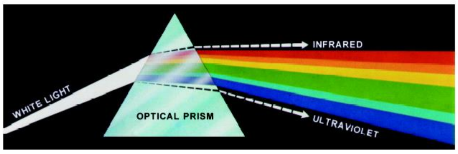
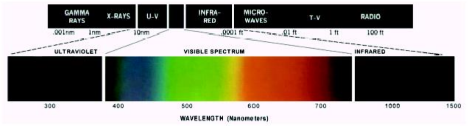


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

1666 Sir Isaac Newton, 24 year old, discovered white light spectrum.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Electromagnetic Spectrum



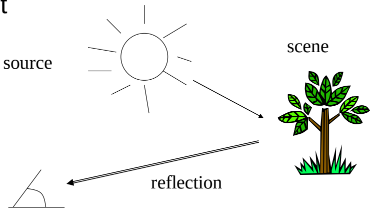
Visible light wavelength: from around 400 to 700 nm

1. For an achromatic (monochrome) light source,
there is only 1 attribute to describe the quality: intensity

2. For a chromatic light source, there are 3 attributes to describe
the quality:
Radiance = total amount of energy flow from a light source (Watts)
Luminance = amount of energy received by an observer (lumens)
Brightness = intensity

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

- The color that human perceive in an object = the light reflected from the object



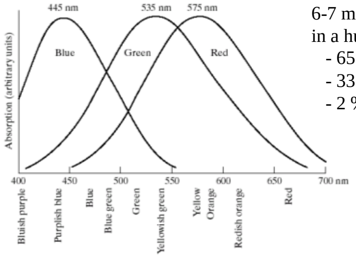
Illumination source

scene

reflection

eye

Sensitivity of Cones in the Human Eye



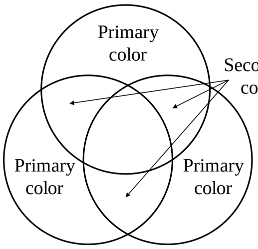
6-7 millions cones
in a human eye
- 65% sensitive to Red light
- 33% sensitive to Green light
- 2 % sensitive to Blue light

Primary colors:
Defined CIE in 1931
Red = 700 nm
Green = 546.1nm
Blue = 435.8 nm

CIE = Commission Internationale de l'Eclairage
(The International Commission on Illumination)

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Primary and Secondary Colors



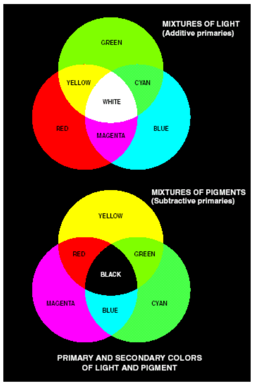
Primary color

Secondary colors

Primary color

Primary color

Primary and Secondary Colors (cont.)



Additive primary colors: RGB
use in the case of light sources
such as color monitors

RGB add together to get white

Subtractive primary colors: CMY
use in the case of pigments in
printing devices

White subtracted by CMY to get
Black

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Light and Color

The frequency (or mix of frequencies) of the light determines the color.

The amount of light(sheer quantity of photons) is the intensity.

Three independent quantities are used to describe any particular color. : hue, saturation, and lightness or brightness or intensity.

The ***hue*** is determined by the dominant wavelength.(the apparent color of the light)

When we call an object "red," we are referring to its hue. Hue is determined by the dominant wavelength.

Light and Color

The saturation of a color ranges from neutral to brilliant. The circle on the right is a more vivid red than the circle on the left although both have the same hue.

The ***saturation*** is determined by the excitation purity , and depends on the amount of white light mixed with the hue. A pure hue is fully saturated, i.e. no white light mixed in. Hue and saturation together determine the *chromaticity* for a given color.

Light and Color

Lightness or brightness refers to the amount of light the color reflects or transmits.

Finally, the ***intensity*** is determined by the actual amount of light, with more light corresponding to more intense colors (the total light across all frequencies).

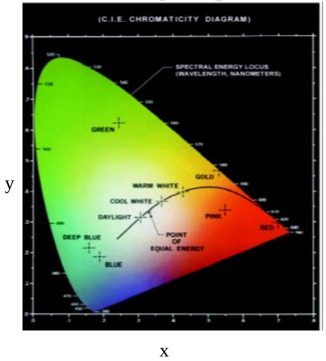
Color Characterization

Hue:	dominant color corresponding to a dominant wavelength of mixture light wave
Saturation:	Relative purity or amount of white light mixed with a hue (inversely proportional to amount of white light added)
Brightness:	Intensity

$$\left.\begin{array}{l}\text{Hue}\\ \text{Saturation}\end{array}\right\}\ \text{Chromaticity}$$

amount of red (X), green (Y) and blue (Z) to form any particular color is called *tristimulus.*

CIE Chromaticity Diagram



Trichromatic coefficients:

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

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

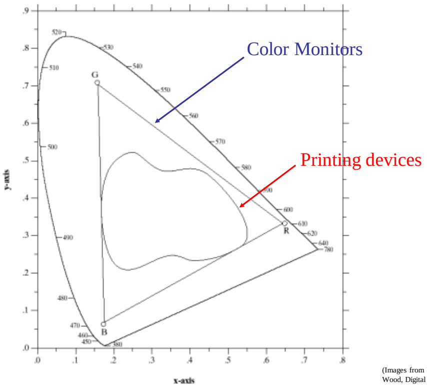
$$z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

Points on the boundary are fully saturated colors

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2^{nd} Edition.

Color Gamut of Color Monitors and Printing Devices



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2^{nd} Edition.

Color Fundamentals (con't)

- Tri-stimulus values: The amount of Red, Green and Blue needed to form any particular color
  Denoted by: X, Y and Z

- **Tri-chromatic coefficient:**

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

Color Models

- The purpose of a color model (also called color space or color system) is to facilitate the specification of colors in some standard, generally accept way.
- **RGB** (red, green, blue) : monitor, video camera.
- **CMY**(cyan, magenta, yellow),**CMYK** (CMY, black) model for color printing.
- and **HSI** model, which corresponds closely with the way humans describe and interpret color.

RGB (red, green, blue)

The RGB colour space is related to human vision through the tristimulus theory of colour vision.

The RGB is an additive colour model. The primary colours red, green and blue are combined to reproduce other colours.

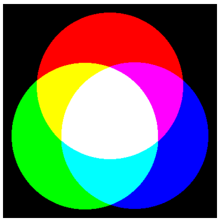
In the RGB colour space, a colour is represented by a triplet (*r*,*g*,*b*)

r gives the intensity of the red component
g gives the intensity of the green component
b gives the intensity of the blue component

Here we assume that r,g,b are real numbers in the interval [0,1].
You will often see the values of r,g,b as integers in the interval [0,255].

RGB Color model

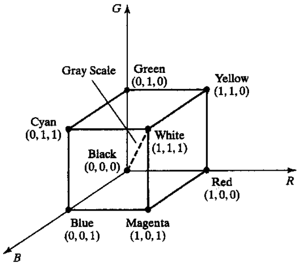
Source: www.mitsubishi.com



Active displays, such as computer monitors and television sets, emit combinations of red, green and blue light. This is an **additive** color model

The RGB Color Spaces

Purpose of color models: to facilitate the specification of colors in some standard



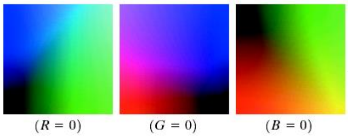
RGB color models:
- based on Cartesian coordinate system

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

RGB Color Cube

R = 8 bits
G = 8 bits
B = 8 bits

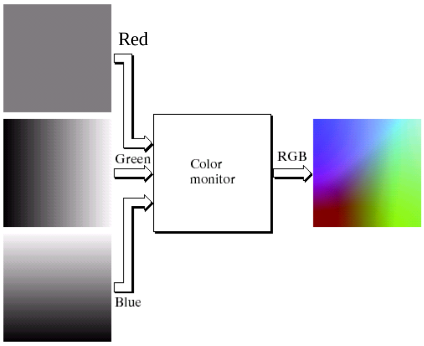
Color depth 24 bits = 16777216 colors



Hidden faces of the cube

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

RGB Color Model



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

RGB Color Model (cont.)

- Most modern computer monitors can transmit “true color,” or 24-bit color. This means each “channel” (R, G, or B) contains 8 bits per channel that can transmit color.
- Eight bits means the channel can make eight combinations of on or off of the color, per pixel, 256 colors total. You have three channels. How many colors can be generated?
- 256 x 256 x 256=16,777,216 possible colors.

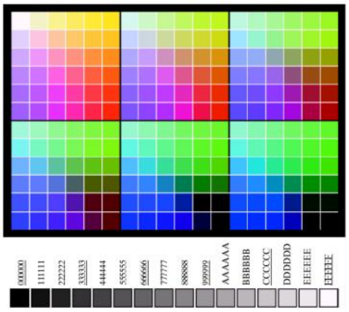
RGB Color Model (cont.)

- Eight-bit color also exists, 256 colors total.
- These are called “web-safe” colors, because they are sure to render accurately on anyone’s monitor.
- Nowadays we don’t have to worry about that as much.
  - (Below: 8-bit vs. 24-bit color.)

Safe RGB Colors

Safe RGB colors: a subset of RGB colors.

There are 216 colors common in most operating systems.



a
b

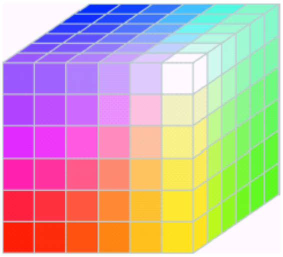
FIGURE 6.10 (a) The 216 safe RGB colors. (b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

RGB Safe-color Cube

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.



The RGB Cube is divided into 6 intervals on each axis to achieve the total $6^3 = 216$ common colors.

However, for 8 bit color representation, there are the total 256 colors. Therefore, the remaining 40 colors are left to OS.

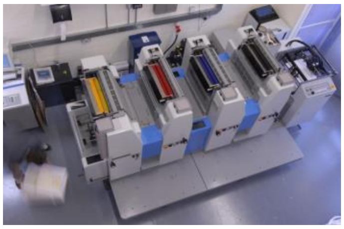
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

CMY Color model

- Additive color won’t work for printing because we can’t begin with black.
- We must begin with a piece of paper, and that’s usually white.
- White, as we know, is all colors. So we can’t add to all colors. We must subtract.
- Furthermore, an offset printing press can’t generate the enormous number of colors available on a computer screen.
- We need to run a piece of paper through the press for each ink.

CMY Color model

- The press below has four heads, one for each ink in the CMYK system.

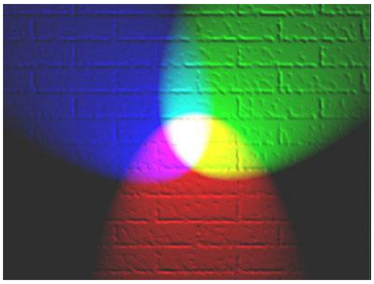


CMY Color model

- Printed color, therefore, is based on the subtractive system.
- While the additive primaries (used to generate all colors) are RGB, beginning with black…
- …the subtractive primaries are Cyan, Magenta, Yellow and Black (CMYK), and begin with white.
- Cyan=blue-green. Magenta=red-blue. Yellow=red-green.
- Note the relationship between the additive and subtractive primaries.

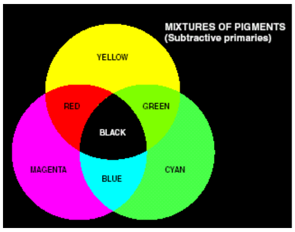
CMY Color model

- You can actually project the additive colors to produce the subtractive.



CMY Color model

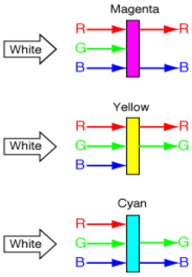
C = Cyan
M = Magenta
Y = Yellow
K = Black



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

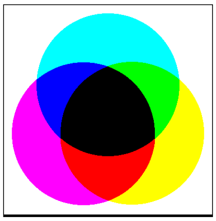
CMY Color model

- Why?
  - ➢ Pigments absorb light
- Thinking:
  - ➢ the Color Filters
- Question:
  - ➢ Yellow + Cyan=?



CMY Color model

Source: www.hp.com

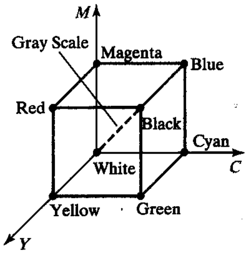


Passive displays, such as color inkjet printers, **absorb** light instead of emitting it. Combinations of **cyan**, **magenta** and **yellow** inks are used. This is a **subtractive** color model.

CMY

CMY cartridges for colour printers.

The CMY and CMYK Color Spaces



The CMY and CMYK Color Models

- Cyan, Magenta and Yellow are the secondary colors of light
- Most devices that deposit colored pigments on paper, such as color printers and copiers, require CMY data input.

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

The conversion from RGB to CMY is given by the formula

$$\begin{bmatrix} c \\ m \\ y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

Example 11.2: The red colour is written in RGB as (1,0,0). In CMY it is written as

$$\begin{bmatrix} c \\ m \\ y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} r \\ g \\ b \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 1 \end{bmatrix}$$

that is, magenta and yellow.

Example 11.3: The magenta is written in CMY as (0,1,0). In RGB it is written as

$$\begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

giving,

$$\begin{bmatrix} r \\ g \\ b \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}$$

that is, red and blue.

CMYK Color model

The image on the left was printed with only CMY inks
Black inks add contrast and depth to image on the image on the right

CMYK Color model

- Subtractive primaries are based on ink colors of CMYK.
- Black is abbreviated “K” by tradition, perhaps because it is the “key” color.
- In color printing, you need black to make the other colors vibrant and snappy.
- This is why the subtractive process is also called the four-color process, producing color separations, or “seps.”
- Colors used are called the process colors.

CMYK Color model

For printing and graphics art industry, CMY is not enough; a fourth primary, K which stands for black, is added.

Conversions between RGB and CMYK are possible, although they require some extra processing.

HSI color model

- Will you describe a color using its R, G, B components?
- Human describe a color by its hue, saturation, and brightness
  - Hue : color attribute
  - Saturation : purity of color (white->0, primary color->1)
  - Brightness : achromatic notion of intensity

HSI Color Model

RGB, CMY models are not good for human interpretation

HSI Color model:

Hue: Dominant color

Saturation: Relative purity (inversely proportional to amount of white light added)

} Color carrying information

Intensity: Brightness

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

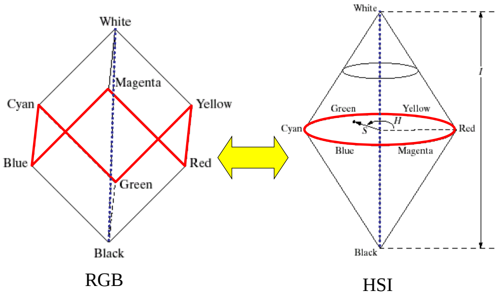
HSI Color Model

Source: http://www.cs.cornell.edu/courses/cs631/1999sp/

HSI Color Model

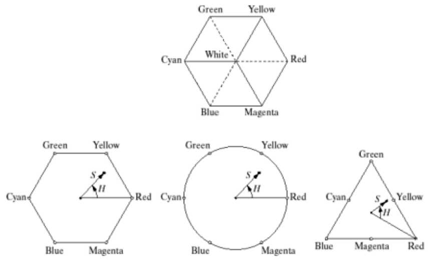
- **Hue** is defined as an angle
  - 0 degrees is **RED**
  - 120 degrees is **GREEN**
  - 240 degrees is **BLUE**
- **Saturation** is defined as the percentage of distance from the center of the HSI triangle to the pyramid surface.
  - Values range from 0 to 1.
- **Intensity** is denoted as the distance “up” the axis from black.
  - Values range from 0 to 1

Relationship Between RGB and HSI Color Models



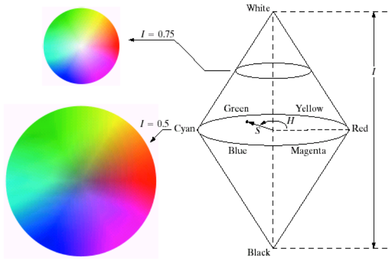
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Hue and Saturation on Color Planes



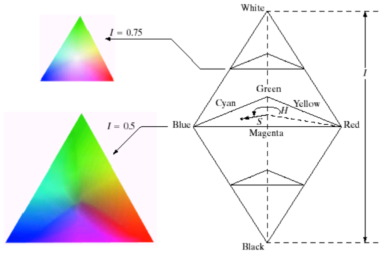
1. A dot is the plane is an arbitrary color
2. Hue is an angle from a red axis.
3. Saturation is a distance to the point.

HSI Color Model (cont.)



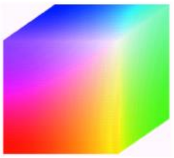
Intensity is given by a position on the vertical axis.

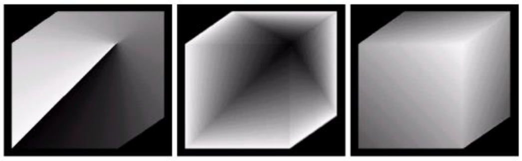
HSI Color Model



Intensity is given by a position on the vertical axis.

Example: HSI Components of RGB Cube


RGB Cube



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Converting Colors from RGB to HSI

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

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

$$S = 1 - \frac{3}{R+G+B}$$

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

Converting Colors from HSI to RGB

RG sector: $0 \le H < 120$

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

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

$$G = 1-(R+B)$$

GB sector: $120 \le H < 240$

$$H = H - 120$$

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

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

$$B = 1-(R+G)$$

BR sector: $240 \le H \le 360$

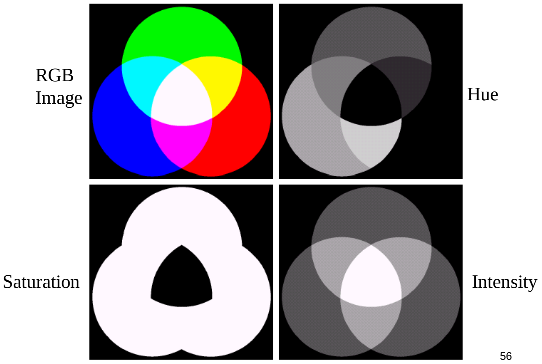
$$H = H - 240$$

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

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

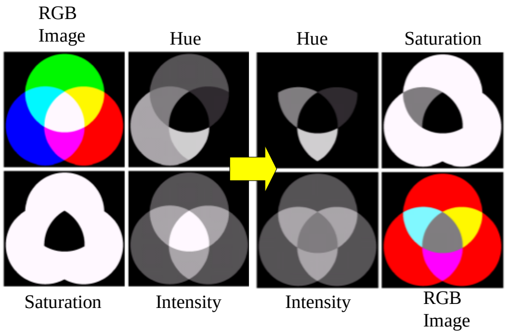
$$R = 1-(G+B)$$

Example: HSI Components of RGB Colors



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Example: Manipulating HSI Components



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Image Processing

There are 2 types of color image processes

1. Pseudocolor image process: Assigning colors to gray values based on a specific criterion. Gray scale images to be processed may be a single image or multiple images such as multispectral images

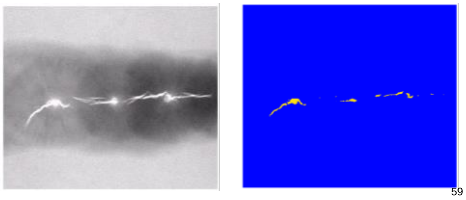
2. Full color image process: The process to manipulate real color images such as color photographs.

Pseudocolor Image Processing

Pseudo color = false color : In some case there is no "color" concept for a gray scale image but we can assign "false" colors to an image.

Why we need to assign colors to gray scale image?

Answer: Human can distinguish different colors better than different shades of gray.



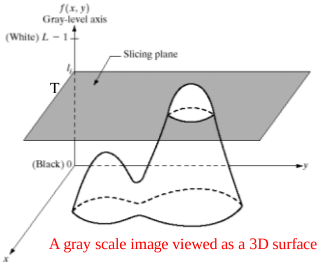
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Intensity Slicing or Density Slicing

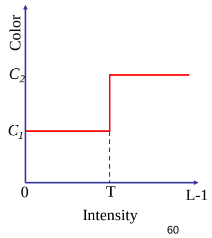
Formula:

$$g(x,y)=\begin{cases} C_1 & \text{if } f(x,y) \le T \\ C_2 & \text{if } f(x,y) > T \end{cases}$$

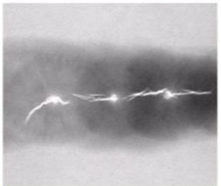
C_1 = Color No. 1
C_2 = Color No. 2



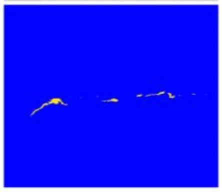
A gray scale image viewed as a 3D surface.



Intensity Slicing Example



An X-ray image of a weld with cracks



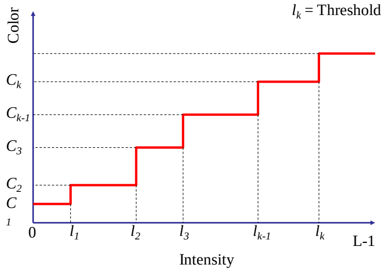
After assigning a yellow color to pixels with value 255 and a blue color to all other pixels.

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Multi Level Intensity Slicing

$$g(x,y) = C_k \quad \text{for } l_{k-1} < f(x,y) \le l_k$$

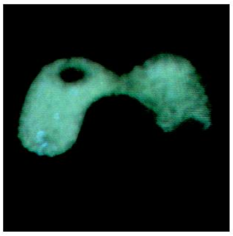
C_k = Color No. k
l_k = Threshold level k



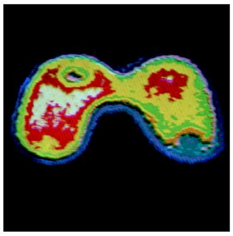
Multi Level Intensity Slicing Example

$$g(x,y) = C_k \quad \text{for } l_{k-1} < f(x,y) \le l_k$$

C_k = Color No. k
l_k = Threshold level k



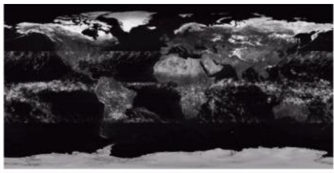
An X-ray image of the Picker Thyroid Phantom.



After density slicing into 8 colors

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

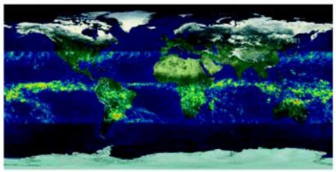
Multilevel Intensity Slicing Example….



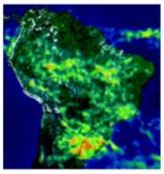
A unique color is assigned to each intensity value.

Gray-scale image of average monthly rainfall.

Color map



Color coded image

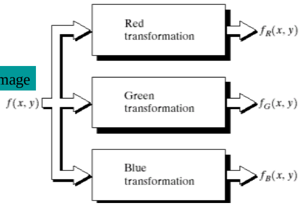


South America region

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Gray Level to Color Transformation

Assigning colors to gray levels based on specific mapping functions



Gray scale image

Red component

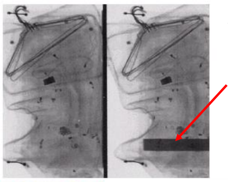
Green component

Blue component

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Gray Level to Color Transformation Example

An X-ray image of a garment bag

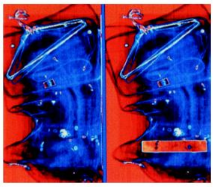


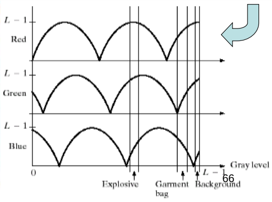
An X-ray image of a garment bag with a simulated explosive device

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Transformations

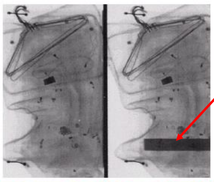
Color coded images





Gray Level to Color Transformation Example

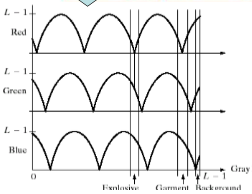
An X-ray image of a garment bag

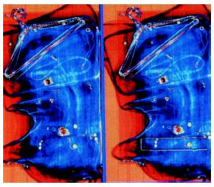


An X-ray image of a garment bag with a simulated explosive device

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Transformations

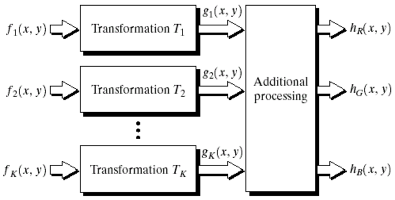




Color coded images

Pseudocolor Coding

Used in the case where there are many monochrome images such as multispectral satellite images.

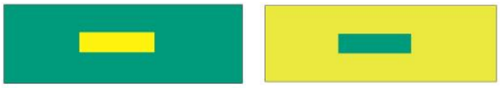


(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color theory

Some general guidelines for choosing color:

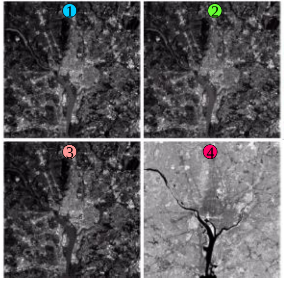
- Differences will be emphasized. For example, yellow surrounded by green will tend to appear more yellow; green surrounded by yellow will tend to appear more green. This is the rule of simultaneous contrast.



Pseudocolor Coding Example

Visible blue
λ= 0.45-0.52 μm
Max water penetration

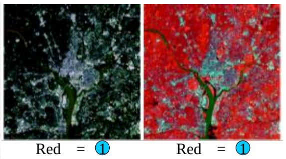
Visible green
λ= 0.52-0.60 μm
Measuring plant



Visible red
λ= 0.63-0.69 μm
Plant discrimination

Near infrared
λ= 0.76-0.90 μm
Biomass and shoreline mapping

Color composite images



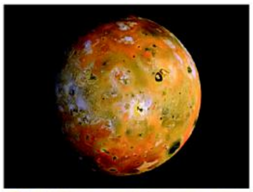
Red = ①
Green = ②
Blue = ③

Red = ①
Green = ②
Blue = ④

Washington D.C. area

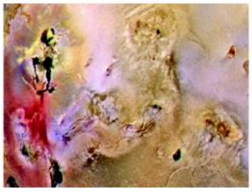
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Pseudocolor Coding Example



Psuedocolor rendition of Jupiter moon Io

Yellow areas = older sulfur deposits.
Red areas = material ejected from active volcanoes.



A close-up

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.