

4-1 Color Image

The use of color in image processing is motivated by two principal factors. First, color is a powerful descriptor and often simplifies object identification and extraction from a scene. Second, humans can discern thousands of color shades and intensities, compared to about only two dozen shades of gray. This second factor is particularly important in manual (i.e., when performed by humans) image analysis.

Color image processing is divided into two major areas: full-color and pseudocolor processing. In the first category, the images in question typically are acquired with a full-color sensor, such as a color TV camera or color scanner. In the second category, the problem is one of assigning a color to a particular monochrome intensity or range of intensities. Until recently, most digital color image processing was done at the pseudocolor level. However, in the past decade, color sensors and hardware for processing color images have become available at reasonable prices. The result is that full-color image processing techniques are now used in a broad range of applications, including publishing, visualization, and the Internet.

Basically, the colors that humans and some other animals perceive in an object are determined by the nature of the light reflected from the object. Visible light is composed of a relatively narrow band of frequencies in the electromagnetic spectrum. A body that reflects light that is balanced in all visible wavelengths appears white to the observer. However, a body that favors reflectance in a limited range of the visible spectrum exhibits some shades of color. (Figure 5.1)

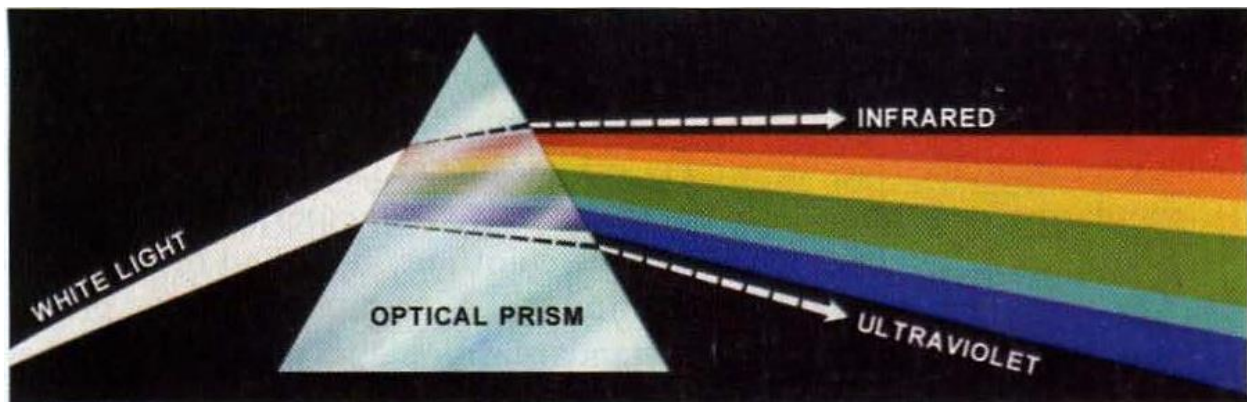


Figure 4.1: Color spectrum seen by passing white light through a prism.

4-2Color Image Scheme

Several color schemes (also called color space, models or formats) have been developed to represent color mathematically.

There are 4 commonly used color schemes:

- RGB Color Scheme
- CMY or CMYK Color Scheme
- HSB or HSI (Hue, Saturation, Brightness/Intensity) Color Scheme
- YCbCr Color Scheme

4-2-1 RGB Color Scheme

Colors are represented by a numeric triplet specifying R, G and B intensities. This model is convenient for CRTs since the numeric values can be easily mapped to voltages for the R, G, and B guns.

Any color can be defined by giving its R, G and B values, or coordinates, (red, green, blue). This is referred to as an ordered triplet.

The smallest value, 0, indicates the absence of color. The largest value, 255, indicates full intensity or saturation. The triplet (0, 0, 0) is black, because all colors are missing, and the triplet (255, 255, 255) is white. Other colors have various combinations:

(255,0,0) is pure red, (0,255,255) is a pure cyan (what one gets when green and blue are mixed), and (0,128,128) is a mid-cyan (a mix of mid-green and mid-blue tones). The possible combinations of the three basic color components are $256 \times 256 \times 256$, or 16,777,216 colors. Figure (4.2) shows Color specification of the RGB Color Cube.

The process of generating colors with three basic components is based on the RGB Color cube as shown in the figure (4.2). The three dimensions of the color cube correspond to the three basic colors.

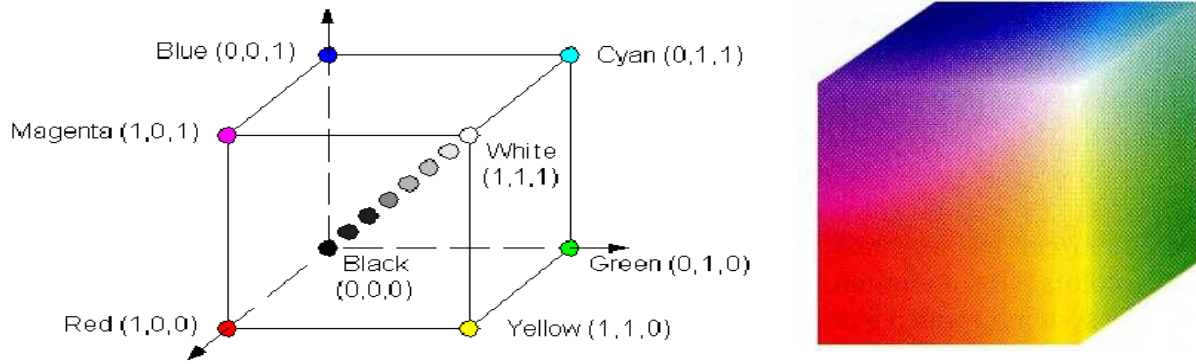


Figure 4.2: RGB24-bit color cube.

The cube's corners are assigned each of the three primary colors, their complements, and the colors black and white. Complementary colors are easily calculated by subtracting the Color values from 255. For example, the color (0, 0,255) is a pure blue tone.

Additive Mixing: All the colors in the spectrum can be created with the primary colors. This is called additive color property and it works for the mixing of primary color that are emitting light. Example, mixing R and G yields yellow. When R, G and B colors all mixed together, an entire spectrum of colors can be created. Figure (4.3)

It is noticed that the components of the colors at the corners of the cube have either zero or full intensity. As we move from one corner to another along the same edge of the cube, only one of its components changes value. For example, as we move from the Green to the Yellow corner, the Red component changes from 0 to 255.



Figure 4.3: Additive Mixing RGB Colors

All the colors in the spectrum can be created with the primary colors. This is called additive color property and it works for the mixing of primary color that is emitting light. Example, mixing R and G yields yellow. When R, G and B colors all mixed together gives white color, an entire spectrum of colors can be created.

4-2-2 CMY/CMYK Color Scheme

cyan, magenta, and yellow are the secondary colors of light or, alternatively, the primary colors of pigments. For example, when a surface coated with cyan pigment is illuminated with white light, no red light is reflected from the surface. That is, cyan subtracts red light from reflected white light, which itself is composed of equal amounts of red, green, and blue light.

Theoretically, if Cyan, Magenta, and Yellow are mixed, then all the RGB colors are subtracted, and we get black. However, in practice inks are not pure, hence a special black ink is used. Figure (4.4)

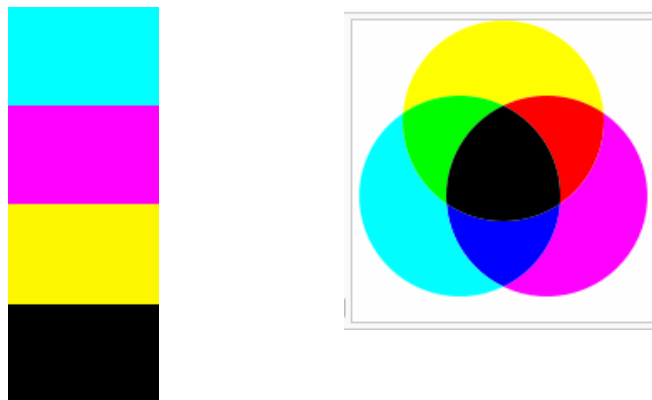


Figure 4.4: Secondary Color (Subtractive Mixing).

Secondary Colors: Cyan, Magenta and Yellow (CMY) are secondary colors or subtractive primary colors.

Subtractive Mixing: Subtractive color mixing is based on reflective colors rather than emissive colors. It generates color by mixing secondary colors. For example, mixing magenta and yellow yields red. Figure (4.5)

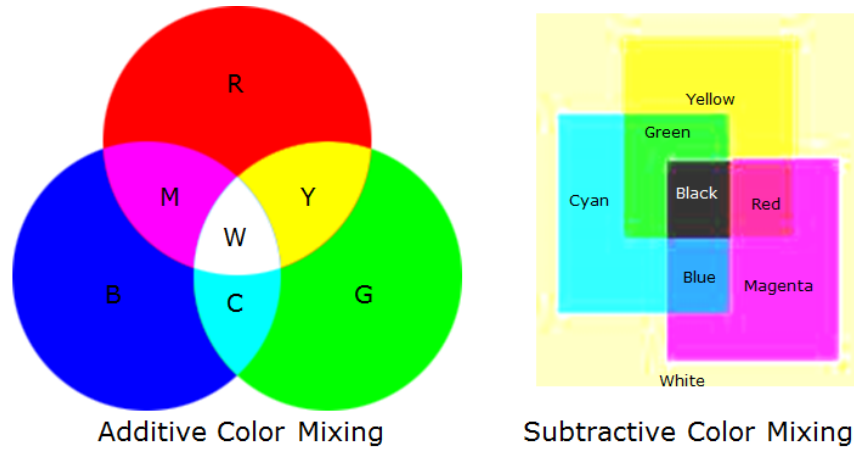


Figure 4.5: Additive and Subtractive Mixing.

In subtractive mixing, unwanted colors are selectively absorbed and the required color is reflected. The yellow color absorbs the blue component, and the magenta absorbs the green component, resulting in red.

Subtractive mixing is used primarily in the printing industry, by printing the three subtractive colors in differing proportions on white paper can generate all the colors in the spectrum.

Addition: primary colors: R, G, B (e.g., TV monitor)

$$\text{Red} + \text{Blue} = \text{Magenta}$$

$$\text{Green} + \text{Blue} = \text{Cyan}$$

$$\text{Red} + \text{Green} = \text{Yellow}$$

(Secondary colors: Magenta, Cyan, Yellow)

Subtraction (absorb primary color and reflect others, e.g., printer)

$$\text{white} - \text{green} = \text{Magenta}$$

$$\text{white} - \text{red} = \text{Cyan}$$

$$\text{white} - \text{blue} = \text{Yellow}$$

$$\text{White} - \text{red} - \text{green} - \text{blue} = \text{black} = \text{Magenta} + \text{Cyan} + \text{Yellow}$$

$$\text{white} = \text{red} + \text{green} + \text{blue}$$

Most devices that deposit colored pigments on paper, such as color printers and copiers, require CMY data input or perform an RGB to CMY conversion internally. This conversion is performed using the simple operation.

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

where, the assumption is that all color values have been normalized to the range [0, 1].

5-2-3 HSB/HSL Color Scheme

Computer monitors display colors by emitting color dots (red, green, blue).

Creation of color is based on function of three characteristics:

Hue & saturation & brightness / lightness. (HSB / HSL)

Colors are represented by a triplet representing hue (hue is dominant color of a sample and is represented by an angular value varying from red to green to blue at 120° intervals), saturation (purity of the color) and brightness (luminance, or intensity of the color). Figure (4.6)

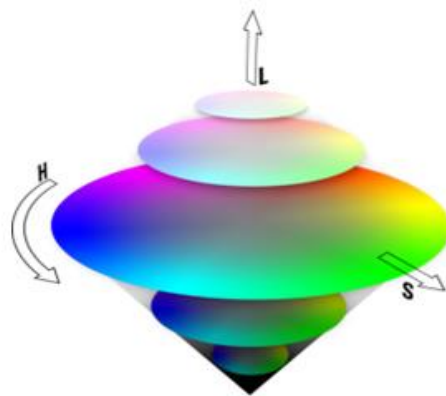


Figure 4.6: HSL color Scheme.

Hue: It is the color sensation produced in an observer due to the presence of certain wavelengths of color. Each wavelength presents a different hue. Hue is based on a vector value moving from 0 to 360 degrees on a color wheel.

Saturation: This is a measure of color intensity, for example, the difference between red and pink. Although the two colors have the same predominant wavelength, one may have more white color mixed in with it and hence appear less saturated. (100% = pure color, 0% = black, white, gray)

Intensity / Luminance / Brightness / Value: This is a measure of the light emitted or reflected by an object. Certain colors appear brighter than others as the human eye does not respond in the same way to all colors. The human eyes see finer details in image scene more because of brightness variations than because of color variations.

The RGB color (R,G,B) is mapped to the HSI color (H,S,I) by the following equations:

The H component of each RGB pixel is obtained using the equation

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

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

The saturation component is given by

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

Finally, the intensity component is given by

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

This mapping can be seen as the definition of the HSI space.

4-2-4 YCbCr Color Scheme

Another color space in which luminance and chrominance are separately represented is the YCbCr. The Y component takes values from 16 to 235, while Cb and Cr take values from 16 to 240. They are obtained from gamma-corrected R, G, B values as follows:

$$\begin{pmatrix} Y \\ C_b \\ C_r \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.500 \\ -0.500 & -0.419 & -0.081 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

The YCbCr transform is used in JPEG image compression and MPEG video compression.

4-3Color Dithering

Usually, digitized images are 24 bit, 16 million color depth.

If display system is limited to less than 16 million colors, the image must be transformed for display in the lesser color environment (color dithering).

Color Dithering – the process through which colors are changed to meet the closest available color based on the available palette.

color are substituted with closest available colors (output device) The quality of dithering will depend on the algorithm used to select the closest color.

4-4Basic Relationships between Pixels

Several important relationships between pixels in a digital image are considered. As mentioned before, an image is denoted by $f(x, y)$. When referring in this section to a particular pixel.

1. Neighbors of a Pixel

a. **N4(p) : four neighbors of pixel P.**

- Any pixel $p(x, y)$ has two vertical and two horizontal neighbors, given by:
 $(x+1, y)$, $(x-1, y)$, $(x, y+1)$, $(x, y-1)$
- This set of pixels are called the 4-neighbors of P, and is denoted by $N4(P)$

- Each of them is at a unit distance from P., and some of the neighbors of p lie outside the digital image if (x, y) is on the border of the image.

b. ND(p) : four diagonal neighbors of pixel P, denoted by ND(p).

- have coordinates $(x+1, y+1)$, $(x+1, y-1)$, $(x-1, y+1)$, $(x-1, y-1)$.
- Each of them are at Euclidean distance of 1.414 from P.

c. N8(p) These points, together with the 4-neighbors, are called the 8-neighbors of p, denoted by N8 (p).

- As before, some of the points in ND(p) and N8(p) fall outside the image if (x, y) is on the border of the image.

$F(x-1,y-1)$	$F(x-1,y)$	$F(x-1,y+1)$
$F(x,y-1)$	$F(x,y)$	$F(x,y+1)$
$F(x+1,y-1)$	$F(x+1,y)$	$F(x+1,y+1)$

$N_8(P)$

2. Adjacency

- Two pixels are connected if they are neighbors and their gray levels satisfy some specified criterion of similarity. For example, in a binary image two pixels are connected if they are 4-neighbors and have same value (0/1)
- Let v: a set of intensity values used to define adjacency and connectivity.
- In a binary Image $v=\{1\}$, if we are referring to adjacency of pixels with value 1.
- In a Gray scale image, the idea is the same, but v typically contains more elements, for example $v= \{180, 181, 182, \dots, 200\}$.
- If the possible intensity values 0 to 255, v set could be any subset of these 256 values.