

# **FUNDAMENTAL CONCEPTS OF COLOR**

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# CONCEPTS OF COLOR

## 1. Introduction:

The field of digital image processing relies on mathematical and probabilistic formulations accompanied by human intuition and analysis based on visual and subjective judgements. As such, among the various elements of image interpretation, color plays a crucial role in identifying and extracting objects from an image. Color image processing can be broadly classified into two categories- full color and pseudo color processing. Color images are usually acquired by a color TV camera/ color scanner whereas pseudo color images are created by assigning color to a gray scale image of monochrome intensity. A beam of light passing through a glass prism branches into a continuous spectrum of light ranging from violet, blue, green, yellow, orange to red. The colors that all living beings perceive in an object are basically due to the nature of light reflected from the object. Within the electromagnetic spectrum, visible light is composed of a very narrow band of frequencies. Achromatic light (i.e., light in a single color) can be characterized based on its scalar measure of intensity ranging from black, to gray and finally to white. On the other hand, chromatic light can be described using radiance, luminance and brightness. Radiance, measured in watts refers to the total amount of energy that flows from any light source. Of this, the amount of light energy perceived by an observer is termed as luminance, measured in lumens (lm). Brightness is one of the essential factors in describing color sensation. This module will discuss the fundamentals of color space.

## 2. Fundamentals:

In the human eye, the sensors responsible for color vision are termed as cones. Studies have established that, of the 6-7 million cones of the human eye, approximately 65% are sensitive to red light, 33% to green light and 2% to blue. Hence, colors to the human eye will primarily be variable combinations of the primary colors of red, green and blue. The word primary instills the impression that the three primary colors when mixed in varying proportions will produce all visible colors. This interpretation will be proved wrong by the end of this chapter.

The best example for additive nature of light colors is provided by a color Television. Color TV tube interior will normally comprise of numerous arrays of triangular patterns of electron-



sensitive phosphor. When excited, the dot within each triad tends to produce light in one of the three primary colors. The intensity of lights is modulated by electron guns inside the tubes that generate pulses corresponding to the red energy seen by the TV camera. Similar function is offered in the other two colors as well. The final effect seen on the TV, is the addition of three primary colors from each triad perceived by the cones in the eye as a full color image. The illusion of a continuously moving image is created by thirty such successive image changes per second.

Colors are distinguished from one another using the characteristics of hue, saturation and brightness. Hue refers to the dominant wavelength in a mixture of light waves and hence it stands for the dominant color as perceived by an observed. When we see an object as blue or yellow, we are actually referring to the hue of the object. Saturation stands for the amount of white light mixed with hue. Together, hue and saturation can be termed as chromaticity. If X, Y and Z be the amount/intensity of red, green and blue colors needed to generate any color, then a color can be specified by the following terms:

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

Where X, Y, and Z are termed as tristimulus values. Curves or tables compiled using experimental results (Poynton (1996), Walsh (1958) Kiver (1965), can be used to estimate the tristimulus values required to generate color corresponding to any wavelength of light in the visible spectrum.

Colors can also be specified using chromaticity diagrams, that show color composition as a function of x (red) and y(green) and z (1- (x+y)). In the chromaticity diagram (Figure 1), the pure colors from violet to red will usually be indicated along the boundary of the diagram while the colors within the diagram will represent a mixture of spectrum colors. Within the diagram, a straight line joining any two pure colors (of the boundary) will define all the different color variations which can be generated using these two colors. Similarly, to determine the range of colors which can be generated using any three given colors from the chromaticity diagram, connecting lines need to be drawn to each of the three color points. The resulting triangular

region will enclose all the colors that can be produced by varying combinations of the three corner colors.

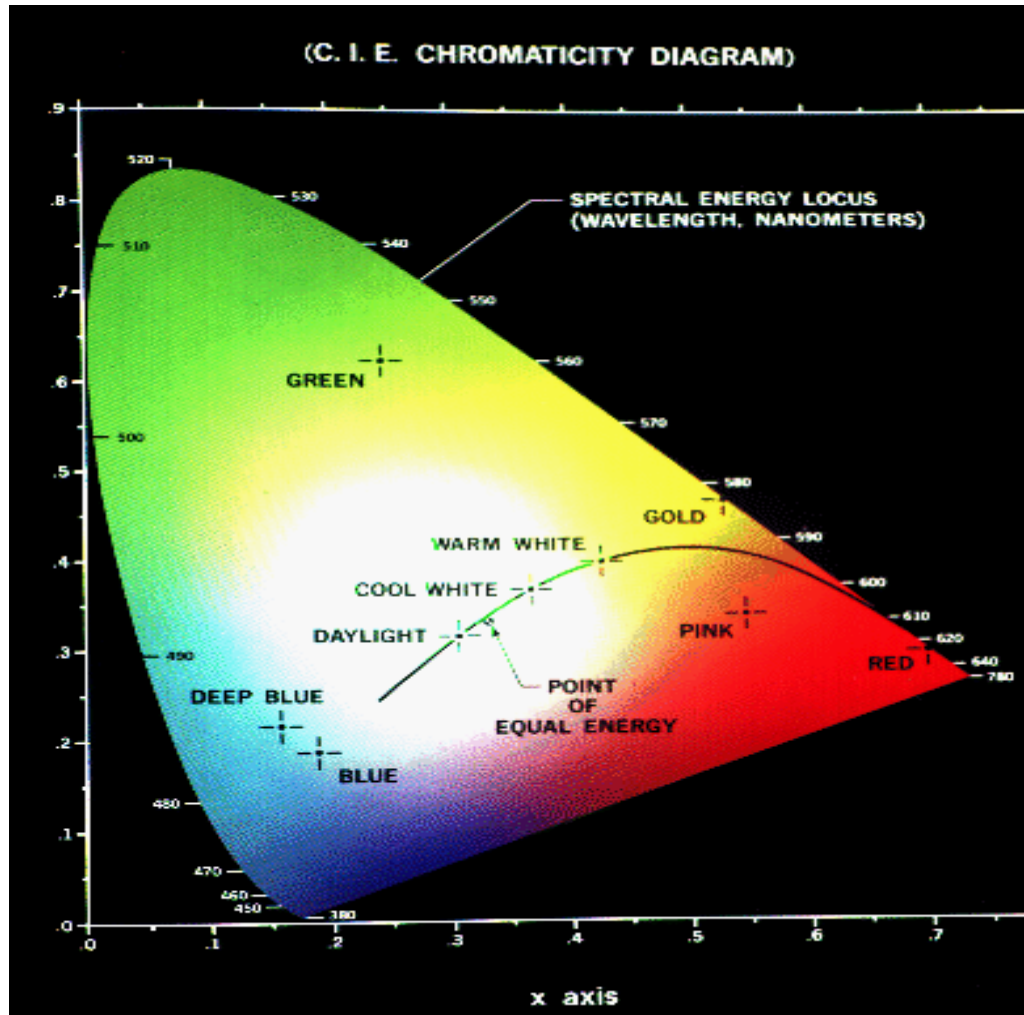


Figure 1: Chromaticity Diagram

### 3. Color Space

A color space/color system specifies a coordinate system within which each color can be represented by a single point. The most commonly used models are the RGB (red, green, blue), CMY (cyan, magenta, yellow), CMYK (cyan, magenta, yellow, black), IHS (intensity, hue, saturation). The RGB models are usually used in video cameras, CMYK models for color printing and IHS models resemble with the way humans interpret color. These models are briefly described here.

## 2.1 RGB

In the RGB model, the primary colors of red, green and blue are used within a Cartesian coordinate system. The RGB color model is shown in Figure 2 where the primary colors of red, blue and green represent the three corners with black at the origin and cyan, magenta and yellow representing the other three corners of the cube. The cube shown is a unit cube with the underlying assumption that all color values have been normalized. Pixel depth is the name given to the number of bits used to represent each pixel within an RGB space. An RGB image represented by 24 bit consists of  $(2^8)^3$  colors.

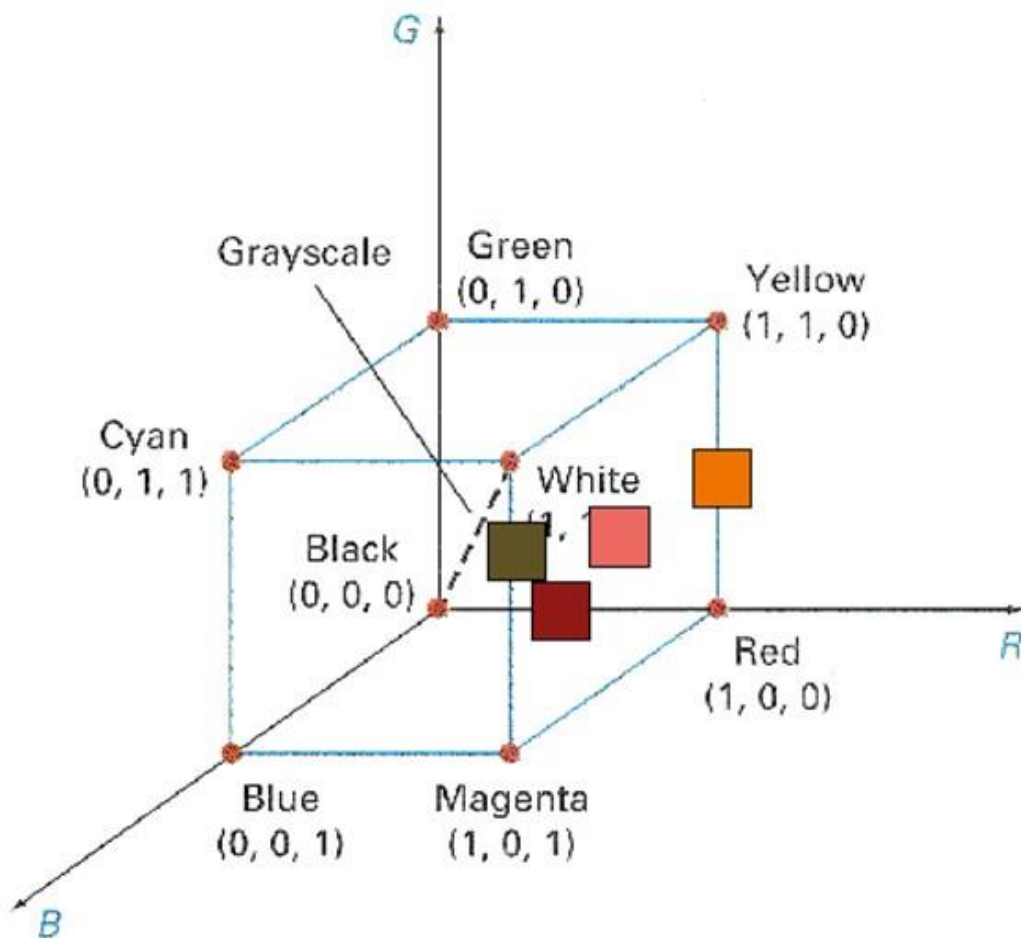


Figure 2: RGB color space

## 2.2 CMYK and CMY color models

Cyan, magenta and yellow comprise the secondary colors of light. A cyan color tends to subtract red from reflected white light. CMY to RGB conversion can be performed using the relation:

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

CMY color space (Figure 3) is used usually to generate hardcopy output. Practically, a combination of cyan, magenta and yellow produces a faint muddy black color when it should theoretically produce pure black color. Hence, in order to produce pure black color, a fourth color, black is added which results in CMYK color model. A four color printing means CMY color model along with black color.

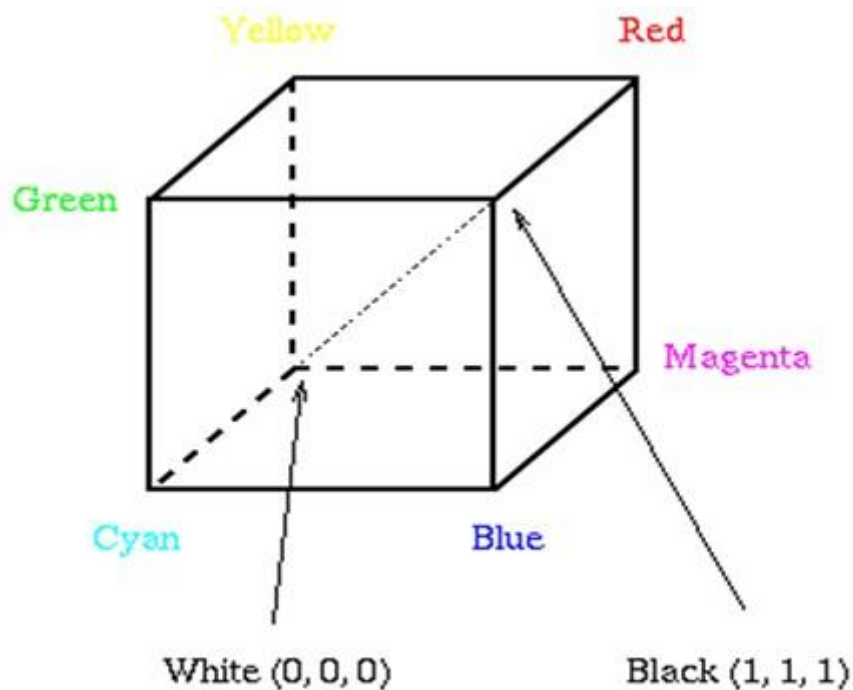


Figure 3: CMY color space

### 2.3 IHS color model

The RGB and CMY models fail to describe colors that are of practical interest to humans. Humans define color in an object in terms of its hue, saturation and brightness. IHS color model presents intensity (I), hue (  $\theta$  ) and saturation (S) within a color image and hence is suitable for algorithms based on color descriptions more intuitive to humans. Within the IHS sphere, intensity axis represents variations in brightness (black being 0 to white being 255). Hue represents the dominant wavelength of color. (0 at mid point of red tones and increases anti clockwise to 255). Saturation represents the purity of color and ranges from 0 at the center of the sphere to 255 at the circumference. A saturation of 0 represents a completely impure color, in which all wavelengths are equally represented (in grey tones).

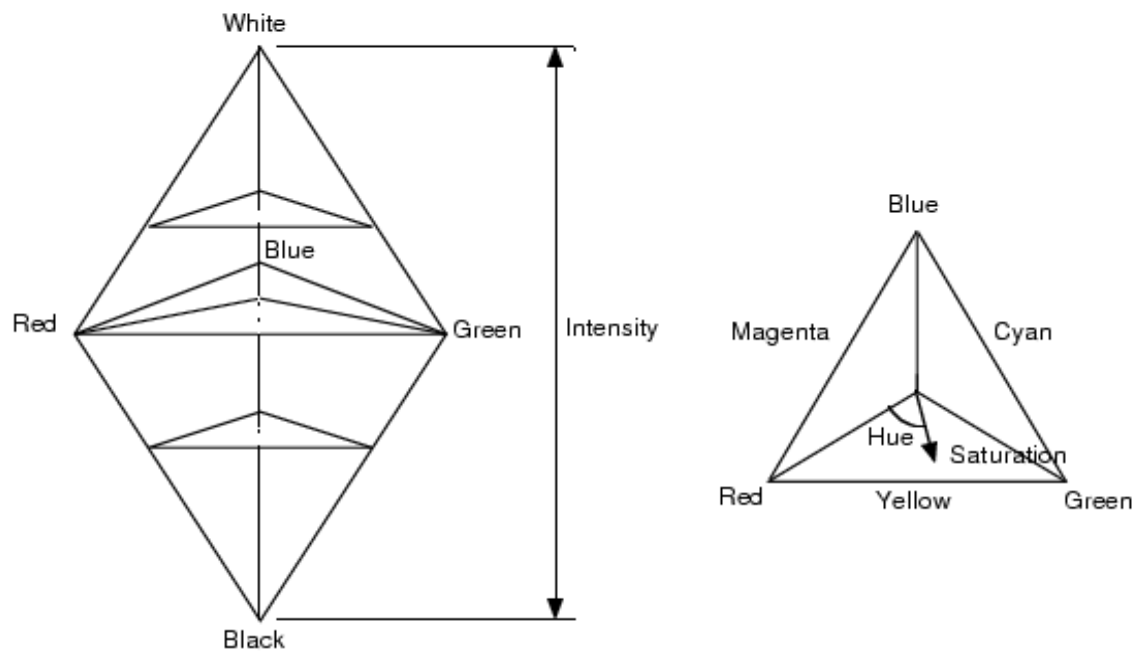


Figure 4: The IHS model which shows the IHS solid on the left and the IHS triangle on the right formed by taking a slice through the IHS solid at a particular intensity.

As shown in the figure, the corners of the equilateral triangle are located at the position of the red, green and blue hue. The vertical axis represents intensity ranging from black (0) to white (255); no color is associated with this axis. The circumference represents hue, i.e., the dominant wavelength of color which commences with 0 at the midpoint and increases counter clockwise direction around the triangle from red to green to blue and again to red with values increasing

to a maximum of 1 at the corners. Saturation denotes purity of color ranging from 0 at centre of color sphere to 255 at the circumference. High values of saturation represent purer and intense colors while intermediate values show pastel shades. The IHS system in detail can be found in Buchanan (1979).

## 2.4 Color Transformations

Bands of a sensor data, combined in the RGB system result in color images that lack saturation even after contrast stretching due to the highest degree of correlation between the spectral bands. To correct this issue, a technique is devised which enhances saturation:

### 2.4.1 Transformation from RGB to IHS

A conversion from RGB to IHS model can be obtained using the relations

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

Where

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

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

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

The Intensity images (I) will generally have high values for sunlit slopes, low values for water and intermediate values for vegetation and rocks. In hue (H) image, vegetation will have intermediate to light tones. In Saturation (S) image, just the shadows and rivers will be bright indicating high saturation for these features. To enhance clarity to a remotely sensed image, contrast stretching can be performed on the original saturation image. This will essentially improve the overall discrimination between different terrain types due to increased brightness of the enhanced image. The IHS images can be transformed back into images of RGB system; which can then be used to prepare a new color composite image. This image will be a significant improvement over its original counterpart. The HIS transformation and its inverse are useful for combining images of different types.





The stretched IHS representation can be subjected to inverse transform to convert back to RGB coordinates. The color transformation method can be used to combine images from different sources. For example, images with good resolution such as that from Landsat ETM+ and SPOT HRV sensors can be combined with low resolution images. Such transformations find wide application in geological applications. Further details regarding IHS transformation can be obtained from Blom and Daily (1982), Foley et al. (1990), Mulder (1980), Massonet (1993).

#### 2.4.2 Transformation from IHS to RGB

Inverse transformation using the values of RGB can be obtained, given the values of HIS depending on the values of H. Details regarding the range of H, and R, G, B equations are provided in the table below:

Range of H	R	G	B
$0^{\circ} \leq H \leq 120^{\circ}$	$I \left[ 1 + \frac{S * \text{Cos}H}{\text{Cos}(60^{\circ} - H)} \right]$	$3 * I - (R + B)$	$I * (1 - S)$
$120^{\circ} \leq H < 240^{\circ}$	$I(1 - S)$	$I \left[ 1 + \frac{S * \text{Cos}H}{\text{Cos}(60^{\circ} - H)} \right]$	$3 * I - (R + G)$
$240^{\circ} \leq H \leq 360^{\circ}$	$3 * I - (G + B)$	$I * (1 - S)$	$I \left[ 1 + \frac{S * \text{Cos}H}{\text{Cos}(60^{\circ} - H)} \right]$

#### 2.5 Color Composites

The bands of a multispectral image usually comprise of the three primary color bands of red, green and blue. When the colors of the resulting composite image resemble closely what would be observed by the human eyes, they lead to true color composite images. Then, the appearance of the displayed image will essentially represent a visible color photograph wherein vegetation appears in green, water in blue, soil in grey etc. Such images are known as true color images. Some refer to it as “natural color” images. For example, a Landsat Thematic Mapper image can be assigned red to band 3, green to band 2, blue to band 1 to create true color composite. The choice for color assignment can be done arbitrarily for any band of a multispectral image. When the color of such a resulting image has no resemblance to its actual color, it results in a false color composite (FCC). The principal use of such images is to aid in human visualization and interpretation of gray scale events in an image or in a sequence of images. Examples of

FCC from Landsat are illustrated in Figures below. In TM images, usually healthy vegetation shows up in shades of red because photosynthesizing vegetation absorbs most of the green and red incident energy but reflects approximately half of the incident near-infrared energy. Urban areas may appear as steel gray as these reflect approximately equal proportions of near-infrared

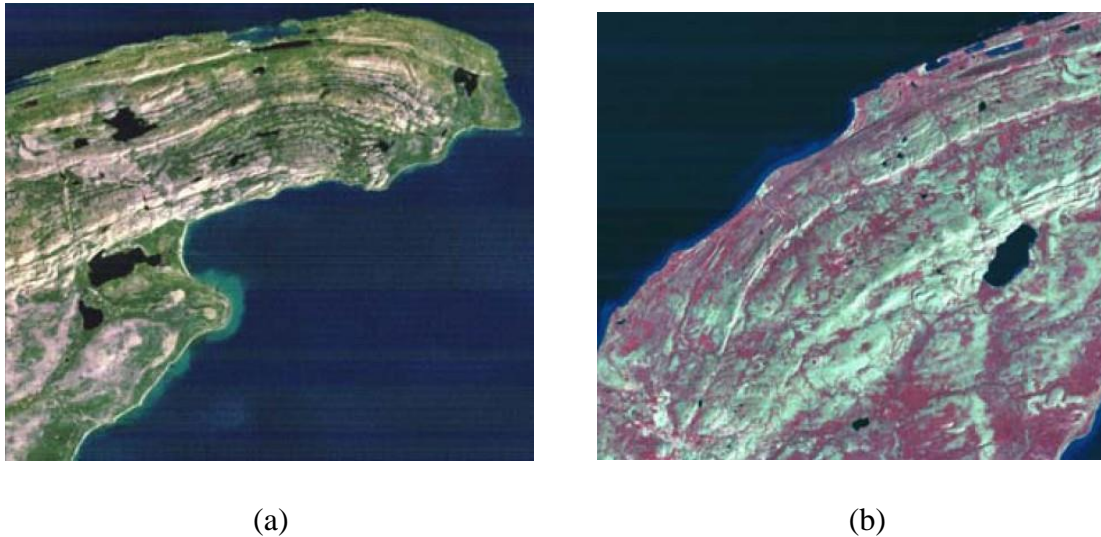


Figure 5 : (a) True color composite (band 321) (b) False color composite (band 543)

### 2.5.1 Optimum Index factor (OIF)

It should be noted that TM data can be used to generate two or more 3-band color composites. Chavez et al (1984) came up with an index known as optimum index factor (OIF) which can be relied to select the best combination of bands. OIF ranks all the three band combinations that can possibly be generated using the six bands of TM data. OIF is given by the expression:

$$OIF = \frac{\sum_{K=1}^3 S_K}{\sum_{J=1}^3 Abs(R_J)}$$

Here,  $S_K$  denotes the standard deviation for band  $K$ ,  $R_J$  is the absolute value of the correlation coefficient between any two of the three bands which are being evaluated. OIF is based on the total variance and correlation within and between the various band combinations. The combination having the largest value of OIF is generally treated as having the highest amount of information as measured by variance with the least amount of duplication (as measured by correlation).

## Bibliography / Further reading

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