- Imaging using colors
- Tristimulus Theory of Color Perception
- The HSI Model

Previous Next

Imaging using colors

The human visual system can distinguish thousands of varying color shades and intensities but only around 100 shades of gray. Therefore, in an image, a great deal of extra information is contained in the form of color. The extra information can be used to simplify image analysis such as object identification and extraction. Color sensation scattered from liquid crystals covering a surface is generated by a number of factors. These include the orientation of the crystals over the surface, the spectral characteristics of light used for illumination, and the spectral response of the color-sensing detector which could be a human eye or an imaging sensor in a color camera. The procedure for recording color images from a surface covered with liquid crystals using a color camera connected to a computer is discussed here.

Previous Next

Tristimulus Theory of Color Perception

According to physiological studies, the rods and cones of the human eye decompose color into a combination of Red, Green, and Blue (in short, RGB) and are called the primary colors. Current machine vision systems have implemented this natural tristimulus decomposition as an attempt to emulate human vision. These systems store the appropriate red, green and blue values needed to produce correspondingly matched color response at each point in an image.

A color model is simply a convenient way to represent color in numerical terms. Most color models use a three dimensional (3D) coordinate system. Each point within the system's subspace represents a unique color. The RGB color model, for example, can be visualized as a cube where Red is the X-axis, Blue is the Y-axis and Green is the Z-axis. Each one of the many million colors possible is described as a unique point within the cube.

There are many other color models in use.

Different Color Models

- RGB (Red, Green, Blue) model
- HSI model (Hue, Saturation, Intensity) and the HSV color model (Hue, Saturation, Value). These are frequently used in digital image processing.
- CMY (Cyan, Magenta, Yellow) model: standard used to describe color in the color printing industry, and
- YIQ color model (Y-axis, In-phase, Quadrature): used the television industry.

The RGB model is difficult to use directly because it requires three values of red, green, and blue to interpret temperature at a point – namely, a pixel. It is preferable to have a quantity that will have a single value corresponding to a particular temperature. The HSI model serves this purpose as discussed in the next section.

Previous Next

The HSI Model

In the HSI model, color is specified by the three quantities namely,

- hue,
- saturation and
- intensity.

Hue

In the visible spectrum, hue directly corresponds to the dominant wavelength of color.

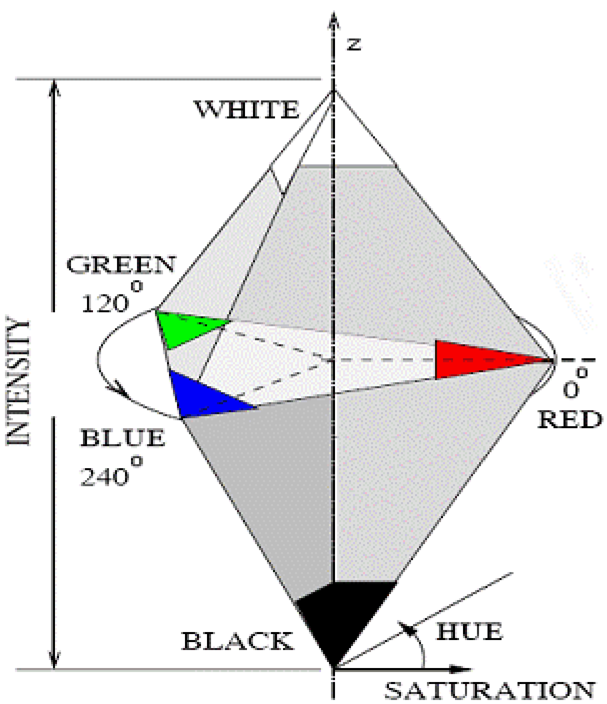
Saturation

Saturation refers to the degree to which a color deviates from a neutral grey of equal intensity. It is also identified as pastel and vividness. Saturation may also be defined as color's purity or the amount of white contained in a specific color (Camci, 1992). When highly desaturated, any color of the spectrum should approach the standard white color. The analogy here is to white noise when the signal strength is progressively reduced.

Intensity

Intensity of a color refers to its relative brightness in the color mixture. It represents spectral energy at the specific wavelength arriving at the sensor from all directions.

The HSI model can be represented in terms of the color-space by defining a three dimensional cylindrical coordinate system and a subspace as shown in Figure 6.1. The hue distribution (H) is represented as an angle varying from 0^o to 360^o . Saturation (S) corresponds to the radius, varying from 0 to 1. Intensity (I) varies along the Z-axis with 0 being black and 1 being white. Adjusting hue will vary the color from red at 0^o through green at 120^o , blue at 240^o , and back to red at 360^o .



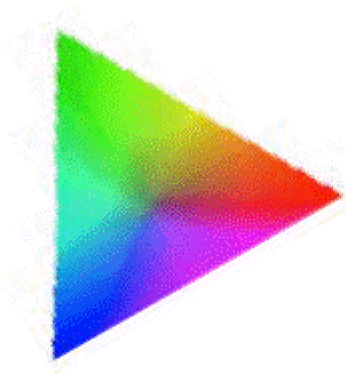


Figure 6.1 Double cone model of HSI color space; Color triangle is suitable for color matching.

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The HSI -coordinates shown in the RGB color cube (Figure 6.2) establish the required relationship between the two set of coordinates.

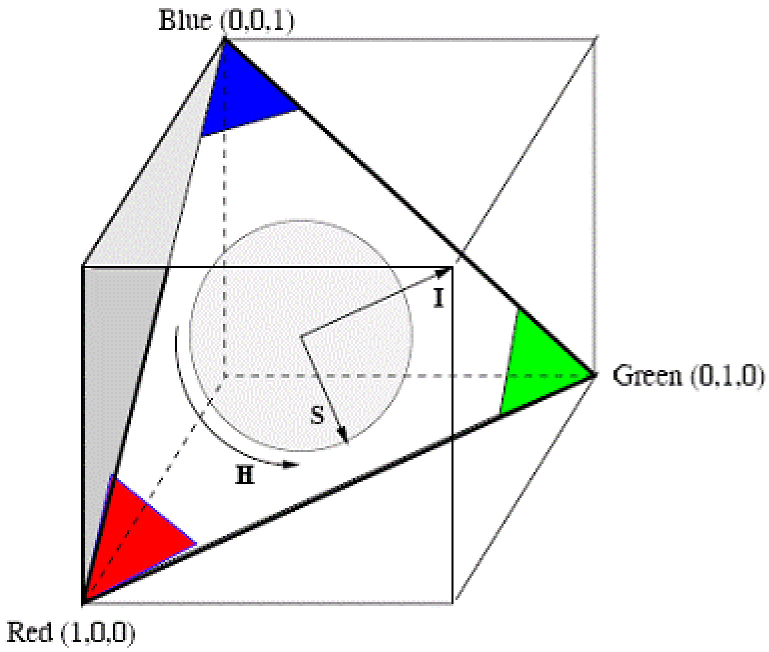

Figure 6.2: HSI coordinates shown in RGB color cube.

The hue component in both color spaces is an angular measurement, analogous to angular position on a color wheel. However, such color spaces are not unique, and a number of definitions of hue can be found in the literature. The following formula is one of them and can be used to convert RGB values to HSI values (Smith, 2001). Experience shows that it yields the lowest average uncertainty while retaining computational simplicity.

$$H = \arctan\left[\frac{\sqrt{3}\,(G-B)}{2R-G-B}\right]$$

Software packages such as MATLAB use an alternative definition

$$H = \theta \qquad if\ B \le G$$
$$H = 360 - \theta \qquad if\ B \ge G$$

where

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

Saturation is defined as

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

It is a fraction between 0 and unity. Intensity is defined as

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

In camera measurements, the individual values of R , G and B would vary over 0 to 255 (8-bit resolution).

Often, intensity is expressed as a fraction between 0 and unity by dividing the value derived as above by 255. Similarly, hue can be normalized by dividing the value derived above by 360 (degrees).

In experiments involving temperature measurements, the primary quantity of interest is hue (H). Other quantities (S and I) need not be computed since they show small variation with temperature. Hence, the major advantage of using hue as a sensitizer of temperature is the one-to-one relationship obtained (as opposed to 3-to-1 in the RGB data).

Previous Next

Contd...

The HSI (Hue , Saturation, Intensity) model describes color in terms of how it is perceived by the human eye. It is what an artist refers to as pigment; it is what we think of as color - yellow, orange, cyan and magenta are examples of different hues. An artist usually starts with a highly saturated (pure), and intense (bright) pigment. Some white is then added to reduce its saturation and some black to reduce its intensity. Red and Pink are two different saturations of the same hue, namely Red. The main advantages of HSI model is that, it is useful while comparing two colors, or for changing a color from one to another. For example, changing a value from Cyan to Magenta is more easily accomplished in an HSI model; only the H value needs to be changed. Making the same change in an RGB view is less intuitive; since we must know the correct amounts of Red, Green and Blue needed to create Magenta. In short, the RGB model is suited for image color generation, whereas the HSI model is suited for image color description. Owing to these inherent advantages, hue is best suited to establish a unique relation between hue and temperature in the pertinent LCT experiments. Therefore, though the colors of the thermochromic liquid crystals (TLCs) are observed by a data acquisition system that senses RGB, the R-, G-, and B-data are not used to calibrate the TLCs. Instead. the RGB color space is first transformed to the HSI color space. Invariably, temperature turns out to be a monotonic function of the hue. Thus, a calibration curve is immediately obtainable. The calibration data is mostly insensitive to image intensity and external illumination.

Previous Next

Light Intensity Effect

According to the tri-receptor theory of vision, the human eye detector evaluates the intensity of an image by summing the stimuli from the three receptors, while the chromatic attributes, hue and saturation, are determined by the ratios of the stimuli. Thus, light sources having widely different spectral distribution may give exactly the same visual color sensation as long as the amount and ratios of the total simulation are equal. To investigate the effect of the strength of illumination on the hue-temperature calibration curve, Wang (1996) performed the LCT calibration test at two different intensity levels of illumination. The experiment was repeated under similar test conditions but with 50 percent of the fluorescent tube surface covered. The author observed that the change in illumination intensity does not alter calibration except at the high temperature end of the curve.

The clarity of the picture seen by the camera depends on the background intensity. If it is low, then the picture will be dark and the camera may not be able to capture the color changes. If the background intensity remains high, the actual color may be lost in the white-light effect. Therefore, it becomes necessary to establish the background intensity, provide uniform lighting and ensure correct threshold setting to record meaningful color information. An optimum intensity for the background is typically between 80 and 100, on an eight-bit scale of 0-255 (Ekkad, 2000).

A sufficiently bright and stable white light source without the infrared (IR) and ultra-violet (UV) radiation in the output spectrum is ideally needed for liquid crystal thermography. Any IR energy present in the incident light will cause unwanted radiant heating of the test surface. Exposure to UV radiation can cause rapid deterioration of the liquid crystal surface, leading to an unreliable performance in terms of the color-temperature response. Consistent light source setting and viewing arrangement between calibration and the experiment is essential to minimize color-temperature interpretation errors. In the experience of the authors, the LC test surface is best illuminated with a collimated white light source, which utilizes four 150 W ANSI code halogen bulbs covered by a sheet of heat absorbing glass.

Previous Next