Hyperspectral Color Imaging

Background

The human eye is sensitive to visible light, or light with wavelengths between about 380 and 750 nm, with violet in the lower wavelength end of the spectrum and red in the higher wavelength range . Different colors are produced when light hits an object, causing different combinations of wavelength intensities to reach the eye.

Human perception of color is characterized by a set of vectors called the Standard Observer, created to reduce a spectrum to a three value, xyz, color-space. When combined with information about the particular light source used, the xyz values can be converted into a number of other standard color measures, such as standard Red Green Blue (sRGB), commonly used for computer monitors, HDTVs and digital cameras. Another color space, Lab, depicts light intensity (L) , red-green (a) and yellow-blue (b)component dimensions, as illustrated in Figure 1.

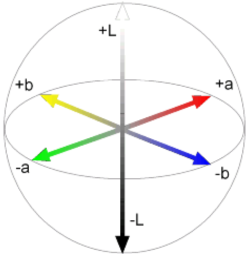

Figure 1. Lab color component dimensions.

Hyperspectral cameras provide more information than the red, green and blue components perceived by a human eye, or observed by a standard RGB camera (Fig. 2). The full spectrum has much more information because every point in the spectrum is recorded, whereas RGB cameras, as well as the human eye condense the information of the object's interaction with light to three single values. Specim's visible spectral cameras can discern color differences ten times better than the human eye.

The ability to monitor color during production is important to numerous industries. Such in-process monitoring is possible with push-broom Hyperspectral Imaging (HSI) cameras. These cameras capture an image in one spatial dimension, acquiring each wavelength at exactly the same time. The other spatial dimension is gathered over time, and a hyperspectral image (datacube) is built line-by-line. This requires either the camera or the sample to be moving, and so is the ideal choice for in-process applications in quality control or manufacturing industries. In addition, push-broom cameras require that the sample only be line-illuminated, which saves the sample from long exposure to potentially damaging light levels. The exposure time for a single frame is also significantly shorter, 15-30 times shorter, than other hyperspectral imagers, allowing faster data collection and analysis. Depending on the spatial resolution and size of the sample, measurements may only take 1-5 seconds.

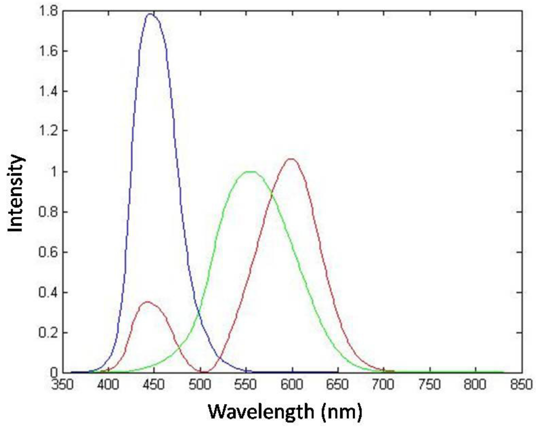

Figure 2. International Commission on Illumination (CIE) 1931 2° Standard Observer. This graph represents the chromatic response of human viewing through a 2-degree angle, the approximate arc of the fovea which contains color-sensitive cones. Red = X, Green = Y, Blue = Z.

Example Measurement System

The measurement system consists of a hyperspectral camera, a frame to hold the camera, a line illumination system (or a simple row of halogen lights), a moving mechanism to transport the sample under the camera and a computer to control the camera, collect the data, synchronize the movement of the motorized stage, process the data and calculate the color coordinates."

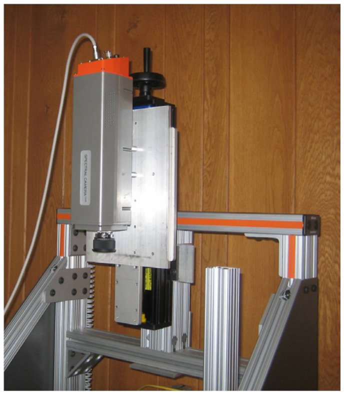

Figure 3. HS-V8E Hyperspectral Camera system.

Specim HS-V8E visible hyperspectral camera specifications

- Push-broom style camera
- Camera Link interface
- 720 Spectral by 1600 Spatial resolution
- Up to 4x binning in both axes
- Up to 30 frames per second
- 400nm – 800nm sensitivity

Example Measurements

The following images show paint color swatches that were analyzed with a visible wavelength range hyperspectral camera. Red colors toward the higher end of the visible wavelength spectrum are typically more difficult for the human eye to differentiate, as shown in the standard RGB camera image below.

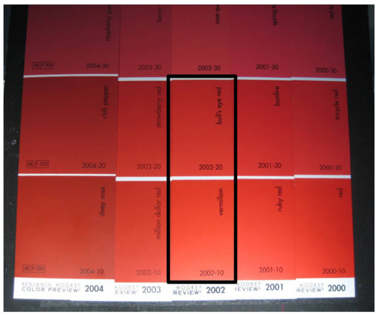

Figure 4. Multiple shades of red paint.

Middleton Research is able to compute the Lab color space dimensions, which are used here to differentiate between similar colors. The L, a, and b magnitude plots below show clear differences in swatch colors that are extremely similar in the 15-swatch standard RGB image (Figs. 4 and 5). For example, the "Bull's Eye Red" and "Vermilion" swatches (boxed in the RGB image) are almost indistinguishable to the naked eye, and each of the corresponding spectra (Fig. 6) depicts a large peak in the red region. With the Lab calculations, however, their spectra were different enough to clearly separate in the b dimension.

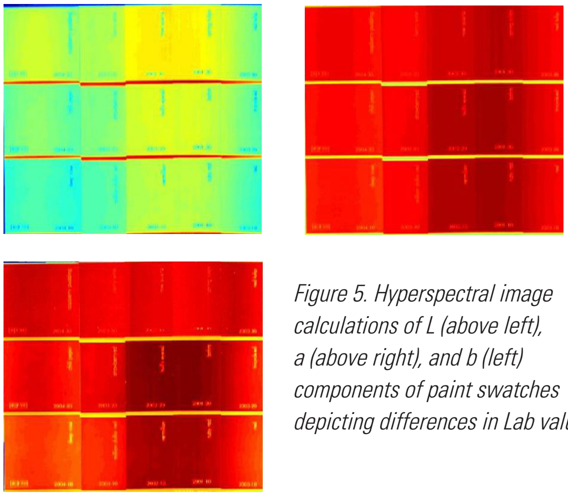

Figure 5. Hyperspectral image calculations of L (above left), a (above right), and b (left) components of paint swatches depicting differences in Lab values.

Each color space dimension accentuates differences differently, so by calculating all three one can improve greatly upon the color differentiation by the human eye alone.

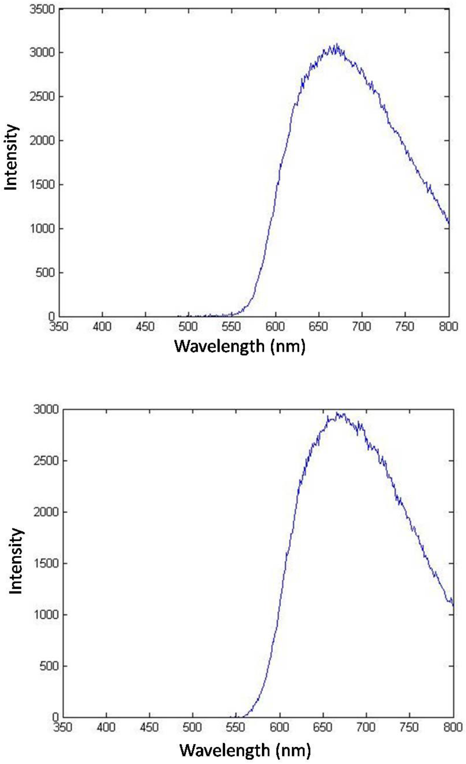

Figure 6. Top: Spectrum of Bull's Eye Red (L,a,b) = (36.11, 56.69, 80.54). Bottom: Spectrum of Vermilion (L,a,b) = (33.25, 57.11, 77.30).

Other Applications

Color analysis applies to many industries. For example, textile manufacturers can evaluate color uniformity or inspect color patterns during the manufacturing process. Similarly, cosmetics, food, printing, building materials and numerous other products can be monitored during production. In addition, hyperspectral color analysis may be used for evaluating single objects as well. There is a wide range of items that could be analyzed including art work, custom signs or posters, embroidery, quilts, and colorful antiques.

In-depth color analysis with hyperspectral technology provides great advantages over inspections by the human eye to ensure that products are manufactured according to color consistency and uniformity specifications and to evaluate color patterns in individual items.