Colorimetric Fundamentals

CIELAB

The CIE 1976 L*a*b* color space is the most widely used method for measuring and ordering object color. It is routinely employed throughout the world by those controlling the color of textiles, inks, paints, plastics, paper, printed materials, and other objects. It is sometimes referred to as the CIELAB color space.

The 1976 CIELAB color space is a mathematical transformation of the colorimetric system first published by the CIE in 1931. Both the 1931 and 1976 color spaces share the same fundamental principles, that:

- Color is a sensation resulting from the combination of a light, an object, and an observer
- A light source illuminates an object.
- An object modifies light, and reflects (or transmits) it to an observer.
- An observer senses the reflected light.
- Tristimulus values are coordinates of color sensation, computed from the CIE (light, object, and observer) data.

The 1976 CIE L*a*b* system offers the following important advantages over the 1931 system:

- It is more perceptually uniform.
- It is based on the useful and accepted theory of opponent colors.

These ideas are expressed below in more detail.’

1931 CIE System – A beginning

The 1931 CIE system offered users the ability to describe and order colors. Through its system of color coordinates and associated diagrams, that system also allowed the comparison of colors. Graphical and numeric data were used to describe colors (and differences) using functions such as: Y, x, y, purity, and dominant wavelength.

Although the 1931 system proved useful, its practical application was limited as it did not express differences between colors in a uniform perceptual manner. The visual perceptions of differences (in lightness, purity, and dominant wavelength) were not usually consistent with the numeric information available from the system.

1976 CIE L*a*b* - perceptual uniformity

The 1976 CIELAB system improved on the 1931 system by organizing colors so that numeric differences between colors agreed consistently well with visual perceptions. This improvement facilitated and simplified the communication of color difference information between parties.

Opponent color coordinates

The method of describing (and ordering) colors by an opponent-type system has proven to be useful, and widely accepted. This approach follows the idea that somewhere between the eye and the brain, information from cone receptors in the eye gets coded into light-dark, red-green, and yellow blue signals. The concept follows the "opponent" basis that a color cannot be red and green at the same time, or yellow and blue at the same time. However, a color can be considered as a combination of red and yellow, red and blue, green and yellow, or green and blue.

In the CIE L*a*b* uniform color space, the coordinates are:

L* - the lightness coordinate.
a* - the red/green coordinate, with +a* indicating red, and -a* indicating green.
b* - the yellow/blue coordinate, with +b* indicating yellow, and -b* indicating blue.

Using the CIELAB color system

The CIELAB color space can be visualized as a three dimensional space, where every color can be uniquely located. The location of any color in the space is determined by its color coordinates; L*, a*, and b*.

The L*, a*, b* color coordinates (of an object) are calculated as follows:

1. The object is measured by a spectrophotometer.
2. A light source (illuminant) is selected.
3. An observer (2° or 10°) is selected.
4. Tristimulus values (X, Y, Z) are computed from the light-object-observer data.
5. L*, a*, and b* are computed from the X, Y, Z data, using the CIE 1976 equations.

The L*, a*, and b* coordinate axis define the three dimensional CIE color space. Thus, if the L*, a*, and b* coordinates are known, then the color is not only described, but also located in the space.

A color can also be described and located in CIELAB color space using an alternate method, that of specifying its L*, C*, and h* coordinates. In this method, the L* coordinate is the same as in L*a*b*, while the C* and h* coordinates are computed from the a* and b* coordinates. The same color is still in the same location in the color space, but there are two different ways to describe its position (L*a*b* or L*C*h*).

The L*C*h* color space is also three dimensional, but the color is located using cylindrical coordinates, as follows:

L* - the lightness coordinate, same as in L*a*b*.
C* - the chroma coordinate, the distance from the lightness axis.
h* - the hue angle, expressed in degrees, with 0° being a location on the +a* axis, then continuing to 90° for the +b* axis, 180° for -a*, 270° for -b*, and back to 360° = 0°.

Many CIE system users prefer the L*C*h* method of specifying a color, since the concept of hue, and chroma agrees well with visual experience.

CIE a*, b* diagram

The a*,b* diagram is a useful way to display the location of colors in the CIELAB color space. The colors can be located using either a* and b* coordinates, or C* and h* coordinates. In both cases, the L* coordinate is usually displayed separately, as a number.

Color differences in the CIELAB system

CIELAB color difference, between any two colors in CIE space, is the distance between the color locations. This distance can be expressed as delta E CIE L*a*b*, where:

ΔE* = (ΔL*2 + Δa*2 + Δb*2)1/2 .
ΔL* being the liqhtness difference.
Δa* being the red/green difference.
Δb* being the yellow/blue difference.

For those preferring to express differences in chroma and hue terminology, instead of da* and db*, the following terms are utilized:

ΔC* being the chroma difference.
Δh* being the hue angle difference.
ΔH* being the metric hue difference.
ΔE* = (ΔL*2 + ΔC*2 + ΔH*2)1/2

The ΔE* and ΔL* differences are the same, whether using L*a*b* or L*C*h*.

Color tolerances in the CIELAB system

The CIELAB system is often used to facilitate the quality control of colored products. In these cases, the color of the production sample is located in CIELAB space, and compared to the color standard for production. Color differences between the production sample and standard are computed, and then usually compared to the limits (tolerances) of customer acceptability for the colored product.

Acceptability tolerances are usually established between a supplier and his customer, based on historical experiences, and commercial factors. The CIELAB system is often used to help order and quantify the acceptability tolerances, for each customer and color combination.

When establishing acceptability tolerances, it is usually best to determine separate tolerances for ΔE*, ΔL*, Δa*, and Δb* (or ΔE*, ΔL*, ΔC*, and Δh*). The separate tolerances allow the CIE system to be employed in acceptability applications, even as the customer acceptability criteria deviate from the uniform perceptibility of CIELAB color space.