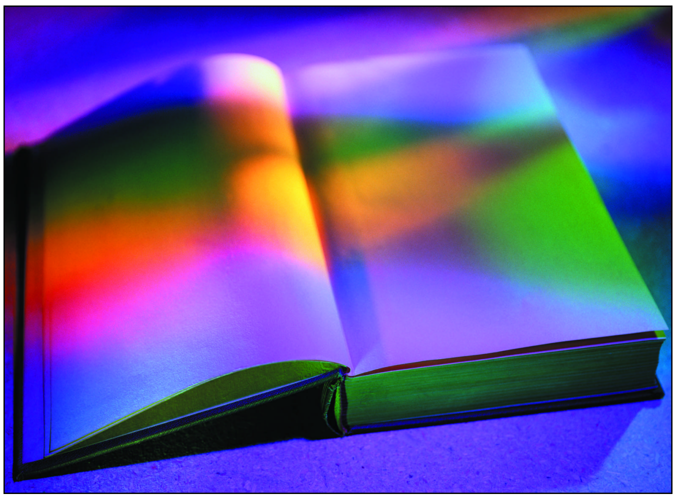
by Annette Groscup | Formulabs Inc.

The Language of Color



The growing appeal and affordability of digital cameras has placed overwhelming demands on inkjet suppliers to develop photo-capable printers, inks and media for use in both homes and offices. More and more companies are jumping on the photo bandwagon, and supply options are expanding daily. The proliferation of photo-capable and photo-compatible supplies has resulted in an end user who is much more demanding and discerning than ever before. It is becoming increasingly critical to develop a cartridge system that will meet these stringent requirements for accurate color reproduction.

What is Color?

Color is simply the way we perceive light rays. There are numerous articles and scientific studies regarding the various roles that physics, chemistry, psychology and physiology play in color perception. For the purposes of this article, it is only necessary to understand that the brain and eyes work together to transform light into color. White light contains all colors of the visible spectrum, and the reflection or absorption of this light on an object is what imparts color to that object. The human eye can perceive more variations in warm colors (reds and oranges) than cooler ones (blues and greens), so particular attention must be paid to color matches in the warmer tones.

Factors Affecting Color Perception

There are several psychological factors that affect our perception of color. Color memory and color expectation can influence our impression of a particular color. A child who grew up in the city may have a very different opinion or expectation of what color "sky blue" is than a child who grew up in the country. Personal color preferences and cultural and religious backgrounds can also greatly affect our interpretation of color, as well as our fondness for or dislike of certain color shades.

Physical factors such as color context and contrast effects can also cause noticeable differences in our perception of color. For instance, red on a white background looks brighter than the same red when viewed on a black background. Colors on textured substrates usually appear duller than the same color on a smooth substrate, and glossy prints look brighter and more vivid than matte prints. Finally, different light sources can affect an object's appearance. Metamerism, simply put, refers to visible variations in colors when viewed under different light sources. Anyone who has ever bought articles of clothing that matched under the store's fluorescent lighting, but then discovered that they did not match in sunlight or incandescent lighting has witnessed metamerism.

History of Color Measurement

Since color is literally in the eye of the beholder, it is necessary to identify analytical and objective means of measuring color in order to provide a consistent basis for communicating color information. The history of color measurement begins with the color circle first developed by Sir Isaac New-

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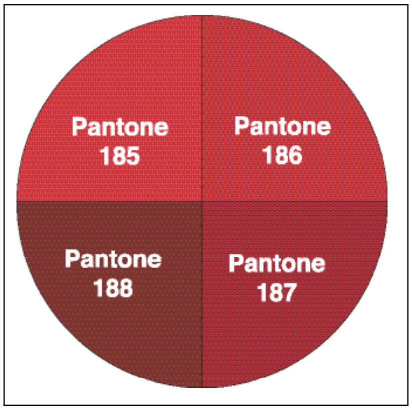
ton in 1666. Newton's color circle has been modified many times, and today's three most common color measurement systems (Pantone, Munsell and CIELAB) are based on Newton's original principle. The Pantone system is a two-dimensional system that is readily available and has a well-known set of standards for more than 1,100 colors. It is highly subjective, as it traditionally requires a human viewer to visually match colors to a standard set of color chips. The Munsell system was developed in 1905 as a means of identifying and interrelating colors of surfaces. It is a three-dimensional system, but still requires some subjective human judgement in matching colors to a set of standards. In 1931, CIELAB (Commission Internationale de l'Éclairage, or International Commission on Illumination) was developed. CIELAB provides instrument-derived data that removes subjective judgements of the human eye. This results in a number-based, objective system that permits more accurate and consistent communication of information about color.



Sample shades of red in the Pantone color matching system.

Today, there are three recognized components of color: hue, saturation and lightness. The hue refers to an object's basic color, such as blue or orange. The saturation (or chroma) deals with the purity or vividness of the color. Lightness is a measure of how bright or dark a color is. For anyone familiar with absorbance spectroscopy, the hue refers to the wavelength of maximum absorbance, the saturation relates to how wide the absorbance peak is, and the lightness correlates to the height of the peak. Color measurement devices record and interpret these color components differently, and the choice of instrument is influenced by the application requirements.

Color Measurement Tools

Several types of instruments using Pantone, Munsell or CIELAB color matching systems are now available to assist in color measurement. Densitometers, spectrophotometers and colorimeters are the most commonly used color matching instruments. All color-matching instruments do something the human eye cannot — assign a specific numerical value to a color that can be consistently analyzed in terms of numeric tolerances and control limits.

Densitometers measure and compute how much of a known amount of light is reflected from (or transmitted through) an object. These instruments are relatively inexpensive, portable, easy to use and have found widespread application and acceptance in pigmented-based systems. Densitometers, however, are typically limited in their flexibility in measuring reflected spectra.

A spectrophotometer measures the amount of light energy reflected from an object at several intervals along the visible spectrum. The pattern of wavelengths (or spectral data) that leaves an object is unique to that object and is often referred to as a fingerprint. A spectrophotometer measures and plots the object's spectral data and these measurements result in a complex set of values that are interpreted as a spectral curve. Spectrophotometers are accurate and flexible color measurement tools, and spectral data can be used to calculate colorimetric and densitometric values. Spectrophotometers are considered by many to be the best way to describe, specify or identify color, and are especially useful for non-traditional, specialty or spot colors.

A colorimeter breaks light down into its red, green and blue components in a manner similar to that of the human eye. Each color component is given a value: lightness is referred to as L* and can have a value between 0 and 100; saturation (or chroma) is measured by a*, which plots from green to red, and b*, which plots from yellow to blue. The hue is based on the relationship between a* and b*. (It is interesting to note that hue, which is most easily discernible by eye, is not directly measured, but it is the relationship between the independently measured a* and b*.) These three measurements, L*a*b*, define the color value of the object being measured and provide data for three-dimensional mapping of the color.

To compare a sample to a standard for color matching, or to determine lightfastness of ink, one frequently employs Delta E*. Delta E* is the statistical average of the changes in a*, b* and L*. It does not differentiate whether the changes are in lightness or in hue, so determinations cannot be made as to whether the color sample merely faded or shifted to a different hue. It is generally accepted that the human eye cannot readily distinguish a Delta E* of less than four. The human eye is significantly more sensitive to small changes in hue than to equivalent changes in saturation or lightness, so depending on the nature of the color change, Delta E* of up to ten may acceptable to the viewer.

Color Gamut

The spectral characteristics (L*a*b*) of the measured inks will determine a color space or gamut that can be consistently reproduced using these inks. The traditional four-color (CMYK) ink set produces a gamut that is acceptable for most inkjet printing applications. In order to expand the gamut to achieve accurate tonal and color reproduction for photo applications, a six-color (CcMmYK) set is typically used. The addition of light black, gray or spot colors further enlarges the total gamut. Seemingly inconsequential changes in any of the colors in the ink set can have a measurable impact on the resulting gamut. Each set of inks has a finite gamut, and colors outside of this gamut cannot be reproduced. To achieve certain desired characteristics such as lightfastness, sacrifices in total gamut volume may be necessary. The characteristics of the substrate, and the manner in which the colorants are transported to and secured on the surface of the substrate also have a profound effect on the resulting gamut.

Color Verification

Every color printing process has its own way of delivering color and its own specific requirements for color matching. Understanding the variations in color that can occur is a necessary first step in defining color requirements. One must then choose an objective color measurement and verification system that is appropriate for the printing process and that meets end-user demands.

It is important to keep in mind, however, that ultimate acceptance and rejection of color is typically based on application performance. Use of color measurement instruments should complement, rather than replace, human examination of printed images. Valuable information and insight can be obtained with the proper use of color measurement instruments, but no instrument has ever been developed that can interpret or predict human beings' psychological reactions to color.

Throughout history, human beings have been fascinated by color. The growing appeal and increasing use of color will continue to shape the way we live and work, as well as what we buy. Those who understand the importance of objective color analysis and measurement will position themselves to take full advantage of the growing opportunities in color imaging. R

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