

Color concept in textiles: a review

Abbreviations: CIE, international commission on illumination; CCT, correlated color temperature; SED, spectral energy distribution; CMC, color measurement committee; SPD, spectral power distribution; MI, metamerism index

Introduction

Color is extremely important in the modern world. In most cases color is an important factor in the production of the material and it is often vital to the commercial success of the product. It is obvious that a standard system for measuring and specifying color is much desirable. The color of an object depends on many factors, such as lighting, size of sample, and background and surrounding colors. In considering the appearance of an object, factors such as texture and gloss are important, as well as color. Almost all modern color measurement is based on the CIE (International Commission on Illumination) system of color specification. The system is empirical, i.e. is based on experimental observations rather than on theories of color vision.^{1,2}

Color is the result of the physical modification of light by colorants as detected by the human eye (called a response process) and interpreted in the brain (called a perceptual process, which induces psychology). The existence of color requires a source of light, an object, and an observer to see the light. The reflectance of light by an opaque object as a function of wavelength describes the color of the object. The color of a textile material is often one of its most important features. Color is a subjective (individual/personal) perception and in a color-using industrial environment, objectivity is of great importance.³

Illuminants and sources

The reflectance distribution of a surface is constant and it is independent of the illumination under which is viewed. However, the color of the surfaces changes under different illuminations. The colors of goods are usually different when they are viewed under the lamps used in a department store and viewed later under daylight. The difference is the result of the spectral power distribution differences of the illuminations and also because of the changes of the lighting.

When we speak of illuminants and sources, we are usually concerned with their spectral distribution of radiant flux (spectral power distribution) in Figure 1. More specifically, we are concerned with the spectral radiant flux incident per unit area of our object that is we are concerned with the spectral irradiance provided by our illuminant or source.⁴

There are many different light sources under which we can view the objects, the most important of which is daylight. Also there are many man-made sources such as incandescent lamps and fluorescent lamps. It is impossible to make color measurements under all these sources. Fortunately, it is not necessary to make color measurements under many different sources, and, in general, a measurement under one source is all that is required. However, it is necessary to distinguish between a source and an illuminant. Whereas a source refers to a physical emitter of radiant energy, such as a lamp or the sun and sky, an illuminant refers to a specific spectral power distribution incident

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on the object viewed by the observer. The spectral power distribution which defines an illuminant may not necessarily be exactly realizable by a source. For example, Illuminant A can be obtained in laboratory conditions, but there is no standard method for obtaining D65 in the laboratory. As illuminants refer to an energy distribution, more than one illuminant can be achieved by using only a single source, e.g. xenon flash tube.

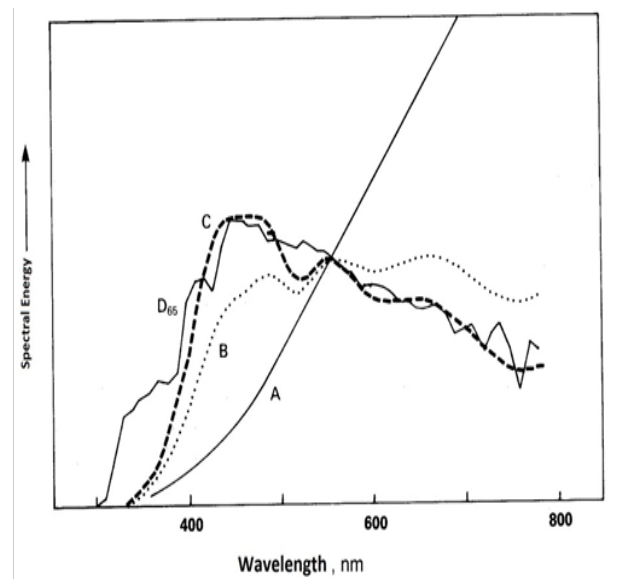


Figure 1 Spectral power distributions of certain illuminants.

When illuminants having different spectral power distributions are used with object colors, two different effects can take place. First, the tristimulus values of the colors can change (illuminant colorimetric shift); second, the observer's state of chromatic adaptation can change (adaptive color shift). If a single object color is viewed first under one illuminant, and then under an illuminant having a different chromaticity, its appearance in the second illuminant will be combined result of both the illuminant color shift and the adaptive color shift taking place. Under different illuminating conditions, because of the possible changes in the calculated tristimulus values, the color coordinates may be computed into different results when different color systems (CIELAB and Hunter) are used.

CIE advised the usage of different illuminants which were derived basically from the spectral energies of different sources of light through the years. CIE illuminant D65, with an approximate correlated color temperature (CCT) of 6500 K (Kelvin), contains a spectral energy distribution (SED) which is a good approximation of average daylight. D65 is the primary illuminant of color measurement applications. CIE illuminant A, with an approximate correlated color temperature of 2856 K, was devised as a means of defining light typical to that from a gas-filled tungsten filament lamp. The amount of energy emitted at the longer wavelengths is far greater than that emitted at the shorter wavelengths. CIE illuminant F11 (fluorescent illuminant), with an approximate correlated color temperature of 4000 K, is commercially known as TL84 and contains a spectral energy distribution which is a good approximation of store lighting. Fluorescent illuminants have very high SED(s) at narrow bandwidths.

Calculation of tristimulus values

Tristimulus values are the fingerprints of a color and they are calculated by taking the basic concepts of color into consideration which are the object, illumination and observer. They represent the amounts of standard lights (red, green and blue) to reproduce a color.

$$X = \sum S_{\lambda} R_{\lambda} \bar{x}_{\lambda} \quad (1) \quad (\text{Red primer})$$

$$Y = \sum S_{\lambda} R_{\lambda} \bar{y}_{\lambda} \quad (2) \quad (\text{Green primer})$$

$$Z = \sum S_{\lambda} R_{\lambda} \bar{z}_{\lambda} \quad (3) \quad (\text{Blue primer})$$

Where;

X, Y, Z: Tristimulus values (red, green and blue)

S_{λ} : Spectral power of the illuminant (at λ wavelength)

R_{λ} : Percent reflectance (at λ wavelength)

$\bar{x}_{\lambda}, \bar{y}_{\lambda}, \bar{z}_{\lambda}$: Color matching functions

Y tristimulus value is also a measure of the luminance and has a value of 0 for black and a value of 100 for white.

Numerical specification of color was visualized by the use of the chromaticity diagram and the three chromaticity coordinates (x, y and z) were calculated by the use of the three tristimulus values. Chromaticity is an objective specification of the quality of a color regardless of its luminance. The most useful display was found to be the x, y chromaticity diagram Figure 2 to locate the colors on a two dimensional map.

Chromaticity coordinates are:

$$x = (X / X + Y + Z) \quad (4)$$

$$y = (Y / X + Y + Z) \quad (5)$$

$$z = (Z / X + Y + Z) \quad (6)$$

$$x + y + z = 1 \quad (7)$$

CIE color specification system

Numerous color appearance models have emerged over the years,

along with various sets of color measurement terms. Although the CIELAB system is widely accepted in the field of textiles, some practitioners use other models. CIELAB and Hunter are based on established theory and are well documented. However, the practical differences between the various systems can be confusing to a dyer.

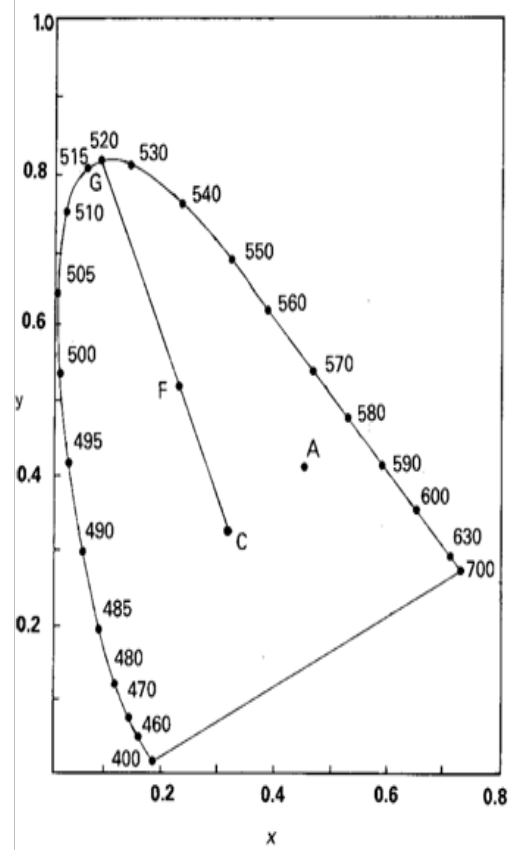


Figure 2 CIE chromaticity diagram.

The CIE (Commission Internationale de l'Eclairage) color order system is numerical. CIE recommended CIE L*a*b* color space (also known as CIELAB system) and color-difference formula in 1976. CIELAB color space was developed from attempts to transform the X, Y, Z system (tristimulus values) to a visually uniform color-system through experiments which correlate tristimulus values with visual perceptions of color.

CIELAB color space is an opponent-type color space and consists of three axis perpendicular to each other. The a^* axis represents the red-green opponent pair (a^* +is red and a^* -is green), the b^* axis represents the yellow-blue opponent pair (b^* +is yellow and b^* -is blue), and the L^* axis represents the white-black opponent pair. The a^* and b^* coordinates define a chromaticity plane. The third axis, L^* , is the lightness axis and it is perpendicular to the chromaticity plane and runs from 0 for black to 100 for white. Colors are plotted on the a^* - b^* plane ($L^*=50; a^*=0, b^*=0$) and chroma and hue angle are calculated on this plane by using a^* and b^* values. The L^* , a^* and b^* color coordinates are the numerical results obtained according to established formulations and they represent the location of a color (shade) in the CIELAB color space. Hunter system (Hunter L, a, b scale) is a uniform color scale devised by Hunter in 1958 for use in color difference meter, e.g. a reflectance spectrophotometer. It is

based on Hering's opponent-color theory of vision and it uses the CIELAB color space for the presentation of color coordinates and color differences which were calculated according to the Hunter Lab scale as shown in Figure 3.

CIELAB color coordinates are calculated as follows:⁵

$$L^* = 116(Y/Y_0)^{1/3} - 16 \quad (8)$$

$$a^* = 500[(X/X_0)^{1/3} - (Y/Y_0)^{1/3}] \quad (9)$$

$$b^* = 200[(Y/Y_0)^{1/3} - (Z/Z_0)^{1/3}] \quad (10)$$

$$C^* = [(a^*)^2 + (b^*)^2]^{1/2} \quad (11)$$

$$h = \arctan(b^*/a^*) \quad (12)$$

Where;

L*: Lightness axis

a*: Red-Green axis

b*: Yellow-Blue axis

C*: Chroma (Saturation)

h: Hue angle

X, Y, Z: Tristimulus values of the illuminant

X₀, Y₀, Z₀: Tristimulus values of the color

CIELAB (1976) color difference is calculated as follows:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (13)$$

In the calculation of the Δ values, the calculation is made according to "sample value-standard value".

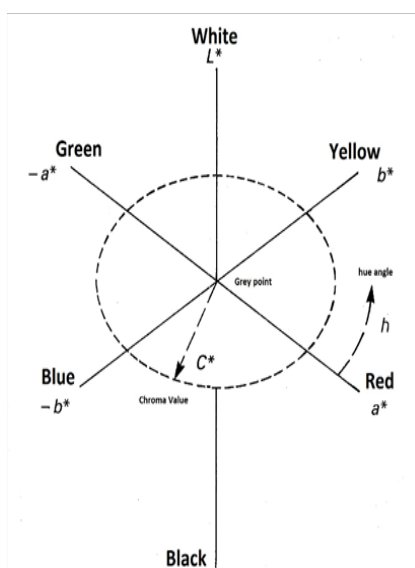


Figure 3 CIELAB color space.

Many studies were performed on establishing a uniform color difference equation and today CIE system of color specification is widely used. In 1975 CIE established two recommendations as CIE 1976 L*u*v* color space and color difference formula and CIE 1976 L*a*b* color space and color difference formula. Although both CIELAB and CIELUV were recommended as approximately visually equal spaced color-difference species of similar performance, CIELAB has been used much more extensively than CIELUV in industries manufacturing materials. Although CIE achieved its goal of a single color space, there has been less success in defining a single color-difference equation (formula), though all the current equations (formulae) use CIELAB as a starting point. Following the development of JPC79 equation, it was recognized an opportunity to make an improvement in instrumental color control and color difference. Originating from JPC79, the Color Measurement Committee (CMC) of United Kingdom's SDC established the CMC (l:c) equation for calculating small color differences of textiles, and in 1995 it was incorporated by the ISO for evaluating the colorfastness of textiles (ISO 105-J03). The CMC equation corrects the major deficiency which is the chroma position dependency in CIELAB. Today considering color differences according to CMC is more preferred in textiles.

The assessment of the color difference (ΔE^* or DE^*) is made by comparison between two colors. One is chosen as the standard (or target) and the other one is chosen as the sample. The numerical color difference between these two colors is calculated according to the calculation methods of different color difference formulae. The drawback of the CIELAB color space is that it is not truly visually uniform throughout the space which means that equal color difference magnitudes appear of different visual magnitudes in different regions of the color space. For that reason the color difference formula which is chosen to assess the difference between two colors must take the non uniformity of the color space into account. The CMC (l:c) equation defines an ellipsoid around the standard color which is the volume of acceptance. This volume varies in size and shape depending on position in color space. CIELAB equation uses rectangular coordinates and defines a cube around the standard color. The shape of the cube is the same at every point in the color space unless the tolerances have been changed. The CMC equation can fit the acceptance ellipsoid for different hues but the CIELAB cannot fit the cube of tolerance to the acceptability volume in CIELAB color space. For that reason it is more convenient to work with CMC in textile industry.

When the difference between two colors are calculated by CIELAB color difference formula, the formula calculates the linear (Euclidean) distance between the two points in the CIELAB color space by using the three color coordinates of L*, a* and b*. Because of the non-uniformity of the CIELAB color space and the setup of CIELAB (1976) formula, the color difference obtained is free from human eye sensitivity. Human eye is sensitive to different kinds of changes in the shade(s) under observation. Human visual system perceives the differences in different magnitudes even though they may have the same color difference calculated by CIELAB (1976) formula. For this reason, the same vector distance may not be perceptually the same for all colors.

There are other color difference formulae which also use the color coordinates calculated in the CIELAB color space. The formulae which use the CIELAB color space are:

A. CIELAB(1976) L*a*b*

- B. CIELCH (1976) L*C*h
- C. CMC (1:c)
- D. CIE94
- E. CIEDE2000 (computes its own L', a' and b')
- F. Hunter (L, a, b)

Color difference is the magnitude and character of the difference between two object colors under specified conditions. In the textile industry, effective color control and communication between designer, dyer, and retailer are critical to obtaining high product quality and cost efficiency. Commonly, color control is achieved both via visual assessment and color measurement. One of the fundamental attributes that defines visual color perception is the spectral power distribution (SPD) (or Spectral Energy Distribution-SED) of the light source used to observe and specify the object color. In textiles, lighting and illuminating conditions must be carefully specified in order to assess the color of an object in case of change in light sources (the lamp) and illuminating.⁶⁻⁸

Uniformity concept of the color space

A perceptually uniform color space is the one in which Euclidean distances highly agree with perceptual color differences. Originating from the problem of inconsistency of calculated and visual color differences, advanced color difference formulae were developed which were based on the modification of CIELAB. New color spaces like CIELAB and color appearance spaces like CIECAM02 were researched in recent years. But perceptual uniformity of these spaces were found insufficient for various applications so that new color difference formulae were developed and standardized, such as CMC(1:c), CIE94 and CIEDE2000. Visual experiments showed that the CIECAM02 space was also not perceptually uniform and new color difference formulae could be applied to enhance the correlation to the visual data. Papers were published to discuss the new formula CIEDE2000.

Human visual system is sensitive to naturals and high-chroma colors depending on their lightness and chroma values. But the sensitivity is ruled in different characteristics in different parts of the CIELAB color space and on a*-b* color plane. For this reason, determination of the exact combination and point of hue angle and its related chroma of a color on a*-b* color plane is important in the calculation of color difference. The advanced color difference formulae differ from each other in the way of more precise calculation of chroma and hue differences in CIELAB color space.

Color is very important for human life because human beings have their own individual color choices in every phase of daily life. In textiles, uniform color is important especially in plain garments because these garments are made of many different parts which were cut in preparation and later associated to each other by means of sewing. But each part cannot be chosen from the same area but collected from different parts of the whole fabric depending on the applications which are carried out by ready cloth making industry. For this reason there is a need for a precise color difference formula for color matching. Questions arise which formula should be used according to different magnitudes in industrial applications or it would be possible to use a hybrid system to deal with different color difference changes.

They extended the CIE recommended color space model, CIECAM02, to form three new uniform color spaces, CAM02-SDC, CAM02-LCD and CAM02-UCS, for estimating small-, large-, and overall ranges of color differences respectively.

Metamerism

In textiles metamerism is a common problem among designer, dyer, retailer and customer. Metamerism is present when two objects having the same color appearance nevertheless have different spectral curves. The layman recognizes metamerism when two objects that match under one illuminant fail to match under a second. From the viewpoint of colorimetry, metamerism occurs when X, Y, and Z values of two specimens match under the first illuminant but not the second.⁸

The types of metamerism that are commonly encountered in textile dyeing industry are illuminant metamerism, observer metamerism, and field metamerism.²

Metamerism presents a unique problem in color difference evaluation because of the number of different type of illuminants that are used in daily life at homes and in stores. Every illuminant has a different energy distribution. Because of this, they obtained tristimulus values differ under each illuminant. Color constancy is the property of a single color and defines the different views of a color under different illuminants. Two different objects must be compared with each other for metamerism. Color constancy and metamerism define different properties of objects. They are both calculated by computing indices, e.g. metamerism index (MI) and color constancy index (CCI), and the calculation of these indices resemble color difference formulae.

Color strength

Color strength of the colored fabrics is given by Kubelka-Munk (K/S) value. K/S values are obtained from the Kubelka-Munk equation as follows:⁹

Kubelka-Munk Equation,

$$K/S = (1-R)^2 / 2R \quad (14)$$

Where;

K: a constant about the light absorption of the dyed fabric,

S: a constant about the light scattering of the dyed fabric,

R: reflectance of the dyed fabric, expressed in fractional form.

K/S is a color value dependent on the light absorption of the dyed fabric at maximum absorption wavelength and is associated with the reflectance of the dyed fabric. K/S value is of primary importance in the discussion of the strength of a dyeing and higher values represent darker and more saturated colors. K/S value is especially used in the recipe calculation of the dyeing made at the mills by the use of color matching softwares. K/S values are usually calculated at the wavelength of maximum absorption of the color (λ_{max}) reflectance curve; however a calculation over the visible region may also be employed.¹⁰

Conclusion

Color is a psychophysical sensation and it is very important in daily life for humans. Human beings have unique sensations of color of their own and they express their feeling also by the color choice of their garments and environment. Sustainable color production is

important in textile industry and quick and right responses to color demands of the retailers are a sign of success in fabric production. Better color communication between the manufacturers and retailers is needed and this communication must be made via color difference results. Development and use of a trustable color difference formula is of vital importance.

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Conflict of interest

Author declares there is no conflict of interest in publishing the article.

References

1. McLaren K. Colour Physics for Industry. In: McDonald R, editor. *Society of Dyers and Colourists*. Bradford, UK; 1987;13(4):264–265.
2. Rigg B. *Colour Physics for Industry*. In: R McDonald, editor. SDC, Bradford, England, UK; 1887.
3. Bartleson CJ. *Optical Radiation Measurements Vol. 2 Colour Measurement*. In: Grum F, Bartleson CJ, editors. Academic Press, New York, USA; 1980;6(3):185–186.
4. Berns RS. *Billmeyer and Saltzman's Principles of Color Technology*. John Wiley & Sons, New York, USA; 2000. p. 1–26.
5. Becerir B, Iskender MA. Dyeing Properties of Some Disperse Dyes on Polyester Microfibre Fabrics. *Indian J Fibre & Text Res.* 2003;28(1):100–107.
6. Becerir B. Assessment of the Results of Different Color Difference Formulae under Different Illuminants by Wash Fastness Tests. *Fibers & Polymers.* 2011;12(7):946–956.
7. McLaren K. *The Colour Science of Dyes and Pigments*. 2nd ed. Bristol: Adam Hilger Ltd; 1983. p. 182.
8. Becerir B. Comparison of Different Colour Difference Formulations in Reactive Dyeing of Cotton Fabrics. *Colourage.* 2006;53(7):49–56.
9. Becerir B. An Approach for Estimating the Relation between K/S Values and Dye Uptake. *Colourage.* 2003;50(5):39–48.
10. Becerir B. Assessment of Colour Properties of Reactive Dyed Cotton Fabrics under Different Illuminants by using CIELAB and Hunter Systems. *Tekstil ve Konfeksiyon.* 2010;20(2):145–154.