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A REVIEW OF COLOR MEASURMENTS IN THE TEXTILE INDUSTRY

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Abstract: *Color is an important factor in the evaluation of aesthetic appearance and functionality of many products, but especially of textile industry ones. In textiles production process, color can be assessed in different stages: the selection of raw materials, the incoming item tests, the preparation of dyeing ingredients, the crocking resistance testing, the color fastness and in all stages, the quality control. Color evaluation can be done visually or using specialized test instruments such as colorimeters or spectrometers, therefore a high accuracy of measurements must be achieved. Standards describe different procedures and testing techniques depending on the product type and the quality level required by the customer. The paper presents the most common systems of color representation and communication, measurement methods and techniques, and standards that define them. The CIE color representation systems have been reviewed, together with the measurement methods offering the repeatability of the process. Most of the standards have been issued in US, but several European and International are stating the color assessment process. We have also conducted a review of latest published papers in the topic of color measurement, comparison and match. Several image processing applications algorithms offers new opportunities for computer assisted evaluation and control of textile color properties.*

Key words: *color measurement, measurement technique, quality control, CIE Lab, spectrophotometer.*

1. INTRODUCTION

Like any other artistic feature, color was a subjective issue in textile industry. A century after the beginning of industrialization, subjective matters started to become standards and measurable attributes. In this respect, the science of color originate almost at the above mentioned date and followed the nowadays quality assurance systems. Color measurement has important application in the selection of raw materials, the preparation of dyeing ingredients, the crocking resistance, ensuring the repeatability of production process, quality control and many others. Early systematic approaches on color matching and color control have been reported by [1], with a method for color quality improvement in dyeing of synthetic and natural fibers.

The quality of the measurement can be determined by the analysis of uncertainty. The quantification of measurement uncertainty is allowing textile manufacturers to maintain under control the quality of products [2]. Also, a comparison between the CIE Lab difference equation and a large group of observers in view of practical validation was carried out in [3]. The paper presents some important conclusions regarding accurate color matching in textile industry. The problems of cotton color measurement was investigated in [4], with a comparison of the classer and HVI color grading, using cotton samples of non-U.S. origin. The authors could replace the organoleptic assessment used for years with the spectrophotometry for grading the quality of cotton.

The paper presents a review on standardized color representation and measurement techniques for the use of textile industry. It also examines the most important papers published in the field, emphasizing their practical application.

2. COLOR REPRESENTATION

Color, as we perceive it, can be characterized by three measures: hue, chroma and lightness, which uniquely identify it and could be used to make the distinction between it and any other. Hue is used to describe the fundamental color, as we can observe, represented on the color wheel. Chroma represents the saturation of the color, as it fades to gray or vivid to the pure hue. The light intensity in a color is measured by lightness, as it varies from white to black at the extremes, as shown in figure 1.

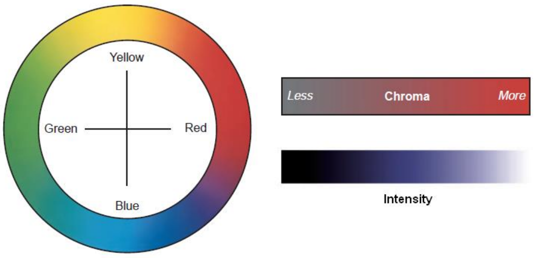

***Fig. 1**: Perceived color components [15]*

Several color spaces have been standardized over the years, with different industrial or scientific applications: Munsell, CIE Lab, CIE Lch, CIE XYZ, Hunter Lab [5]. Albert Munsell proposed in 1905 a human perception based color scale still in use today and known as the Munsell System of Color. It assigns numerical values to the three properties of color: hue, chroma and lightness, and therefore it was the first to represent colors in 3D space. The Munsell Color System was also the base for the more up-to-date representation spaces as CIELab.

Due to the fact that in the formation of visual color, three elements are required, as a light source, the object and the observer, in 1931 the Commission Internationale de l'Eclairage (CIE) has standardized a color system by specifying the light source, the observer and the methodology employed to extract the measures for color description. There are three spaces proposed by CIE, in which a color can be localized by the means of three values: CIE XYZ, CIE Lab and CIE Lch [8].

The first system introduced in 1931 by CIE, was based on tristimulus values XYZ, which unfortunately will have limited use because of a low correlation with visual attributes. If the *Y* value refers to lightness, the two others have no relation with hue and chroma. Therefore it was recommended to use the chromaticity coordinates xyz, as in figure 2. The notation Yxy specifies colors by identifying lightness *Y* and the color in the chromaticity diagram (*x*,*y*). In order to surmount the difficulties using the diagram, CIE standardized two uniform scale spaces in 1976, the Lab and Lch, still in use today.

In the Lab space, *L* represents the lightness, while *a* and *b* represents the chromaticity values, as in figure 2. In the presented diagram, *a* and *b* designate color directions: +*a* is in the red direction, -*a* is in the green direction, +*b* shifts towards yellow and -*b* shift in the blue direction. The center of the diagram located in a vertical axis that is achromatic; as *a* and *b* values moves from the center, color saturation increases. If the CIE Lab uses Cartesian coordinates which represent a color, the CIE Lch employs polar coordinates. The Lch color space uses the same diagram but with cylindrical coordinates as an alternative to the rectangular coordinates, with *L* representing lightness, *c* the chroma value, and *h* the hue angle. The chroma values start from 0 in the center and increases with distance, while hue as an angle, starts at 0 degrees for red, pass through 90° for yellow, 180° for green and 270° for blue (figure 2).

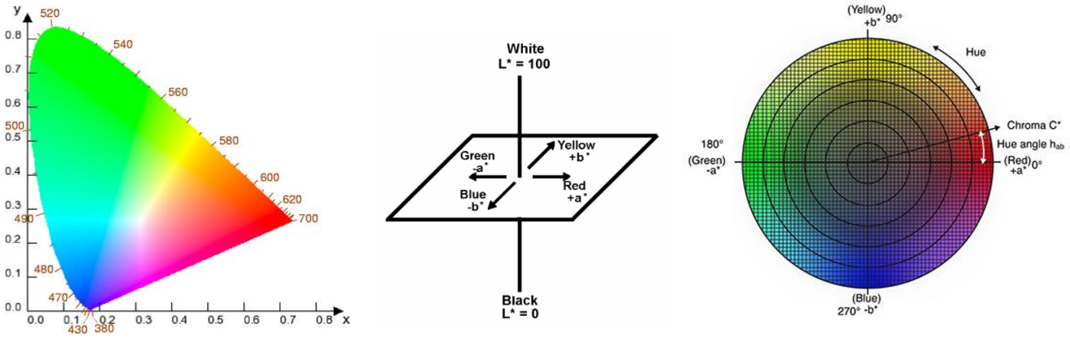

***Fig. 2**: CIE XYZ diagram, CIE Lab and CIE Lch color space[5], [6]*

3. COLOR MEASUREMENT

The observed difference between textile materials colors of different batches is inevitable and it is impossible to completely eliminate even if originates from the same dyeing process. It is very important that the client and manufacturer agree about acceptable and not acceptable products. This can be determined objectively using a color measuring instruments as colorimeter or spectrophotometer. This procedure will replace the subjective human errors, giving quantitative measurements for identifying, specifying and matching colors.

***Fig. 3**: Comparison of two printed weft materials in CIE Lab space*

The differences between the two samples of the material in the CIE Lab space is assessed as a color difference (delta), noted with ΔL, Δa, Δb. The total difference or distance ΔE, can be computed as single value using the following formula:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \qquad \textbf{(1)}$$

If we compare the two printed textile samples in figure 3, for the color in the white circle depicted in the right image, the Lab values are L=56, a=-12, b=-1, while for the same coordinates in the left image L=60, a=-15, b=-3. In this case, the differences will be with ΔL=4, Δa=-3, Δb=-2 and ΔE=5.38, indicating that in the right image, the color values are greener and bluer (figure 2).

A successful quality control and color measurement stands on the accurate assessment of measured samples and the repeatability of the process in standardized appropriate conditions. As a number of spectrophotometers are available on the market, most of them are configured to meet measurement requirements depending on the type of material. The sample is positioned relative to the light source and the observer/instrument and forms what it’s called geometry. The diffuse/8 and 45/0 are the most used methods for color measurements with spectrophotometers.

A spectrophotometer with the diffuse/8 geometry, uses a sphere illuminated by a D65 filtered light, reflects on the surface of the sphere and the reach the sample forming a uniform illumination, as in figure 4. The reflected light is measured by the sensor within an angle of 8° from the normal to the specimen. The advantage of the system is that it minimizes the irregularities of the sample surface. Special applications of the system are in shade matching or dyeing production.

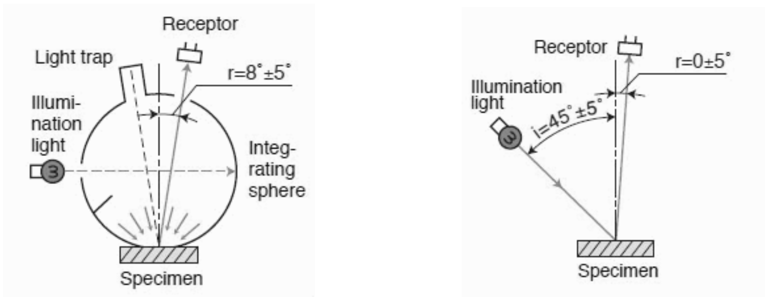

Fig. 4*: Diffuse/8 and 45/0 system geometry[7]*

In the case of the 45/0 spectrophotometer, a light source illuminates the sample in an angle of 45°, while the sensor is placed at 0° in order to measure the sum of reflections from the specimen surface. This type of measurement system is more sensitive to surface irregularities; therefore it also measures the appearance of the sample. Consequently, the 45/0 system is used in quality control applications where the observed differences in texture and finish are important.

4. MEASUREMENT TECHNIQUES

For the quality control program it is important to provide methods ensuring the repeatability of the color measurements. In order to acquire and store valuable measures, samples must be measured multiple times in the same conditions of temperature and humidity. The thickness is also an important factor, as two to four layers are required for knits or woven materials in order to prevent the undesired reflection of light on the background. An opaque material layer will lead to a correct measured value, but thin or light textiles could require more layers. In some cases, a single layer on top of a white tile could be used for comparison purposes, as the reflectance component can be ignored.

Textile materials have an important directional feature, due to the positions of yarns or loops, therefore in order to reduce measurement variability the sample is rotated in four to eight directions. Each time, precaution must be exercised for correct leveling the material and avoid contaminations. The control technique is repeatable if the specimen is removed from the spectrophotometer and when re-measured, the differences are less than 0.15 DE(CMC) units. A common method employed for producing a correct measure is to rotate and reposition eight times the specimen and average the result [7]. The influence of the instrument geometry and the texture of samples were investigated in [8], describing the fact that the difference between D/8 and 45/0 doesn’t depend on the texture and color of samples, but on the color center. The authors concluded that the D/8 produce lighter *L* component values. The most common International, European and US standards establishing the conditions, procedures and measuring instruments are presented in table 1.

In a study report [9], the use of CCD cameras instead of specific instrumentation was considered. It has been shown that on printed CMYK textiles, the RGB CCD camera obtained the best results, and with the use of a calibrated matrix, it allows color detection with higher accuracy then a default matrix. The same comparison in view of an instrument development was presented in [10], were a tri-stimulus camera together with specific software was completed. In the same direction of replacing dedicated instrumentation, the authors in [11] have investigated the possibility of using a flat-bed scanner to assess fabric color with different texture. It was shown that the texture has a strong influence on the measurements performance; the scanner resolution has no influence on the error, but the quantization depth could decrease that influence.

Table 1: *A list of most common standards and their description [7]*

Standard	Description
AATCC Evaluation Procedure 6 Instrumental Color Measurement	a reference document covering instrumental reflectance measurement, related calculations, sample handling techniques
AATCC Test Method 173 CMC: Calculation of Small Color Differences for Acceptability	how to calculate and use the dE CMC color difference scale.
AATCC Test Method 182 Relative Color Strength of Dyes in Solution	determination of color strength of a dye spectrophotometrically by comparing its transmission measurements to reference dye
ASTM E1164 Standard Practice for Obtaining Spectrophotometric Data for Object-Color Evaluation	instrumental measurement requirements for spectrophotometers and colorimeters
ASTM E1345 Standard Practice for Reducing the Effect of Variability of Color Measurement by Use of Multiple Measurements	averaging as a technique for minimizing sample variation
ASTM E1347 Standard Test Method for Color and Color-Difference Measurement by Tristim. Colorimetry	color measurement using tristimulus colorimeters of either 45°/0° or diffuse geometry
ASTM E1349 Standard Test Method for Reflectance Factor and Color by Spectrophotometry Using Bidirectional Geometry	color measurement of opaque samples using a spectrophotometer with a 45°/0° or 0°/45° geometry
ASTM E1767 Practice for Specifying the Geometries of Observation and Measurement to Characterize the Appearance of Materials	different geometries of instruments that measure appearance
ASTM E179 Standard Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials	appropriate instrument types and measurement scales for evaluating appearance characteristics such as color, glossiness, and opacity
ASTM E2022 Standard Practice for Calculation of Weighting Factors for Tristimulus Integration	how to establish tables of weighting factors that are to be used in calculating tristimulus values from spectral reflectance or transmittance data
ASTM E275 Standard Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near-Infrared Spectrophotometers	the requirements of spectrophotometric performance for ASTM methods and explains how to test an instrument
ASTM E284 Standard Terminology of Appearance	terms used in describing appearance, as color and opacity
ASTM E308 Standard Practice for Computing the Colors of Objects by Using the CIE System	the calculation of CIE XYZ and other color scales from spectral reflectance and transmittance values and defines the CIE illuminants and standard observers
ASTM E313 Standard Practice for Calculating Yellowness and Whiteness Indices from Instrumentally Measured Color	the whiteness and yellowness indices
ASTM E805 Standard Practice for Identification of Instrumental Methods of Color or Color - Difference Measurement of Materials	how to effectively communicate color values and all the parameters that affect them
DIN 5033 Colorimetry	visual and instrumental color analysis, color concepts
DIN 6174 Colorimetric Evaluation of Colour Differences of Surface Colours According to the CIELAB Formula	measuring dL*, da*, and db* using an instrument.
ISO 105-J01, J02, J03 Textiles - Tests for colour fastness	general concepts and problems of reflectance color measurement, calculation of the color difference between two samples and allows for the specification of tolerances
ISO 7724-1, 2, 3 Paints and varnishes - Colorimetry	colorimetric terms and fundamental requirements for determining the color coordinates, determining of color values using a spectrophotometer or colorimeter
ISO/CIE 10526 CIE standard illuminants for colorimetry	the CIE standard illuminants
ISO/CIE 10527 CIE standard colorimetric observers	the CIE standard observers

The use of nowadays computer vision techniques in the unsupervised analysis of color and pattern in printed fabric could be found in [12]. The use of a Fuzzy C-Means clustering algorithm has been proved to be successful in the processing of digital images. In the same direction of computer assisted inspection, other papers report on printed fabric segmentation with Mean-Shift algorithm [13] or color separation with back-propagation neural networks [14].

5. CONCLUSIONS

One of the major aspects of quality implies color measurement and control, starting from raw materials and finishing with completed products. The aesthetic appearance is one of the factors that influence client's behaviors, as natural, dyed or printed color. This feature is determined objectively using color measuring instruments and replaces the subjective human errors. Using tools like a colorimeter or spectrophotometer, both quantitative and qualitative information are obtained. Computer based image processing applications could be used in the automation of color measurement, segmentation and control.

Based on the product type, final application and process production, the color measurement technique must be selected among the standardized ones, employing the methods and instruments presented in the paper. Also, we have reviewed the literature published over the last years in this domain.

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