ENGINEERED COLOR APPEARANCE WITH DIGITAL APPROACH

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Abstract

For the past ten years, digital color standard, color evaluation, as well as color communication were proved to be effective way to help manufactures and retailers achieve the most consistent and reliable products with designated color. These will guarantee the color integrity of the standard and significantly reduce the time from conception to production. However, appearance is more than color. Many a time, designer asked manufactures to produce color on different substrate but failed to achieve exact match, as it is quite difficult to have real match on different substrate. In this discussion, some advanced image technologies in the field of color and appearance will be introduced to improve color quality in industrial manufacture. Descriptions and key specifications of engineered digital color appearances are defined.

1. Introduction

In all industry, color is increasingly seen as an important factor to satisfying customer. All manufactures of colored product are willing to supply customer with possible qualified goods with appealing appearance. Reflectance based color evaluation and communication were quite successful in the past decades. Normally, the system contains a computer driven spectrophotometer with color quality control and formulation software, which have basic functions such as color different calculation, pass/fail decision, as well as color formula prediction [1]. Color data will be measured and saved as a file, which could be sent to business partner using email or other web application. This form of color communication was accepted to be a quite useful way for specifier / retailer to control color with their supplier in the global supply chain in textile industry [2][3]. It was estimated that more than forty percent color matters about solid color could be solved. Compared with visual assessment, instrumental color evaluation is more objective and stable; it also became practical with the rapid progress of information technology such as personal computer and internet.

However, there were still a lot of color matters with obstacles, which depend on subjective and variable human visual evaluation. Meanwhile, brain does not measure sample as the way spectrophotometers do, while color number alone can be deceiving [4]. For example, color evaluation on difference substrates or multi-color components; some samples are hard to be measured and evaluated due to sample shape, size, opacity, gloss, as well as many other surface effects[5][6]. Therefore, it is necessary to have precise on-screen color appearance with image and substrate to produce realistic simulation as a substitute of physical sample, as fast color appearance communication is also important. Viewing color appearance of an object on screen would be very practical in a carefully controlled environment and within a limited gamut of colors.

2. Theoretical Basis for Color Appearance Model

Color Specification system was recommended since 1931[7], which has been refined over the years. Three essential elements for specifying a color: light source, objects and observer are defined. Illuminant, reflectance and standard observer were used to digitalize a color. CIE L*a*b* (CIELAB) is a uniform color space specified by the International Commission on Illumination (Commission Internationale d'Eclairage) in 1976. It describes all colors visible to the human eye and was created to serve as a device independent model to be used as a reference. Three coordinates of in CIELAB color space represent the lightness of the color, its position between red and green, and its position between yellow and blue respectively. CIELAB system achieved wider acceptance and usage since then. Fig. 1 and below equation is a simple description of CIELAB color space:

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

Where:
ΔL^* being the lightness difference.
Δa^* being the red/green difference.
Δb^* being the yellow/blue difference.

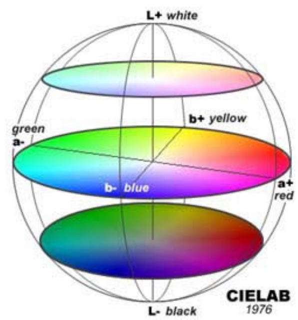

Fig. 1 CIELAB Color Space

The most recent and improved color difference equation recommend by CIE is CIE2000 (ΔL'ΔC'ΔH') [8]. It corrects non-uniformity of the CIELAB color space for small color-differences under reference conditions. Further modifications include not only lightness, chroma, and hue weighting functions, but also an interactive term between chroma and hue differences for improving the performance for blue colors, and a scaling factor for CIELAB a* scale for improving the performance for gray colors. Below equation shows the CIE2000 in details:

$$\Delta E = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)}$$

Since the CIELAB model is a three-dimensional model, it can only be represented properly in a three dimensional space. Meantime, it offers a limited number of perceptual attribute correlates. Therefore, CIE has been incorporating an increasing number of color appearance phenomena into the models. In the past ten years, the CIE Technical Committee 8-01 (Color Appearance Modeling for Color Management Systems) has recommended two major color appearance models. The first one was CIECAM97s [9][10], the CIE 1997 interim color appearance model. The most new one, CIECAM02 [11][12], was developed from this, and formally adopted by the CIE early in 2004 as recommended color appearance model for color management applications. Two major parts of the model are its chromatic adaptation transform-CIECAT02, and its equations for calculating mathematical correlates for the six technically-defined dimensions of color appearance: brightness (luminance), lightness, colorfulness, chroma, saturation, and hue. CIECAM02 account for values of stimulus, tri-stimulus values of an adapting white point, adapting background, surround luminance information, as well as whether or not observers are discounting the illuminant. The model can be used to predict these appearance attributes or with forward and reverse implementations for distinct viewing conditions, to compute corresponding colors. CIECAM02 is now functioned in Windows Vista [13].

A simplified CIECAM02 model is constructed to a three-dimensional color-appearance space, with coordinates [J, a_c, b_c], by the use of equations:

$$a_c = C.\cos(h)$$
$$b_c = C.\sin(h)$$

where [J, C, h] are the lightness, chroma and hue attributes computed using the CIECAM02 model. It was then possible to compute the numerical color differences in this appearance space according to below equation:

$$\Delta E_c = \sqrt{(\Delta J)^2 + (\Delta a_c)^2 + (\Delta b_c)^2}$$

And "CIECAM02 units" is proposed to express the values of ΔE_c.

3. Digitalized Color Appearance System

Datacolor Envision and X-rite ColorTalk are reflectance-based color imaging system for precise and fast color creation and communication. Datacolor Envision was quite accepted by some retailers in the textile industry, especially when comparisons of different fabrics are concerned. Both systems include a calibrated color monitor for precise on-screen color with image and substrate displaying, a spectrophotometer for measuring an object color and a lumen adjustable light booth for viewing object colors under different illuminants. It also includes substrate and surface characteristics on monitors or printouts for life-like products simulation, which will be taken as a substitute of a physical product. Designers can create color palettes or their originalities on the monitor via Datacolor Evision's "Slider" or ColorTalk's "Color Picker", which may include multiple color order systems such as Munsell, NCS or Pantone™, etc. Colors in these systems can be converted to reflectance data, or %R, which could easily communicate with other partners via internet using email or website, for color duplication and quality control. Such color image system in application can avoid expensive color standard, long delivery and leading time, costly physical sample preparation and possibility of contamination, compared with traditional method. Fig. 2 shows precise color in context on Datacolor Envision system. It is confirmed by industry that color image system quite useful in 2-D objects for color evaluation such as even, flat textile fabrics. However, for 3-D color appearance simulation and evaluation, as far as irregular shape, small size, and uneven surface are concerned. Reflectance-based contact color image system could not achieve feasible results.

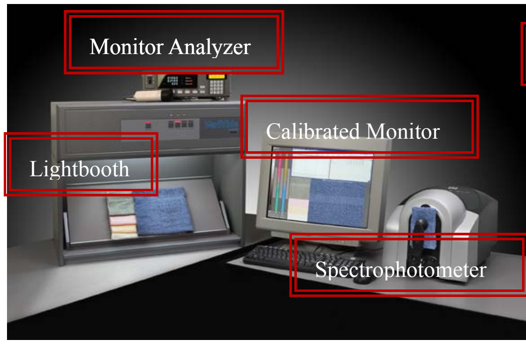

Fig. 2 Datacolor Envision System

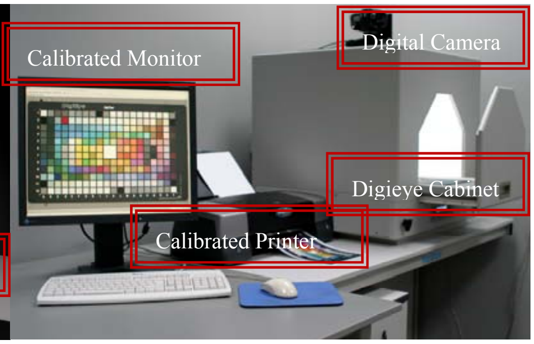

Fig. 3 DigiEye System

Verivide DigiEye is a non-contact color appearance measurement system, using a calibrated monitor and controlled lighting environment, which allow user display and measure color appearance to a great accuracy. The monitor in such virtual color appearance system is calibrated so precisely that a user can be confident to making the same decision when viewing electronic image, the same like viewing actual physical sample. The RGB of the digital camera is characterized against the CIE specification of a standard checker chart, which was measured on spectrophotometer-based system. High-end camera now could have resolution down to single mega pixel. Any objects will be put inside a well-controlled lighting environment with D65 illuminant specifications. DigiEye system also has some other useful features like: embedded most new color difference equation CIE2000 and color appearance model CIECAM02; substrate profiling and simulation, color order and clustering, color fastness auto-grade; 3-D, tiny object and irregular shape color measurements etc. DigiEye could be used in many industries like textile, food, cosmetic, beverage, paint, ceramic, plastic, leather, automobile, electronic devices, where current reflectance based contact measurement technique is immeasurable. Fig. 3 shows a DigiEye system, which include a calibrated color monitor, a calibrated digital camera and a light booth. A comparison had been made for these color appearance system as is shown Table 1.

Table 1Comparison of Contact and None-Contact Measurement Color Appearance System

	Envision / ColorTalk	**DigiEye**
Theoretical basis	RGB-CIE nominated; device independent color space	RGB-CIE nominated; device independent color space
Lighting environment	Controlled	Precisely controlled
Reflectance input/generation	Yes	Yes
Monitor	Calibrated	Calibrated
Pixel grade measurement	No	Yes
Irregular surface	No	Yes
Digital standard reproduce	Yes	Yes
Fastness evaluation	Limited	Accurate and easy
Monitor	LCD	LCD
Measureable sample format	Flat, even, opaque, solid color, preferable 2-D	Any kind of surface, irregular shape, 2-D and 3-D
Sample size	Minimal 3mm	Pixel grade

Field of application	Color representation and communication	Design and color communication
Color model / equation embedded	CIELAB/ CMC/ CIELCh / CIE94 etc.	CIELAB / CIE2000 / CIE94 CIECAM02/CMC etc.
Image capture method	Digital camera or scanner	High-end digital camera
Color quality control/ Communication	Yes	Yes
Image Separation	Yes, embedded	Yes, embedded or external

4. Key Features of a Color Appearance System

Production supply chain has migrated overseas in recently years. Digitalized color appearance could be send to customer at any corner of world in this work for evaluation and reproduction in global industrial supply chain. Once a color measurement and communication system is ready, it is very important that each party have same device, method and procedure. It has been discussed that a color guidebook is very useful to standardize all aspect of color evaluation and communication procedure and minimal variables [14]. Likewise, it is essential to control and identify possibility elements of the color appearance system with both hardware and software requirements. Some important features are listed in table 2 and table 3 in order to achieve success:

Table 2 Hardware and Periphery (* Must)

Features	Description
• High end LED monitor*	Precise and repeat color display
• Monitor calibrator*	Calibrate monitor to specification
• Calibration base*	Color checker or traceable standard
• Light environment	Well controlled, for visually sample evaluation
• Spectrophotometer*	Reflectance input
• Image capture device*	Digital Camera/3-D; Scanner/2-D
• Printer	Calibrated, "Life like" printout

Table 3 Software Related Function (* Must)

Features	Description
• RGB to CIE transformation*	Monitor color to standard CIE color description
• Monitor calibration procedure*	Ensure on-screen color reproduce, device independent
• Reflectance input and generation*	Accept measurements by a spectrophotometer or manually, and transform the data to virtual substrate on-screen for evaluation or adjustment
• Image capture, conversion, separation*	To obtain precise surface information of a sample
• Web based data format or data exchange method*	For Easy color data communication, such as QTX format or Web compatible XML format
• Printer Calibration	For precise color display on printout
• Device independent color space*	CIEL*c*h* or CIEL*a*b*

• Embedded color appearance model*	CIECAM02 is preferred for optimized color display
• Additional color index	Mesmerism，color inconsistency, chromatic adaption, Gloss compensation
• Monitor Color Gamut Profiling*	Ensure all colors within gamut displayed on a monitor
• Illuminants/observer *	Color visualization under different illuminants
• Inter-Monitor Tolerance*	At least less than one CIEL*a*b* unit
• Device independent color space and color difference Equation	Most updated CIE color equations and model, as well as most accepted industry equations
• Colored image creation and selection*	Designer can create/adjust color easily and apply color on objects or different substrate for virtual evaluation
• Colorimetric data generation*	For spectral and colorimetric data display and compare
• Color library	For color search, sort and management
• Accurate color and appearance communication*	Color appearance information can be easily transferred among partners
• Precise on-screen quality control*	Not only can provide visual compare on a calibrated screen, but have color difference data

Once specifications of color appearance system are defined, a time saving with fast-paced color appearance communication model could be described. Though reflectance-based color communication for solid color had been achieved in textile industry within the past decades [17][18], an effective process for color appearance communication is not yet determined. Now, color appearance could be characterized with numerical color appearance data and communicate among partners involved. For any industry, color approval, which was made in weeks or months in the past, now is able to be done in a couple of days with the help of color appearance system and web-based communication method. It could be foreseen that more precise portable spectrophotometer and wireless mobile technique such as 3G would be embedded into such system to obtain higher efficiency and flexible. Fig. 5 shows a typical color appearance communication model and table 4 has defined some key color appearance data required for an effective communication:

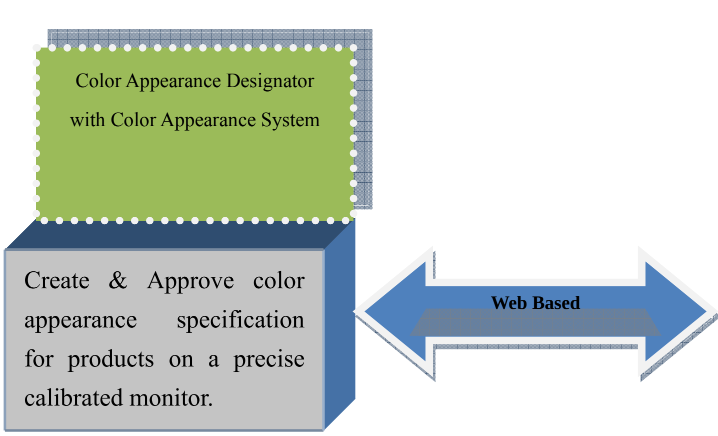

Fig. 5 Color Appearance Communication Model

Table 4 Typical color appearance specifications:

Sample type	Specifications
Opaque	Substrate Image(uncompressed), Reflectance(R %), Substrate Image (Profiled), Gloss Value
Translucent	Substrate Image(uncompressed), Reflectance (ROL/ROD), Substrate Image (Profiled), Contrast Ratio/Opacity, Gloss Value
Transparent	Substrate Image(uncompressed), Transmittance (T %), Medium, Gloss Value

5. Digitalized Color Appearance Vista

In this discussion, several states of art color appearance systems are introduced and summarized. Domination features for an effective color appearance system are listed. Computer based image system coupled with advanced color appearance science and technology, now can provide industry with more accurate digital color presentation and application possibility. The resulting color appearance with digital approach allows users to digitally create or evaluate color appearance and avoid the time-consuming and costly traditional method of mailing color samples back and forth between sites for approval. Though digital color based virtual reality is still need improve, the trend is inevitable. It can foresee that image based color appearance control and communication, which will solved many appearance related color challenges that current reflectance based system incapable of, will be a beneficial complementary system to existing spectrophotometer based color measurement and communication.

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