

Advances in the Geometric Specifications of Instruments for the Measurement of Color and Color-Differences

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Abstract

At the quadrennial meeting of the CIE held in New Delhi, India in 1995, Division 2 of the CIE on the Optical Properties of Materials established a new technical committee charged with preparing a CIE recommendation and eventually, a CIE standard that clearly defines the geometric requirements for instruments designed to measure the color of materials. The committee was given the designation TC 2-39 and the Danny Rich was appointed as the chairman.

This paper reviews the progress and findings of CIE TC 2-39 during the last five years which have led to the development of draft recommendations on the geometric specifications for color-measuring instrumentation, including the geometric description of the recommended geometries and tolerances around those geometries. The recommendations are based on reports taken from the literature and on original measurement data provide by the committee members. The data clearly show that the existing geometric specifications for instrumental colorimetry are too loosely defined and toleranced for reliable absolute color measurements needed to characterize non-impact printing inks or to reproduce consistent device profiles.

Introduction

At the quadrennial meeting of the CIE held in New Delhi, India in 1995, Division 2 on the Optical Properties of Materials established a new technical committee charged with preparing a CIE recommendation and eventually, a CIE standard that clearly defines the geometric requirements for instruments designed to measure the color of materials. The committee was given the designation TC 2-39 and the Danny Rich was appointed as the chairman. This paper reviews the progress and findings of CIE TC 2-39 during the last five years which have led to the development of draft guidelines on the geometric specifications for color-measuring instrumentation, including the geometric description of the recommend geometries and tolerances around those geometries.

Literature Review

During the first three years the committee searched the technical literature for references to papers that documented the effect of geometry on the measurement of the color of materials. While several papers were identified, there were no papers that systematically reviewed all of the aspects of the geometric tolerances assigned to instruments used for characterizing the color of materials, especially the color of ink on paper. There are three key references that address the geometry of color-measuring instruments. *Publication CIE 15.2, Colorimetry*[1] which is the definitive publication on the measurement of the color of materials. This publication gives no definitions of measurement conditions but assigns some general requirements and tolerances around those requirements. ISO 5-4 which is the definitive publication on the measurement of reflection density[2] and a paper by McCamy[3] which is the basis for the system of notation used in ISO 5-4 and in ASTM E 1767[4]. With the latter papers, the committee was able to specify or explicitly define the basic measurement geometry and then, once defined, to put realistic tolerances onto the definition.

The McCamy system of notation is centered on the specimen or the sampling aperture at which the specimen is positioned during the measurement. It uses the concepts of *Influx* and *Efflux* directions with right circular cones defining the fluxes. The notation, similar to that in ISO 5-4, separates the influx parameters from the efflux parameter with a *colon* rather than with the *slash* or *hash* symbol used in the CIE 15.2 notation. The basic symbols are thus Influx : Efflux.

Definitions of Measurement Geometry

The committee identified three types of measurements for which geometric definitions were required. The measurement of the color of objects by regular and diffuse reflectance, the measurement of the color of transparent materials by regular transmittance and the measurement of the color of translucent materials by diffuse transmittance.

Unlike the CIE system of notation which defines only a diffuse reflectance measurement geometry the proposed system can clearly differentiate between the various measurement systems in either a complete specification or a "short-hand" notation. The symbols of interest are ϕ_i, ϕ_r, ϕ_t the radiant fluxes with ϕ_i being the influx and ϕ_r, ϕ_t being the effluxes for reflection and transmission, respectively. The symbol θ describes the anormal angle for the centroid of each flux, the symbol η describes the azimuthal angle for the centroid of each flux and the symbol κ describes the half-angle of the right circular cone of each flux.

The influx ϕ_i can be described by its orientation with the Z axis by the angle θ_i and by its orientation with the X axis by the angle η_i . The influx forms a cone with half-angle given by κ_i. To describe a complete measuring system requires only the angles and half angles of interest in the influx and efflux planes. For example, a biconical reflectance factor measurement was specified by CIE 15 as 45/0 and in the proposed notation as R(45:0).

We now know that such a simplified notation is incomplete and the cone half-angles must also be specified to complete the description. It is also true that in the CIE notational system there is no way to distinguish between two fluxes in a single plane and an azimuthal ring of influxes at 45°. The new notation allows for a describing multiple, continuous or discrete fluxes. Table I gives the geometric definitions for each of the various geometries described above. Note that the new notation is so flexible than it can clearly distinguish between the various designs of bidirectional instruments that are commercially available[5] – unidirectional geometry, such as the Techkon SP820, annular influx, such as seen in the GretagMacbeth SpectroEye and circumferential efflux, such as used on the X-Rite 938. In the latter case, the locations of each of the fiber optic bundles will be identified in terms of the angular position and width with respect to the sampling aperture.

Table I - Recommended Geometric Definitions for Color Measurements in the Exact Notation

Measurement	**Exact Notation**
Reflectance	$R(\kappa_I,\theta_i,\eta_i,\kappa_e,\theta_e,\eta_e : \kappa_r,\theta_r,\eta_r)$
Regular	R(5,0,0:5,0,0)
Hemispherical	R(90,0,90,-6,8,0 : 3,8,0)
Total	R(90,0,90 : 3,8,0)
Bidirectional	$R(\kappa_i,\theta_i,\eta_i : \kappa_r,\theta_r,\eta_r)$
Uniplanar	R(2,0,0:2,45,0)
Annular	R(2,0,0:2,45,360)
Circumferential	R(2,0,0:2,45,0-10;60-70;120-130;180-190;240-250;310-320)
Transmittance	$T(\kappa_i,\theta_i,\eta_I: \kappa_t,\theta_t,\eta_t)$
Regular	T(5,0,0:5,0,0)
Diffuse	T(90,0,0::5,0,0)

While the notation is both powerful and flexible, it can be very cumbersome to describe an instrumental reading in a data report or in a publication using the full notation. The CIE Technical Committee 1-56, who is revising CIE 15.2, is recommending a new set of short-hand notations for the major geometries used in color measurement. Table II shows the same measurement conditions as Table I giving the short-hand notation for the general case. Several distinctly different instruments may be described by the short-hand notation but not so with the exact notation. It is anticipated that manufacturers and users of color-measuring instruments will want to refer to the instruments using the short-hand notation but that technical literature and specifications will be written out in the exact notation.

Table II - Recommended Geometric Definitions for Color Measurements in Short-Hand Notation

Measurement	**Short-Hand Notation**
Reflectance	R( )
Regular	R(0: 0)
Hemispherical	R(de:8)
Total	R(di:8)
Bidirectional	R( )
Uniplanar	R(0:45)
Annular	R(0:45a)
Circumferential	R(0:45c)
Transmittance	T( )
Regular	T(0:0)
Diffuse	T(0:d)

Tolerances on Measurement Geometry

Tolerances can be inserted into the notation by adding a ± and the tolerance after each default angular specification. Thus for the hemispherical diffuse geometry, the normal angle, given the tolerance of "any angle less than 10°" by the CIE can be toleranced as 0° ± 1° in the new system.

Recent studies by the CIE TC 2-39 committee, especially the members from Japan, and by the NPL in England have shown that the definitions and tolerances given in documentary standards like CIE 15, ISO 5, ISO 7724[6], and JIS Z8722[7] were too general and too tolerant for use in commercial colorimetry. Two instruments, designed in conformance to any of those specifications could produce color readings of identical materials that differed by more than the required commercial tolerances. Such poor inter-instrument agreement is no longer acceptable in a global economy.

Today, global producers of colored goods must either standardize on a single instrument manufacturer, develop empirical models to convert one instrument's readings to another for a given material type or rely completely on visual inspection and the interchange physical samples of the product standard and production sample. This latter procedure has been shown to be less reliable than modern color tolerance formulas. The second method has been shown to be viable in applications where the product requirements are not too stringent. The first method is used when very tight production tolerances are demanded but tends to very restrictive and may border on restraint of trade. The only viable approach then is to restrict the tolerances on the instrument design so that instruments designed and produced by different vendors will have a higher level of inter-instrument agreement

The recommendations of CIE TC 2-39 are designed to provide three levels of inter-instrument agreement. Table III shows the specifications and tolerances for a bidirectional (biconical) reflectance factor, a geometry of critical interest to producers and users of non-impact printers.

Table III - Recommended Geometric Specifications and Tolerances for Bidirectional Geometry

Specification	Tolerances (A, B, C levels)
Influx	
θ=0°	± 0.5°, 1°, 2°
κ=2°	± 0.25°, 3°, 5°
η=0° or 360°	annular, ≥6 point circumferential, ≥4 point circumferential
Efflux	
θ=45°	± 0.5°, 1°, 2°
κ=2°	± 0.25°, 3°, 5°
η=0° or 360°	annular, ≥6 point circumferential, ≥4 point circumferential

It must be emphasized that the categories A, B, C in the tolerances do not represent the quality of an instrument or even the accuracy of an instrument. The tolerances were categorized because of the global nature of color communications and the need to have maximum inter-instrument agreement of color measurements.

Conclusions

The work of CIE TC 2-39 is drawing to a close. The original terms of reference specified that it would last for only four years. Due to difficulties in obtaining appropriate measurement data and some struggles in defining a "goodness" metric for the uniformity and "diffuseness" of the diffuse geometry the work of the committee has stretched beyond its original goal. It is now the intent of the committee to have its final recommendations ready for submission to the division at the next annual meeting in May, 2001.

At this year's meeting of the division in April, the committee met at the NPL in Teddington, England. There, representatives of ISO TC 130 Graphic Arts and ISO TC 42 Photography attended the meeting. They presently have a joint subcommittee responsible for preparing revisions of the four parts of ISO 5. The present consensus of that subcommittee is very much in line with the recommendations of CIE TC 2-39. The ISO joint subcommittee will be recommending a change in the geometric specifications for densitometry. Comparison of anecdotal data from the ISO subcommittee, the NPL Spectrophotometry group and CIE TC 2-39 are all in good agreement. Figure 1 below shows one area in which the three committees have full agreement – the reduction of the tolerances on the normal angle in a 45°: 0° geometry.

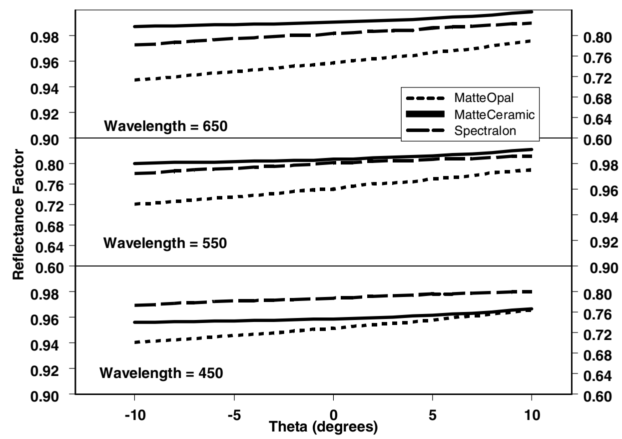

Figure 1. Variation of 45°: 0° Reflectance Factor With Changes in Normal Angle from -10° to +10° for Matte White Standards

Due to level of agreement between the CIE and ISO committees and to recent support of the recommendations by experimental data, such as shown above, the ISO committee requested that CIE TC 2-39 consider adding the geometry for opal glass diffuse transmission density to its list of specified geometries. The CIE committee agreed to look into this as long as it did not greatly extend the time frame required to develop the final recommendations. The addition of opal glass diffuse transmission to the integrating sphere transmission specifications and tolerances will provide NIP vendors a complete set of specifications for instruments to characterize the color and transparency of inks printed on scattering substrates or clear film.

References

1. Publication CIE 15.2, *Colorimetry*, 2nd Edition, Commission International de l'Éclairage, Vienna, Austria (1986).
2. C. S. McCamy, "Concepts, Terminology, and Notation for Optical Modulation", *Photographic Science and Engineering*, **10**, (6), 314-325, (1966).
3. ISO 5-4, *Photography - Density Measurements - Part 4: Geometric conditions for reflection density,* International Organization for Standards, Geneva, Switzerland.
4. ASTM E 1767 *Standard Practice for Specifying the Geometry of Observations and Measurements for Characterizing the Appearance of Materials*, American Society for Testing and Materials, West Conshohocken, PA, USA.

5. References to a color-measuring instrument and its manufacturer do not imply a recommendation of that instrument or maker by either Sun Chemical, the CIE or IS&T but are cited as examples of common commercial instruments with a given geometric configuration.

Biography

Danny C. Rich holds B. S. and M. S. degrees in Physics and a Ph.D. in Color Science. He has worked in industrial color research for the Sherwin-Williams Company, Applied Color Systems, Datacolor International and most recently for Sun Chemical Corporation. At Sun Chemical he is leading the team in the Color Research Laboratory, who are involved in global color standardization of the scales of instrumental and visual color measurements of ink and printing. He is President-Elect of the Inter-Society Color Council and chairman of CIE Technical Committee 2-39 on Geometric Tolerances for Color Measurement. Email: richd@sunchem.com