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Graphic technology — Spectral measurement and colorimetric computation for graphic arts images

Technologie graphique — Mesurage spectral et calcul colorimétrique relatifs aux images dans les arts graphiques

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 130, *Graphic technology*, in collaboration with Technical Committee ISO/TC 42, *Photography*.

This third edition cancels and replaces the second edition (ISO 13655:2009), which has been technically revised to:

— clarify the requirements of measurement mode M1;

— restrict the use of unnecessarily wide bandpass and sampling intervals;

— provide more realistic specification for the optical properties of a white backing material;

— restrict the adjustment method of predicting the fluorescent reflectance factor to UV activated substrates.

Introduction

There are many choices allowed when making spectral measurements and performing colorimetric computations. The specific choices made can result in different numerical values for the same property for the same sample. Thus, it might not be possible to make valid comparisons unless the data being compared are all based on the same set of measurement and computational choices. The purpose of this document is to specify a limited number of such choices for the measurement and computation of the colorimetric characteristics of graphic arts images and specimens, such as test charts, to allow valid and comparable data to be obtained. While this document references ISO 3664, the International Standard established for viewing conditions in graphic arts and photography, it is not expected that measured colorimetric data will provide an absolute correlation with visual colour appearance.

When the prior revision of this document was started, it was observed that almost all graphic arts specimens exhibited fluorescence. In most cases, this was due to optical brightening agents (OBA) contained in the paper substrates. In rare cases, the printing inks were fluorescent. According to the recommendations of the 1996 version of this document, this would have meant that the source used for the measurements (i.e. the spectral power distribution of the specimen illumination) was required to closely match CIE illuminant D50. Yet when the 2009 revision was started, not a single colour-measuring instrument sold for the graphic arts market provided an illumination system that closely matched CIE illuminant D50. Instead, most instruments used incandescent lamps for light sources. The spectral power distributions of such lamps have varying amounts of UV content. The variation in UV content between instruments could easily amount to a colour difference of 5 Δb^* when measuring substrates with a high level of optical brightening agents. Consequently, the measurement results for unprinted paper substrates and lighter colours differed appreciably between different instrument models. For a thorough study of fluorescence effects, see CIE Publication 163.

It had also been observed that graphic arts viewing booths vary with respect to UV content, even those that comply with the 1996 version of ISO 3664. The practical result was that specimens that have nearly identical measured colorimetric properties, at times will not visually match when viewed in the viewing booth, and vice versa. Only part of such discrepancies can be attributed to fluorescence. There can also be metameric effects due to “non-standard” observers and to instrument wavelength errors, in addition to deviations in the measurement source away from CIE D50. Despite these other potential influences, it was deemed important to provide measurement solutions that would minimize the systematic errors introduced by the interaction of paper fluorescence and variations in the spectral power distribution of the sample illumination. Methods for the correction of instrument errors and procedures for reliable visual evaluation of colour images are outside of the scope of this document.

In the 2009 revision, four measurement choices were defined for reflective measurements. Measurement condition M0 requires the source illumination to closely match that of illuminant A; this provides consistency with existing instrumentation and ISO 5-3. Measurement condition M1 requires the colorimetry of the specimen illumination to closely match CIE illuminant D50. Measurement condition M2 only requires that the spectral power distribution of the specimen illumination be provided in the wavelength range from 400 nm to at least 700 nm and have no substantial radiation power in the wavelength range below 400 nm (often referred to as “UVCut”). Measurement condition M3 has the same sample illumination requirements as M2 and includes a linear polarizer in the influx and efflux portions of the optical path with their principal axes of polarization in the orthogonal or “crossed” orientation. For specimens in which the fluorescence is primarily that of a UV activated blue emission, it is possible to use the method of a virtual fluorescent standard reported by Imura of Konica Minolta[24][25] to determine the total radiance factors for M0, M1 and M2 conditions. In this revision, Annex A has been revised providing a slightly narrower and more realistic set of spectral tolerances on the white backing materials. The properties of the white backing material are critical to reproducibility of readings of packaging printing on clear or translucent films.

Finally, as the CIE has been recommending the use of 5 nm intervals for practical tristimulus integration since the second revision of CIE Publication 15 and as graphic images can be composed of colour stimulus functions with very narrow transitions from the low values to the high values, this revision recommends that tristimulus values be based on spectral data collected with a 5 nm interval and a 5 nm bandpass. Since many of the instruments now in use in the field are equipped with 10 nm intervals and 10 nm bandpass spectrometers, such readings are allowed with the recommendation that tristimulus calculations be preceded by applying bandpass correction to the spectral data as specified in ASTM E2729. The use of instruments with wider sampling intervals and bandpass has been deprecated with the exception of the use of such non-standard instruments to monitor the state of previously characterized materials or objects.

The requirements of this document are focused on colorimetric measurement equipment intended for use in the graphic arts environment. Helpful information on issues such as substrate backing materials, reporting, standardization, standard and improved colour difference metrics, fluorescence and ways to improve the inter-instrument agreement are included. These will be useful to technical advisors of graphic arts associations, specialized graphic arts research institutes, and practitioners with an interest in the basics of measurement and process control.

Graphic technology — Spectral measurement and colorimetric computation for graphic arts images

1 Scope

This document specifies procedures for the measurements and colorimetric computations appropriate to objects that reflect, transmit and emit light, such as flat-panel displays. It also specifies procedures for computation of colorimetric parameters for graphic arts images. Graphic arts include, but are not limited to, the preparation of material for, and volume production by, production printing processes that include offset lithography, letterpress, flexography, gravure, screen and digital printing.

This document does not address spectral measurements appropriate to other specific application needs, such as those used during the production of materials, for example, printing paper and proofing media.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5-2, *Photography and graphic technology — Density measurements — Part 2: Geometric conditions for transmittance density*

ISO 5-4:2009, *Photography and graphic technology — Density measurements — Part 4: Geometric conditions for reflection density*

ISO 3664, *Graphic technology and photography — Viewing conditions*

ISO 11664-1, *Colorimetry — Part 1: CIE standard colorimetric observers*

ISO 11664-3, *Colorimetry — Part 3: CIE tristimulus values*

ISO 11664-4, *Colorimetry — Part 4: CIE 1976 L*a*b* Colour space*

ISO 28178, *Graphic technology — Exchange format for colour and process control data using XML or ASCII text*

CIE Publication 15:2004, *Colorimetry, 3rd ed.*

CIE Publication 167:2005, *Recommended practice for tabulating spectral data for use in colour computations*

CIE Publication 176:2006, *Geometric Tolerances for Colour Measurements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
adopted white
spectral radiance distribution as seen by an image capture or measurement device and converted to colour signals that are considered to be perfectly achromatic and to have an observer adaptive luminance factor of unity, i.e. colour signals that are considered to correspond to a perfect white diffuser

[SOURCE: ISO 22028-1]

3.2
bandwidth
width of the spectral response function of the instrument, measured between the half-power points often termed full width at half maximum (FWHM)

3.3
calibration
set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards

Note 1 to entry: Contrary to a common usage, calibration is not the process of adjusting a measurement system such that it produces values that are believed to be correct. Calibration permits either the assignment of values of measurands to the indications (creating a reference table) or the decision to reset or adjust the device. Following the resetting or adjusting of the device, a calibration needs to be verified to ensure that the new device setting(s) provide indications within the accepted values.

[SOURCE: ISO/IEC Guide 99 (VIM)]

3.4
CIE illuminant
illuminant (3.6) defined by the International Commission on Illumination (CIE) in terms of relative spectral power distribution

[SOURCE: IEC 60050-845-03-12]

EXAMPLE CIE illuminants A, C, and various D illuminants.

3.5
CIELAB chromaticness difference
ΔC_h
difference between two colours of approximately the same lightness projected onto a constant lightness plane in the CIELAB colour space

Note 1 to entry: This is calculated as $\Delta C_\mathrm{h} = \sqrt{\left(\mathrm{CIE}\,a_1^* - \mathrm{CIE}\,a_2^*\right)^2 + \left(\mathrm{CIE}\,b_1^* - \mathrm{CIE}\,b_2^*\right)^2}$

3.6
illuminant
numeric tabulation of the relative spectral distribution of the radiant (light) flux incident on the specimen surface

Note 1 to entry: The CIE defines an illuminant as "radiation with a relative spectral power distribution defined over the wavelength range that influences object colour perception". In everyday English, the term is more widely used to mean any kind of light falling on a body or scene. See IEC 60050-845 for further information.

[SOURCE: IEC 60050-845-03-10]

3.7
opacity
<of a substrate> measure of the property that describes the ability of a specimen to hide a surface behind and in contact with it

Note 1 to entry: The numerical value of opacity as used in this document is 100 times the ratio of the luminous reflectance factor of the substrate over black backing (as defined in A.2) to the luminous reflectance factor over white backing (as defined in A.3). This is different from the measurement of opacity used by the paper manufacturing industry and defined in ISO 2471.

3.8
opaque substrate
substrate whose *opacity* (3.7), measured according to A.3, is 0,99 or greater

3.9
transparent substrate
clear material having minimal absorption or scattering of transmitted visible light

Note 1 to entry: Clear packaging film is an example of this type of material.

3.10
reflectance factor
ratio of the radiant or luminous flux reflected in the directions delimited by the given cone to that reflected in the same directions by a perfect reflecting diffuser identically irradiated or illuminated

Note 1 to entry: The industry commonly uses the term reflectance rather than reflectance factor.

Note 2 to entry: It is important to specify the geometry that establishes the given conditions of measurement. See Annex B.

[SOURCE: IEC 60050-845-04-64]

3.11
radiance factor
<at a surface element of a non-self-radiating medium, in a given direction, under specified conditions of irradiation> ratio of the radiance of the surface element in the given direction to that of the perfect reflecting or transmitting diffuser identically irradiated and viewed

Note 1 to entry: For photoluminescent (fluorescent) media, the radiance factor contains 2 components, the reflected radiance factor, β_R, and the luminescent radiance factor, β_L. The sum of the reflected and luminescent radiance factors is the total radiance factor, β_T: $\beta_T = \beta_R + \beta_L$. The subscript R is used here for the reflected radiance factor because it is more intuitive than the traditional S and avoids confusion with the use of S to denote a state of polarization.

[SOURCE: IEC 60050-845-04-68]

3.12
specimen backing
material placed behind and in contact with the specimen during measurement

Note 1 to entry: For this document, this can be either white or black.

3.13
spectrophotometer
instrument for measuring the relative spectral *reflectance factor* (3.10) or *transmittance factor* (3.18) of a material across the visible spectrum in order to derive colorimetric quantities

3.14
spectroradiometer
instrument for measuring radiometric quantities in narrow wavelength intervals over a given spectral region

[SOURCE: IEC 60050-845-05-07]

3.15
standardization
process of forcing or adjusting a measurement system to produce readings that correspond to a previously established *calibration* (3.3) using one or more homogeneous specimens or certified reference materials

Note 1 to entry: As defined here, standardization is normally carried out by an instrument user.

3.16
telespectroradiometer
spectroradiometer (3.14) that uses an optical relay component to allow measurements to be made at a distance from the specimen

3.17
transmittance (for incident radiation of a given spectral composition, polarization, and geometrical distribution)
ratio of the transmitted radiant or luminous flux to the incident flux in the given conditions

Note 1 to entry: It is important to specify the geometry that establishes the given conditions of measurement, for example, rectilinear geometry produces regular transmittance and integrating sphere produces diffuse transmittance. But an opal glass diffuser does not produce the same readings as an integrating sphere geometry. See Annex B.

[SOURCE: IEC 60050-845-04-59]

3.18
transmittance factor
ratio of flux transmitted by a specimen in a given optical system to the flux transmitted when the specimen is removed from the sampling aperture

Note 1 to entry: For example, this is the case when radiation penetrating a slide situated in a projector and reaching a screen is compared to the radiation when the slide is removed from a projector and only an empty slide mount is in the projector.

4 Spectral measurement requirements

4.1 Instrument standardization and adjustment

The measurement device or system shall be verified (standardized and possibly adjusted) in accordance with its manufacturer's instructions. See also Annexes C and D.

NOTE 1 ISO 15790 defines the use of a certified reference material (CRM) to check calibration of a measurement system. It also provides additional information relating to the use of CRMs, the determination of combined standard uncertainty and data reporting.

NOTE 2 Where multiple instruments are used for measurement, there can be differences in the resulting data due to the individual characteristics of the instruments and variations in measurement conditions. Annexes C and D provide information on the improvement of inter-instrument agreement and the use of certified reference materials.

4.2 Reflectance factor measurement

4.2.1 Wavelength range, wavelength interval and bandwidth

The data should be measured from 380 nm to 780 nm and shall be measured from 400 nm to 700 nm, inclusive. Data should be measured at 5 nm intervals with a spectral response function that is triangular with a 5 nm bandwidth at the half-power point, as specified in ISO 11664-3. Where unknown data are measured at other intervals and bandwidths, the sampling interval and bandwidth shall not exceed 10 nm. For applications where the spectral properties of the specimens are well established, conformance to process requirements may be assessed using 20 nm sampling. Measurement data taken at greater than 10 nm interval shall be converted to 10 nm using one of the interpolation methods recommended in CIE Publication 167:2005. Where measurement data are collected at bandwidths and intervals of less than 5 nm, it may be widened using the method of Annex E.

4.2.2 Illumination requirements and measurement conditions

4.2.2.1 Measurement condition M0

Historically, many spectrophotometers used in the graphic arts have used an incandescent lamp with a relative spectral power distribution that is close to CIE standard illuminant A, as defined in ISO 11664-2. In addition, this illuminant has historically been required for the measuring of density. M0 is provided to allow the identification of data measured using existing instrumentation or instrumentation optimized for photographic density measurements (see ISO 5-3).

The relative spectral power distribution of the flux incident on the specimen surface should conform to CIE illuminant A (corresponding to an incandescent source with a correlated colour temperature of 2 856 K). In practical instruments, this may be achieved using any source that provides radiant power at all wavelengths within the spectral range of 400 nm to 700 nm.

Because the specification of correlated colour temperature does not define UV, the UV content is not controlled under M0, and it is therefore recommended that M1 be used when there is the need to interchange data measured on samples that exhibit fluorescence. When instruments meeting M1 are not available and relative data are sufficient for process control or other data exchange applications, M0 instruments of like manufacturer and model provide a viable alternative.

4.2.2.2 Measurement condition M1

To minimize the variations in measurement results between instruments due to fluorescence (by optical brighteners in the substrate and/or fluorescence of the printing and/or proofing colorants), the spectral power distribution of the light flux incident on the specimen surface for the measurement should match CIE illuminant D50.

NOTE 1 Because ISO 3664 also specifies the use of D50, this will improve the consistency between measurement results made under condition M1 and visual assessment in viewing booths that meet the requirements of ISO 3664.

NOTE 2 For material testing as defined in ISO 5631-3, the UV-content of the illumination on the test piece has been adjusted to conform to that of CIE illuminant C. Therefore, measurements conforming to ISO 5631-3 might not be compatible with measurements conforming to this document.

There are two methods to achieve conformance to condition M1.

a) The spectral power distribution of the measurement source at the sample plane should match CIE illuminant D50. It shall conform to the requirements for viewing condition P1 of ISO 3664. This method shall be used when both luminescent colorants and optical brighteners are of concern. The instrument manufacturer shall supply a representative spectral power distribution of the measurement source at the sample plane with the instrument documentation.

b) A spectral match of the spectral power distribution of the measurement source in the range from 400 nm to 700 nm at the sample plane is not required if a compensation method is used with a controlled adjustment of the radiant power in the UV spectral region below 400 nm[24][25]. This can be done by active adjustment of the relative power in this range with respect to a calibrated standard for D50. This compensation aims only to correct the effects of fluorescence of optical brighteners in the substrate. The spectral power distribution in the range from 400 nm to 700 nm shall contain radiant power at all wavelengths in this range.

It should be noted that for the proper evaluation of materials with optical brightening agents, it is important that the ratio of the power in the region between 300 nm and 400 nm to the power in the region between 400 nm to 500 nm be very similar to the ratio of D50 between these same regions.

The conformance of M1 measurement condition shall be judged indirectly by measuring a set of certified reference materials (CRMs) (see Annex D) that includes a specimen material with a high concentration of optical brighteners where the difference in CIE b^* measured with and without UV energy incident on the specimen material is greater than 3. Where the indicated values, including the combined uncertainty, are within the specified tolerances of the CRM, and the required documentations are provided, the instrument can be considered to be in conformance with this document.

NOTE 3 Annex F provides information on fluorescence and techniques to test for its presence.

NOTE 4 In cases where a printing ink fluoresces and accurate colorimetric data are required, measurement condition M1, Method 1 is the only choice. However, in most situations, instruments meeting Method 1 are not available and relative data is sufficient for process control or other data exchange applications. In such situations, comparison of data from instruments of like manufacturer and model can provide a viable alternative.

4.2.2.3 Measurement condition M2

To exclude variations in measurement results between instruments due to fluorescence of optical brightening agents in the substrate surface, the spectral power distribution of the measurement source at the sample plane shall only contain substantial radiation power in the wavelength range above 400 nm. This may be accomplished through appropriate design of the source or through the addition of a filter between the source and the specimen.

The visible fluorescence of optical brightener agents in paper is typically excited in the UV range from 300 nm up to 410 nm. In order to eliminate completely any fluorescence excitation of optical brighteners, the optimum cut-off wavelength for the UV component would be 420 nm. However, it is desirable also to measure reflectance factors at 400 nm and 410 nm. Therefore, for each instrument type, the optimum trade-off has to be found between a sufficient suppression of residual fluorescent excitation and a reasonable signal-to-noise ratio of the measurement signal.

NOTE 1 For common spectrophotometers with a tungsten light source, a typical UV-cut filter has the following transmittance characteristics:

— greater than 0,85 in the visible range above 420 nm;

— less than 0,50 at 410 nm;

— less than 0,10 at 400 nm;

— less than 0,01 at 395 nm.

Appropriate suppression of the UV portion of the spectral power distribution of the flux at the sample plane shall be verified using the test procedure of Annex G.

For measurement condition M2, the source is not explicitly specified. However, it shall provide radiant power at all wavelengths in the wavelength range from 420 nm to at least 700 nm. The radiative power in each wavelength interval shall be sufficiently high, in order to enable precise calibration and repeatable measurement results according to the instrument specifications.

The utility of M2 data can be determined by first considering whether the substrate of the samples to be measured contains any optical brightening agents. If it does not, measurement conditions M0, M1 and M2 will ideally produce the same results. In this case, the primary differences will be due to specific differences in instruments.

NOTE 2 Annex F provides information on fluorescence and techniques to test for its presence.

4.2.2.4 Measurement condition M3

For use in the special cases detailed in informative Annex H, an instrument may be equipped with means for polarization in order to suppress the influence of first-surface reflection on the colour coordinates. An instrument fitted with a polarization filter shall also meet the requirements of 4.2.2.3. Using the test method of ISO 5-4:2009, Annex H, as modified below, the gloss suppression factors shall be determined for CIE *X*, CIE *Y*, CIE *Z*; none of which shall be lower than 50.

When using the test method of ISO 5-4 to evaluate an instrument providing colour coordinates, substitute “measured value reaches a maximum” for “reflection density reaches a minimum”. Formula (1) becomes:

$$P = \frac{X_2}{X_1} \tag{1}$$

where

P is the gloss suppression factor;

X_1 is the value measured without the polarization means;

X_2 is the value measured with the polarization means.

The gloss suppression factor is computed in a similar manner for CIE *Y* and CIE *Z*.

For directional and uniplanar measurement geometries, which are not specified by this document, the polarization vectors of the illumination and measurement channels need to be either parallel or perpendicular to the plane of incidence of the test object.

4.2.3 Sample backing material

The specimen shall be backed by either a black or a white material that conforms to A.2 or A.3, respectively. Where samples being measured by reflection are transparent, the backing used shall be white and the method shown in A.5 may be used to correct such measurements to an absolute reference.

NOTE For guidance concerning which sample backing material to use, refer to application standards such as those from the ISO 12647 series of process control standards.

4.2.4 Measurement geometry

The measurement geometry shall be (45°:0°) or (0°:45°), annular or circumferential (see Annex B). It shall also conform to the geometric conditions defined in CIE Publication 176:2006 and shall meet the requirement that the realized boundary of the larger of the illuminator region and the receiver region shall be outside the boundary of the smaller by at least 0,5 mm, as specified for small sampling apertures. While being measured the sample shall lie on a flat surface. The instrument base and the sample surface shall lie in the same plane.

NOTE 1 For angles and nomenclature for geometries, see B.1.1.

NOTE 2 The use of (45°:0°) or (0°:45°) geometry will not always adequately address variations in all surface characteristics. Other instrumentation might be used to detect specific characteristics such as surface reflectance effects.

NOTE 3 Annex B provides further information on minimum sampling aperture size.

4.2.5 Data reporting

Reflectance factor shall be reported to the nearest 0,001 relative to a perfect reflecting diffuser having a reflectance factor of 1,000 at all wavelengths. This data shall be reported as either reflectance factor or percent reflectance factor (i.e. reflectance factor multiplied by 100). If the data are to be used for further calculations, then in order to minimize the accumulation of round-off errors, the full precision of the calculation should be carried forward. Bandpass characteristics of data should be reported, including function shape (triangular, trapezoidal, etc.) and bandwidth (FWHM). See Annex L for information on the impact of instrumental bandpass on the calculation of spectral quantities. For non-opaque specimen-substrate materials, the CIEXYZ data for the unprinted substrate material read over