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Graphic technology — Multispectral imaging measurement and colorimetric computation for graphic arts and industrial application —

Part 1:
Parameters and measurement methods

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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 document 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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This document was prepared by Technical Committee ISO/TC 130, *Graphic technology*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Multispectral imaging is an image capture technology with more than three channels or wavelengths. This document focuses on multispectral image capture of surfaces with spatially varying colour. To achieve this, a contiguous band of wavelengths are sampled including the visible range and, in some cases, including ultraviolet and infrared.

NOTE The term hyperspectral imaging is typically used for systems capturing multiple wavelength bands such as infrared, visible, ultraviolet and other electromagnetic ranges[1]. Usually, these bands are non-contiguous or are overlapping. The boundary between multispectral and hyperspectral in practice is sometimes not precise and the usage of each term is often inaccurate, often for marketing reasons. To avoid any confusion, this document uses the term multispectral imaging to mean capture of image data across a single continuous band of wavelengths sampled at regular intervals across the visible range and which can extend into the infrared or ultraviolet.

In the past, assessment of object surfaces with spatially varying colour was carried out by visual inspection by experienced personnel. In some cases, area-averaging (pointwise) measurements were made to obtain the average value of the spatially varying colour of the object surfaces. The object surface was sampled at regular spatial intervals, however low spatial resolution and imprecise re-positioning between repeated measurements limited the success of such approaches. With the advent of modern lighting and 2D-sensor technologies, multispectral imaging devices are increasingly being used for this purpose.

Many laminations, decorations and materials containing patterns of various colours are produced by printing processes that include offset lithography, letterpress, flexography, gravure, screen and digital printing. To characterize the appearance of these objects effectively, the spectral reflectance factor must be read at many points across and down the object. Multispectral imaging devices can do this very effectively and provide an unprecedented advantage allowing pixel-wise evaluation of colour image difference to be used for quality assessment. Improved digital colour transforms based on this assessment can be used to reduce spatial colour differences leading to better reproductions. One benefit over RGB-based imaging systems is the improved colour accuracy when characterizing printing systems that use process colorants beyond CMYK, for example including orange, green and violet inks.

There are only a few choices allowed by the CIE when making spectral measurements and performing colorimetric computations. The specific choice will result in numerical values for the specific property for a specific specimen that are in agreement with the results from national standardizing laboratories. Similarly, two instruments from different manufacturers, that are both different from the CIE recommendations can be different from each other.

ISO 13655 specifies a limited number of such choices for the measurement and computation of the colorimetric characteristics of single printed patches providing a solid foundation for consistent colour communication within the graphic arts community. There is a need to have multispectral measurement system attributes documented and standardized in order to achieve a similar solid foundation so that multispectral images can reliably be compared.

Spectral imaging systems aim for spectrally resolved pixel data of an image of a scene. The objectives of these systems include object or material identification, and monitoring of manufacturing processes. Current multispectral imaging technologies restrict the number of spectral image channels to a set that is smaller than the minimum required by ISO 13655 for spectral measurements (400 nm to 700 nm at 20 nm intervals, requiring 16 channels). While such systems might be become more widely available in future, this document provides requirements for systems with fewer channels.

There are many commercially available multispectral imaging systems which provide spectral diffuse reflectance factor measurements at many pixels, from which colorimetric values can be calculated. The majority of these instruments do not conform to ISO 13655 guidelines for spectral measurements. In practice, it might not be possible to achieve all requirements of speed, spatial resolution and ISO 13655 spectral sampling in a cost-effective multispectral imaging system. One trade-off is to decrease the number of spectral channels. This can result in different numerical values for the colorimetry of a specimen when compared to measurements conforming to ISO 13655. Unless the data being compared are all based on the same set of measurement and computational choices it is not be possible to make reliable comparisons.

This document is aligned with some aspects of ISO 13655, making use of many definitions such as light sources and tables for colorimetric computation. When using a non-standard number of spectral bands, ASTM E2022-16[2] provides a method to be used to calculate tables of weighting factors for tristimulus integration using custom spectral power distributions and spectral sampling intervals and ranges. This document is part of a series of standards that allows for different choices for measurement and computation for different application areas. Subsequent parts set out the specification needed for each application area following the structure defined in this document.

In light of the variation in the number of spectral channels, the inter-instrument agreement between a multispectral imaging system and ISO 13655 compliant spectrophotometers can be significantly poorer than the agreement between ISO 13655 compliant instruments. The user of multispectral imaging devices is advised to weigh the benefits of an imaging device with colour fidelity better than an RGB camera with the drawback of measurements that do not agree with spectrophotometers.

Graphic technology — Multispectral imaging measurement and colorimetric computation for graphic arts and industrial application —

Part 1:
Parameters and measurement methods

1 Scope

This document establishes procedures for the spatially resolved spectral measurement of reflecting flat objects, including inline colour measurements. It also establishes procedures for computation of colorimetric parameters for graphic arts multispectral imaging devices.

Graphic arts includes, but is not limited to, the preparation of material for and volume production by production printing processes that include offset lithography, letterpress, flexography, gravure, screen and all kind of digital printing.

This document does not address spatially resolved spectral measurements of transmitting or self-illuminating objects including flat-panel displays. This document is not applicable to step and repeat spot reading scanning instruments. It does not address printing on a metallic or interference foil.

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 13655, *Graphic technology — Spectral measurement and colorimetric computation for graphic arts images*

ISO 23603, *Standard method of assessing the spectral quality of daylight simulators for visual appraisal and measurement of colour*

CE Publication No. 15, *Colorimetry*

3 Terms and definitions

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

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

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

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

3.1
multispectral imaging device
digital imaging system, capturing spectral data with more than three channels or bands of wavelengths

Note 1 to entry: Although the spectral range is typically found to be from 400 nm to 700 nm, energy slightly below and above that range contributes to the visual signal. Therefore, multispectral imaging systems can be considered that cover a spectral range from 380 nm to 730 nm.

Note 2 to entry: The channels are usually of limited spectral bandwidth, also known as narrowband, from which the spectral distribution of a captured image can be estimated for colorimetric evaluation. Typically, the differences between estimated and original spectral or colorimetric data of the captured image are reduced with increasing number of channels. Here, the original spectral or colorimeter data refer to those data collected by using a traditional single point spectrometer or colorimeter. If a higher number of channels does not result in the colorimetric distinctness of human beings anymore (typically more than 32 channels), the notation of hyperspectral image capture is used.

Note 3 to entry: Contrary to the definition of ILV[3], which defines multispectral image capture as image capture with six or more broadband sensors, it was found that also systems with 4 channels can be considered to provide a reasonable spectral reconstruction accuracy.

3.2
spectral bandwidth
wavelength interval between which the spectral product has decreased to a designated percentage of its maximum

[SOURCE: ISO 5-3:2009, 3.9]

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 13655:2017, 3.3]

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

[SOURCE: IEC 60050-845-03-12, modified — Note 1 to entry has been added[4]]

Note 1 to entry: CIE standard illuminants include illuminant A, illuminant D50 and illuminant D65.

3.5
illuminant
radiation with a relative spectral power distribution defined over the wavelength range that influences object colour perception

Note 1 to entry: In everyday English, the meaning of the term "illuminant" is not restricted to this sense, but is also used for any kind of light falling on a body or scene.

[SOURCE: *CIE ILV, International Lighting Vocabulary*, modified — Note 1 to entry has been added]

3.6
reflectance factor
ratio quotient of the flux reflected in the directions delimited by a given cone with apex at a surface element and the flux reflected in the same directions by a perfect reflecting diffuser identically irradiated or illuminated

Note 1 to entry: The reflectance factor is expressed by

$R = \emptyset_n / \emptyset_d$

where

$\emptyset_n$ is the flux reflected in the directions delimited by a given cone;

$\emptyset_d$ is the flux reflected in the same directions by an identically irradiated diffuser of reflectance equal to 1.

Note 2 to entry: The definition holds for a surface element, for the part of the reflected radiation contained in a given cone with apex at the surface element, and for incident radiation of given spectral composition, polarisation and geometric distribution.

Note 3 to entry: Reflectance factor is equivalent to radiance factor or luminance factor when the cone angle is infinitely small, and is equivalent to reflectance when the cone angle is 2π sr. These quantities are also defined spectrally and called spectral radiance factor β(λ) and spectral reflectance factor R(λ).

Note 4 to entry: The ideal isotropic (Lambertian) diffuser with reflectance or transmittance equal to 1 is called a perfect diffuser.

Note 5 to entry: For regularly reflecting surfaces that are irradiated or illuminated by a beam of small solid angle, the reflectance factor may be much larger than 1 if the cone includes the mirror image of the source.

Note 6 to entry: If the solid angle of the cone approaches 2π sr, the reflectance factor approaches the reflectance for the same conditions of irradiation.

Note 7 to entry: If the solid angle of the cone approaches 0, the reflectance factor approaches the radiance factor or luminance factor for the same conditions of irradiation.

Note 8 to entry: The reflectance factor has unit one.

[SOURCE: *CIE ILV, INTERNATIONAL LIGHTING VOCABULARY*[4]]

3.7
reference plane
plane in which the surface of the specimen is placed for observation or measurement

3.8
influx
radiant flux directed towards a specimen

Note 1 to entry: A reflection standard or an open sampling aperture influx may also be used as adjective indicating that the object is associated with the radiant flux being directed toward the specimen, standard or open aperture.

3.9
efflux
radiant flux reflected by a specimen or reflection standard, in the case of reflection measurements and sensed by the receiver

Note 1 to entry: Efflux may also be used as an adjective indicating that the object is associated with the radiant flux being sensed by the receiver.

3.10
spatially resolved spectral measurement
contiguous pixel array containing 4 or more spectral measurements at each pixel, that allow the estimation of the original spectral reflectance distribution of a test subject

Note 1 to entry: In most cases, these values are sampling values measured within a particularly defined narrowband spectral bandwidth.

3.11
spectrocolorimeter
spectrometer, one component of which is a dispersive element (such as a prism, grating, or interference filter or wedge or tunable or discrete series of monochromatic sources) that is normally capable of producing as output the colorimetric data (such as tristimulus values and derived coordinates) in addition to the underlying spectral data from which colorimetric data are derived

[SOURCE: ASTM E 284:2017]

3.12
spectrophotometer
spectrometer, one component of which is a dispersive element (such as a prism, grating, or interference filter or wedge or tunable or discrete series of monochromatic sources) that is normally capable of producing as output the spectral *reflectance factor* (3.6) or spectral transmittance of a material specimen

Note 1 to entry: A spectrophotometer is essentially a reflectance or transmittance spectrometer, utilizing either a bidirectional or a hemispherical optical measuring system. The suffix photometer derives from the time the light transducer used was the human eye. It is now almost always superseded by an optoelectronic receiver system.

[SOURCE: ASTM E 284:2017]

4 Multispectral measurement requirements

4.1 Instrument calibration and adjustment

The measurement device or system shall be calibrated and adjusted in accordance with its manufacturer's instructions. Although this document makes no provision for performance, the information in ISO/TS 23031[5] may be used to measure performance of a multispectral instrument when required.

NOTE Calibration in that respect refers to the manufacturer's calibration procedure and reference material to set the scale that was assigned to the instrument at the manufacturer's factory.

4.2 Illumination requirements

4.2.1 Wavelength range

The spectral power distribution shall have sufficient energy at all wavelengths in the range from 400 nm to 700 nm inclusive to make measurements with low noise.

4.2.2 Measurement conditions

For D50 based measurements, measurement conditions M0, M1 or M2 shall be used as defined in ISO 13655. For non-fluorescent substrates or inks, the choice of ISO 13655 measurement condition does not matter.

There are applications where CIE Standard Illuminant D65 is used. When measurements are made and colorimetric values calculated for CIE D65 on specimens with significant fluorescence [6], the instrument light source shall be configured to simulate the relative spectral distribution of CIE D65. The source shall be assessed according to ISO 23603 and M_V of the source shall be less than 1,0, M_U shall be less than 1,5 and the u'_{10}, v'_{10} chromaticity coordinates shall be within a radius of 0,00 5.

NOTE 1 The tolerances for M_V, M_U and chromaticity correspond to ISO 3664:2009[7] illumination requirements for viewing condition P1.

If this is not available using an instrument with M1 and calculating CIE D65 colorimetry may be used. If that is used that shall be reported.

NOTE 2 For fluorescent samples, the calculation will include an error since the fluorescence emission is different between D50 and D65 radiation.

The uniformity required for the pertinent uses cases covered should be defined by stipulating:

a) the size of the measured point,

b) the number of lines to be measured,

c) the number of points on the line to be measured, and

d) by specifying the method to assess the illumination field.

The measurement geometry shall be defined, preferably by using conditions and tolerance schemas provided in CIE 176[8]. The default measurement geometry for an imaging system is 45°:0° influx:efflux, the efflux optics along the normal to the surface of the substrate.

While being measured the specimen shall lie on a flat surface. The reference plane of the measuring instrument and the sample surface shall lie in the same plane.

If additional environmental or temporal parameters are required, they may be defined in addition.

4.3 Specimen preparation and backing requirements

Many multispectral imaging systems are used during production where it is not possible to use a standard backing material as the product is in contact with the manufacturing device, for example a roller, when measurements are required. Where substrates are opaque, this does not change the final result significantly. For non-opaque substrates, the same backing should be used when comparing measurements and should be either a black or a white backing that conforms to ISO 13655. If that is not possible, a backing correction towards black or white backing shall be used and the method shall be reported.

For not fully opaque substrates, the CIEXYZ data for the unprinted substrate shall be reported for both black and white backing, so that a white/black conversion as described in ISO 13655 can be carried out, whenever necessary.

Where appropriate, further requirements for the specimen preparation and backing material are provided in subsequent parts of the ISO 24585 series.

4.4 Light capturing requirements

4.4.1 Spatial resolution

The spatial resolution depends on many factors including the structure or texture of the specimen. Imaging systems used for different application often provide higher spatial resolutions to be useable for many different industrial applications. In such cases, the image processing steps may adjust the spatial resolution accordingly using a suitable filter where necessary.

The required spatial resolution shall be defined by providing the number of horizontal and vertical pixels and its effective pixel size.

4.4.2 Wavelength range, wavelength interval and bandwidth

The wavelength range shall be at least 400 nm to 700 nm and the wavelength interval, spacing between each spectral channel, shall be 50 nm or less.

NOTE 1 Although recent super resolutions methods (such as Reference [9]) are known to provide reasonable spectral accuracy with less than 7 bands, for well behaving scenes or specimen, actual measurement systems are known to use 7 or more spectral bands. That was reported in many studies, in particular in the series of the international symposium on multispectral colour science.

NOTE 2 CIE Publication 214[10] provided a description of one method to determine the spectral bandwidth of a spectrocolorimeter. Annex A of CIE Publication 214 provides guidance on how to execute the Richardson-Lucy bandpass reduction method.

As an alternative, the wavelength scale may also be specified using physical objects, resulting in a reduction in colorimetric accuracy.

4.5 Multispectral image storage

In cases when the multispectral imaging data, also known as data cube, needs to be saved and made accessible for later use, a file format described in CIE 223:2017[11] should be used. The used measurement backing shall be communicated.

Reflectance factor should 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).

4.6 Tristimulus image computation requirements

One of the current challenges for multispectral imaging systems is to define explicitly how to transform image data from a small number of channels, less than 16, into accurate tristimulus values. Such a transform is subject to many influential parameters[12] as the metrics to compare spectral reflectance curves[13]. For that reasons it is not required to specify the method from channel responses to the reflectance factors.

When D50/2° colorimetry is required tristimulus integration shall be based on CIE illuminant D50 and the CIE 1931 standard colorimetric observer (referred to as the 2° standard observer) as defined in ISO 13655 (providing the product of CIE illuminant D50 and the 2° standard observer data).

In case of D65 and 10° colorimetry, the tristimulus values shall be computed as defined in CIE 15.

NOTE ASTM E308[14] is written to provide the ability to capture abridged spectral data, either 10 nm sampling or 20 nm sampling. It uses the CIE recommendation of 1 nm sampling for tristimulus integration and the weights are designed to estimate by interpolation the missing, unmeasured data. Interpolating interpolated data can produce errors.

4.7 Requirements for comparing multispectral images

Where appropriate, methods to compare two multispectral images are provided in subsequent parts of the ISO 24585 series.

4.8 Requirements for comparing tristimulus images derived from multispectral images

Where appropriate, methods to compare two tristimulus images are provided in subsequent parts of the ISO 24585 series.

5 Data reporting requirements

Refer to subsequent parts of the ISO 24585 series for specific reporting requirements.