TECHNICAL SPECIFICATION

ISO/TS 17321-4

Second edition
2022-11

Graphic technology and photography — Colour characterization of digital still cameras (DSCs) —

Part 4:
Programmable light emission system

Technologie graphique et photographie — Caractérisation de la couleur des appareils photonumériques —

Partie 4: Système d'émission de lumière programmable

Reference number
ISO/TS 17321-4:2022(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of 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 www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 42, *Photography*.

This second edition cancels and replaces the first edition (ISO/TS 17321-4:2016), which has been technically revised.

The main changes are as follows:

— reorganized introduction and Clause 4;

— Clause 4 is concentrated on the hardware evaluation of programmable light emission system (PLES). New Annexes B and C were added to the second edition;

— a new Clause 5 and a new Annex A using VSA (Vector Space Arithmetic) formulation for simpler-conceptual explanation of spectral match for PLES were added;

— removed unnecessary explanations on spectral generation (Annexes A, B, C, D, E, F and explanation of spectral match in Clause 4), accordingly.

A list of all parts in the ISO 17321 series can be found on the ISO website.

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

This document describes a programmable light emission system. This system may be used to create spectra that are arbitrary combinations of the lights contained within or may be used to create a spectral match to a target reference spectrum. Unless the lights are of high dimensionality (ideal spectral shape at each wavelength) such a match will generally be only approximate. Therefore, evaluation methods for the spectra generated by the system are also described.

An example hardware description of a programmable light emission system is presented in Clause 4. While any programmable light emission system that meets the tolerances specified may be utilized, this document considers systems comprised of light emitting devices such as inorganic or organic LEDs, quantum dots, and laser diodes (if equipped with suitable spatial filtering).

Graphic technology and photography — Colour characterization of digital still cameras (DSCs) —

Part 4:
Programmable light emission system

1 Scope

This document describes a programmable light emission system to produce various spectral radiance distributions, intended for DSC colour characterization applications.

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 7589, *Photography — Illuminants for sensitometry — Specifications for daylight, incandescent tungsten and printer*

ISO/CIE 11664-5, *Colorimetry — Part 5: CIE 1976 L*u*v* colour space and u', v' uniform chromaticity scale diagram*

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
colour-matching functions
tristimulus values (3.5) of monochromatic stimuli of equal radiant flux

[SOURCE: CIE S 017:2020, 17-23-039]

3.2
digital still camera
DSC
device which incorporates an image sensor, and which produces a digital signal representing a still picture

Note 1 to entry: A digital still camera is typically a portable, hand-held device. The digital signal is usually recorded on a removable memory, such as a solid-state memory card or magnetic disk.

[SOURCE: ISO 17321-1:2012, 3.2]

3.3
light-emitting diode
LED
semiconductor diode that emits non coherent optical radiation through stimulated emission resulting from the recombination electrons and photons, when excited by an electric current

Note 1 to entry: For an example of LED, CIE S 017:2020, 17-27-050 shall be referred to.

[SOURCE: IEC 60050-521:2002, 521-04-39]

3.4
programmable light emission system
PLES
system that produces various spectral radiance distributions using light emitting devices

3.5
tristimulus values
amounts of the reference colour stimuli, in a given trichromatic system, required to match the colour of the stimulus considered

Note 1 to entry: See *colour matching functions* (3.1).

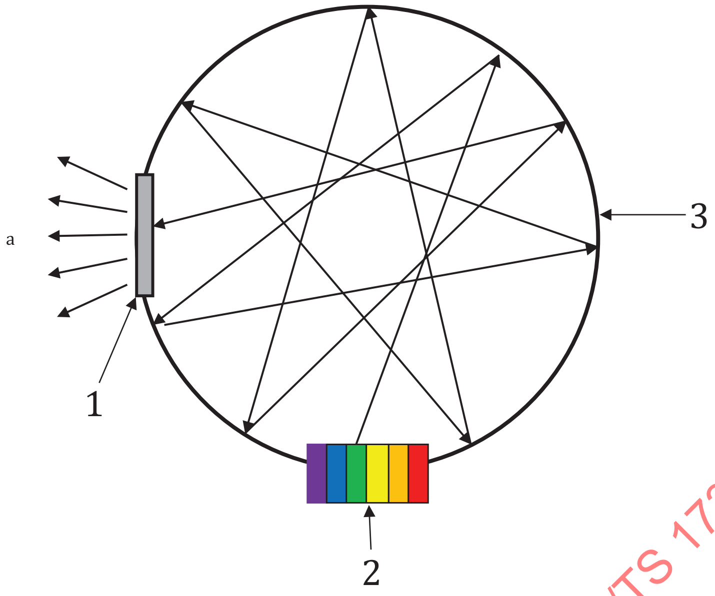
[SOURCE: CIE S 017:2020, 17-23-038]

4 Description

4.1 General

Figure 1 shows a cross-section of an example of a programmable light emission system (PLES). An integrating sphere in the Figure 1 is utilized to ensure good spatial uniformity for the light emission. Light emitting devices are placed at the bottom and an output window is placed on the side to allow the mixed light to be emitted. The ability to measure absolute XYZ values is a requirement. A tele-spectrophotometer is one of such measurement methods to obtain these values and used to verify the accuracy of the generated spectra.

There are many kinds of light emitting devices. For example, if LEDs are used for the light emitting devices, the LEDs are electrically modulated and the emitted flux will be mixed (integrated) by multiple reflections from the inner surface of the sphere, in order to produce a required spectral distribution of light flux.



Key

1 output window

2 light emitting device array

3 integrating sphere

a Uniform light emission on the output window.

Figure 1 — Schematic configuration of the programmable light emission system (PLES)

Annex B shows LED driving methods of the PLES.

As a more compact alternative to integrating sphere, flat panel diffusers can also be designed to produce near-uniform output by the light levels of the individual LED modules.

4.2 Operating condition

The light emitting system shall be designed to operate consistently under the ranges described in Table 1.

Table 1 — Operating conditions

Operating condition	Range
Temperature	18 °C to 28 °C
Relative humidity	15 % to 80 %

NOTE The temperature requirements were taken from ISO 12646.

4.3 Description of the system

4.3.1 General

This clause describes the PLES. An example for the PLES conditions is described in Annex C.

Warm-up time shall be chosen to be long enough so that the system has reached stable state and stabilized at the desired operating temperature after power-on of the PLES. It is recommended that a default spectral distribution is outputted during warm-up time in order to reduce warm-up time. This warm-up time is applied to all of spectral distribution measurement.

Every spectral measurement shall be performed after 5 s to 10 s when the PLES outputs different spectral distribution.

4.3.2 Wavelength

The wavelength range over which the combined set of the light emissive devices is evaluated should be at least broad enough to cover the range of spectral sensitivity of the DSC of interest and shall be specified. Generally, this will be 380 nm to 730 nm though longer wavelengths into the near-infrared should be included.

4.3.3 Resolution of digital-analogue conversion for light emitting devices

Sufficient resolution of digital-analogue conversion shall be used assuming that the PLES is setup such that there is a linear relationship between the power applied to each light emitting device and the resulting intensity from each light emitting device.

NOTE See Annex C for more information.

4.3.4 Output window size

The output window (see Figure 1) shall be large enough for the intended use.

NOTE See Annex C for more information.

4.3.5 Luminance

The maximum luminance of the output window shall have sufficient luminance when simulating various light sources including fluorescent and LED light sources.

NOTE See Annex C for more information.

4.3.6 Uniformity

For circular shaped output windows, luminance is measured at the centre and at 8 points evenly spaced next to the circumference of the output window at 45° intervals. The luminance measurements are made normal to the plane of the output window at each measurement point.

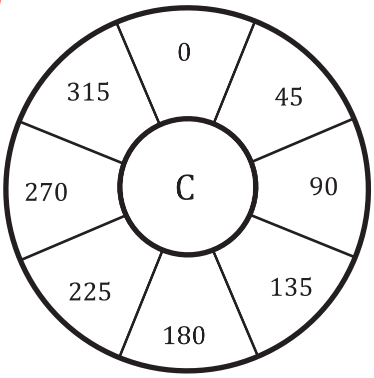


Figure 2 — Measurement points on the output window with every 45°

Figure 2 shows measurement points on the output window to calculate uniformity characteristics.

Uniformity is defined by Formula (1):

$$\Delta Y_u = \max_{i \in c, 0° \sim 315°} \left| \frac{Y_i - Y_{\text{ave}}}{Y_{\text{ave}}} \right| \times 100 \quad (1)$$

where

Y_{ave} is the average of the luminance measured on the output window;

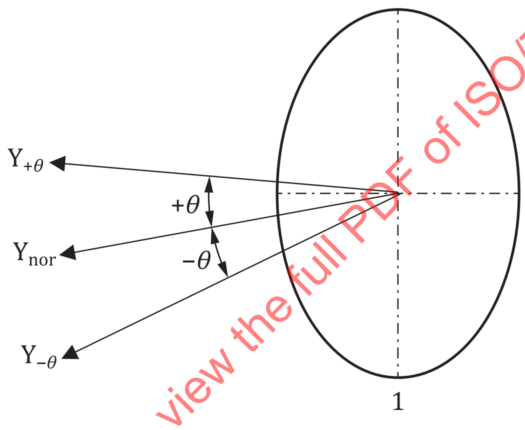
Y_i is the luminance measured either at centre or at each location next to the circumference of the output window.

NOTE See Annex C for more information.

4.3.7 Angular characteristics

The luminance is measured within a 10° cone angle to the normal line of the centre of the output window.

An integrating sphere could be used in order to ensure uniformity across the output window. Figure 3 shows angular characteristic measurement method. It is the typical method for a colour target having an arrangement of an output window and light sources shown in Figure 1.



Key

1 output window

Figure 3 — Angular characteristics measurement method

The luminance measured along the axis which is inclined +*θ* or -*θ* to the normal axis is given by Formula (2):

$$\Delta Y_\theta = \max_{i \in +\theta, -\theta} \left| \frac{Y_i - Y_{nor}}{Y_{nor}} \right| \quad (2)$$

where

Y_{nor} is the luminance measured along the axis normal to the output window;

$Y_{+\theta}$ or $Y_{-\theta}$ is the luminance measured along the axis which is inclined +*θ* or -*θ* to the normal axis, respectively. Maximum *θ* is 5° of arc.

NOTE See Annex C for more information.

4.3.8 Repeatability

4.3.8.1 General

There are two use cases for measuring the light intensity repeatability performance. The first one is short-term repeatability for continuous use within a day described in 4.3.8.2 where suffix "$_S$" is used.

The second is long-term repeatability for intermittent use on day to day described in 4.3.8.3 where suffix "$_L$" is used.

4.3.8.2 Short-term repeatability

The following specifies the method for characterizing method for continuous use repeatability.

Step 1: Generate a spectral match to CIE illuminant D55 in accordance with ISO 7589 using the light emitting system with a recommended luminance level of close to 400 cd/m^2. The actual luminance shall be reported.

Step 2: Allow the system to warm-up for an optimum time to reach stable state.

Step 3: Measure the absolute XYZ tristimulus values every five minutes for a total of seven sets of $X_iY_iZ_i$ tristimulus values. Suffix i (i = 1,7) describes seven different measurements per one day. And calculate mean $Y_{S,\ mean}$ value using seven Y_i data.

NOTE The XYZ tristimulus values are simply calculated using convolution operation of the colour-matching function and spectral distribution.

Step 4: Calculate u_S' and v_S' chromaticity using the absolute $X_iY_iZ_i$ tristimulus values:

$$u_i' = 4X_i / (X_i + 15Y_i + 3Z_i) \tag{3}$$

$$v_i' = 9Y_i / (X_i + 15Y_i + 3Z_i) \tag{4}$$

Refer ISO/CIE 11664-5 for u' and v' calculation.

Step 5: Calculate standard deviations $\sigma(Y_S)$, $\sigma(u_S')$ and $\sigma(v_S')$ of the 7 measurements.

Step 6: Report $Y_{S,\ mean}$, $\sigma(Y_S)$, $\sigma(u_S')$ and $\sigma(v_S')$.

4.3.8.3 Long-term repeatability

The following specifies the method for characterizing intermittent use repeatability.

Steps 1 to 2 described in 4.3.8.2 are repeated seven times over the course of seven different days. Power on/off is executed on each measurement day.

Step 3: Measure the absolute $X_jY_jZ_j$ tristimulus values for seven days. Suffix j (j = 1,7) describes seven different days. And calculate mean $Y_{L,\ mean}$ value using seven Y_j data.

Step 4: Calculate u_L' and v_L' chromaticity using the absolute $X_jY_jZ_j$ tristimulus values. Same formulae in step 4 of 4.3.8.2 are used

Step 5: Calculate standard deviations $\sigma(Y_L)$, $\sigma(u_L')$ and $\sigma(v_L')$ of the 7 measurements.

Step 6: Report $Y_{L,\ mean}$, $\sigma(Y_L)$, $\sigma(u_L')$ and $\sigma(v_L')$.

4.4 Reporting form

Reporting form for PLES hardware evaluation is described in Table 2.

Table 2 — Reporting form for hardware requirements

Classification	Content
Date of measurement	yyyy.mm.dd
Model name	xxxxxxxxx

Table 2 *(continued)*

Classification	Content
Operating conditions	Temperature: xx,x °C Relative humidity: xx,x %
Wavelength range	xxxx nm – yyyy nm
Bit-depth resolution for A/D conversion	xx bits
Window size	Xx mm ϕ
Luminance(maximum)	xxx,x cd/m^2
Uniformity	ΔY_u: x,x %
Angular characteristics	ΔY_θ: x,x %
Short-term repeatability Mean luminance level $Y_{\mathrm{S,\,mean}}$ $\sigma(Y_\mathrm{S})$ $\sigma(u_\mathrm{S}')$ $\sigma(v_\mathrm{S}')$	xxx,xx cd/m^2 $\sigma(Y_\mathrm{S})$: 0,xxxxx cd/m^2 $\sigma(u_\mathrm{S}')$: 0,000xxxx $\sigma(v_\mathrm{S}')$: 0,000xxxx
Long-term repeatability Mean luminance level $Y_{\mathrm{L,\,mean}}$ $\sigma(Y_\mathrm{L})$ $\sigma(u_\mathrm{L}')$ $\sigma(v_\mathrm{L}')$	xxx,xx cd/m^2 $\sigma(Y_\mathrm{L})$: x,xxxx cd/m^2 $\sigma(u_\mathrm{L}')$: 0,000xxxx $\sigma(v_\mathrm{L}')$: 0,000xxxx

5 Generation and evaluation of a spectral match

5.1 Generation of a spectral match

Figure 1 shows a cross-section of an example of the PLES.

In the ideal linear case, the light output of the PLES will be a linear combination of the individual amounts of the individual lights. Since generalized numerical optimization will likely be used with popular software applications to compute a given spectrum, this class of problem is most commonly posed using simple vector space arithmetic style convention extensions to linear algebra. The amounts of the spectral power distributions of the individual lights required to best match a given reference spectrum is given by:

$$\boldsymbol{r} = \boldsymbol{La} \tag{6}$$

where

$\boldsymbol{r}$ is a column vector containing the reference spectrum specified for each wavelength;

$\boldsymbol{L}$ is a matrix containing columns for each light spectrum from which the match to the reference spectrum will be computed and rows for each specified wavelength;

$\boldsymbol{a}$ is a resulting vector containing the amounts of the individual light spectra that best match the reference spectrum.

Either or both of $\boldsymbol{r}$ and $\boldsymbol{L}$ may be relative or absolute since $\boldsymbol{a}$ are the absolute amounts of the scale of $\boldsymbol{L}$ that best match the scale of $\boldsymbol{r}$, given that $\boldsymbol{r}$ and $\boldsymbol{L}$ have the same units and correct dimensions.

The solution for $\boldsymbol{a}$ is found by using generalized numerical optimization to minimize residual error in:

$$\text{error} = \left\| f(\boldsymbol{r}) - f(\boldsymbol{La}) \right\| \tag{7}$$

which solves for $\boldsymbol{a}$ such that the difference between the reference spectrum and the best match are minimized in accordance with the merit function f. An example spectral match generation solution using RMS as the merit function for f is given in Annex A.

Since it will not generally be possible to produce an exact spectral match to the reference spectrum, the merit function will include any necessary constraints or other considerations and will be application-specific. The amounts will have a lower bound of 0 since it is not possible to have negative lights, but no upper bound. Amounts greater than unity indicate that the power of the lights is insufficient to match the scale of the reference spectrum and that adjustments in scale or power are required, or that a relative match may be created by scaling the elements of $\boldsymbol{a}$ to the maximum element of $\boldsymbol{a}$.

5.2 Evaluation of a spectral match

Once the amounts of the lights that best match the reference spectrum have been determined, the predicted spectral match $\boldsymbol{m}$ is:

$$\boldsymbol{m} = \boldsymbol{La} \tag{8}$$

and the error e between the reference spectrum and the spectral match is given by:

$$e = g(\boldsymbol{r}, k\boldsymbol{m}) \tag{9}$$

where

- g is the evaluation function;
- k is the computed scale factor that minimizes e between any arbitrary $\boldsymbol{r}$ and $\boldsymbol{m}$.
- $\boldsymbol{m}$ is the intended PLES output and should be confirmed by spectral measurement.

For application-specific evaluation, the generation and evaluation functions should be identical since these functions (and therefore the resulting error metric) are application-specific.

For the case where multiple PLES devices produce potentially different matches to the same reference, the same uniform evaluation function shall be used for the evaluation of all matches, irrespective of any application-specific merit function used to generate the spectral match.

An example spectral match, scaling, and evaluation is given in Annex A.

Annex A
(informative)

Spectral match generation, scaling, and evaluation examples

A.1 Generation

The simplest case in Formula (6) is the unconstrained solution for the amounts of the individual light spectra that minimize the spectral error between the reference spectrum and the computed match with the solution given by Formula (A.1):

$$\boldsymbol{a} = \left[\boldsymbol{L}^t \boldsymbol{L}\right]^{-1} \boldsymbol{L}^t \boldsymbol{r} \tag{A.1}$$

The implied merit function in Formula (7) is the sum of squares errors between reference and match as given in Formula (A.2):

$$f = \left\| \boldsymbol{r} - \boldsymbol{La} \right\|^2 \tag{A.2}$$

A.2 Scaling

There may be cases where it may be desirable to scale the resulting spectral match in Formula (8) before comparing to the intended target reference spectrum:

— the resulting scale of $\boldsymbol{a}$ exceed unity and have been scaled to create a relative match;

— the power or scale of $\boldsymbol{L}$ are insufficient to match the power or scale of $\boldsymbol{r}$;

— different matches to the same reference are compared from different PLES devices whose sets of lights may be different from each other;

— the same evaluation function g is used to evaluate various matches to $\boldsymbol{r}$, irrespective of the actual merit function used to generate the match.

There are many possible scaling candidates such as peak wavelength, average power, etc., but may have the disadvantage that such scaling can exaggerate apparent errors at some wavelengths while minimizing apparent errors at others, especially if the merit function is unknown. For any merit function, the optimal scalar k which minimizes f above, for example, with a given $\boldsymbol{r}$ and any $\boldsymbol{m}$ is given by Formula (A.3):

$$k = \left[\boldsymbol{m}^t \boldsymbol{m}\right]^{-1} \boldsymbol{m}^t \boldsymbol{r} \tag{A.3}$$

and the scaled match $\boldsymbol{m}'$ becomes Formula (A.4):

$$\boldsymbol{m} \; = k\boldsymbol{m} \tag{A.4}$$

A.3 Evaluation

In the general case, the merit and evaluation functions are not identical. However, the merit function may not be known to the evaluator, or it may be desirable to use a uniform scale-invariant metric (i.e. relative sum-of-squares errors between reference and match) such as Formula (A.5):

$$g = \|\boldsymbol{r} - \boldsymbol{m}'\| / \sum \boldsymbol{r} \tag{A.5}$$

This example of g is referred to as *N-RMS* in this document. *N-RMS* is scale-invariant and *N-RMS* may be useful in comparing arbitrary sets of (scaled) spectral power distributions.

A.4 Repeatability, constant signal to noise measure

In rare cases, it may be known a-priori that the signal to noise ratio of the PLES is constant across all power level for a given illuminant. When this is guaranteed, an additional Coefficient of variation metric may be optionally included as shown in Formula (A.6):

$$Y_{CV} = \sigma(Y) / Y_{\mathrm{mean}} \tag{A.6}$$