TECHNICAL REPORT

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

Part 5: Colour targets including saturated colours for colour characteristic evaluation test for colorimetric image capture

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

Partie 5: Cibles de couleurs incluant des couleurs saturées pour l'essai d'évaluation des caractéristiques chromatiques pour la capture d'images en mode colorimétrique

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Foreword

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

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

Introduction

There are many application areas such as medical imaging, cosmetics, e-commerce, sales catalogue, fine art reproduction, art archive etc. where colorimetric image capture and colorimetric image reproduction are desired. When precise colorimetric reproduction is required for the subjects that include highly-saturated colours, it is desirable that overall sensor spectral sensitivities are close to linear combinations of CIE 1931 colour matching functions.

On the other hand, real DSCs have overall sensor spectral sensitivities that deviates from linear combination of CIE 1931 colour matching functions, and yet reproduces reasonable colours for general low-saturated colour objects. This is because most of spectral distribution of real-existing objects are well self-correlated in the wavelength direction. This is also true for the frequently-used colour target such as X-rite colour checker classic.

Therefore, when the precise colour reproduction is required for highly-saturated colour objects, it is important to use spectral distribution that are less self-correlated in the wavelength direction, for the evaluation of overall sensor spectral sensitivities.

For this purpose, Clause 3 proposes two methods for generating highly-saturated colour targets. The first method is statistical extension of existing objects spectra, and the second one is selection from artificial (LED-based) spectra.

Clause 4 then describes how these highly-saturated colour targets can be used for goodness evaluation of overall sensor spectral sensitivities. Applicability of several existing evaluation metrics (such as Vora's μ-factor and Sharma's FOM) are compared, using highly-saturated targets generated by the methods proposed in Clause 4.

Annex B gives details on colour gamut of boundary colour and Annex F gives more information on colour differences of patches of CDSW target.

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

Part 5: Colour targets including saturated colours for colour characteristic evaluation test for colorimetric image capture

1 Scope

This document describes sample methods to generate spectra for colour targets comprised of highly saturated colours for colour characteristic evaluation of colorimetric image capture capability of digital still cameras (DSCs).

2 Normative references

There are no normative references in this document.

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:

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

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

3.1
colour-difference-sensitive wavelength
CDSW
wavelength sensitive to colour difference

3.2
colour matching functions
tristimulus values of monochromatic stimuli of equal radiant power

[SOURCE: CIE Publication 17.4, 845-03-23]

3.3
digital still camera
DSC
device which incorporates an image sensor and produces a digital signal representing a still picture

[SOURCE: ISO 12232:2012, 3.40, modified — Notes 1 and 2 to entry have been deleted.]

3.4
light-emitting diode
LED
semiconductor diode that emits non coherent optical radiation through stimulated emission resulting from the recombination of electrons and photons, when excited by an electric current

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

3.5
overall sensor spectral sensitivities
OSSS
spectral sensitivities of overall sensor components, which could be derived as spectral sensitivities' product of optical elements (including IR/UV-cut filter), colour filter sets, and image sensor

3.6
tristimulus values
amounts of the three reference colour stimuli, in a given trichromatic system, required to match the colour of the stimulus considered. *(see colour matching functions)*

[SOURCE: CIE Publication 17.4, 845-03-22]

4 Highly-saturated colour targets

4.1 General

This document proposes two different methods for generating highly-saturated colour targets.

First one is "Extension of real existing spectra using an eigenvector method". Naturally existing saturated colour spectra are usually very difficult to obtain by measurement. Therefore, computed spectra are extended from the eigenvectors generated from spectral databases.

Second one is "Artificial (LED-based) spectra whose wavelength peak is on colour-difference-sensitive wavelength (CDSW)". Mathematical analysis was performed to select the wavelengths which were colour-difference-sensitive. Artificial (LED-based) spectra were then generated whose peak matches colour-difference-sensitive wavelength (CDSW).

4.2 Extension of real existing spectra using eigenvector method

4.2.1 General

The eigenvector-based procedure for generating highly-saturated colour targets is as follows:

— selection of spectral database (see 4.2.2);

— spectral reconstruction from the eigenvectors (see 4.2.3);

— calculation of boundary colours (see 4.2.3.2);

— calculation of saturated-colours using reference spectral distribution (see 4.2.3.3).

4.2.2 Selection of spectra database

The wavelength range and wavelength increment are user-definable. ISO 17321-1[7] described that the wavelength range is 380 nm to 730 nm with a sampling interval of 10 nm or less. The spectral distribution set selected depends on user's application.

The brightness level of the spectral distribution selected can be ignored because the brightness level is tuneable by scaling the eigenvectors used for spectral distribution reconstruction. Hue angle of the selected spectral distribution is very important and the use of evenly-spaced hue angle is recommended.

An example of the eigenvector sets (E_{ij}) is calculated on the selected spectral distribution set (described in Annex A).

4.2.3 Spectral reconstruction from the eigenvectors

4.2.3.1 General

Spectra from the original dataset using Formula 1 can be computed as linear combination of eigenvectors.

The following notation is used for this example:

M : number of wavelengths to be used,

N : number of eigenvectors to be used,

E_{ij} : i-th wavelength component of the j-th eigenvector ($i = 1, M$; $j = 1, N$),

w_j : weight of j-th eigenvector ($j = 1, N$),

r_i : i-th wavelength component of a spectrum ($i = 1, M$).

$$r_i = \sum_{j=1}^{N} \left(w_j \cdot E_{ij} \right) \tag{1}$$

Conversely, the weights required to reconstruct a reflectance spectrum from the dataset are a linear combination of the reflectance spectrum and the eigenvectors:

$$w_j = \sum_{i=1}^{M} \left(r_i \cdot E_{ij} \right) \tag{2}$$

Two cases are considered here:

a) The boundary colour case determines the set of spectra that represent the chromatic limit as a function of hue maximally achievable based on the fundamental characteristics of an underlying spectral dataset where the resulting spectra are linear combinations of a subset of selected dataset eigenvectors.

b) The saturated colour case produces arbitrary highly saturated spectra from a linear combination of a subset of selected eigenvectors of a spectral dataset even though the target spectra are not from the dataset from which the eigenvectors are computed and therefore will only be an approximate match to the target spectra.

Both use Formula (1) but have different constraint conditions for the optimization process.

4.2.3.2 Boundary colour generation

Boundary colours are those colours whose spectral distributions have maximum chroma for a given hue angle.

There are numerous ways to identify which spectral reflectance vectors r_i have to be selected. The simplest method is to index through all weights w_j at a reasonable increment to produce a large set of r_i, compute the resulting hue and chroma values for the set of r_i, then select the subset of r_i that yields maximum chroma for each hue angle of interest.

However, it is preferred to recast Formula (1) so that it can be constrained for maximum chroma, hue angle, smoothness, or other conditions that are suitable for the intended application and to use general-purpose numerical optimization methods to solve for the optimal weights w_j directly. The resulting spectral reflectance vector r_i is constrained to the range [0,0,1.0]. Annex H describes those spectral distributions.

4.2.3.3 Saturated-colour generation using the reference spectra distribution set

It is possible to approximate an arbitrary target spectrum *r* using the eigenvectors of a spectral dataset, even if the target spectrum does not share the same fundamentals as the reference spectral dataset from which the eigenvectors were derived. This approximation *r*' is the least-squares match to the target spectrum *r*, typically subject to constraints.

For instance, it is possible to calculate highly saturated colour target spectra *r*' having a C^* value larger than a reference spectrum while maintaining L^* and hue angle. This C^* for each reference colour target is determined prior to nonlinear optimization described in Annex C. Objective parameter for nonlinear optimization is to keep predetermined C^*. Annex C shows an example in the case of Pointer's surface colours. There are many metamers of the candidate spectrum and users need to select the appropriate spectrum from many metamers. This step is applicable to other cases where any reference distribution and its objective chromaticity are given.

Annex C shows a generation method which calculates spectral distribution corresponding to CIELAB values of Pointer's surface colour[6]. Annex H describes those spectral distributions.

Given an arbitrary highly saturated target spectrum *r*, the goal is to produce an approximate match *r*' from a selected subset of the eigenvectors of the reference spectral dataset. However, there are many possible candidate matches *r*' depending on the initial w_j selected for the optimization process. One approach is to compute the starting weights for nonlinear numerical optimization with Formula 2. The weights *w* are substituted into Formula 1 producing an approximate match *r*' and *w* is iterated until the error between *r*' and *r* is minimized. Using generalized numerical optimization, this method calculates w_j to minimize the sum of the squares of the differences between the closest matching spectrum achievable *r*' by the selected eigenvector subset.

4.3 Artificial (LED-based) spectra whose wavelength peak is on colour-difference-sensitive wavelength (CDSW)

4.3.1 General

The wavelength range for colour target spectra for camera uses is from 380 nm to 730 nm according to ISO 17321-1.

The CDSW-based procedure for generating highly-saturated colour targets is as follows:

— The method to define CDSW (See 4.3.2)

— Selection of CDSW (See 4.3.3)

4.3.2 The method to define the colour-difference-sensitive wavelength (CDSW)

Factors of colour difference, *Fac_a** and *Fac_b** are defined based on the colour matching functions as shown in Formulae (3) and (4). *Fac_a** and *Fac_b** are function of X and Z, respectively. The reasons and the processes of deriving *Fac_a** and *Fac_b** are described in Annex D.

$$Fac\_a^*(\lambda) = 500 \times \left\{ f\left(\frac{\breve{x}(\lambda)}{Xn} \right) - \frac{16}{116} \right\} \quad (3)$$

$$Fac\_b^*(\lambda) = 200 \times \left\{ f\left(\frac{\breve{z}(\lambda)}{Zn} \right) - \frac{16}{116} \right\} \quad (4)$$

where

$$f(t)=\begin{cases} t^{1/3}, & t>0,008856 \\ 7,787\times t+0,138. & t\leq 0,008856 \end{cases}$$

Xn=0,9504, Zn=1,0889

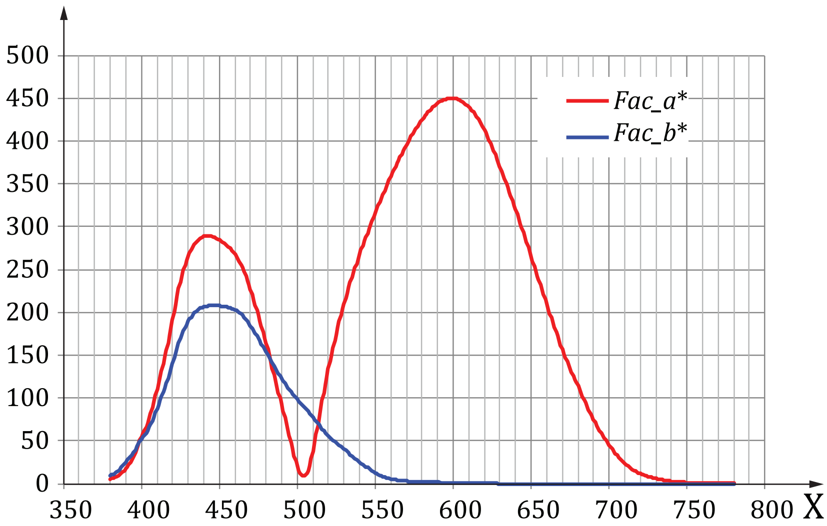
$$\text{Diff } Fac\_a^*(\lambda)=\frac{Fac\_a^*(\lambda+\Delta)-Fac\_a^*(\lambda)}{\Delta} \quad (5)$$

$$\text{Diff } Fac\_b^*(\lambda)=\frac{Fac\_b^*(\lambda+\Delta)-Fac\_b^*(\lambda)}{\Delta} \quad (6)$$

Calculated values of the factors are drawn against wavelength in Figure 1. It can be said that the wavelength where the colour difference between the colour matching functions and the camera is most likely to be the maximum and peak wavelength of the slope of the waveform in Figure 1. Wavelength ranges where the Δa^* and Δb^* have peak values are very similar to those of the maximum, minimum and inflection points of the curves of the factors.

In order to find those points, the derivatives of Fac_a^* and Fac_b^* with wavelength as shown in Formulae (5) and (6) are calculated (Figure 2). Wavelengths at which large colour differences most likely appear are determined by the points where the derivative is maximum, minimum and crosses zero from plus to minus and vice versa. Wavelengths corresponding to those points are 420 nm, 440 nm, 480 nm, 500 nm, 505 nm, 510 nm, 600 nm and 650 nm. These wavelengths are listed Table 1 and also indicated in Figure 2.

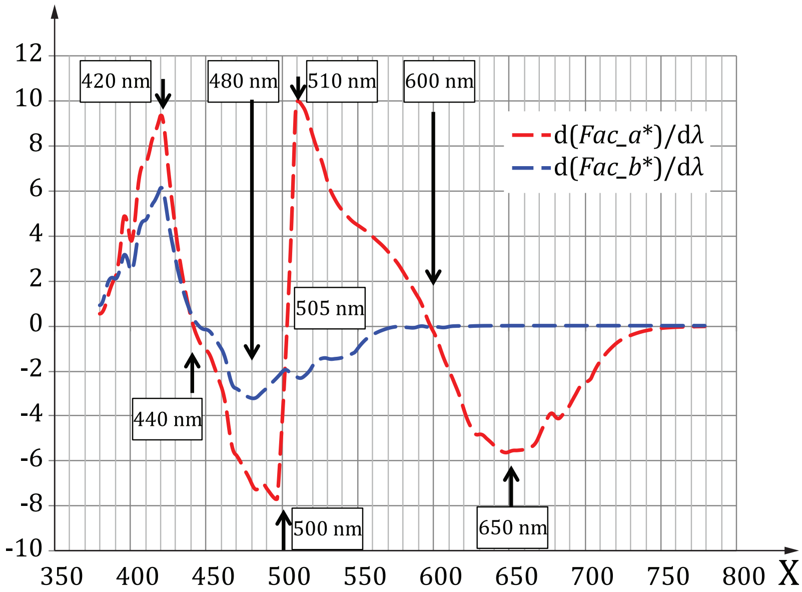
NOTE The reasons why we use the wavelength where the derivative is maximum, minimum and zero are as follows. The optimization process to obtain conversion matrix from camera sensitivity to colour matching function was carried out using the least square method to minimize ΔS. In the process, each one of transformed XYZ functions is adjusted to one of the matching functions by increasing (decreasing) intensity at peak wavelength where the derivative is zero, and simultaneously decreasing (increasing) it at steep slope's wavelength where the derivative is maximum or minimum. Therefore, at wavelengths where derivative is maximum, minimum and zero, colour differences can often appear.



Key

X wavelength, λ, in nm

Figure 1 — *Fac_a and *Fac_b**plot against wavelength**



Key

X wavelength, λ, in nm

Figure 2 — Differentiated values of *Fac_a and *Fac_b***

Wavelengths of 500 nm, 505 nm and 510 nm are very close to each other and their effect on colour difference is similar and so the wavelength of 505 nm is chosen to represent these three wavelengths.

Table 1 — Candidate of CDSW corresponding to maximum, minimum and zero of derivative

	420	440	480	500	505	510	600	650
d(*Fac_a**)/dλ	max	0	min	↗	0	max	0	min
d(*Fac_b**)/dλ	max	0	↘	min	↗	↗	→	→

↗,↘ and →signs in Table 1 mean “increase”, “decrease” and “no change” respectively.

Based on this analysis, wavelengths of 420 nm, 440 nm, 480 nm, 505 nm, 600 nm and 650 nm are selected as the colour-difference-sensitive wavelengths (CDSW).

4.3.3 Selection of LED for CDSW targets

In the next step, the spectral distribution of highly saturated colour target will be specified based on CDSWs.

It is ideal for CDSW target to use laser devices. However considering availability at this time, LEDs are recommended and may be more practical. Appropriate devices in accordance with technology progress in future will be adopted.

It is recommended that LEDs used for CDSW targets have the following conditions.

— Use existing LEDs which has the peak wavelength of LEDs is within +- 3 nm of CDSWs,

— Or Find similar LEDs with the peak wavelength defined by CDSW (peak does not have to be exact).

— Find LED-like width and generate the spectra artificially.

