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Colorimetry —

Part 6: CIEDE2000 colour-difference formula

Colorimétrie —

Partie 6: Formule de la différence de couleur CIEDE2000

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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 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 the International Commission on Illumination (CIE) in cooperation with Technical Committee ISO/TC 274, *Light and lighting*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 139, *Paints and varnishes*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO/CIE 11664-6:2014), of which it constitutes a minor revision. The changes are as follows:

— normative references updated;

— previous Clause 3 split into Clauses 3 and 4;

— Clause 6: previous NOTE 1 changed to body text;

— minor editorial changes.

A list of all parts in the ISO/CIE 11664 series can be found on the ISO website and the CIE website.

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

Introduction

The three-dimensional colour space produced by plotting CIE tristimulus values (X, Y, Z) in rectangular coordinates is not visually uniform. Neither is the (x, y, Y) space nor the two-dimensional CIE (x, y) chromaticity diagram. Equal distances in these spaces and the respective diagram do not represent equally perceptible differences between colour stimuli. For this reason, the CIE has standardized two more-nearly uniform colour spaces (known as CIELAB and CIELUV), whose coordinates are non-linear functions of X, Y and Z. Numerical values representing approximately the relative magnitude of colour differences can be described by simple Euclidean distances in these spaces or by more sophisticated colour-difference formulae that improve the correlation with the relative perceived size of differences. The purpose of this document is to define one such formula, the CIEDE2000 formula. This document is based on CIE 142-2001.

The formula is an extension of the CIE 1976 $L^*a^*b^*$ colour-difference formula (ISO/CIE 11664-4) with corrections for variation in colour-difference perception dependent on lightness, chroma, hue and chroma-hue interaction. Reference conditions define material and viewing environment characteristics to which the formula applies.

Colorimetry —

Part 6:
CIEDE2000 colour-difference formula

1 Scope

This document specifies the method of calculating colour differences according to the CIEDE2000 formula.

This document is applicable to input values of CIELAB L^*, a^*, b^* coordinates calculated according to ISO/CIE 11664-4. It can be used for the specification of the colour difference between two colour stimuli perceived as belonging to reflecting or transmitting objects. This includes displays if they are being used to simulate reflecting or transmitting objects and if the tristimulus values representing the stimuli are appropriately normalized.

This document does not apply to colour stimuli perceived as belonging to areas that appear to be emitting light as primary light sources or that appear to be specularly reflecting such light.

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/CIE 11664-4, *Colorimetry — Part 4: CIE 1976 L*a*b* colour space*

CIE S 017, *ILV: International Lighting Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in CIE S 017 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/

CIE maintains a terminology database for use in standardization at the following address:

— CIE e-ILV: available at https://cie.co.at/e-ilv

4 Symbols

L^*	CIELAB lightness
a^*, b^*	CIELAB a^*, b^* coordinates
C^*_{ab}	CIELAB chroma
h_{ab}	CIELAB hue angle

L'	CIEDE2000 lightness
$\overline{L'}$	arithmetic mean of the CIEDE2000 lightnesses of two colour stimuli
a', b'	CIEDE2000 a', b' coordinates
C'	CIEDE2000 chroma
$\overline{C'}$	arithmetic mean of the CIEDE2000 chromas of two colour stimuli
h'	CIEDE2000 hue angle
$\overline{h'}$	arithmetic mean of the CIEDE2000 hue angles of two colour stimuli
G	switching function used in the modification of a^*
$\Delta L'$	CIEDE2000 lightness difference
$\Delta C'$	CIEDE2000 chroma difference
$\Delta h'$	CIEDE2000 hue-angle difference
$\Delta H'$	CIEDE2000 hue difference
ΔE_{00}	CIEDE2000 colour difference
S_L	lightness weighting function
S_C	chroma weighting function
S_H	hue weighting function
T	T-function for hue weighting
R_T	rotation function
$\Delta\theta$	hue dependence of rotation function
R_C	chroma dependence of rotation function
k_L	lightness parametric factor
k_C	chroma parametric factor
k_H	hue parametric factor

5 Reference conditions

The CIEDE2000 formula is intended to be applicable to objects viewed under the following reference conditions:

— Illumination: source simulating the relative spectral irradiance of CIE standard illuminant D65.

— Illuminance: 1 000 lx.

— Observer: normal colour vision.

— Background field: uniform, neutral grey with L^* = 50.

— Viewing mode: object.

— Sample size: sample pair subtending a visual angle greater than 4°.

— Sample separation: minimum sample separation achieved by placing the sample pair in direct edge contact.

— Sample colour-difference magnitude: 0 to 5 CIELAB units.

— Sample structure: homogeneous colour without visually apparent pattern or non-uniformity.

When conditions of use deviate appreciably from the reference conditions, parametric factors may be used to correct for the effects of material or experimental variables, as described in Clause 7.

NOTE CIE 230:2019 discusses and shows some application limitations of CIEDE2000 for CIELAB colour differences < 2 units.

6 Calculation method

All angular quantities in this document shall be evaluated in degrees.

CIELAB L^*, a^*, b^* and C^*_{ab} coordinates of the two samples shall be calculated according to ISO/CIE 11664-4.

Modified CIELAB coordinates shall be calculated according to Formulae (1) to (7).

$$L' = L^* \tag{1}$$

$$a' = (1+G)\,a^* \tag{2}$$

$$b' = b^* \tag{3}$$

$$C' = (a'^2 + b'^2)^{1/2} \tag{4}$$

$$h' = \begin{cases} \arctan\left(\dfrac{b'}{a'}\right) & \text{if} \quad a' > 0 \quad \text{and} \quad b' \geq 0 \\ \arctan\left(\dfrac{b'}{a'}\right) + 360° & \text{if} \quad a' > 0 \quad \text{and} \quad b' < 0 \\ \arctan\left(\dfrac{b'}{a'}\right) + 180° & \text{if} \quad a' < 0 \\ 90° & \text{if} \quad a' = 0 \quad \text{and} \quad b' > 0 \\ 270° & \text{if} \quad a' = 0 \quad \text{and} \quad b' < 0 \end{cases} \tag{5}$$

$$h' = 0° \text{ if } \quad a' = 0 \quad \text{and} \quad b' = 0 \tag{6}$$

where

$$G = 0{,}5\left(1 - \sqrt{\frac{\left(\overline{C^*_{ab}}\right)^7}{\left(\overline{C^*_{ab}}\right)^7 + 25^7}}\right) \tag{7}$$

and $\overline{C^*_{ab}}$ is the arithmetic mean of the C^*_{ab} values for the two samples of the colour-difference pair.

Formula (5) ensures that h' is the angular position of the point a', b' in the range from 0° to 360° measured from the positive a' axis in the a', b' plane. In cases where $a' = b' = 0$, h' is indeterminate and shall be assigned a value of zero as indicated in Formula (6).

The L', a', b', C' and h' values should be used only for the calculation of colour difference and should not be used as an alternative uniform colour space. When reporting CIELAB colour space coordinates, L^*, a^*, b^*, C^*_{ab} and h_{ab} values should be used.

Differences between two samples denoted by subscripts 0 (usually the reference) and 1 (usually the test) shall be calculated according to Formulae (8) to (14).

$$\Delta L' = L'_1 - L'_0 \tag{8}$$

$$\Delta C' = C'_1 - C'_0 \tag{9}$$

$$\Delta H' = 2\left(C'_0\ C'_1\ \right)^{1/2} \sin(\Delta h'/2) \tag{10}$$

where

$$\Delta h' = 0° \qquad \text{if } C'_0\, C'_1 = 0 \tag{11}$$

$$\Delta h' = h'_1 - h'_0 \qquad \text{if } C'_0\, C'_1 \neq 0 \text{ and } |h'_1 - h'_0| \leq 180° \tag{12}$$

$$\Delta h' = h'_1 - h'_0 - 360° \qquad \text{if } C'_0\, C'_1 \neq 0 \text{ and } (h'_1 - h'_0) > 180° \tag{13}$$

$$\Delta h' = h'_1 - h'_0 + 360° \qquad \text{if } C'_0\, C'_1 \neq 0 \text{ and } (h'_1 - h'_0) < -180° \tag{14}$$

NOTE 1 Formulae (11) to (14) avoid possible computational difficulties when h'_0 and h'_1 are in different quadrants or when one of the chromas is zero. They are based on Reference [6].

NOTE 2 In information technology and other fields, the subscripts r (for reference) and t (for test) are sometimes used instead of 0 and 1, respectively. Similarly, in industrial evaluation of small colour differences, s (for standard) and b (for batch) are sometimes used.

A three-term version of Formula (15) valid in a micro-space around the reference is given in Annex A.

The CIEDE2000 colour difference, ΔE_{00}, between the two samples shall be calculated according to Formula (15).

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)\right]^{1/2} \tag{15}$$

where the symbols are defined according to Formulae (8) to (10) and Formulae (16) to (22):

$$S_L = 1 + \frac{0{,}015(\overline{L'} - 50)^2}{\sqrt{20 + (\overline{L'} - 50)^2}} \tag{16}$$

$$S_C = 1 + 0{,}045\,\overline{C'} \tag{17}$$

$$S_H = 1 + 0{,}015\,\overline{C'}\,T \tag{18}$$

$$T = 1 - 0{,}17\cos(\overline{h'} - 30°) + 0{,}24\cos(2\overline{h'}) + 0{,}32\cos(3\overline{h'} + 6°) - 0{,}20\cos(4\overline{h'} - 63°) \tag{19}$$

$$R_T = -\sin(2\Delta\theta)R_C \tag{20}$$

$$\Delta\theta = 30° \exp\{-[(\overline{h'} - 275°)/25°]^2\} \tag{21}$$

$$R_C = 2\sqrt{\frac{(\overline{C'})^7}{(\overline{C'})^7 + 25^7}} \tag{22}$$

k_L, k_C and k_H are parametric factors explained in Clause 7.

NOTE 3 The $\overline{L'}$, $\overline{C'}$ and $\overline{h'}$ values used in Formulae (16) to (22) are the arithmetic means of the corresponding values of the colour-difference pair. A consequence of this is that the total colour difference is reversible, that is, the total colour difference between a pair is the same whether the first or second sample is used as the standard for calculation of colour-difference components.

NOTE 4 The locus of points of equal total colour difference from a standard is not an exact ellipsoid and is not exactly centred on the standard.

Users should take care in calculating the mean hue angle if the colour-difference pair has samples in different quadrants. For example, if a colour-difference pair has hue angles of 30° and 300°, the simple mean, 165°, is incorrect, the correct value being 345°. To determine the mean correctly, Formulae (23) to (26)[6] shall be used.

$$\overline{h'} = (h'_0 + h'_1)/2 \qquad \text{if } |h'_0 - h'_1| \leq 180° \text{ and } C'_0\, C'_1 \neq 0 \tag{23}$$

$$\overline{h'} = (h'_0 + h'_1 + 360°)/2 \qquad \text{if } |h'_0 - h'_1| > 180° \text{ and } (h'_0 + h'_1) < 360° \text{ and } C'_0\, C'_1 \neq 0 \tag{24}$$

$$\overline{h'} = (h'_0 + h'_1 - 360°)/2 \qquad \text{if } |h'_0 - h'_1| > 180° \text{ and } (h'_0 + h'_1) \geq 360° \text{ and } C'_0\, C'_1 \neq 0 \tag{25}$$

$$\overline{h'} = h'_0 + h'_1 \qquad \text{if } C'_0\, C'_1 = 0 \tag{26}$$

NOTE 5 Some worked examples of the calculations are given in CIE 142-2001, Reference [4] and Reference [6]. Reference [6] also gives some useful implementation notes and mathematical observations.

7 Parametric factors

Experimental observation and material variables can have parametric effects that influence the visual colour-difference results.[1] The parametric factors k_L, k_C and k_H may be used to correct for these effects.

Under the reference conditions, the parametric factors have assigned values of unity and do not affect the total colour difference.

The parametric factors provide a method to correct for deviation in experimental conditions from the defined reference conditions. Users are cautioned against indiscriminate use of these parametric factors without thorough experimental validation. Industry groups may define parametric factors to correspond to typical experimental conditions for that industry.

NOTE In the textile industry it is common practice to set the lightness parametric factor to 2. However, the experimental conditions leading to this parametric correction to lightness-difference sensitivity are not yet well understood.