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Colorimetry —

Part 6:
CIEDE2000 Colour-difference formula

Colorimétrie —

Partie 6: Formule d'écart de couleur CIEDE2000

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Foreword

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ISO/CIE 11664-6 was prepared by CIE Technical Committee TC 1-57 of Division 1 *Vision and colour*. as CIE S 014-6.

ISO/CIE 11664 consists of the following parts, under the general title *Colorimetry*:

— *Part 1: CIE standard colorimetric observers*

— *Part 2: CIE standard illuminants*

— *Part 3: CIE tristimulus values*

— *Part 4: CIE 1976 L*a*b* Colour space*

— *Part 5: CIE 1976 L*u*v* Colour space and u', v' uniform chromaticity scale diagram*

— *Part 6: CIEDE2000 Colour-difference formula*

CIE S 014-6/E:2013

COMMISSION INTERNATIONALE DE L'ECLAIRAGE
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International Standard

Colorimetry –
Part 6: CIEDE2000 Colour-Difference Formula

Colorimétrie – Partie 6: Formule d'écart de couleur CIEDE2000

Farbmessung – Teil 6: CIEDE2000-Farbabstandsformel

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Foreword

International Standards produced by the Commission Internationale de l'Eclairage are concise documents on aspects of light and lighting that require a unique definition. They are a primary source of internationally accepted and agreed data which can be taken, essentially unaltered, into universal standard systems.

This CIE International Standard has been prepared by CIE Technical Committee TC 1-57*. It has been approved by the Board of Administration and Division 1 "Vision and Colour" of the Commission Internationale de l'Eclairage and the CIE National Committees.

The following ISO and IEC committees and working groups co-operated in the preparation of this International Standard:

IEC TC100/TA2 (Audio, video and multimedia systems)

ISO TC6 (Paper, board and pulps)

ISO TC35/SC9/WG22 (Paints and varnishes)

ISO TC38/SC1/WG7 (Textiles)

ISO TC42 (Photography)

ISO TC130 (Graphic technology)

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CONTENTS

Colorimetry – Part 6: CIEDE2000 Colour-Difference Formula

Introduction

The three-dimensional colour space produced by plotting CIE tristimulus values (X, Y, Z) in rectangular coordinates is not visually uniform, nor is the (x, y, Y) space nor the two-dimensional CIE (x, y) chromaticity diagram. Equal distances in these spaces and diagrams 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 CIE International Standard is to define one such formula, the CIEDE2000 formula. The Standard is based on CIE Technical Report 142-2001.

The formula is an extension of the CIE 1976 $L^*a^*b^*$ colour-difference formula (ISO 11664-4:2008(E)/CIE S 014-4/E:2007) 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.

1 Scope

This CIE International Standard specifies the method of calculating colour differences according to the CIEDE2000 formula.

The Standard is applicable to input values of CIELAB L^*, a^*, b^* coordinates calculated according to ISO 11664-4:2008(E)/CIE S 014-4/E:2007. The Standard may 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. The Standard 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 referenced documents are indispensable for the application 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.

CIE 142-2001. *Improvement to industrial colour-difference evaluation*, 2001.

CIE S 017/E:2011. *ILV: International Lighting Vocabulary*, 2011.

ISO 11664-4:2008(E)/CIE S 014-4/ E:2007. Joint ISO/CIE Standard: *Colorimetry – Part 4: 1976 L*a*b* Colour Space*, 2008.

3 Definitions, Symbols and Abbreviations

For the purposes of this International Standard, the terms and definitions given in CIE S 017/E:2011 (International Lighting Vocabulary), and the following symbols and abbreviations apply.

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

4 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 6.

NOTE 1 A proposed Technical Report of CIE TC 1-63 "Validity of the Range of CIE DE2000" will discuss and may show some application limitations of CIEDE2000 for CIELAB colour differences < 1 unit or > 5 units and for the CIE 1931 standard colorimetric observer (CIE 2 degree observer).

NOTE 2 A proposed Technical Report of CIE TC 1-81 "Validity of Formulae for Predicting Small Colour Differences" will discuss and may show some application limitations of CIEDE2000 for CIELAB colour differences < 2 units.

5 Calculation Method

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

CIELAB L^*, a^*, b^*, and C^*_{ab} coordinates of the two samples shall be calculated according to ISO 11664-4:2008(E)/CIE S 014-4/E:2007.

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

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

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

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

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

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

$$h' = 0^\circ \qquad \text{if} \quad a' = 0 \quad \text{and} \quad b' = 0 \quad (6)$$

where

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

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

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

NOTE 1 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 alter native 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 s ubscripts 0 (usually the reference) and 1 (usually the test) shall be calculated as follows:

$$\Delta L' = L'_1 - L'_0 \quad (8)$$

$$\Delta C' = C'_1 - C'_0 \quad (9)$$

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

where

$$\Delta h' = 0^\circ \qquad \text{if } C'_0 C'_1 = 0 \quad (11)$$

$$\Delta h' = h'_1 - h'_0 \qquad \text{if } C'_0 C'_1 \neq 0 \text{ and } \left|h'_1 - h'_0\right| \leq 180^\circ \quad (12)$$

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

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

NOTE 2 Equations (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 Sharma et al., 2005.

NOTE 3 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.

The CIEDE2000 colour difference, ΔE_{00} between the two samples shall be calculated by

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

where

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

$$S_C = 1 + 0{,}045\,\overline{C'} \quad (17)$$

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

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

$$R_T = -\sin(2\Delta\theta) R_C \quad (20)$$

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

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

k_L, k_C and k_H are parametric factors explained in Clause 6.

NOTE 4 The $\overline{L'}$, $\overline{C'}$ and $\overline{h'}$ values used in equations (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 5 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 30º and 300º, the simple mean, 165º, is incorrect, the correct value being 345º. To determine the mean correctly, the following equations (Sharma et al., 2005) shall be used.

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

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

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

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

NOTE 6 Some worked examples of the calculat ions are given in CIE 142-2001, Luo et al., 2001 and Sharma et al., 2005. Sharma et al. also give some useful implementation notes and mathematical observations.

6 Parametric Factors

Experimental observation and material variables can have parametric effects that influence the visual colour-difference results (CIE, 1993). 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.

Annex A
(Informative)
Three-Component Micro-Spaces

For certain applications, such as apportioning a colour difference into lightness, chroma and hue components for shade sorting and attributing size and direction to a specific difference in recipe prediction, it is useful to have a three-term version of equation (15) valid in a micro-space around the reference. The following equations accomplish this (Nobbs, 2002).

$$\tan(2\varphi) = R_{\mathrm{T}} \frac{(k_{\mathrm{C}} S_{\mathrm{C}})(k_{\mathrm{H}} S_{\mathrm{H}})}{(k_{\mathrm{H}} S_{\mathrm{H}})^2 - (k_{\mathrm{C}} S_{\mathrm{C}})^2} \tag{A.1}$$

with φ taken to be between –90° and 90°.

NOTE 1 If $k_{\mathrm{H}}S_{\mathrm{H}} = k_{\mathrm{C}}S_{\mathrm{C}}$, then 2φ is equal to 90° and φ is equal to 45°.

$$\Delta C'' = \Delta C' \cos(\varphi) + \Delta H' \sin(\varphi) \tag{A.2}$$

$$\Delta H'' = \Delta H' \cos(\varphi) - \Delta C' \sin(\varphi) \tag{A.3}$$

$$S''_{\mathrm{C}} = (k_{\mathrm{C}} S_{\mathrm{C}}) \sqrt{\frac{2(k_{\mathrm{H}} S_{\mathrm{H}})}{2(k_{\mathrm{H}} S_{\mathrm{H}}) + R_{\mathrm{T}}(k_{\mathrm{C}} S_{\mathrm{C}}) \tan(\varphi)}} \tag{A.4}$$

$$S''_{\mathrm{H}} = (k_{\mathrm{H}} S_{\mathrm{H}}) \sqrt{\frac{2(k_{\mathrm{C}} S_{\mathrm{C}})}{2(k_{\mathrm{C}} S_{\mathrm{C}}) - R_{\mathrm{T}}(k_{\mathrm{H}} S_{\mathrm{H}}) \tan(\varphi)}} \tag{A.5}$$

$$\Delta L_{00} = \frac{\Delta L'}{k_{\mathrm{L}} S_{\mathrm{L}}} \tag{A.6}$$

$$\Delta C_{00} = \frac{\Delta C''}{S''_{\mathrm{C}}} \tag{A.7}$$

$$\Delta H_{00} = \frac{\Delta H''}{S''_{\mathrm{H}}} \tag{A.8}$$

$$\Delta E_{00} = [(\Delta L_{00})^2 + (\Delta C_{00})^2 + (\Delta H_{00})^2]^{1/2} \tag{A.9}$$

NOTE 2 Equation (A.9) gives a value of colour difference ΔE_{00} identical to that calculated using equation (15). However, the definition of the three-dimensional “micro-space” is different for each colour centre.

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