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Colorimetry —

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

Colorimétrie —

*Partie 5: Espace chromatique L*u*v* et diagramme de chromaticité uniforme u', v' CIE 1976*

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Foreword

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For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 274, *Light and lighting*.

This first edition of ISO/CIE 11664-5 cancels and replaces ISO 11664-5:2009, of which it constitutes a minor revision. (ISO 11664-5:2009 was prepared by CIE Technical Committee TC 1-57 of Division 1.)

ISO 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*

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

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

— *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, in 1976, the CIE introduced and recommended two new spaces (known as CIELAB and CIELUV) whose coordinates are non-linear functions of *X*, *Y* and *Z*. The recommendation was put forward in an attempt to unify the then very diverse practice in uniform colour spaces and associated colour difference formulae.[2][8] Both these more-nearly uniform colour spaces have become well accepted and widely used. Numerical values representing approximately the relative magnitude of colour differences can be described by simple Euclidean distances in the spaces or by more sophisticated formulae that improve the correlation with the relative perceived size of differences. The purpose of this part of ISO/CIE 11664 is to define procedures for calculating the coordinates of the CIE 1976 L*u*v* (CIELUV) colour space and the Euclidean colour difference values based on these coordinates. This part of ISO/CIE 11664 also defines a related chromaticity diagram that is a projection of the CIE x,y chromaticity diagram maintaining straight lines of dominant and complementary wavelengths. This part of ISO/CIE 11664 does not cover the alternative uniform colour space, CIELAB,[5] nor does it cover more sophisticated colour difference formulae based on CIELAB, such as the CMC formula,[3] the CIE 94 formula,[1] the DIN 99 formula,[4] and the CIEDE2000 formula.[6]

Colorimetry —

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

1 Scope

This part of ISO/CIE 11664 specifies the method of calculating the coordinates of the CIE 1976 L*u*v* colour space including correlates of lightness, chroma, saturation and hue. It includes two methods for calculating Euclidean distances in this space to represent the relative perceived magnitude of colour differences. It also specifies the method of calculating the coordinates of the u′,v′ uniform chromaticity scale diagram.

This part of ISO/CIE 11664 is applicable to tristimulus values calculated using the colour-matching functions of the CIE 1931 standard colorimetric system or the CIE 1964 standard colorimetric system. This part of ISO/CIE 11664 may be used for the specification of colour stimuli perceived as belonging to a reflecting or transmitting object, where a three-dimensional space more uniform than tristimulus space is required. This includes self-luminous displays, like cathode ray tubes, if they are being used to simulate reflecting or transmitting objects and if the stimuli are appropriately normalized. This part of ISO/CIE 11664, as a whole, does not apply to colour stimuli perceived as belonging to an area that appears to be emitting light as a primary light source or that appears to be specularly reflecting such light. Only the u′,v′ uniform chromaticity scale diagram defined in 4.1 and the correlates of hue and saturation defined in 4.3 apply to such colour stimuli.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11664–1/CIE S 014-1, *Colorimetry — Part 1: CIE standard colorimetric observers*

ISO 11664–2/CIE S 014-1, *Colorimetry — Part 2: CIE standard illuminants*

CIE S 017, *ILV: International Lighting Vocabulary*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

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

3.2 Symbols and abbreviated terms

X, Y, Z	tristimulus values of a test stimulus calculated using the colour-matching functions of the CIE 1931 standard colorimetric system (also known as the CIE 2° standard colorimetric system)
Y_n	tristimulus value, Y, of a specified white colour stimulus calculated using the colour-matching functions of the CIE 1931 standard colorimetric system
x, y	chromaticity coordinates of a test stimulus calculated using the colour-matching functions of the CIE 1931 standard colorimetric system
L^*	CIELUV lightness
u^*, v^*	CIELUV u^*,v^* coordinates
u', v'	CIE 1976 chromaticity coordinates
u'_n, v'_n	CIE 1976 chromaticity coordinates of a specified white stimulus
s_{uv}	CIELUV saturation
C^*_{uv}	CIELUV chroma
h_{uv}	CIELUV hue angle
$\Delta(u',v')$	CIELUV chromaticity difference
ΔL^*	CIELUV lightness difference
$\Delta u^*, \Delta v^*$	CIELUV u^*,v^* differences
ΔC^*_{uv}	CIELUV chroma difference
Δh_{uv}	CIELUV hue angle difference
ΔH^*_{uv}	CIELUV hue difference
ΔE^*_{uv}	CIELUV colour difference

If the character “Δ” is not available, it may be replaced by the character “D”.

The terms “CIE 1976 L*u*v*” and “CIELUV” may be used interchangeably.

Where tristimulus values are calculated using the colour-matching functions of the CIE 1964 standard colorimetric system (also known as the CIE 10° standard colorimetric system), a subscript 10 shall be added to all the above symbols.

4 Calculation method

4.1 Uniform chromaticity scale diagram (UCS diagram)

The CIE 1976 uniform chromaticity scale diagram is a projective transformation of the CIE x,y chromaticity diagram yielding perceptually more uniform colour spacing. It is produced by plotting, as abscissa and ordinate, respectively, quantities defined by the following formulae:

$$u' = 4X/\left(X + 15Y + 3Z\right) \tag{1}$$

$$v' = 9Y \Big/ \left(X + 15Y + 3Z \right) \tag{2}$$

where *X, Y, Z* are the tristimulus values of the test colour stimulus based on the CIE 1931 standard colorimetric system defined in ISO 11664-1/CIE S 014-1.

The same quantities may be obtained by the following formulae:

$$u' = 4x \Big/ \left(-2x + 12y + 3 \right) \tag{3}$$

$$v' = 9y \Big/ \left(-2x + 12y + 3 \right) \tag{4}$$

where *x* and *y* are obtained by the following formulae:

$$x = X \Big/ \left(X + Y + Z \right) \tag{5}$$

$$y = Y \Big/ \left(X + Y + Z \right) \tag{6}$$

Euclidean distances in this diagram can be used to represent approximately the relative perceived magnitude of colour differences between colour stimuli of negligibly different luminances, of approximately the same size, and viewed in identical surroundings, by an observer photopically adapted to a field with the chromaticity of CIE standard illuminant D65 defined in ISO 11664-2/CIE S 014-2. The values given by this part of ISO/CIE 11664 may not correlate well with relative perceived colour differences in other viewing conditions. The Euclidean distances are defined by the following formula:

$$\Delta \left(u', v' \right) = \left[\left(\Delta u' \right)^2 + \left(\Delta v' \right)^2 \right]^{1/2} \tag{7}$$

where

$$\Delta u' = u_1' - u_0' \tag{8}$$

$$\Delta v' = v_1' - v_0' \tag{9}$$

and the subscripts 0 (usually the reference) and 1 (usually the test) indicate the two stimuli being compared.

4.2 Uniform colour space

The CIE 1976 L*u*v* colour space is a three-dimensional, approximately uniform colour space produced by plotting in rectangular coordinates, *L**, *u**, *v**, quantities defined by the following formulae:

$$L^* = 116 f \left(Y / Y_{\mathrm{n}} \right) - 16 \tag{10}$$

$$u^* = 13 L^* \left(u' - u_{\mathrm{n}}' \right) \tag{11}$$

$$v^* = 13 L^* \left(v' - v_{\mathrm{n}}' \right) \tag{12}$$

where

$$f\left(Y/Y_n\right) = \left(Y/Y_n\right)^{1/3} \quad \text{if } \left(Y/Y_n\right) > \left(6/29\right)^3 \tag{13}$$

$$f\left(Y/Y_n\right) = \left(841/108\right)\left(Y/Y_n\right) + 4/29 \quad \text{if } \left(Y/Y_n\right) \leq \left(6/29\right)^3 \tag{14}$$

In these formulae, Y, u' and v' describe the test colour stimulus and Y_n, u'_n and v'_n describe a specified white stimulus.

In the case of simulated reflecting or transmitting objects produced on a self-luminous display, all the tristimulus values shall first be normalized by the same factor so that Y would be equal to 100 for an object with 100 % reflectance or transmittance.

If the angle subtended at the eye by the test stimulus is between about 1° and 4°, the tristimulus values X, Y, Z calculated using the colour-matching functions of the CIE 1931 standard colorimetric system should be used. If this angular subtense is greater than 4°, the tristimulus values X_{10}, Y_{10}, Z_{10} calculated using the colour-matching functions of the CIE 1964 standard colorimetric system should be used. The same colour-matching functions and the same specified white stimulus shall be used for all stimuli to be compared with each other.

If the tristimulus values X, Y, Z are obtained by spectrophotometry, the tristimulus values X_n, Y_n, Z_n of the specified white stimulus shall be calculated using the same method as used for the test stimulus (same colour-matching functions, same range and interval of wavelength, and same bandwidth). If the tristimulus values X, Y, Z are obtained by direct measurement using a tristimulus colorimeter, X_n, Y_n, Z_n shall be measured using the same tristimulus colorimeter and a white reflectance standard calibrated relative to a perfect reflecting diffuser.

NOTE 1 For real object colours, the specified white stimulus normally chosen for X_n, Y_n, Z_n is light reflected from a perfect reflecting diffuser illuminated by the same light source as the test object. In this case, X_n, Y_n, Z_n are the tristimulus values of the light source normalized by a common factor so that Y_n is equal to 100. For simulated object colours, the specified white stimulus normally chosen is one that has the appearance of a perfect reflecting diffuser, again normalized by a common factor so that Y_n is equal to 100.

NOTE 2 Examples of values of X_n, Y_n and Z_n for specific illuminants and specific calculation methods have been published.[2]

NOTE 3 Formula (14) is based on a suggestion by Reference [7].

NOTE 4 A value of 7,787 is approximately equal to the term (841/108) in Formula (14). The approximate value may be used in practice.

NOTE 5 A value of 0,008 856 is approximately equal to the term $(6/29)^3$ in Formula (13) and Formula (14). The approximate value may be used in practice.

NOTE 6 The fractions 6/29 and 4/29 in Formula (13) and Formula (14) are exactly equal to the fractions 24/116 and 16/116 appearing in CIE 15:2004.

NOTE 7 The term (841/108) in Formula (14) is derived from and exactly equal to $(1/3)(29/6)^2$.

NOTE 8 Formula (10) reduces to $L^* \approx 903{,}3(Y/Y_n)$ when $Y/Y_n \leq (6/29)^3$.

When CIELUV values are reported, they should be accompanied by all relevant information relating to the measurement conditions and the procedures used to calculate the input tristimulus values.

4.3 Correlates of lightness, saturation, chroma and hue

Approximate correlates of the perceived attributes lightness, saturation, chroma, and hue shall be calculated as follows:

CIE 1976 lightness: L^* as defined in 4.2

CIE 1976 u,v saturation (CIELUV saturation):

$$s_{uv} = 13\left[\left(u' - u'_n\right)^2 + \left(v' - v'_n\right)^2\right]^{1/2} \tag{15}$$

CIE 1976 u,v chroma (CIELUV chroma):

$$C^*_{uv} = \left[\left(u^*\right)^2 + \left(v^*\right)^2\right]^{1/2} \tag{16}$$

CIE 1976 u,v hue angle (CIELUV hue angle):

$$h_{uv} = \arctan\left(v^*/u^*\right) \tag{17}$$

The CIELUV hue angle, h_{uv}, shall lie between 0° and 90° if u^* and v^* are both positive, between 90° and 180° if v^* is positive and u^* is negative, between 180° and 270° if v^* and u^* are both negative, and between 270° and 360° if v^* is negative and u^* is positive.

4.4 Colour differences

Euclidean distances in CIELUV colour space can be used to represent approximately the relative perceived magnitude of colour differences between object colour stimuli of approximately the same size, viewed in identical white to middle-grey surroundings, by an observer photopically adapted to a field with the chromaticity of CIE standard illuminant D65 defined in ISO 11664-2/CIE S 014-2. The values given by this part of ISO/CIE 11664 may not correlate well with relative perceived colour differences in other viewing conditions.

Differences between two stimuli denoted by subscripts 0 (usually the reference) and 1 (usually the test) shall be calculated as follows:

$$\Delta L^* = L^*_1 - L^*_0 \tag{18}$$

$$\Delta u^* = u^*_1 - u^*_0 \tag{19}$$

$$\Delta v^* = v^*_1 - v^*_0 \tag{20}$$

$$\Delta C^*_{uv} = C^*_{uv,1} - C^*_{uv,0} \tag{21}$$

$$\Delta h_{uv} = h_{uv,1} - h_{uv,0} \tag{22}$$

$$\Delta H^*_{uv} = 2\left(C^*_{uv,1} \cdot C^*_{uv,0}\right)^{1/2} \sin\left(\Delta h_{uv}/2\right) \tag{23}$$

For small hue-angle differences, Formula (23) reduces to

$$\Delta H^*_{uv} \approx \left(C^*_{uv,1} \cdot C^*_{uv,0}\right)^{1/2} \Delta h_{uv} \tag{24}$$

where the value of Δh_{uv} is in radians.

If the line joining the two colours crosses the positive u^* axis, Formula (22) will give a value outside the range ±180°. In this case, the value of Δh_{uv} should be corrected by adding or subtracting 360° to bring it within this range.

NOTE 1 The quantity ΔH^*_{uv} is introduced to provide congruence with the perceptual understanding that a colour difference can be divided into a vector sum of a lightness difference, a chroma difference and a hue difference.

NOTE 2 The division of CIELUV colour differences into hue and chroma differences is progressively less useful as the absolute value of Δh_{uv} approaches 180°.

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. In other applications, std (for standard) and spl (for sample) are sometimes used.

The CIE 1976 u,v colour difference, ΔE^*_{uv}, between two colour stimuli is calculated as the Euclidean distance between the points representing them in the space:

$$\Delta E^*_{uv} = \left[\left(\Delta L^*\right)^2 + \left(\Delta u^*\right)^2 + \left(\Delta v^*\right)^2 \right]^{1/2} \tag{25}$$

or

$$\Delta E^*_{uv} = \left[\left(\Delta L^*\right)^2 + \left(\Delta C^*_{uv}\right)^2 + \left(\Delta H^*_{uv}\right)^2 \right]^{1/2} \tag{26}$$

These two definitions of ΔE^*_{uv} are equivalent.

Other ways of calculating ΔH^*_{uv} are as follows:

$$\Delta H^*_{uv} = \left[\left(\Delta E^*_{uv}\right)^2 - \left(\Delta L^*\right)^2 - \left(\Delta C^*_{uv}\right)^2 \right]^{1/2} \tag{27}$$

where ΔE^*_{uv} is calculated from Formula (25) and ΔH^*_{uv} has the same sign as Δh_{uv}

$$\Delta H^*_{uv} = k\left[2\left(C^*_{uv,1} \cdot C^*_{uv,0} - u^*_1 \cdot u^*_0 - v^*_1 \cdot v^*_0 \right) \right]^{1/2} \tag{28}$$

where $k = -1$ if $u^*_1 \cdot v^*_0 \geq u^*_0 \cdot v^*_1$; otherwise, $k = 1$ and

$$\Delta H^*_{uv} = \left(u^*_0 \cdot v^*_1 - u^*_1 \cdot v^*_0 \right) \Big/ \left[0{,}5\left(C^*_{uv,1} \cdot C^*_{uv,0} + u^*_1 \cdot u^*_0 + v^*_1 \cdot v^*_0 \right) \right]^{1/2} \tag{29}$$

NOTE 4 Formula (29) cannot be used when either of the compared chromas is zero and is imprecise when either chroma is close to zero.

NOTE 5 More details on the various methods of calculating ΔH^*_{uv} are given by Reference [9] for Formula (23), by Reference [11] for Formula (28), and by Reference [10] for Formula (29).

Annex A
(informative)

Reverse transformation

The following formulae represent the reverse transformation, i.e. the calculation of X, Y, Z when L^*, u^*, v^* are given.

$$f\left(Y/Y_n\right) = \left(L^* + 16\right)/116 \tag{A.1}$$

$$Y = Y_n\left[f\left(Y/Y_n\right)\right]^3 \qquad \text{if } L^* > 8 \tag{A.2}$$

$$Y = \left(108/841\right)Y_n\left[f\left(Y/Y_n\right) - 4/29\right] \quad \text{if } L^* \le 8 \tag{A.3}$$

$$u' = u^*/13L^* + u_n' \tag{A.4}$$

$$v' = v^*/13L^* + v_n' \tag{A.5}$$

$$x = 9u'/\left(6u' - 16v' + 12\right) \tag{A.6}$$

$$y = 4v'/\left(6u' - 16v' + 12\right) \tag{A.7}$$

$$X = xY/y \tag{A.8}$$

$$Z = \left(1 - x - y\right)Y/y \tag{A.9}$$

NOTE 1 The condition in Formula (A.2) is equivalent to $f\left(Y/Y_n\right) > 6/29$.

NOTE 2 The condition in Formula (A.3) is equivalent to $f\left(Y/Y_n\right) \le 6/29$.

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