SMPTE STANDARD

$Y'D'_ZD'_X$ Color-Difference Computations for High Dynamic Range X′Y′Z′ Signals

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Foreword

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SMPTE Engineering Documents are drafted in accordance with the rules given in its Standards Operations Manual.

SMPTE ST 2085 was prepared by Technology Committee 10E.

Intellectual Property

At the time of publication no notice had been received by SMPTE claiming patent rights essential to the implementation of this Standard. However, attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. SMPTE shall not be held responsible for identifying any or all such patent rights.

Introduction

This section is entirely informative and does not form an integral part of this Engineering Document.

This standard defines the color-difference computation to be used with high dynamic range X′Y′Z′ signals. The nonlinear encoding to X′Y′Z′ affects the optimization of weighting coefficients, as does the selection of a target color for zero color-difference. The coefficients defined in this document have been optimized for X′Y′Z′ encoded with the inverse of the EOTF defined in SMPTE ST 2084 to yield zero color-difference for a target of D65 (x,y chromaticity 0.3127, 0.3290, as specified in Section 3.1.1 of SMPTE RP 177) at 500 cd/m^2.

1 Scope

This standard defines $Y'D'_ZD'_X$ color-difference computations to be used with high dynamic range X′Y′Z′ signals. The computations have been optimized for the EOTF specified in SMPTE ST 2084, primarily for use in non-broadcast content.

2 Conformance Notation

Normative text is text that describes elements of the design that are indispensable or contains the conformance language keywords: "shall", "should", or "may". Informative text is text that is potentially helpful to the user, but not indispensable, and can be removed, changed, or added editorially without affecting interoperability. Informative text does not contain any conformance keywords.

All text in this document is, by default, normative, except: the Introduction, any section explicitly labeled as "Informative" or individual paragraphs that start with "Note:"

The keywords "shall" and "shall not" indicate requirements strictly to be followed in order to conform to the document and from which no deviation is permitted.

The keywords, "should" and "should not" indicate that, among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited.

The keywords "may" and "need not" indicate courses of action permissible within the limits of the document.

The keyword “reserved” indicates a provision that is not defined at this time, shall not be used, and may be defined in the future. The keyword “forbidden” indicates “reserved” and in addition indicates that the provision will never be defined in the future.

A conformant implementation according to this document is one that includes all mandatory provisions ("shall") and, if implemented, all recommended provisions ("should") as described. A conformant implementation need not implement optional provisions ("may") and need not implement them as described.

Unless otherwise specified, the order of precedence of the types of normative information in this document shall be as follows: normative prose shall be the authoritative definition; tables shall be next; followed by formal languages; then figures; and then any other language forms.

3 Terms and Definitions

The following terms and definitions are used in this document:

3.1 XYZ

The linear tristimulus values as defined in CIE 1931 standard colorimetric system.

3.2 X′Y′Z′

XYZ tristimulus values encoded as nonlinear values.

4 $X'Y'Z'$ to $Y'D'_ZD'_X$ Computation

The luminance component value Y' shall be preserved.

Color-difference component values D'_Z and D'_X shall be computed as follows:

$$D'_Z = \frac{c_1 Z' - Y'}{2.0}$$

$$D'_X = \frac{X' - c_2 Y'}{2.0}$$

where

$c_1 = 0.986566$

$c_2 = 0.991902$

D'_X and D'_Z are in the range [-0.5, 0.5]

X′, Y′ and Z′ are in the range [0.0, 1.0]

The coefficients c_1 and c_2 have been optimized for the target of D65 with the inverse-EOTF specified in SMPTE ST 2084 at 500 cd/m^2. Annex B describes the derivation of c_1 and c_2.

D'_Z and D'_X may be further quantized for digital representation. An example digital representation can be found in Annex A.

5 $Y'D'_ZD'_X$ to $X'Y'Z'$ Computation

The $Y'D'_ZD'_X$ color-difference computation is invertible using its mathematical inverse to compute X′, Y′ and Z′.

The luminance component value Y' shall be preserved.

X' and Z' shall be computed from the $Y'D'_ZD'_X$ color-difference values as follows:

$$X' = 2D'_X + c_2 Y'$$

$$Z' = (2D'_Z + Y')/c_1$$

where

$c_1 = 0.986566$

$c_2 = 0.991902$

D'_X and D'_Z are in the range [-0.5, 0.5]

X′, Y′ and Z′ are in the range [0.0, 1.0]

The coefficients c_1 and c_2 have been optimized for the target of D65 with the inverse-EOTF specified in SMPTE ST 2084 at 500 cd/m^2. Annex B describes the derivation of c_1 and c_2.

Annex A Example Digital Representation (Informative)

A.1 Digital Representation

An example digital representation is shown which encodes color-difference values into digital code values.

A.2 Code Value Mapping

Digital code values are computed as follows:

$$Y'_D = \text{Floor}(876\, Q\, Y' + 64\, Q + 0.5)$$

$$D'_D = \text{Floor}(896\, Q\, D' + 512\, Q + 0.5)$$

where

Y' is the luminance component value in the range [0.0, 1.0]

Y'_D is the resulting luminance digital code

D' is the color-difference component value in the range [-0.5, 0.5]

D'_D is the resulting color-difference digital code

$Q = 2^{n-10}$

n is an integer greater than or equal to 10, corresponding to the number of bits per code value

The unary function Floor yields the largest integer not greater than its argument.

This scaling places the extrema of Y' at code words 040h(64) and 3ACh(940) and the extrema of D'_X and D'_Z at code words 040h(64) and 3C0h(960) in a 10-bit representation.

A.3 Inverse Code Value Mapping

Color-difference values are computed from their digital code values as follows:

$$Y' = (Y'_D - 64\, Q)/(876\, Q)$$

$$D' = (D'_D - 512\, Q)/(896\, Q)$$

where

Y'_D is the luminance digital code

Y' is the resulting luminance component value in the range [0.0, 1.0]

D'_D is the color-difference digital code

D' is the resulting color-difference component value in the range [-0.5, 0.5]

$Q = 2^{n-10}$

n is an integer greater than or equal to 10, corresponding to the number of bits per code value

Annex B Color-Difference Weighting Coefficients (Informative)

B.1 Objective of Weighting Coefficients

Color-difference signals are calculated as a weighted difference. The weighting coefficients determine the target color for which the color-difference signal will have zero value. If equal weighting were utilized, zero color-difference would be aligned with the XYZ equal energy neutral axis. Zero color-difference can be aligned more optimally with the picture content white by adjusting the weighting. The nonlinear encoding of XYZ using the inverse of an EOTF can introduce a curvature in the alignment of color-difference values, as is the case for the inverse of the SMPTE ST 2084 EOTF. Therefore the weighting can be optimized for a specific chromaticity and luminance level, such as D65 (x,y chromaticity 0.3127, 0.3290, as specified in Section 3.1.1 of SMPTE RP 177) at 500 cd/m^2.

B.2 Calculation of Weighting Coefficients

The weighting coefficients are dependent on the encoding to X′Y′Z′ according to an inverse-EOTF. The method takes as its input the X′Y′Z′ values of the target chromaticity and luminance with zero color-difference. The following steps are used to calculate the coefficients:

Step 1:

Intermediate scaling coefficients are computed as follows:

$$a = \frac{Z'}{Y'}$$

$$b = \frac{X'}{Y'}$$

$$c = min(1, 1/a)$$

$$d = min(1, 1/b)$$

Step 2:

The color-difference scaling coefficients are computed as follows:

$$p = a \times c$$

$$q = c$$

$$r = d$$

$$s = b \times d$$

$$\begin{bmatrix} E'_{Dz} \\ E'_{Dx} \end{bmatrix} = \begin{bmatrix} 0 & -p/2 & q/2 \\ r/2 & -s/2 & 0 \end{bmatrix} \cdot \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix}$$

For the specified optimization target, the scaling coefficients p and r evaluate to 1, resulting in the simplified equations of Section 4 and Section 5 with the scaling coefficients c_1 and c_2 taking the values of q and s, respectively.

Annex C Bibliography (Informative)

CIE S 014-2/E:2006, Colorimetry Part 2: CIE Standard Illuminants [ISO 11664-2:2007]

SMPTE RP 177-1993, Derivation of Basic Color Television Equations

SMPTE ST 2084:2014, High Dynamic Range Electro-Optical Transfer Function of Mastering Reference Displays