BT.709 YUV to RGB Conversion | Color

Introduction

BT.709 is also known by the abbreviations Rec. 709. It standardizes the format of high-definition television, having 16:9 (widescreen) aspect ratio. YPbPr color model used in analog component video and its digital version YCbCr used in digital video.Y′ stands for the luma component (the brightness) and U and V are the chrominance (color) components. Luminance is denoted by Y and luma by Y′. Prime symbols (‘) denote gamma compression, with **Luminance** meaning physical linear-space brightness, while **Luma** is (nonlinear) perceptual brightness.

Conversion Coefficients

Luminance is defined as a weighted sum of the color components. Weighted values of R, G, and B are summed to produce Y′. U and V are computed as scaled differences between Y′ and the B and R values.

Kg = 1- Kr - Kb
Y = Kr*R + Kg*G + Kb*B
V = (R-Y)/(1-Kr) = R - G * Kg/(1-Kr) - B * Kb/(1-Kr)
U = (B-Y)/(1-Kb) = - R * Kr/(1-Kb) - G * Kg/(1-Kb) + B
R = Y + V*(1-Kr)
G = Y - U*(1-Kb)*Kb/Kg - V*(1-Kr)*Kr/Kg
B = Y + U*(1-Kb)

Values of Kr, Kb and Kg are

Y′= 0.2126 R' + 0.7152G' + 0.0722B'

BT.709 Conversion Matrix

R’G’B’ and Y’PbPr is ranging from 0 to 1. R’G’B’ reference black is zero and reference white is unity. Conversion matrix are

$$\begin{bmatrix} {}^{709}Y' \\ P_B \\ P_R \end{bmatrix} = \begin{bmatrix} 0.2126 & 0.7152 & 0.0722 \\ -0.114572 & -0.385428 & 0.5 \\ 0.5 & -0.454153 & -0.045847 \end{bmatrix} \bullet \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}$$

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.5748 \\ 1 & -0.187324 & -0.468124 \\ 1 & 1.8556 & 0 \end{bmatrix} \bullet \begin{bmatrix} {}^{709}Y' \\ P_B \\ P_R \end{bmatrix}$$

Equation 0: BT.709 Conversion Matrix

First row of top equation (R’G’B’ to Y’PbPr conversion matrix) comprises the luma coefficients; these sum to unity. The second and third rows each sum to zero, a necessity for color difference components.

RGB To YCbCr Conversion

In 8-bit systems, a luma offset of +16 is added at the interface, placing black at code 16 and white at code 235. An offset of +128 is added to Cb and Cr, yielding a range of 16 through 240 inclusive. In a 10-bit interface, the 8-bit interface levels and prohibited codes are maintained; the extra two bits are appended as least-significant bits to provide increased precision. To obtain Y'CbCr from R'G'B' ranging 0 to 1, scale the rows of the matrix in **Equation 0** by the factors [219, 224, 224], corresponding to the excursions of each of the components.

$$\begin{bmatrix} {}^{709}_{219}Y' \\ C_B \\ C_R \end{bmatrix} = \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix} + \begin{bmatrix} 46.559 & 156.629 & 15.812 \\ -25.664 & -86.336 & 112 \\ 112 & -101.730 & -10.270 \end{bmatrix} \cdot \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}$$

Equation 1: RGB to YUV 8 Bit

In the 8-bit encoding, R', B', G', and Y' channels have a range of [16..235], and the Cb and Cr channels have a range of [16..240]. So in R'G'B', reference black is [16, 16, 16] and reference white is [235, 235, 235]. In Y'CbCr, reference black is [16, 128, 128], and reference white is [235, 128, 128]. Values 0 and 255 are reserved as timing references, and may not contain color data. BT.709 nominal ranges are the same as those defined in BT.601.

Studio RGB To YCbCr

In studio equipment, 8-bit R'G'B' components have the same 219 excursion as the luma component of Y'CbCr. To encode 8-bit Y'CbCr from R'G'B' in the range [0…219], scale the above matrix by (256/219).

$$\begin{bmatrix} {}^{709}_{219}Y' \\ C_B \\ C_R \end{bmatrix} = \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix} + \frac{1}{256} \begin{bmatrix} 54.426 & 183.091 & 18.483 \\ -30.000 & -100.922 & 130.922 \\ 130.922 & -118.918 & -12.005 \end{bmatrix} \cdot \begin{bmatrix} {}_{219}R' \\ {}_{219}G' \\ {}_{219}B' \end{bmatrix}$$

Studio RGB 8 Bit To YCbCr 8 Bit Conversion

Computer RGB To YCbCr

Black is at code 0 and white is at 255 if 8-bit R'G'B' components has no headroom and no footroom. To encode 8-bit Y'CbCr from R'G'B' in this range [0….255], scale the matrix of **Equation1** by (256/255) i.e.

$$\begin{bmatrix} {}^{709}_{219}Y' \\ C_B \\ C_R \end{bmatrix} = \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix} + \frac{1}{256} \begin{bmatrix} 46.742 & 157.243 & 15.874 \\ -25.765 & -86.674 & 112.439 \\ 112.439 & -102.129 & -10.310 \end{bmatrix} \cdot \begin{bmatrix} {}_{255}R' \\ {}_{255}G' \\ {}_{255}B' \end{bmatrix}$$

Full RGB 8 Bit To YCbCr 8 Bit Conversion

Reference: Rec.709