Electronic Image Color Conversion between Different Illuminants by Perfect Color-Constancy Actuation in a Color-Vision Model based on the OSA-UCS System

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Abstract

In digital image capturing, the camera signals produced by D65 illuminant, once translated into tristimulus values of the CIE 1931 standard colorimetric observer, are considered appropriate for an accurate rendering. The image likelihood requires that the camera-tristimulus values, for any illuminant other than D65, must be transformed into the corresponding ones produced by the D65 illuminant. Many techniques exist for producing this transforma-tion with different performances [1]. In digital image capturing, this transformation requires color constancy [2][3][4][5][6][7] [8]. This research is for a transformation suited to realize perfect color constancy or perfect illuminant discounting (although the perfect color constancy and the perfect illuminant discounting are non-existing for human color vision) by using the color-vision model based on the Optical Society of America-Uniform Color Scales (OSA-UCS) system [9][10]. This transformation is repre-sented by a matrix obtained by minimizing the Root Mean Square value between the pairs of the uniform scale chromatic responses related to tristimulus values of the 24 color samples of the Macbeth ColorChecker, measured under a pair of different illumi-nants, one of which is D65. The solution is obtained by a conver-gent iteration. This transformation is a color conversion, not a simple white conversion. The performance of the result is quantified by a color difference computation.

Adaptation and chromatic response functions in the OSA-UCS system

In 2005, the author wrote a paper [10] with a set of hypotheses for chromatic opponency functions with uniform perceptual scales according to the OSA-UCS system for 10° visual field, and according to the MacAdam ellipses for 2° visual field. Let us recall the first three hypotheses, useful to write the chromatic opponent functions with uniform perceptual scales.

"**Hypothesis I:** The lightness and the chromatic channels are supposed independent and parallel channels, and the color signals are the products of the perceptual chromatic functions times the lightness.

Hypothesis II: The first linear transformation **T** consists of a mixing of the cone activations (L, M, S) as follows:

$$\begin{pmatrix} A \\ B \\ C \end{pmatrix} = \mathbf{T} \begin{pmatrix} L \\ M \\ S \end{pmatrix} = \begin{bmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{bmatrix} \begin{pmatrix} L \\ M \\ S \end{pmatrix} \qquad (1)$$

and transforms from the cone activation space to a reference frame in the tristimulus space defined by three independent primary stimuli **A**, **B**, and **C**. Let us call this the *main-reference frame* and A, B, and C the *main tristimulus values*. Transformation **T** is specific of any given visual situation and of any observer.

Hypothesis III: The chromatic opponency, represented in the main reference frame and termed *main chromatic opponency*, is represented by a pair of the following three mutually dependent functions:

$$\ln\left(\frac{A}{B}\right),\ \ln\left(\frac{B}{C}\right),\ \ln\left(\frac{C}{A}\right) \qquad (2)$$

… Their property is to represent, separately, uniform scales of colors."

The main chromatic opponencies (2) specify the chromatic sensation, that can be obtained starting from different cone activations and different adaptations. Matrix **T** represents a part of the adaptation process, known as "second site adaptation", while the logarithmic compression of hypothesis III represents the Weberian adaptation, known as "first site adaptation" [11][12]. Therefore, matrix **T** is typical of any visual situation and of any observer. As shown in the original paper, the main-chromatic opponency functions represent uniform scales of perceived colors. Color constancy phenomenon, if it exists, is an effect produced by the transformation **T**. Particularly, the effect of the transformation **T** on the color-matching functions is a separation and a sharpening, recalling the well known sharpening proposed by Finlayson-Drew-Funt [13].

Since equal main-tristimulus values can be obtained from color stimuli of different visual situations, characterized by different matrices **T**, the perceptual scales can be translated into the scales of the "cone activations", once the matrix **T** related to the visual situations is known.

This work gives matrix **T** for visual situations with complete adaptation to a set of illuminants, in the hypothesis that the perfect color constancy holds true. This is not the case of the human visual system, but it is required for a digital color camera. In the original paper [10], the matrix **T** is given for the CIE 1931 observer adapted to the C illuminant and for the CIE 1964 observer to the D65 illuminant. In this work, related to digital cameras, only the CIE1931 observer is considered.

The request for perfect color constancy for the digital camera says that equal main chromatic opponencies correspond to different tristimulus values of the same color sample under different illuminants. Color rendering requires adaptation to the illuminant D65. Then the tristimulus values of an image captured under the illuminant S with an adaptation matrix $\mathbf{T}_S$, can be transformed into the tristimulus values produced under the D65-illuminant and adaptation $\mathbf{T}_{D65}$ by the matrix product

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{D65} = \mathbf{T}_{D65}^{-1} \cdot \mathbf{T}_S \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_S \qquad (3)$$

Empirical data, computational process and results

The empirical data considered for the definition of the matrix **T** are the 24 color-sample specifications of the Macbeth

Color-Checker obtained by computation from the spectral reflectance factors and different CIE illuminants.

Since non-selfluminous color samples are used, color constancy cannot be exact. This is clear by considering non-selfluminous metameric colors under an illuminant, which are no longer metameric under another illuminant.

The matrix **T** is obtained by minimizing the *RMS*

$$RMS = \sqrt{\frac{1}{24}\sum_{i=1}^{24}\left(\Delta E_i\right)^2} \qquad (4)$$

where

$$\Delta E_i = \left[\left(\ln\frac{A_{i,S}}{B_{i,S}} - \ln\frac{A_{i,\mathrm{D65}}}{B_{i,\mathrm{D65}}}\right)^2 + \left(\ln\frac{B_{i,S}}{C_{i,S}} - \ln\frac{B_{i,\mathrm{D65}}}{C_{i,\mathrm{D65}}}\right)^2 + \left(\ln\frac{C_{i,S}}{A_{i,S}} - \ln\frac{C_{i,\mathrm{D65}}}{A_{i,\mathrm{D65}}}\right)^2\right]^{1/2} \qquad (5)$$

is the distance between pairs of main-chromatic opponencies of the *i*-th sample of the ColorChecker, corresponding to pairs of tristimulus values ($A_{i,\mathrm{D65}}$, $B_{i,\mathrm{D65}}$, $C_{i,\mathrm{D65}}$) and ($A_{i,\mathrm{S}}$, $B_{i,\mathrm{S}}$, $C_{i,\mathrm{S}}$) under two different illuminants, one of which is the D65 and the other one, S, is one of the considered illuminants. The choice of minimizing the distance (4) is a consequence of the uniform perceptive scales of the three main-chromatic opponencies. Strictly speaking, only two main-chromatic opponencies should be considered, because only two are independent.

The minimization is made following the deepest descent of the *RMS* associated to almost continuous shifts of the main reference frame *ABC* and of the neutral stimulus, required to define the units of the stimuli **A**, **B** and **C**. The minimization of the *RMS* (4) regards the chromaticities, therefore defines the transformation up to a scale factor, that is evaluated by minimizing the color differences ΔE_E [14] between color samples lit by D65 and by illuminant S, after the transformation (3). The ΔE_E is a generalization of a recently published Euclidean color-difference formula [14] based on the same color-vision model [10]. (The published ΔE_E formula is based on the D65-color-difference data used for the CIEDE2000 and is here adapted to any illuminant and any observer. This adapted formula is in a very advanced study and soon will submitted for publication. Therefore the ΔE_E values given here have to be considered as preliminary.)

The ΔE_E values with those of ΔE_{94}* quantify the performance of the algorithm presented in this work. The lowest *RMS* values, which are some units × 0.0001, are obtained for color temperatures around 6500K.

The values of *RMS*, ΔE_E and ΔE_{94}*, obtained by optimization process for the considered illuminants, are summarized in table 1, and the chromaticities of the points **A**, **B**, **C** and of the neutral point **N** for the illuminants A, F11 and D50 are given in the Figures 1-3. Any figure of these is subdivided into two parts, (a) and (b). Part (a) represents the **ABC** chromaticity triangle with the palettes of the ColorChecker under two illuminants, of which one is the D65. Part **(b)** represents the CIE 1931 chromaticity diagram with the chromaticities of the color samples of the ColorChecker under two illuminant, of which one is the D65, and under D65 obtained from transformation (6), (7) or (8). The judgment of chromatic differences on the CIE diagram must take into account the non uniformity of perceived scale of the CIE 31 diagram.

Matrices **T** are obtained for all the CIE and F illuminants.

Moreover the chromaticity of the neutral point is close but not equal to that of the illuminant [15][16].

It has to be remarked that this color-conversion technique is not a simple white point conversion and is based on color samples producing the best color accordance under different illuminants, relatively to the set of considered color samples.

Once obtained matrices **T**, it is possible to translate the tristimulus values produced by an illuminant into the tristimulus values produced by another illuminant, and vice versa. The transformations ($\mathbf{T}_{\mathrm{D65}}^{-1}\cdot\mathbf{T}_{\mathrm{S}}$) related to three illuminants, A, F11 and D50, and for color specification in the *XYZ* CIE 1931 reference frame are given as examples with the corresponding ColorChecker chromaticities in figures 1-3

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{\mathrm{D65}} = \mathbf{T}_{\mathrm{D65}}^{-1}\cdot\mathbf{T}_{\mathrm{A}} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{\mathrm{A}} = \begin{bmatrix} 0.4922 & 0.2836 & 0.3932 \\ -0.3317 & 1.3438 & 0.1441 \\ 0.0869 & -0.1421 & 3.2022 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{\mathrm{A}} \qquad (6)$$

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{\mathrm{D65}} = \mathbf{T}_{\mathrm{D65}}^{-1}\cdot\mathbf{T}_{\mathrm{F11}} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{\mathrm{F11}} = \begin{bmatrix} 0.8161 & -0.0058 & 0.1456 \\ -0.0916 & 0.9801 & 0.1064 \\ -0.0033 & 0.0216 & 1.5852 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{\mathrm{F11}} \qquad (7)$$

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{\mathrm{D65}} = \mathbf{T}_{\mathrm{D65}}^{-1}\cdot\mathbf{T}_{\mathrm{D50}} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{\mathrm{D50}} = \begin{bmatrix} 0.8353 & 0.0877 & 0.0778 \\ -0.1142 & 1.1045 & 0.0242 \\ 0.0067 & -0.0155 & 1.3429 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{\mathrm{D50}} \qquad (8)$$

The color difference of the ColorChecker samples are generally lower or very lower that 3 units for any illuminant. The differences greater than 3 units regard few samples: samples 12 and 18 for the illuminants with lowest T_c, i.e. A, F4, F12, F3, F11, F9, F6, F2 and F10; samples 3 and 7 for the illuminants A, F4 and F12.

The daylight and Planckian illuminants, denoted by D*T* and P*T* (T=T_c/100, T_c in kelvin), respectively, are considered at many color temperatures T_c and the coordinates of the points **A**, **B**, **C** and **N** have very regular values inducing us to fit these data and produce a matrix transformation function of T_c (fig. 4-5).

Table 1: Average RMS (4), ΔE_E and ΔE_{94}* values obtained by optimization process for the CIE illuminants A, B, C, D50, D55, D65, D75 and F's. The ordering follows the correlated color temperature Tc.

T_c[K]	illuminant	*RMS*	ΔE_E	ΔE_{CIE94}
2856	A	0.0009	1.4	1.7
2940	F4	0.0015	1.9	2.2
3000	F12	0.0007	1.4	1.6
3450	F3	0.0011	1.6	1.8
4000	F11	0.0005	1.5	1.6
4150	F9	0.0001	0.9	1.0
4150	F6	0.0009	1.4	1.4
4230	F2	0.0008	1.3	1.6
4857	B	0.0001	0.8	0.9
5000	F8	0.0001	0.5	0.5
5000	F10	0.0004	1.2	1.2
5000	D50	0.0001	0.6	0.6
5500	D55	0.0001	0.8	1.1
6350	F5	0.0006	1.4	1.6
6430	F1	0.0005	1.4	1.4
6500	F7	0.0001	0.4	0.4
6500	D65	-	-	-
6774	C	0.0001	0.7	1.0
7500	D75	0.0001	0.7	1.0

	x	y
A	0.886	0.151
B	1.382	0.539
C	0.185	0.094
N	0.380	0.377
F11	0.3805	0.3769

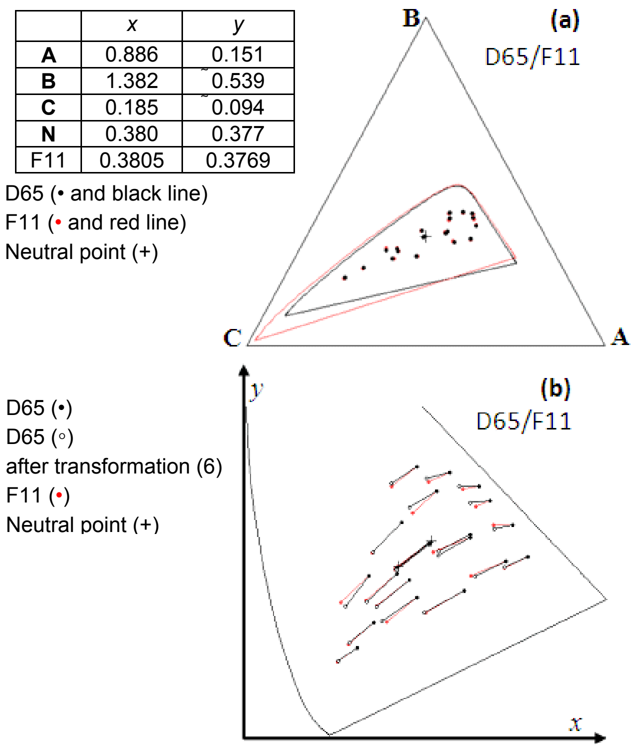

***Figure 1**. (a) **ABC** triangle with spectrum loci and ColorChecker palette. (b) CIE 31 diagram with ColorChecker chromaticities.*

	x	y
A	0.772	0.242
B	0.896	0.086
C	0.343	0.028
N	0.451	0.403
A	0.4476	0.4074

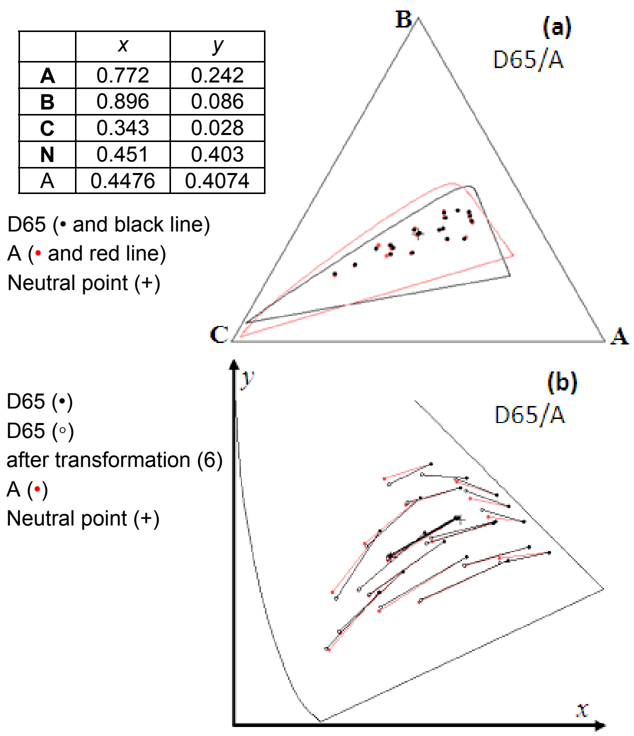

***Figure 2**. (a) **ABC** triangle with spectrum loci and ColorChecker palette. (b) CIE 31 diagram with ColorChecker chromaticities.*

	x	y
A	0.883	0.160
B	1.194	0.337
C	0.187	0.004
N	0.347	0.357
D50	0.3457	0.3585

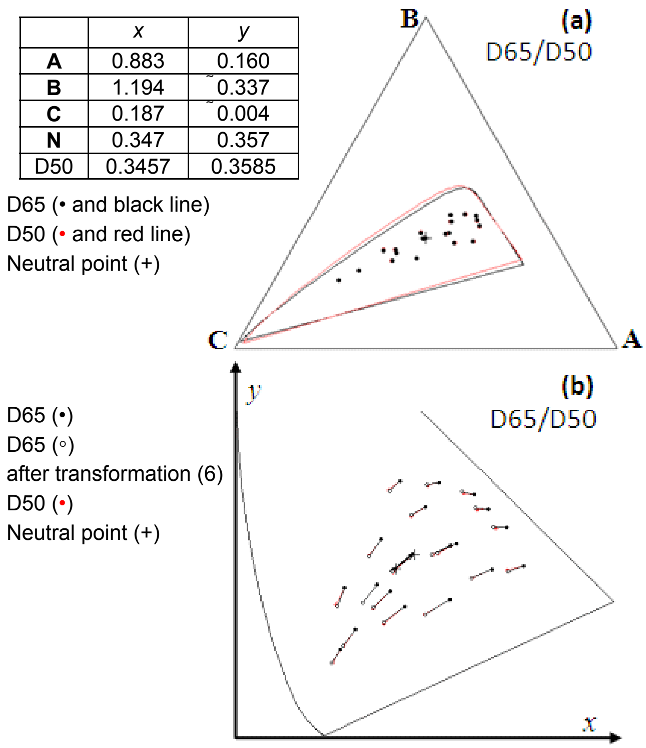

***Figure 3**. (a) **ABC** triangle with spectrum loci and ColorChecker palette. (b) CIE 31 diagram with ColorChecker chromaticities.*

For the Planckian illuminant with $2500 \le T_c \le 8000$ K, the matrix is

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{\mathrm{D65}} = \mathbf{T}_{\mathrm{D65}}^{-1} \cdot \mathbf{T}_{PT} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{PT} = \mathbf{T}_{PT\to \mathrm{D65}} \cdot \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{PT} = \begin{bmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{bmatrix} \cdot \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{PT} \tag{9}$$

where

$P_{11} = 0.2660 + 0.3115\,t - 0.0178\,t^2$, $RMS = 0.02$

$P_{12} = 0.7829 - 0.2109\,t + 0.0134\,t^2$, $RMS = 0.02$

$P_{13} = -0.19 + (-1.4078 + 1.1126\,t - 0.0082\,t^2)^{-1}$, $RMS = 0.02$

$P_{21} = -0.8267 + 0.2008\,t - 0.0110\,t^2$, $RMS = 0.01$

$P_{22} = 2.0106 - 0.2781\,t + 0.0180\,t^2$, $RMS = 0.04$

$P_{23} = -0.07 + (-4.2633 + 3.3367\,t - 0.0773\,t^2)^{-1}$, $RMS = 0.03$

$P_{31} = -0.08 + (-7.2560 + 6.1785\,t + 0.4687\,t^2)^{-1}$, $RMS = 0.004$

$P_{32} = 0.11 - (-5.6957 + 4.4019\,t - 0.3085\,t^2)^{-1}$, $RMS = 0.005$

$P_{33} = -0.29 + (-0.3713 + 0.2739\,t - 0.0143\,t^2)^{-1}$, $RMS = 0.06$

with $t \equiv T_c/10000$ and T_c in kelvin.

For the daylight illuminants with $4000 \le T_c \le 8000$ K, the matrix is

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{\mathrm{D65}} = \mathbf{T}_{\mathrm{D65}}^{-1} \cdot \mathbf{T}_{DT} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{DT} = \mathbf{T}_{DT\to \mathrm{D65}} \cdot \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{DT} = \tag{10}$$

$$= \begin{bmatrix} D_{11} & D_{12} & D_{13} \\ D_{21} & D_{22} & D_{23} \\ D_{31} & D_{32} & D_{33} \end{bmatrix} \cdot \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{DT}$$

where

$D_{11} = -0.5063 + 0.3791\,t - 0.0226\,t^2$, $RMS = 0.02$

$D_{12} = 0.7706 - 0.1927\,t + 0.0116\,t^2$, $RMS = 0.009$

$D_{13} = 0.7939 - 0.2054\,t + 0.0127\,t^2$, $RMS = 0.005$

$D_{21} = -0.8503 + 0.2001\,t - 0.0109\,t^2$, $RMS = 0.008$

$D_{22} = 1.6868 - 0.1542\,t + 0.0079\,t^2$, $RMS = 0.03$

$D_{23} = 0.2075 - 0.0508\,t + 0.0029\,t^2$, $RMS = 0.001$

$D_{31} = 0.1745 - 0.0511\,t + 0.0035\,t^2$, $RMS = 0.005$

$D_{32} = -0.2798 + 0.0791\,t - 0.0053\,t^2$, $RMS = 0.005$

$D_{33} = 4.9524 - 1.0507\,t + 0.0676\,t^2$, $RMS = 0.05$

with $t \equiv T_c/10000$ and T_c in kelvin.

The quality of the transformations (9) and (10), whose matrix elements are function of T_c, is evaluated comparing the color differences averaged on the ColorChecker samples with the corresponding color differences evaluated by the transformation obtained directly by optimization process. This comparison is in the tables 2 and 3 and shows very good agreement inducing us to consider the transformation with matrix elements function of the color temperature as practically good. In few cases the color difference related to the transformations (9) and (10) is lower than the corresponding related to the optimization process and this is due to the fact that the optimization process is made in two steps, the first one regarding the RMS minimization and the second the color difference minimization.

Table 2: Average values of ΔE_E and ΔE_{94}* obtained by optimized transformations and by transformations (9) for the Planckian radiator with 2500 ≤ T_c ≤ 8000 K.

Planckian radiator T_c[K]	Optimal result		Best fit (9)	
	ΔE_E	ΔE_{94}*	ΔE_E	ΔE_{94}*
2500	1.6	2.1	2.6	2.6
3000	1.5	1.7	2.3	2.4
3500	1.0	1.1	1.8	1.9
4000	1.0	1.2	1.2	1.3
4500	0.6	0.7	0.7	0.7
5000	0.7	0.9	0.4	0.4
5500	0.6	0.9	0.5	0.5
6000	0.2	0.2	0.7	0.8
6500	0.3	0.5	0.8	0.8
7000	0.7	1.0	0.7	0.7
7500	0.9	1.2	0.4	0.5
8000	0.7	0.8	0.7	0.7

Table 3: Average values of ΔE_E and ΔE_{94}* obtained by optimized transformations and by transformations (10) for the CIE Daylight illuminants with 4000 ≤ T_c ≤ 8000 K.

T_c[K]	Daylight illuminant	Optimal result		Best fit(10)	
		ΔE_E	ΔE_{94}*	ΔE_E	ΔE_{94}*
4000	D40	1.1	1.2	1.2	1.2
4500	D45	0.9	0.9	0.9	0.9
5000	D50	0.6	0.6	1.0	1.0
5500	D55	0.8	1.1	0.5	0.6
6000	D60	0.5	0.7	0.4	0.4
6500	D65	-	-	0.7	0.7
7000	D70	0.4	0.5	0.7	0.7
7500	D75	0.7	1.0	0.3	0.3
8000	D80	0.8	1.1	1.0	1.0

The Euclidean color difference ΔE_E is given as further confirmation of the goodness of the fitting and for showing the general agreement between this new formula and the CIE 94 one.

Table 4 gives a further evaluation of the transformations (9) and (10), applied to all the CIE and F illuminants with equal color temperature. As expected, greater color differences are in correspondence of the fluorescent lamps, whose line spectra produce color stimuli with lower regularity as function of the color temperature. The average color difference for fluorescent lamps is generally over 3 units, with exclusion of F8, F9, F10 and F11. It results that the transformation with matrix elements fitted on the Planckian radiator could be applied for any illumination, Planckian light or Daylight, with equal color temperature, including the F8, F9, F10 and F11. This promising conjecture has to be checked generally with images really obtained as shots of a digital camera with a correct profile for the D65 illuminant.

Table 4: Average values of ΔE_E and ΔE_{94}* obtained by transformation (9) and (10) for the CIE illuminants A, B, C, D50, D55, D65, D75 and F's at equal correlated color temperature T_c. Daylight is not defined below 4000K, anyway the transformations (10) are applied also in this region.

T_c[K]	illuminant	Planckian (9)		Daylight (10)	
		ΔE_E	ΔE_{94}*	ΔE_E	ΔE_{94}*
2856	A	2.4	2.5	4.7	4.5
2940	F4	5.3	5.3	6.4	6.4
3000	F12	3.4	3.4	4.6	4.5
3450	F3	5.0	4.9	4.8	4.9
4000	F11	2.3	2.5	3.0	3.2
4150	F9	1.6	1.6	2.6	2.7
4150	F6	5.9	5.5	5.0	4.8
4230	F2	4.1	3.9	4.1	4.1
4857	B	0.9	0.9	2.6	2.7
5000	F8	1.3	1.3	1.2	1.2
5000	F10	2.4	2.4	2.4	2.6
5000	D50	1.3	1.3	1.0	1.0
5500	D55	0.9	1.0	0.5	0.6
6350	F5	4.6	4.2	4.5	4.2
6430	F1	3.4	3.1	3.4	3.1
6500	F7	1.2	1.2	1.3	1.2
6500	D65	0.8	0.9	0.7	0.7
6774	C	1.5	1.6	1.8	1.8
7500	D75	1.1	1.2	0.3	0.3

Conclusion

For a digital camera it is required that the perfect color constancy holds true, in order to convert the tristimulus values
produced in a visual situation into the corresponding ones produced in another visual situation.

Since in a color appearance model defined on the OSA-UCS system [10] the second site adaptation is represented by a matrix **T**, it is supposed that this matrix, properly defined, represents the color-constancy process needed in a digital camera. This transformation is obtained by an iterative process for all the CIE A, B, D's and F's illuminants. The empirical data are the tristimulus values produced by the 24 color samples of the Macbeth ColorChecker lit with the considered illuminants. The quality of the given algorithm is quantified by two color difference formulas, the ΔE_{94}, and the Euclidean ΔE_E [14] (formula defined on the same color-vision model used for defining this same algorithm). The average ΔE_{94} values related to different illuminants range between 0.4 and 2.2 units.

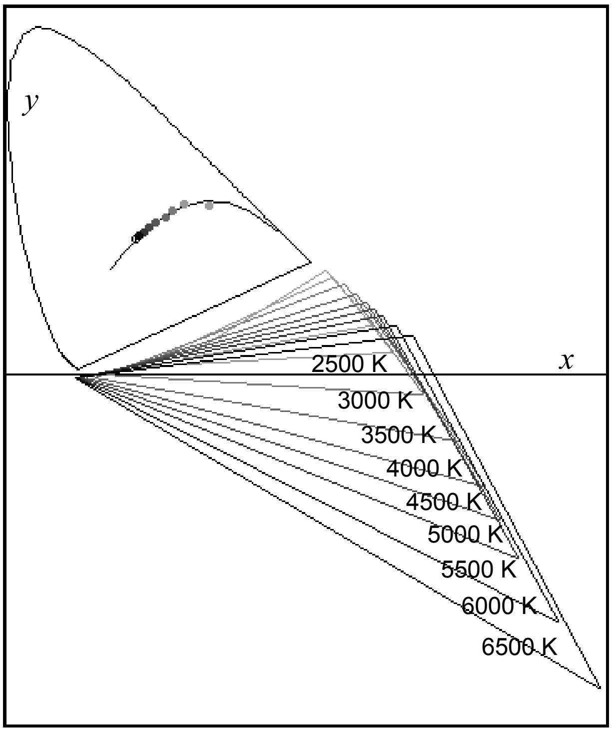

***Figure 4**. CIE 31 diagram with **ABC** triangles related to Planckian illuminant at color temperature between 2500K and 6500K obtained by optimization process.*

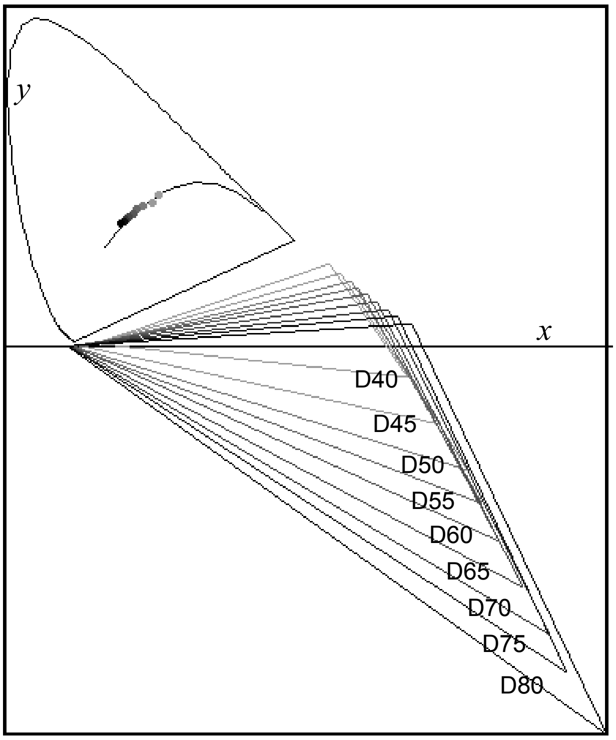

***Figure 5** CIE 31 diagram with **ABC** triangles related to Daylight illuminant at color temperature between 4000K and 8000K obtained by optimization process.*

The color-conversion matrices for Daylight and Planckian illuminants at different color temperature T_c show high regularity as functions of T_c, inducing us to write the matrix elements as function of T_c. These functions are obtained by least mean square fitting. Comparison of these transformations for Planckian illuminants with the corresponding ones obtained by optimization process related to CIE and F illuminants with equal T_c, suggests that transformations for Planckian illuminants could be applied for any illumination with equal correlated color temperature.

Unavoidable metamerism errors are present in the considered color-conversion, therefore the analysis should be extended to real cases with almost all the colors of realty.

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Claudio Oleari was born in 1944, "Dottore in Fisica" at Padua University in 1969 with full marks; in 1981 Associated Professor in Theoretical Physics; Today he is regularly teaching at Parma University: "Physical Optics"; "Colorimetry" and "Biophysics". Member of eight technical Committees of the CIÉ; Emeritus Member of the Italian Society of Optics and Photonics (SIOF); Member of the OSA. He is the author of more than 100 papers on color science, and editor and co-author of the book "Misurare il colore", Hoepli Ed. Milano,2nd ed. 2008. In 1989, obtained an award at the "40th Festival of the International Scientific Film Association" for the film "Color and Colorimetry". He was the initiator in Italy of the Working Group in Colorimetry and Reflectoscopy of SIOF (today "Italian Color Group") of the SIOF.

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