The CAM97s2 Model

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Abstract

The CICAM97s model was modified to overcome some problems in image applications. The new model is named CAM97s2.

Introduction

The CIECAM97s model[1] adopted by the CIE in 1997 was modified for colour imaging applications. The revised model is called CAM97s2. The revisions were in two respects: a) to make the lightness (J) zero when the Y tristimulus value is zero, under all surround conditions, b) to modify the chromatic induction factor (Nc) from 1.10 to 0.95 for the dim surround condition. The paper also describes an alternative mode to achieve a more nearly exact reversibility between the forward and reverse modes.

The Achromatic Signal (A) for CAM97s2

For different surround conditions (average, dim and dark), the lightness values (J) calculated from the CIECAM97s model show different black points corresponding to Y tristimulus values of zero. The results show that for Y equal to zero, the J values are 3.93, 6.29, 8.53 and 14.62 respectively for average, dim, dark and cut-sheet surround conditions (L_A value was set at 16 cd/m^2 in this case). When J values are less than these values, the luminance factors become negative. This disagrees with conventional colorimetry that the black point should correspond to Y=J=0, and can be corrected by replacing the noise constant of 2.05 with 3.05. The new formulae are given in Equation (1) for calculating the achromatic signals of sample (A) and reference white (A_w).

$$
\begin{aligned}
A &= [2R_a^{'} + G_a^{'} + (1/20)B_a^{'} - 3.05]N_{bb} \\
A_w &= [2R_{aw}^{'} + G_{aw}^{'} + (1/20)B_{aw}^{'} - 3.05]N_{bb}
\end{aligned}
\tag{1}
$$

The Chromatic Induction Factor (Nc) for CAM97s2

When comparing the images across different media, the viewing conditions play a significant role. The average, dim and dark surround conditions used in the CIECAM97s model typically apply to reflection images viewed under a high luminance level, CRT images viewed under a dim luminance level, and 35 mm slides projected in a completely darkened room, respectively. This results in two effects. First, the exponential factors are the largest for the average surround, less for the dim surround and the least for the dark surround. This is reflected by the CIECAM97s values of 0.69, 0.59 and 0.525 for the constants for the average, dim and dark surround conditions respectively. Secondly, the colourfulness percept of a stimulus is also affected by the surround conditions. The chromatic induction factors in CIECAM97s use 1.0, 1.1 and 0.8 for the average, dim and dark surround conditions, respectively. These factors were obtained by fitting to the LUTCHI data,[2] using single colour patches. Moroney[3] noted that the sizes of the gamut volumes are expected to rank average, dim and dark surround in the order of decreasing size. The sRGB[4] colour space was used to represent all available colour spaces. He found that, using the sRGB gamut, the ranking from the largest to the smallest is dim, average and dark. This is caused by the values of the chromatic induction factor used. For image applications, it seems plausible to change Nc for dim surround condition from 1.1 to 0.95 as suggested in the Hunt colour appearance model.[5]

An Alternative Method for the Reverse CIECAM97s

For the majority of cases encountered in practical applications, the forward and reverse CIECAM97s modes are closely equivalent6, but some differences could occur for colours close to the boundary of the chromaticity diagram.

The problem is caused by the calculation of Y in the reverse mode. The current method can only approximate Y. A more accurate method is derived based upon the following procedures.

From the reverse mode for calculating Y, the relevant equations in the forward mode can be rewritten as follows:

$$
\begin{aligned}
RY &= R_c Y / [D(R_{wr} / R_w) + 1 - D] \\
GY &= G_c Y / [D(G_{wr} / G_w) + 1 - D] \\
B &= \tau\{| B_c \,| Y / [D(B_{wr} / B_w^p) + 1 - D]\}^{1/p} Y^{-1/p}
\end{aligned}
\tag{2}
$$

where,

$$\tau = 1 \quad \text{if} \quad B_c Y > 0 \ ; \quad \tau = -1 \quad \text{if} \quad B_c Y < 0 \tag{3}$$

and

$$p = (B_w/B_{wr})^{0.0834} \quad (4)$$

In Equation (2), RY and GY can be calculated except for B, because Y is unknown.

From the forward mode, the X, Y and Z values are computed by Equation (5):

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = M_{BFD}^{-1} \begin{pmatrix} RY \\ GY \\ BY \end{pmatrix} \quad (5)$$

where

$$M_{BFD}^{-1} \begin{pmatrix} 0.98699 & -0.14705 & 0.15996 \\ 0.43231 & 0.51836 & 0.04929 \\ -0.00853 & 0.04004 & 0.96849 \end{pmatrix}$$

Hence, Equation (6) can be formed by using Equations (2) and (5).

$$\begin{aligned} Y &= 0.43231RY + 0.51836GY + 0.04929BY \\ &= \delta + \alpha Y^{\beta} \end{aligned} \quad (6)$$

where

$$\delta = 0.43231RY + 0.5183GY$$

$$\alpha = 0.04929\tau\{\ |B_c Y| / [\ [D(B_{wr}/B^{\ p}_{\ w}) + 1 - D]\}^{1/p} \quad (7)$$

$$\beta = 1 - 1/p$$

Since parameters δ, α and β in Equation (7) are known, Y can be calculated from Equation (6). Because an analytical procedure is not possible, a numerical method has to be used. Finally, the tristimulus X, Y and Z can be obtained from Equation (5). The suggested CAM97s2 reverse mode is given below:

First, rewrite Equation (6) as the F(Y) function and calculate F'(Y) as shown below.

$$F(Y) = Y - [\delta + \alpha Y\beta],\ F'(Y) = 1 - \alpha\beta Y^{\beta-1}$$

Then the Newton's method is proposed:

Choose initial guess Y_0

For k=0,1 ….. till "convergence" do

$$Y_{k+1} = Y_k - \frac{F(Y_k)}{F'(Y_k)}, \quad \text{where } F'(Y_k) \neq 0)$$

The convergence rule can be

$$|Y_{k+1} - Y_k| \leq eps$$

or

$$|F(Y_{k+1})| \leq eps$$

where eps is a predetermined tolerance precision, e.g. eps=10^{-4}. It is proposed to set $Y_0 = Y_C$, where Y_C is defined by Equation (8) and is currently used in the reverse mode for approximating Y value. It was found that the number of iterations of the Newton's method for the convergence never exceeds 4.

$$Y_C = 0.43231R_C Y + 0.51836G_C Y + 0.04929B_C Y \quad (8)$$

Conclusion

Two suggestions were made to revise the CIECAM97s model. First, the noise factor of 2.05 for calculating the achromatic signal (A) should be 3.05. This will ensure that lightness (J) will be zero corresponding to a luminance factor (Y) of zero, no matter which surround conditions are used. Second, the chromatic induction factor (Nc) should be changed from 1.1 to 0.95 for typical dim surround condition. This seems to be reasonable for image applications. When the model is used with the revision it is suggested that it should be designated CAM97s2, to avoid confusion. A revised reverse model was also derived to provide a more nearly exact reversibility between the forward and reverse modes. (This modification can also be applied to the chromatic adaptation transformation, CMCCAT97,[6] which is imbedded in CIECAM97s.)

References

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