CIE Colour Appearance Models, Their Past and Future

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Introduction

Early CIE measures related to colour appearance included dominant wavelength and purity, but it was not until the CIELUV and CIELAB colour spaces were introduced in 1976 that approximately uniform correlates of lightness, hue, chroma, and saturation, became available. These spaces provide no correlate of brightness that includes the effects of adaptation, and no correlate of colourfulness; also, there is no allowance for the effects of changes in the colour and level of illumination, the nature of the background, and the type of surround. The CIE Colour Appearance Models CIECAM02 and CIECAM97s make allowance for these effects, and include the missing correlates.

Comparison of CIECAM02 with CIECAM97s

Chromatic adaptation transforms

In both models, the chromatic adaptation transform (CAT) is based, not on cone responses, but on sharpened cone responses, R, G, B; this results in better predictions of corresponding colours (colour stimuli that in a reference adaptation condition have the same appearance as a that of a test colour in a test set of adaptation conditions). A disadvantage of the CAT used in CIECAM97s was the inclusion of a power function in the blue channel; this made reversing the transform difficult. By optimising the matrix used to go from XYZ values to the RGB sharpened responses, the power function in the blue channel could be eliminated without impairing the predictions. The corresponding-colour tristimulus values, X_c, Y_c, Z_c, are then transformed to cone responses, ρ, γ, β.

Cone dynamic response functions

The cone dynamic response function used in CIECAM02 covers a greater range, and this results in the saturation of colours in shadow series (kX, kY, kZ, where k is a constant) remaining almost exactly constant, whereas in CIECAM97s the saturation varies; better chroma predictions of pale colours also results in CIECAM02.

Correlates of yellowness-blueness, *b*, and redness-greenness, *a*

In both models three colour difference signals are inherent, $C_1 = \rho - \gamma$, $C_2 = \gamma - \beta$, and $C_3 = \beta - \rho$; and yellowness-blueness, b, is determined as the average of the departures from unique red (for which $C_1 = C_2$) and unique green (for which $C_1 = C_3$); and redness-greenness, a, is determined as the departure from unique yellow (for which $C_1 = C_2/11$). Because the criteria for the four unique hues are all diffferent (that for unique blue being $C_1 = C_2/4$), there is a discontinuity as the colour considered passes from one, to a neighbouring, hue quadrant. It would, therefore, be more correct to have, in future, two correlates of redness-greenness, a_y for yellowish colours, and a_b for bluish colours and two for yellowness-blueness, b_r for reddish colours, and b_g for greenish colours.

Correlate of brightness, *Q*

In both models the correlate of brightness, Q, depends on the achromatic signal for the reference white, A_w. As the adapting luminance decreases, A_w, decreases, and this decreases Q, as required; but in CIECAM02 the decrease is insufficient, so the formula includes a power of F_L, a luminance-level adaptation factor. However, if F_L were altered, in future, to increase the separation of the dynamic-response function curves along the log stimulus-intensity axis, it might be possible to avoid having to use F_L in the formula for Q, (as in CIECAM97s); a more physiologically plausible result.

Correlate of colourfulness, *M*

In both models, the correlate of colourfulness, M, depends on the correlate of chroma, C, and on F_L. The correlate of chroma, C, is derived as a ratio of $[(a^2 + b^2)^{0.5}]$ over $[\rho + \gamma + (21/20)\beta]$, and hence if ρ, γ, and β are all multiplied by the same constant (as tends to happen when the adapting luminance changes), the value of C is not changed. This necessitates the inclusion of a power of F_L in the formulae for M, to make M decrease as the adapting luminance decreases. But if, in future, M were made to depend on $[(a^2 + b^2)^{0.5}]$ without the $[\rho + \gamma + (21/20)\beta]$ divisor, then the decrease in M would depend only on the dynamic response function; a more physiologially plausible result.

Correlate of saturation, *s*

Saturation is colourfulness judged in proportion to brightness. In CIECAM02 the correlate of saturation, s, depends, correctly, on the ratio of the correlate of colourfulness, M, to the correlate of brightness, Q : the formula being: $s = 100(M/Q)^{0.5}$. But the correlate of saturation in CIECAM97s does not depend on this ratio, but on the ratio $[(a^2 + b^2)^{0.5}]/[\rho+ \gamma+ (21/20)\beta]$, which is less satisfactory.

Performance of the models in predicting colour percepts

The performance of both models in predicting colour percepts was evaluated by comparing experimentally-determined magnitude estimations, V, with model predictions, P. Coefficients of variation, CVs, were computed as $100[\Sigma(V_i - P_i)^2/n]^{0.5}/[\Sigma(V_i)/n]$ where n is the number of samples, and i is the sample considered in a particular data set. For a perfect performance by a model the CV should be zero.

CV for	CIECAM02	CIECAM97s	Observer Spread
Lightness	14	14	13
Brightness	20	20	10
Hue	7	7	8
Colourfulness	19	18	18
Saturation	22	44	16

The performance of the two models is similar except for saturation, where CIECAM02 is far superior. Also shown are the CVs for the spread of the observers results. It is clear that for lightness, hue, and colourfulness, the CVs for the predictions and for the observer spread are similar. This is a level of model performance that is about as good as can be expected. For brightness and saturation there is room for improvement.

Future models

The CIECAM97s model was recognised as being simple in that there were many aspects of colour appearance that were not included. The CIECAM02 model did not attempt to address these shortcomings, concentrating instead on improving convenience and performance in the same domain. More comprehensive models are needed, and the following are among the features that such models should ideally include: the Purkinje effect, cone bleach factors, the Helson-Judd effect, a low-luminance tritanopia factor, the Helmholtz-Kohlrausch effect, the Bezold-Brűcke effect, simultaneous contrast, the effects of gloss and translucency, spatial and temporal effects, and the rod response. A model for unrelated colours is also required. Finally models that combine both colour appearance and the evaluation of colour differences would be very useful.