The Performance of CIECAM02

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Abstract

A new CIE color appearance model (CIECAM02) has been developed. This paper describes the three major drawbacks of the earlier CIECAM97s model, and shows how the new model performs in these color regions. In addition, both models were tested using available data groups. The results are consistent in that CIECAM02 performed as well as, or better than, CIECAM97s in almost all cases, there being a large improvement in the prediction of saturation. The CIECAM02 model can therefore be considered as a possible replacement for CIECAM97s for all image applications.

Introduction

Color appearance models are capable of predicting color appearance under a variety of viewing conditions, including different light sources, luminance levels, surrounds, and lightness of backgrounds. They are particularly useful for achieving successful cross-media color reproduction. Hence, there is a strong need by color imaging engineers to integrate a color appearance model with color management systems. This would allow original and reproduction images from these systems to be easily adapted according to the desired input and output viewing conditions, respectively. In 1997, CIE TC 1-38 *Testing color appearance models* adopted a model called CIE 1997 Interim Color Appearance Model (Simple Version),[1,2] CIECAM97s. In 1998, CIE TC 8-01 *Color Appearance Models for Color Management Systems* was formed to test CIECAM97s for its predictions of color appearance, and its appropriateness for engineering and implementation requirements for open color management systems. Various trials were conducted and some problems[3,4] were identified. Methods[5-9] were proposed for improving the model. These resulted in many versions of CIECAM97s. One of the promising models is called the modified power model (MP), which corrects a severe shortcoming of the CIECAM97s, its large variations of the predicted saturation values for colors having the same chromaticity but different luminance factors. More recently, much progress has been made by CIE TC8-01 to develop a new model which it is hoped will replace CIECAM97s and be named CIECAM02; the details of this new model are given in another paper in these proceedings.[10] The new model is not only a refinement of CIECAM97s in that it removes many shortcomings, but it is also an improvement in that it provides equivalent or better predictions of color appearance data sets[11-17] for the majority of the visual attributes included, especially for the saturation attribute.

This paper is divided into two parts. Part one illustrates three significant drawbacks of CIECAM97s and the superior performance of CIECAM02. Part two reports the performance of CIECAM97s and CIECAM02. In general, CIECAM02 performed as well as or better than CIECAM97s. Most importantly, it removes many uncertain areas in CIECAM97s.

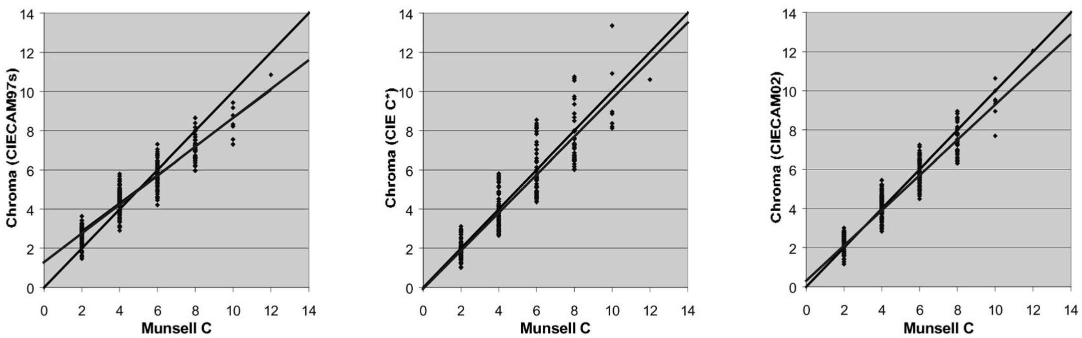
Major Drawbacks in CIECAM97s

Three major drawbacks of CIECAM97s are illustrated here: over-prediction of chroma for near neutral colors, poor prediction of saturation results, and large variation of the predicted saturation values for colors having the same chromaticity but different luminance factors.

Over-Prediction of Chroma for Near Neutral Colors

Newman and Pirrotta[4] have pointed out that the predictions given by CIECAM97s for colorfulness and chroma are too high for colors close to the neutral axis. This is illustrated in Figure 1a in which CIECAM97s chroma is plotted against Munsell chroma. (This was achieved using Munsell data set with known Munsell chroma by setting Yb=20.0, L_a = 60.0 cd/m^2, average surround, and illuminant C/1931 for the adopted white.) Figures 1b and 1c show similar results for CIELAB chroma, C_{ab}*, and CIECAM02 chroma, again plotted against Munsell chroma. (For all the plots in this paper, the predicted results for a model are adjusted to have the same scale as the visual results.). In each plot the 45^0 and best-fit lines are also shown. For perfect agreement, the points should be coincident with the 45^o lines.

Figure 1a clearly shows that CIECAM97s predicts chromas that are too high for colors that are close to neutral (Munsell chroma near zero); Although color appearance models were developed to fit available visual results,[11-15] they should not give too high prediction for near neutral colors.



(a) *(b)* *(c)*

Figure 1. The chroma predictions from (a) CIECAM97s, (b) CIELAB, and (c) CIECAM02 plotted against Munsell chroma.

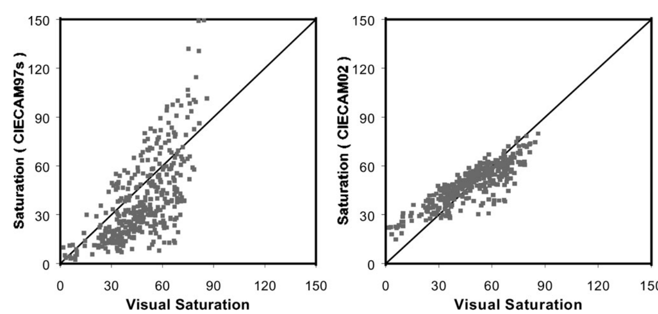
It can be seen from Figures 1a, 1b, and 1c that, judged by the scatter of the points CIECAM02's prediction is the best, then followed by CIECAM97s; the worst is the CIELAB prediction. This is confirmed by the CV values. (CVs are calculated as $100[\bullet(V_i - P_i)^2/n]^{1/2}/\bullet(V_i)/n]$ where V is the experimental result for sample i, P is its prediction, and n is the number of samples used; the lower the CV, the better the performance.) The CV values are 14 for CIECAM02, 19 for CIECAM97s, and 22 for CIELAB.

For color reproduction it is important to reproduce near neutral colors accurately. The intercepts on the vertical axes of the best-fit lines in Figure 1 are a measure of how well the models predict the chroma of near neutral colors; ideally the intercepts should always be zero. These intercepts are 0.6 for CIECAM02, 1.5 for CIECAM97s, and 0.1 for CIELAB. It is thus clear that the CIECAM02 intercept is much better than that of CIECAM97s. (Incidentally, it is encouraging that CIECAM02 predicts the Munsell data reasonably well, although it is an independent data group, which was not used in developing the models.)

Poor Prediction of Saturation Results

The CIECAM97s saturation scale was empirically derived to provide a term for calculating predictors for chroma (C) and colorfulness (M) in order to give a good prediction to the visual results then available. Subsequently, Juan[15,16] conducted a psychophysical experiment to scale saturation. In this experiment, observers were shown cubes of size 4.5 by 4.5 cm. They saw three sides of each cube, comprising a total angular subtense of about 6^o. Cubes of 132 different colors were used and they were viewed on three different backgrounds, white, grey, and black. Observers were then asked to scale saturation. The instructions given to the observers were as follows:

The saturation is the attribute judged by the proportion of colorfulness to brightness. [A DIN color chart was shown to illustrate the concept.] A three-dimensional object colored with a solid color has a constant saturation but different luminance on each side. For example, if each side of a cube is painted the same color the sides could have different colorfulnesses and brightnesses but their saturations would be the same. The more the colorfulness the more the brightness, and vice versa. Please make a judgement of the saturation to give a number, which is in the right relationship to the reference saturation. A neutral color has no saturation and is represented by zero on the scale. For a very dark color, if its hue can be perceived signifocantly, it would have high saturation. This is an open-ended scale since no top limit is set. The saturation of the reference saturation sample, which is displayed beside the test sample, should always be compared so that all subsequent test colors can be related to it. The reference saturation sample has saturation 50 in the phase of the grey background.



(a) *(b)*

Figure 2. The saturation predictions from (a) CIECAM97s and (b) CIECAM02 plotted against the Juan visual data

Figure 2a shows the saturation predictions from CIECAM97s plotted against the experimental data. It can be seen that there is a very large scatter of the points. Thus CIECAM97s gives a poor fit to the experimental data. The CV value for Figure 2a is 44 indicating a very poor agreement. The performance of the saturation predictor in CIECAM02 is shown in Figure 2b. Compared with that in Figure 2a, the scatter in Figure 2b is much smaller, and has a CV value of 22. But note that there is a large intercept for near neutral colors. This could be caused by the scaling technique used, which perhaps resulted in observers having difficulties in scaling saturation accurately for colors close to neutral.

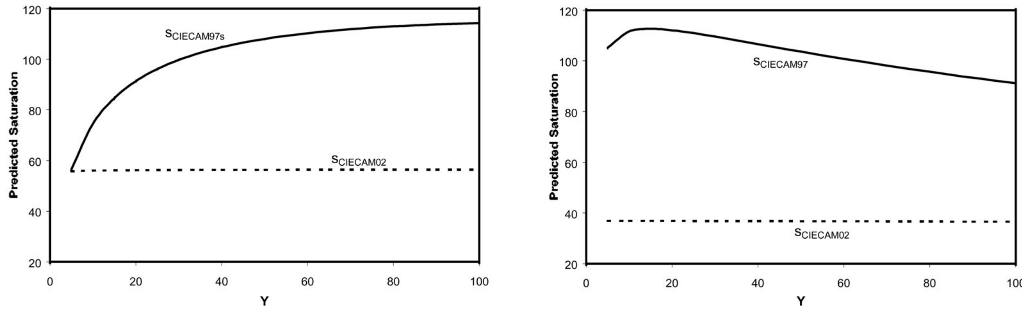


Figure 3. The change of saturation with changes in luminance factor for a typical color as predicted by CIECAM97s (sCIECAM97s) and CIECAM02 (sCIECAM02) for adapting luminance at La of (a) 2 cd/m^2 and (b) 2000 cd/m^2.

Variations of Saturation for Color Stimuli with Fixed Chromaticity

Hunt *et al.*[9] at a later stage found another shortcoming for the saturation scale of CIECAM97s in that, for colors having a given chromaticity but different luminance factors, large changes in the predicted saturation occur, instead of the constant saturation, which is to be expected. This is illustrated in Figures 3a and 3b, for values of the adapting luminance, L_a, equal to 2 and 2000 cd/m^2, respectively. (The color used had $x = 0.3618$ and $y = 0.4483$, the adopted white having $x = 0.3127$, $y = 0.3290$, and $Y = 100$.) It can be seen that the saturation scale ($s_{CIECAM97s}$) of CIECAM97s predicts very large variations for different Y values. However, there is almost no change for the saturation scale ($s_{CIECAM02}$) of CIECAM02.

Comparing the Performance Between CIECAM97s and CIECAM02

In this section, the performances of CIECAM97s and CIECAM02, tested using available data sets,[11-15] are reported in terms of CV values. These data sets are the same as those used to report the performance of CIECAM97s,[11] but also include the Juan data. All data sets were accumulated using the magnitude estimation method. The Juan data includes not only the saturation data but also lightness, colorfulness and hue data. The visual results from this data set were obtained by more observers than in the other experiments.

Lightness and Hue

The lightness and hue scales of CIECAM97s and CIECAM02 were tested using all available data groups in terms of CV values. The results are given in Table 1 together with the weighted mean value from all data groups for each model.

Comparing the lightness predictions of the two models, both models gave similar performance. CIECAM02 performed better for 35 mm, R-Tex and Juan data sets, but gave worse predictions for CRT and R-LL data groups. The weighted mean CV values between the two models are very similar. Comparing hue predictions, CIECAM02 performed slightly better than CIECAM97s in all data groups, except for RHL for which the performance was the same. Both models gave very satisfactory predictions of the hue results. The scatters are much smaller than the *scatters* for the predictions of the lightness results.

Table 1. The Performance of the Models' Lightness and Hue Predictions

		Lightness		Hue	
Data Group	No. of Phases	CAM97s	CAM02	CAM97s	CAM02
LT	10	10.64	11.15	6.09	6.01
35 mm	6	21.46	18.90	7.41	7.04
CRT	11	9.70	11.56	7.08	6.71
R-Tex	3	16.70	14.85	9.05	7.41
Juan	9	16.70	14.17	7.11	6.83
R-HL	6	11.02	10.64	7.08	7.08
R-LL	6	14.36	17.48	8.84	8.06
R-VLH	8	11.84	11.73	6.35	6.01
R-VLL	4	16.12	16.45	9.38	7.81
W.Mean		13.53	13.65	7.41	6.91

Colorfulness

The colorfulness scales of CIECAM97s and CIECAM02 were also tested using all available data groups in terms of CV values. The results are given in Table 2 together with the intercept values.

Comparing the colorfulness predictions of the two models, the weighted mean CV values for CIECAM02 were worse than for CIECAM97s, the latter giving better predictions for the CRT, R-Tex and R-LL data groups. As mentioned earlier, the intercept of the best-fit line is a good indicator for assessing whether models can predict near neutral colors well, the ideal intercept being zero. Comparing the colourfulness intercepts of the two models, it can be seen that CIECAM02 had much smaller, and therefore better, intercepts than CIECAM97s for all data groups. Much effort was spent in trading off between CV values (scatter) and intercepts. Figure 4 shows the degree of scatter between the two models in predicting the visual colorfulness results from the Juan data. Both figures show similar scatter but CIECAM02 performs better for colors close to neutral.

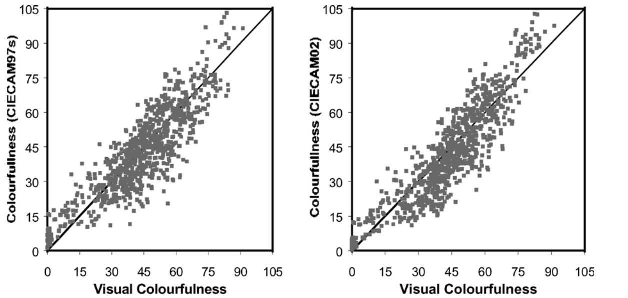


Figure 4. Visual colorfulness data plotted against the models' predictions (a) CIECAM97s and (b) CIECAM02

Table 2. The Performance of the Models' Colorfulness Predictions Together with Its Intercept

Data Group	No. of Phases	Colorfulness CAM97s	Colorfulness CAM02	Intercept CAM97s	Intercept CAM02
LT	10	16.24	14.68	10.91	5.66
35 mm	6	17.60	16.57	9.85	5.58
CRT	11	16.85	19.56	5.99	0.52
R-Tex	3	17.90	24.13	7.56	3.00
Juan	9	20.74	20.62	3.94	-2.37
R-HL	6	18.06	18.14	5.99	0.19
R-LL	6	18.71	19.70	6.43	0.56
R-VLH	8	17.06	16.04	7.57	2.09
R-VLL	4	29.59	30.13	7.56	6.41
W.Mean		18.23	19.16	7.31	2.93

Saturation

The saturation results were discussed in the section 'Poor prediction of saturation results', and showed that those for CIECAM02 were much better than those for CIECAM97s.

Brightness

The brightness scales of CIECAM97s and CIECAM02 were also tested using R-VLH and R-VLL data groups. The results are shown in Figure 5. The CV values are 19.5 and 20.4 units for CIECAM97s and CIECAM02, respectively. Thus both models gave very similar performance but both had a large intercept. This could be caused by the difficulty for all observers to have the same anchoring 'black' point for scaling brightness. (For scaling brightness there was only a reference brightness sample as an anchor point. Observers used their own 'imaginary black' as another anchor point.) Further work will be useful to verify this.

Conclusion

A new CIE color appearance model (CIECAM02) has been developed. It overcomes three major drawbacks of the earlier CIECAM97s model, and performed as well as, or better than, CIECAM97s in almost all cases, there being a large improvement in the prediction of saturation. The CIECAM02 model can therefore be considered as a possible replacement for CIECAM97s for all image applications.

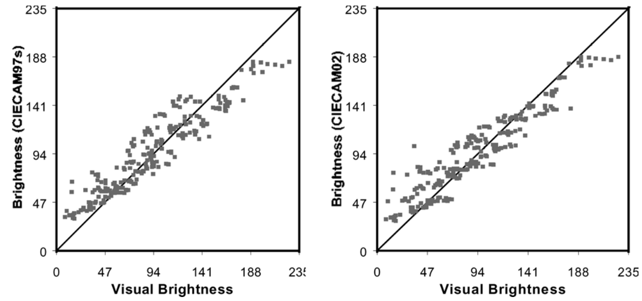


Figure 5. Visual brightness data plotted against the models' Predictions (a) CIECAM97s and (b) CIECAM02

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Biography

The authors of this paper have a combined 100 plus years experience in color science. They include chairs of TC1-3 that prepared CIE publication 15.2, TC1-34 that developed the CIECAM97s model and TC 1-52 that overviews the development of chromatic adaptation transforms. The authors span three time zones, two academic institutions and two corporations.