A case for a CIECAM02 colour appearance space

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ABSTRACT

We have carried out a series of simulations to investigate the effect of monitor gamma on the colours displayed on typical CRT (cathode-ray-tube) monitors. The results were originally computed in the CIELAB colour space, but were re-calculated in terms of the new CIECAM02 colour-appearance model since the experiment is a form of colour management problem. It then became necessary to construct a three-dimensional colour-appearance space for data presentation as an analogue to the CIELAB colour space used earlier.

The paper outlines the simulation experiments, and makes use of some of the results to draw comparisons between the three-dimensional CIELAB colour space and the proposed CIECAM02 colour appearance space. From a user's perspective, a three-dimensional colour-appearance space is a valuable tool for the visualization of colour-appearance attributes when analyzing a colour-management problem. The CIE is encouraged to work towards the formal adoption of such a space.

1. INTRODUCTION

In the recent past, the CIE has recommended two colour appearance models. The first was CIECAM97s, the CIE 1997 interim colour appearance model (simple version) [1]. The second model, designated CIECAM02, was developed from this, and was formally adopted by the CIE early in 2004 as a recommended colour appearance model for colour management applications [2]. Prior to this, the CIE had recommended two uniform colour spaces, CIELAB and CIELUV [3], both originally adopted in 1976, of which CIELAB appears to have achieved wider acceptance and usage, and possesses some of the attributes of a colour appearance model [4].

The authors have carried out two simulation investigations [5, 6] of the influence of monitor gamma on the colours displayed on CRT (cathode-ray tube) monitors, in which the results have been expressed, respectively, in CIELAB and CIECAM02 quantities. In the first simulation [5], the numerical colour differences were expressed in CIELAB units, making use of the Euclidean colour difference formula given in Equation (1):

$$\Delta E^*_{ab} = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2} . \tag{1}$$

It was desired that the results of the second simulation [6], expressed in terms of CIECAM02 colour attributes, be computed in a similar format to those earlier results; and it was accordingly decided to adopt an approach hinted at in the CIECAM97s specification [1], and to apply it to the CIECAM02 data in such a way as to construct a three-dimensional colour-appearance space, with coordinates [J, a_C, b_C], by the use of Equations (2):

$$\begin{aligned} a_C &= C.\cos(h) \\ b_C &= C.\sin(h) \end{aligned} \tag{2}$$

where [J, C, h] are the lightness, chroma and hue attributes computed using the CIECAM02 model. It was then possible to compute the numerical colour differences in this appearance space according to Equation (3):

$$\Delta E_C = \left[(\Delta J)^2 + (\Delta a_C)^2 + (\Delta b_C)^2\right]^{1/2} \tag{3}$$

and we have proposed the use of the term "CIECAM02 units" to express the values of ΔE_C.

2. METHOD

The purpose of the abovementioned investigations [5, 6] was to develop a prediction process for the colours of a range of samples displayed on a CRT monitor for a range of different values of monitor gamma. The gain-offset-gamma (GOG) model [7] of the behaviour of the CRT was applied, with gain and offset values K_1 = 1.15, and K_2 = –0.15 respectively, together with the assumption of "standard" CRT colorimetry, based on the sRGB recommendations [8], to permit an assessment of the influence of monitor gamma on the appearance of the colours reproduced on its screen.

We included a total of 76 numerically-defined colour samples in our simulations, of which 66 were chromatic samples and 10 were achromatic. They were subjected to the influence of 8 different gamma values. A reference gamma of 2.2 was assumed in making comparisons of the displayed colours for the different 'test' gammas with the colours displayed under the reference gamma. The comparisons were expressed as CIELAB colour differences in the first simulation [5], and CIECAM02 colour-appearance differences in the second [6].

3. RESULTS

Figures 1, 2 and 3 illustrate the effects of gamma variation on the display of 24 high-chroma samples, by plotting the CIECAM02 appearance attributes for each simulated colour sample in terms of its a_C and b_C coordinates. Each plot includes the range of gamma values investigated, from 1.4 to 3.0 – yielding eight plotted points for each individual sample. It is noted that gamma will also have an influence on the lightness of each displayed colour [5, 6], but this aspect is not illustrated here.

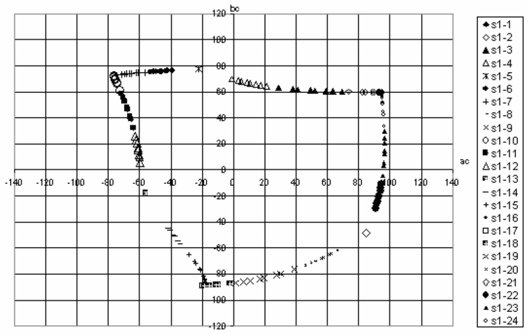

Figure 1: Predicted influence of gamma on displayed colour appearance: Set 1 (high chroma) samples for Average Surround, Average Background[6]

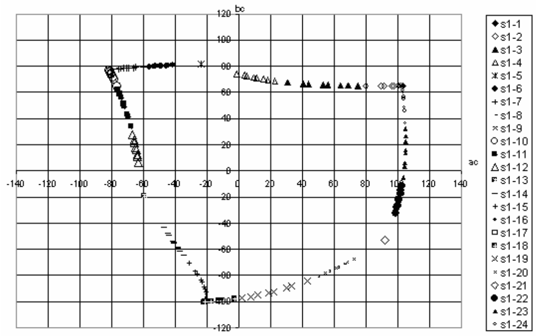

Figure 2: As Fig. 1 but for Average Surround, Dark Background[6]

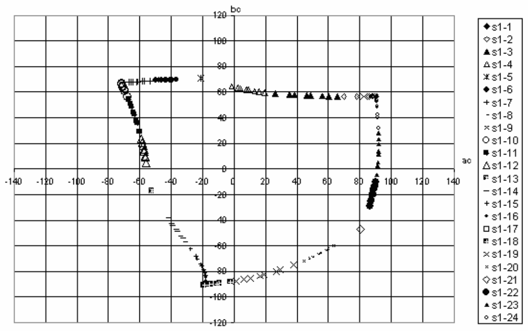

Figure 3: As Fig. 1 but for Dim Surround, Average Background[6]

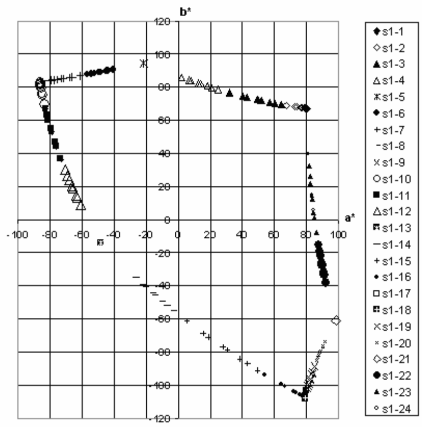

Figure 4: Data of Figures 1–3 calculated in terms of CIELAB ($a*$, $b*$) coordinates[5]

Figures 1 and 2 are for average surround conditions, typical of most offices. Figure 1 represents the viewing of the colour samples against an average background (20% of peak white screen luminance) while Figure 2 represents a dark (8%) background. Figure 3 is for dim surround conditions, typical of the lighting in most homes at night, and an average (20%) background.

Figure 4 is included for comparison, showing the same data as in Figures 1–3, recalculated in terms of the more familiar CIELAB (a^*, b^*) coordinates.

Similar data to the above has been computed for low-chroma samples [5, 6] but space limitations preclude their inclusion here. Figure 5 shows the results of the simulation for a set of ten neutral grey samples, for eight different gamma values, in terms of CIECAM02 apparent lightness *J*.

Our 76 simulated samples covered a wide range of hues, chromas and lightnesses. The overall results of the experiment have been expressed in terms of the root-mean-square (RMS) colour or colour-appearance differences for all 76 samples, as the monitor gamma was varied by ± 0.8 from the reference value of 2.2. RMS colour 'errors' are plotted against gamma 'errors' in Figure 6 (in CIECAM02 units) and Figure 7 (in CIELAB units).

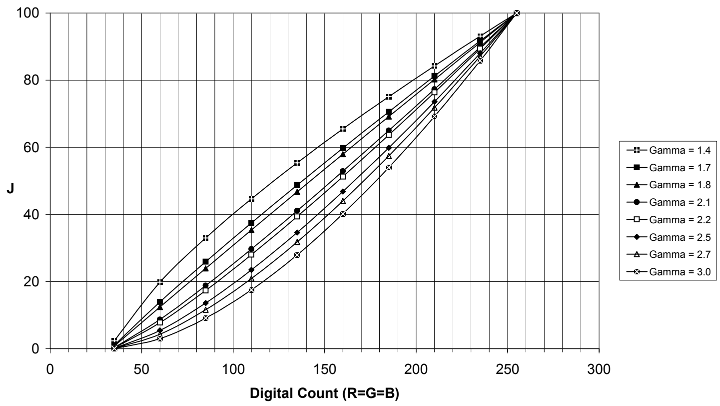

Figure 5: Predicted CIECAM02 lightness *J* for different gamma values for a set of 10 achromatic samples,

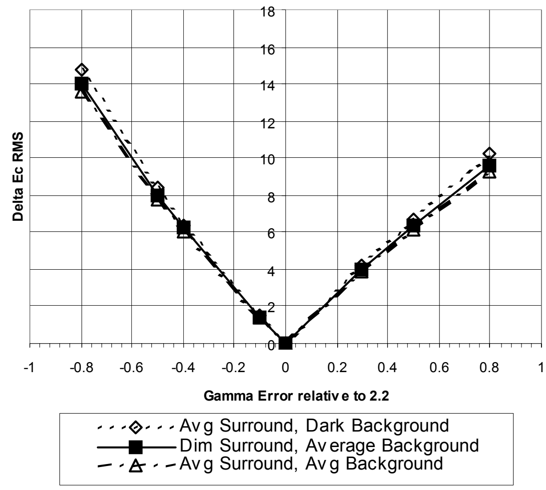

Figure 6: Predicted RMS colour appearance errors in CIECAM02 units for deviations in gamma for all 76 simulated samples [6]

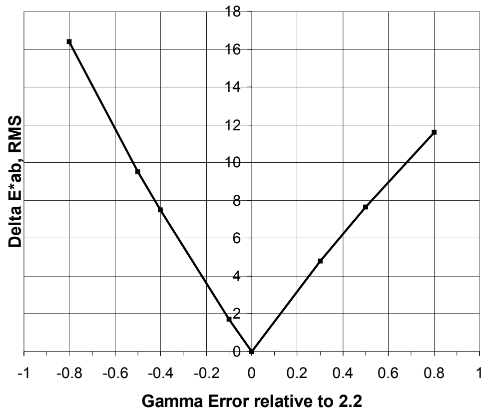

Figure 7: Predicted RMS colour errors in CIELAB units for deviations in gamma for all 76 simulated samples [5]

4. DISCUSSION

In interpreting our results, it should be borne in mind that the use of the CIELAB model (strictly speaking) assumes adaptation to the chromaticity of average daylight [4]. This restriction does not apply to CIECAM02. In following the sRGB recommendations, however, we used D_{65} as the screen white throughout the simulation experiment – and this provides a fair basis for comparison between the two colour models.

Close inspection of the plots in Figures 1–3 will confirm that – in spite of their closely similar appearance – they do, in fact, differ from one another. This is most easily observed by inspecting the gamut enclosed by the plotted points in each of the graphs. This gamut area is smallest in Figure 3 for dim surround and average background, and is greatest for average surround and dark background,

Figure 2. Comparing these graphs with Figure 4 (for CIELAB), it is clear that the CIECAM results provide added information showing how colour appearance is influenced by the surround and background viewing conditions. It is also evident that the distribution of colours in CIELAB space differs noticeably from that in CIECAM02 space – in particular that certain ranges of colours have been shifted out of the fourth quadrant (in CIELAB) and into the third (in CIECAM02).

It is interesting to note that the chromatic content of the samples represented in Figures 1–3 is roughly the same as in Figure 4, *i.e.* the highest chromas lie in the range 100–130 in terms of both CIELAB and CIECAM02 units. However, the hues at which the chromas are highest differ in the two systems. Figures 1–3 also show that the appearance of the colours becomes more or less chromatic in accordance with the viewing conditions.

Figure 5 shows that significant lightness differences can occur as a result of changes in gamma. This was also borne out in the simulation of chromatic samples in both models [5, 6].

There is a high degree of similarity between Figures 6 and 7, both in terms of the general shape of the graphs and in the ΔE ranges, in the two cases. This is likely, at least in part, to be due to the choice of D_{65} as the screen white setting in both cases. It is nevertheless a noteworthy indication that a three-dimensional colour space can be meaningfully associated with the CIECAM02 model. In addition, the three curves plotted in Figure 6 give an indication of the appearance differences resulting from different surround and background luminances – a feature that CIELAB is not able to provide (Figure 7).

5. CONCLUSIONS

It is seen that a three-dimensional colour-appearance space, such as the CIECAM02 space proposed here, is a valuable tool for the colour engineer, providing a means for the visualization of colour-appearance attributes when analyzing a colour-management situation. The CIE is encouraged to work towards the formal adoption of such a colour-appearance space.

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