Testing colour appearance models for unrelated colour*

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Recently, researchers in colour science have paid much attention to colour appearance. As the computer-controlled monitors and colour devices for input and output are developing quickly, many industries, such as printing, dyeing, painting, illuminating, imaging, etc., aim at reproducting colours with high accuracy in different media. There is an urgent necessity to effectively transfer colour information to different customers, but colorimetry based on the CIE system cannot give absolute magnitudes of human colour perceptions under different viewing conditions, which include different lighting sources, illuminance levels and backgrounds. The difficulties in colour appearance research are: all colours are affected by physical means including their spatial properties (size, shape, location in visual field and surface structure), temporal properties (steady state, moving, pulsing) and radiant power distributions; sometimes, the observer's awareness, which includes attention, memory, motivation and emotion, is also an important parameter for the observer's judgement of colour appearance. All these factors result in plentiful phenomena of colour appearance, and the nature of these phenomena is also very complex.

In the recent ten years, many aspects of colour adaptation and colour contrast together with the modern theory of colour vision have been extensively investigated. Colour scientists are now able to establish models of colour appearance, among which are the Hunt model[1], Nayatani model[2], RLAB model[3], ATD model[4], etc. The general characteristic of these models is that they can predict colour appearance using some parameters like CIE tristimulus and colour temperature if the viewing conditions including lighting source,

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observing field, background, etc. are provided in advance. In order to compare these models' performances in predicting colour appearance and to recommend one as a standard for colour appearance quantifying, CIE technical committee 1-34 encourages colour researchers to perform experiments in the field of model testing[5].

An experiment was designed to test the performances of Hunt model, ATD model, CIELAB and CIELUV colour space in predicting colour appearance for unrelated colour. Some preliminary conclusions are drawn here.

1 Experiment method

(1) The unrelated colour samples were produced on an 8 bit, 14" Sony PVM-1442QM monitor. A thick black paper with a 3.5-cm-diameter aperture was used as a mask to cover the monitor. When doing the experiment, the observers sat 0.5 m in front of the monitor and observed the samples under normal viewing condition. The self-luminous samples subtend a visual angle of two degrees at the observer's eyes. The whole experiment was carried out in a darkened room.

(2) 120 samples were prepared. Their luminance range was about $1-100\,\mathrm{cd/m^2}$, and their chromaticity coordinates were plotted on the $u'v'$ chromaticity diagram and covered a wide range of colour gamut.

(3) Five observers aged 20 to 30 with normal colour vision participated in the experiment. Before proceeding the experiment, they were given several hours' training to master the magnitude estimation method for colour appearance scaling[6].

(4) Four colour appearance attributes (hue, brightness, colourfulness, saturation) were scaled, and their definitions were given according to CIE *Colorimetry* published in 1986.

2 Experiment results

(1) All the samples were measured using a Photo Research 1980 B spectroradiometer in its spectral mode. Computer programs were developed to calculate the samples' colour appearance attributes corresponding to different models. For sample i, suppose that the model's predictive value is M_i.

(2) All the samples' colour appearance attributes were scaled by the observers using magnitude estimation method. For different attributes, the raw visual data should be transformed in different ways for analysis[7].

(3) The coefficient of variation (C_v) between the individual observer's visual results (X_i) and the mean results (Y_i) is calculated, which is expressed as a percentage of the

root-mean-square divided by the arithmetic mean of the mean results of all the samples. As far as the mean results are concerned, the arithmetic mean is considered for hue while the geometric mean should be taken for other attributes. The formula can be written as

$$C_v = 100^* \left(\sum_{i=1}^{n} (X_i - Y_i)^2 / n \right)^{\frac{1}{2}} \Big/ \overline{Y}. \tag{1}$$

Here n is the number of samples. The calculated results are listed in table 1.

Table 1 Individual observer's CV and γ in scaling different colour appearance attributes

Colour appearance attributes	Observer C_v and γ	XH	KQ	SM	SY	YZ	Mean
Hue	C_v	6.6	5.6	6.2	7.0	9.5	7.0
	γ	0.991 7	0.993 4	0.990 2	0.992 4	0.983 2	0.990 2
Brightness	C_v	5.6	8.2	4.8	8.9	6.5	6.8
	γ	0.960 6	0.943 3	0.936 8	0.930 5	0.946 5	0.943 5
Colourfulness	C_v	16.1	22.8	20.9	17.1	22.3	19.8
	γ	0.867 5	0.925 0	0.817 2	0.904 5	0.924 5	0.887 7
Saturation	C_v	17.2	22.5	15.5	15.1	24.3	18.9
	γ	0.868 0	0.911 8	0.887 8	0.897 4	0.936 0	0.900 0

XH KQ, SM, SY, YZ are the abbreviation of the five observers name.

(4) A regression line was established to determine the correlation coefficient γ between the individual observer's visual results (X_i) and the mean results (Y_i). The γ value indicates whether there is a linear relationship between the two sets of X_i, Y_i and how they are closed. The calculated results are listed in table 1.

(5) The coefficient of variation between the mean results (Y_i) and the model's predictive value M_i is calculated, which is expressed as C_p differentiated from C_v. The C_p can be used as an indication of the precision of the model's predictive results; the less the C_p, the more precise the model's prediction. Its formula can be expressed as

$$C_p = 100^* \left(\sum_{i=1}^{n} (M_i - Y_i)^2 / n \right)^{\frac{1}{2}} \Big/ \overline{Y}. \tag{2}$$

The calculated results are listed in table 2.

Table 2 The coefficient of variation (C_p) between the mean results (Y_i) and the model's predicting value (M_i)

Colour appearance attributes	Model C_p	HUNT	ATD	CIELAB	CIELUV
Hue	C_p	8.9	11.0	9.9	14.7
Brightness	C_p	11.7	11.8	–[a]	–
Colourfulness	C_p	35.9	–	–	–
Saturation	C_p	40.7	32.1	–	28.3

a) The model has not the measure for the colour appearance attribute, so no C_p value is expected.

(6) In the above calculation, E lighting source is applied when CIELAB and CIELUV colour space are used for predicting the colour appearance. As the 120 samples include grey colours, and it is difficult for the observers to determine their exact hue proportions. 21 samples with very low saturation levels were excluded in the data processing.

3 Conclusion

(1) According to. Luo *et al.*'s statistical data in scaling the related colours[7], the observers' visual results in terms of C_v are about 6, 10, 17 for hue, brightness and colourfulness respectively, and they agree well with the C_v values in table 1, which implies that our experiment data are credible. All the γ values are near 1.0, which indicates that there is a clear linear relationship between the individual observer's results (X_i) and the mean results (Y_i) for the four colour appearance attributes.

(2) When hue is assessed, the Hunt model has the highest predictive precision because its C_p value in table 2 is nearly equal to the mean C_v value in table 1, which means that the error of prediction from the Hunt model is close to the typical error seen between individual observers' and mean visual results. The CIELAB model takes the second place in predicting hue and the CIELUV model performs the worst.

(3) For brightness predicting, the Hunt model and ATD model both have good performance when the corresponding C_v and C_p are compared.

(4) Only Hunt model gives the measure for colourfulness and its predictive precision is not high because the C_p value is much bigger than the C_v value. Of course, the fact that colourfulness is much more difficult to be scaled than hue and brightness results in the big error of the subjective judgements. Our next work will aim at the analysis of the distribution of the error between the visual and model results for colourfulness and make some corrections to Hunt model.

(5) The Hunt, ATD and CIELUV models have the measures for saturation predicting, but none of them seems to exhibit a good performance though CIELUV gives a performance slightly better than the two others. As saturation is derived from colourfulness in the Hunt model, the precision of colourfulness prediction will certainly affect the precision of saturation prediction. The models can be revised if the error between the visual and model results is further analyzed.

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