Evaluation of LED Sources Based on Colour Appearance Data

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ABSTRACT

The current CIE colour rendering index (CRI) has been widely used to test the quality of light sources over 30 years. However, this method is outdated and problematic, especially for evaluating white light emitting diode (LED) sources. A psychophysical experiment was conducted to evaluate the quality of three D65 simulators. The results were also compared with the CRI and the other method, known as CQS. Furthermore, both indices were modified based on CAM02-UCS, and some improvements were found.

Keywords: LED light source, Colour rendering, Colour Rendering Index, Colour Quality Scale, CIECAM02

1. INTRODUCTION

Colour rendering is defined as "Effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant".[1] The current CRI was recommended by CIE in 1974. However, this method is outdated and problematic. First of all, CIE 1964 U*V*W* uniform colour space used to calculate colour differences is obsolete. Secondly, the von Kries chromatic adaptation transform used in the CRI performs poorer than other transforms, such as CAT02 included in the CIE 2002 colour appearance model, CIECAM02. [2] Moreover, none of the eight reflective samples used in the computation of CRI are highly saturated. This is problematic because the colour rendering of saturated colours could be very poor even when the CRI value is good. This is particularly marked for the peaked spectra of white LED sources.[3]

The LED applications have recently grown significantly due to its long life span, high energy efficacy and durability, etc. Furthermore, a wide variety of LEDs with different peak wavelengths covering the visible region are now available. With this in mind, an LED D65 simulator including 8 coloured LEDs was constructed. [4] The lamp was designed to have a close match to the spectral power distribution (SPD) of CIE D65 illuminant. It had a CRI value of 98 and a metamerism index (MI) of A Category (with ΔE^*_{ab} of 0.1). In addition to those sources, a fluorescent lamp supplied by VeriVide and a cool white LED were also used in the experiment. The latter is consisted of blue chip with yellow phosphors. The CRI values are 97 for the fluorescent lamp and 86 for the white LED. Figure 1 shows the SPDs of the three sources studied.

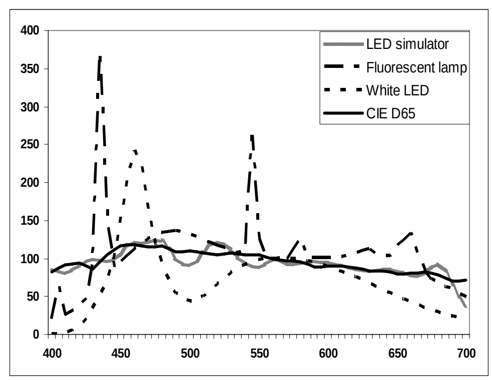

Figure 1 the SPDs of three light sources

2. Visual Experiment

The magnitude estimation method was employed to assess the colour appearance of test samples under different sources. Sixty textile samples which were highly colour inconstant were selected. These samples were chosen due tolarge change of colour appearance when illuminants are varied, especially the white LED. Ten observers participated in the experiment. They were PhD students from the Department of Colour Science, University of Leeds, with great experience in using the magnitude estimation method. Each observer was asked to estimate the colour of the test samples in terms of lightness, colourfulness and hue according to a reference white and a reference colourfulness under a viewing cabinet in a dark room. Each sample subtended about a 2^{o} viewing field. For each observer, a sample was estimated twice, and the results were used to investigate the observer repeatability.

3. Result

The magnitude estimation data were collected and the coefficient of variation (CV) was used to indicate the agreement between any two sets of data. The lower the CV value is, the smaller the variation is for the two data sets. For example, a CV of 30 roughly means 30% variation between two datasets.

$$CV = \frac{100\sqrt{\sum (x_i - f \times y_i)^2 / n}}{\overline{x_i}} , \qquad f = \frac{\sum x_i \times y_i}{\sum y_i^2} \tag{1}$$

where x_i and y_i are two sets of data, $\overline{x_i}$ is the mean for set x_i ; *f* is a scaling factor.

For the three colour appearance attributes studied, CV values were calculated between each individual observer's results and the mean results, and between observer's two repeated results, to represent the performance of observer's accuracy and repeatability, respectively. (Note that the scaling factor in equation (1) was set to one in bother cases.) Table 1 lists the average CV values for observer's repeatability and accuracy under LED D65 simulator, fluorescent lamp and white LED for lightness, colourfulness and hue. The results showed that the observers' performances for all three sources studied are very similar. Besides, there is not much difference between observer's repeatability and accuracy performance.

CV	Repeatability			Accuracy		
	Lightness	Colourfulness	Hue	Lightness	Colourfulness	Hue
LED D65 simulator	20	27	11	20	25	10
Fluorescent lamp (VeriVide)	19	25	10	20	24	9
White LED	19	26	13	20	25	11

Table 1 Observers' repeatability and accuracy for 3 light sources

CIECAM02 was used to predict the colour appearance of test samples under three test sources and under CIE D65 illuminant. The CV value was again used to indicate the agreement between the visual results and CIECAM02 predictions. For lightness and hue, the scaling factor *f* was set to 1; but for colourfulness, the scaling factor *f* was calculated from equation (1). The results are listed in Table 2. The corresponding scatter diagrams are given in Figure 2.

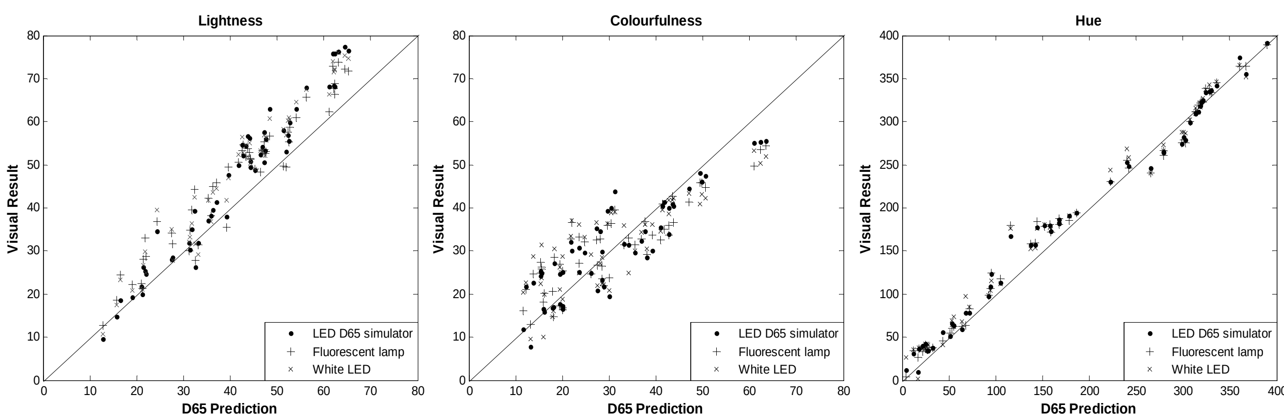

Figure 2 Visual results under test sources against the CIECAM02 predictions under CIE D65

CV	Visual assessment against CIECAM02 prediction under each test light source			Visual assessment against CIECAM02 prediction under CIE D65 illuminant		
	Lightness	Colourfulness	Hue	Lightness	Colourfulness	Hue
LED D65 simulator	18	21	9	18	21	9
Fluorescent (VeriVide)	17	22	9	17	23	9
White LED	20	22	8	19	25	10

Table 2 Comparison between visual result and CIECAM02 prediction

It can be seen in Table 2 that the CV values are similar to or smaller than those in Table 1. This implies that CIECAM02 is a reliable model in predicting the current experimental data. Secondly, the relationship between visual assessments and CIECAM02 predictions under each test light source, and that under D65 illuminant are very close. This suggests that the colour rendering of test samples under the test sources are very similar to that under CIE D65 illuminant. Finally, when comparing the visual results and predictions under D65, it is obvious that there is no significant difference in CV values for the 3 light sources. The CV values are very close for lightness and hue attributes for all test sources. However, the colourfulness judgment under white LED gives the worst result, in which the CV value is slightly larger than those of LED D65 simulator and fluorescent lamp. This implies that for assessing colour appearance, the white LED is only slightly worse than the other test sources for colourfulness, but gave the same performance for lightness and hue, when compared with the reference D65 illuminant.

The results of CRI for the three sources are given in Table 3. The CRI value for the LED D65 simulator is very close to that of fluorescent lamp, but is much better than that of the white LED by around 12 units. This indicates that the LED D65 simulator renders colour similar to the fluorescent lamp but much better than the white LED

Recently, another colour rendering method was proposed by NIST, named colour quality scale (CQS).[3] Its predictions have the similar performance as CRI, in which white LED performed worse than LED D65 simulator and fluorescent lamp. But the CQS gives white LED a much worse value than that of the LED D65 simulator as shown in Table 3. This suggests that both CRI and CQS do not agree with the visual results in the present experiment (Table 2), which showed not much difference between 3 sets of visual results.

Finally, the CRI and CQS were modified based on an extended version of CIECAM02, called CAM02-UCS.[5] This modified version gave an accurate prediction of the colour discrimination data. Their results are also given in Table 3.

	CCT	CRI	CRI CAM02-UCS	CQS	CQS CAM02-UCS
LED D65 simulator	6396	98	99	99	99
Fluorescent lamp (VeriVide)	6405	96	98	98	99
White LED	6937	86	91	77	89

Table 3 Results of different colour rendering calculation method

It can be seen that the two methods based on CAM02-UCS predicted almost the same results between the LED D65 simulator and VeriVide fluorescent lamp, but higher colour rendering values for the white LED than those of the conventional methods. This implies that the new methods agree better with the current visual results than both CRI and CQS. Thus, it can be concluded that the colour rendering calculation based on CAM02-UCS can perform better than the conventional methods.

4. CONCLUSIONS

A psychophysical experiment was conducted under three sources: an LED D65 simulator, a fluorescent lamp and a cool white LED. The findings are summrised below:

- Observers' accuracy and repeatability from the three light sources are very similar.
- The CIE colour appearance model, CIECAM02 gave accurate prediction to the visual results under all sources.
- The visual results from all sources gave similar rendering as those under CIE D65 illuminant.
- The current CRI and CQS under predict the colour rendering of white LED source.
- The modified CRI and CQS based on CAM02-UCS predicted better than the original CRI and CQS with higher colour rending values for white LED.

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