Approach to CRI (Colour Rendering Index) for full colour RGB LED source lighting

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Abstract

The purpose of this study is to examine the colour rendering property of full colour RGB LED lighting. The problem of the conventional CIE CRI method is considered and new models are suggested for the new lighting source. Each of the models was evaluated with visual experiment results obtained by the white light matching experiment. The suggested model is based on the CIE CRI method but replaces the colour space model by CIELAB, colour difference model by CIEDE2000, and chromatic adaptation model by CAT02.

Introduction

Colour rendering is an important criterion for evaluating the quality of light source and is defined by CIE (Commission Internationale de l'Éclairage) as the "*effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant*" [1].

To characterise the colour rendering properties of light sources, the CIE decided to regard the 'test-colour method' [2], which assesses the magnitude of the colour shift of a number of test objects illuminated first under a test source and then under a reference illuminant, as the fundamental method for colour rendering appraisal. A colour rendering index (CRI), which is based on this principle, was recommended by CIE in 1974 as the standard method to evaluate the colour rendering properties of light sources. Thus since 1974, the CIE colour rendering index has been used ever since. However, a large number of papers have been published to criticise it for its outdated colorimetric techniques and its breaking down when compared with visual observations [3], [4]. Moreover, the CIE test-colour method has been found extremely problematic when LED-based light sources have been evaluated together with other traditional light sources.

White RGB LED light sources have spectral power distributions with three significant peaks corresponding to their R, G, and B components. Therefore, they can cause large colour differences compared to the reference illuminant which has broad spectral power distribution curves.

In this paper, the weaknesses of the CIE test-colour method, such as the chromatic adaptation, uniform colour space and the test colour samples, are discussed respectively.

CRI Problems and Modification Suggestions

Problems

The problems of CIE CRI have been pointed out during the past in several previous studies. A large number of papers have been published to criticise the CIE test-colour method. Also pointed out where the method breaks down, and how some new colorimetry procedure, such as more advanced chromatic adaptation transform, colour difference formulae, and colour appearance model, should be applied to improve the colour rendering index.

Modification suggestions

The new method named Color Quality Score (CQS) [5] was proposed by the National Institute of Standards and Technology (NIST) to modify the CIE colour rendering index. The eight mid saturated samples of the CIE CRI was replaced by fairly high chromatic samples. The chromatic adaptation model was changed to CMCCAT2000 [6] from von Kries transform [7]. The 1964 U*V*W* colour space [8] and colour difference equation was replaced by CIELAB [9].

In this paper, three different models based on the CRI are suggested and listed in Table 1. Model 1 is the conventional CIE test method and models 2 and 3 are the suggested modified models. Models 2 and 3 changed the colour space model from CIEU*V*W* to CIELAB model. The colour adaptation model is replaced by CAT02 [11] for models 2 and 3. The reference illuminant is D65 and therefore models 2 and 3 are independent of CCT (correlated colour temperature). The difference between models 2 and 3 are the colour difference equations which are CIEDE for model 2 and CIEDE2000 [11] for model 3.

Table 1: Three suggest models for CRI

	model 1	model 2	model 3
Color Space	CIEU*V*W*	CIELAB	CIELAB
CAT	von Kries	CAT02	CAT02
CCT	CCT Dependent	CCT Independent	CCT Independent
Illuminant	Various reference illuminant	D65	D65
Color difference equation	CIEDE U*V*W*	CIEDE	CIEDE2000

Matching D65

Experiment Setup

Visual experiments were carried out using the Macbeth ColorChecker Chart (GMCC) to provide the spectral data for testing the CRI models. Observers sat in front of two viewing booths, one with a D65 simulated illuminant and other with RGB LED clusters (Fig. 1). The aim of this experiment is to check whether the visually observed colour differences are correlated with the colour differences predicted by the CIE test-colour method or other formulae.

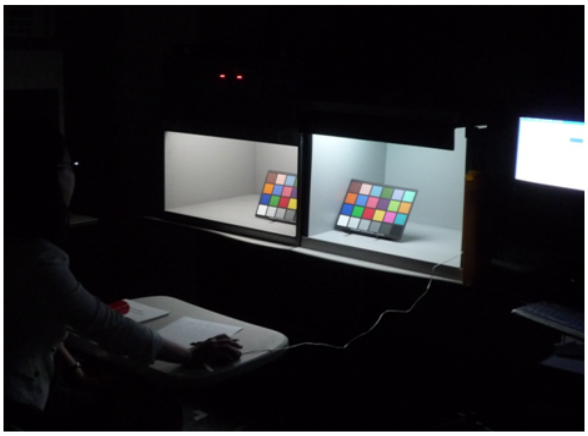

***Figure 1**: Experiment set up*

Fifteen females in their 20s has participated the experiment. The observers were asked to adjust the relative powers of the R, G and B LEDs (digital values 0-255) until a best average match was obtained for all patches to match colour chart under D65 light source. RGB values were adjusted separately with and without the warm white turned on. Note that the luminance of the D65 light source was adjusted to maintain the same value as the LED light source.

Experiment Results

Fig 2 shows the 15 observers' relative spectral power curve of the RGB LED light source matching the D65 light source. The left shows the RGB LED and right shows the RGB LED with the warm white source turned on.

The second task was to evaluate the colour difference of each colour patch on the GMCC chart. The observers gave a score of 5 if it is an exact match and 1 if it is totally different from the D65 viewing booth. Fig 3 shows the GMCC chart along with the sample number starting from 1 to 24. Sample 19 to 24 which are achromatic colours were excluded from the colour difference.

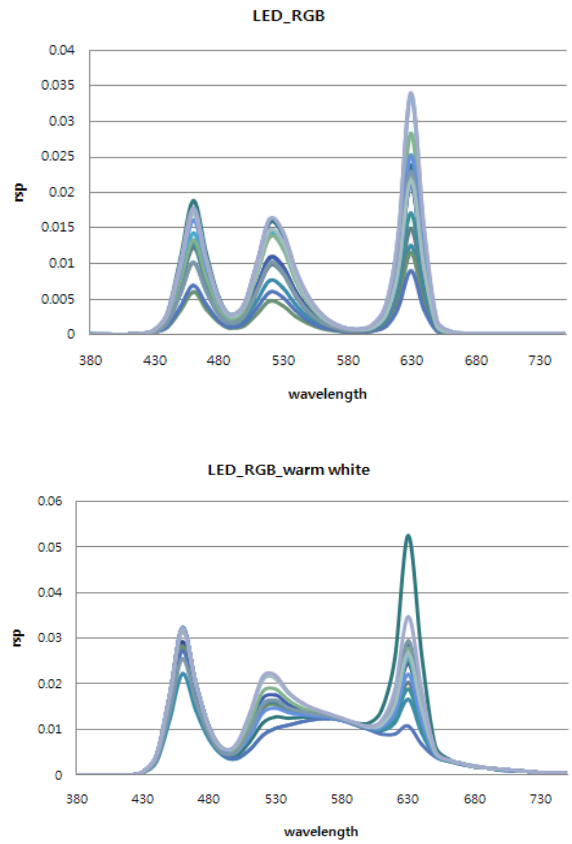

***Figure 2:** Spectral power curve of RGB LED (+ warm white) matching the D65 light source*

1	2	3	4	5	6
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24

***Figure 3:** Experiment set up*

The average scores for all colour patches are shown in Fig 4. The dark and mid grey bars represent the colour difference under RGB LED and RGB LED with warm white respectively. The colour difference is smaller when the warm white is on for all 18 colour samples. In other words, CRI should be higher with the warm white on and it is closer to D65 light source. Therefore, the spectrum with the warm white on along with the RGB LED was used to test the CRI models.

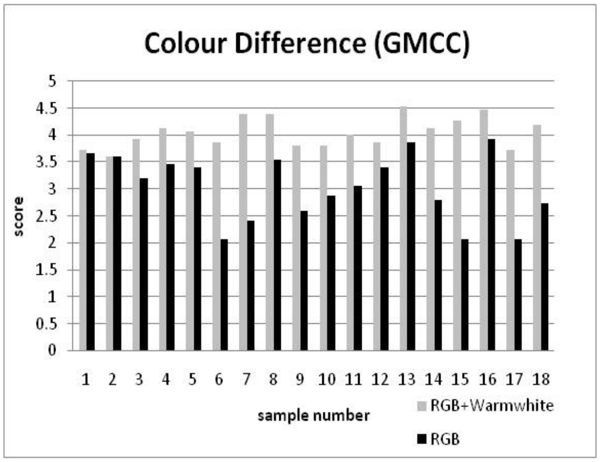

Figure 4: *Colour difference scores for GMCC chart (dark: RGB, mid grey: RGB with warm white)*

Results

Testing different Models

All three models were tested using the spectral power curve of all 15 observers. The spectral power curves were obtained carefully by all 15 observers which should give a high CRI score. The CRI score for all three models of 13 observers (two observers were excluded of poor repeatability) are shown in Fig 5. Note that only the CIE 1964 test samples were used.

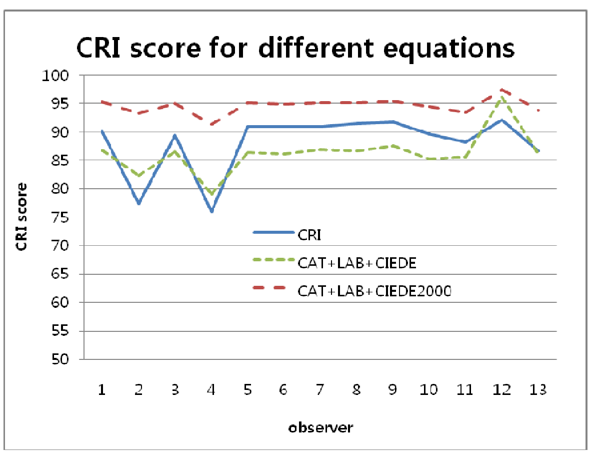

Figure 5: *CRI score for different models*

The full line represents the CRI score for the CIE colour-test method (model 1). The small and large dashed line represents model 2 and model 3 respectively. We know that all 13 observer results showed show high and similar CRI scores to each other. Thus, model 3 shows the best performance among all three models.

Testing Different Models with Different Test Samples

The different models were tested using different test samples. The conventional test samples are the 8 colour samples of CIE 1964 test samples. The CQS test samples are the 15 high chromatic suggested by NIST for LED light sources. The test samples are plotted on CIELAB a*-b* plane in Fig 6. Squares and diamond represent CQS and CIE 1964 test samples respectively. All two samples circle the hue evenly. As the distance from the origin indicates the chromaticity of the samples, CQS test samples show higher and even chromaticity than the CIE 1964 test samples.

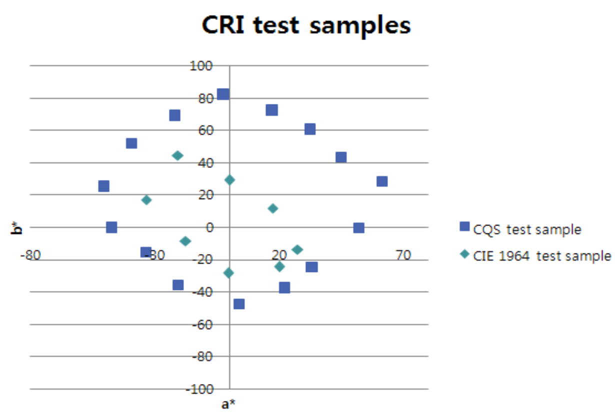

Figure 6: *Test sample plotted on CIELAB a*-b* plane (square: CQS test sample, diamond: CIE 1964 test sample)*

Both test sample set were used to test all three models. The results are shown in Fig 7 and Table 2.

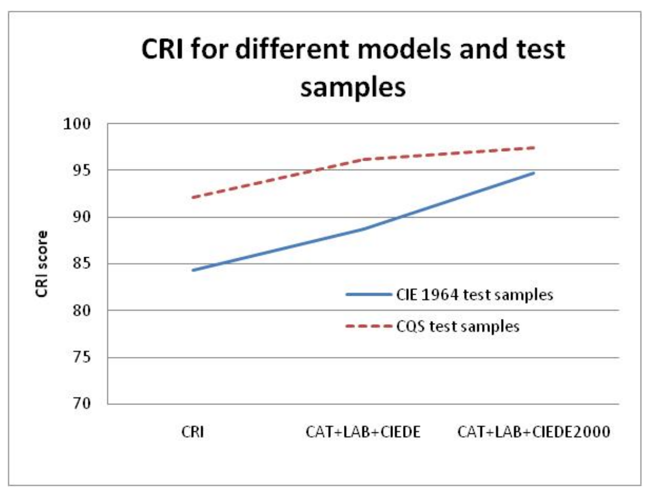

Figure 7: *CRI for different models and test samples.*

The CRI scores predicted by 3 different models are plotted in Fig 7. The full line is results using the CIE 1964 test samples and dotted line is CQS test samples. Model 3 shows similar CRI scores for all two different kinds of test sample sets.

Table 2: CRI score for different models and test samples.

Models Test Samples	CRI (1)	CAT+LAB +CIEDE(2)	CAT+LAB +CIEDE2000(3)
CIE 1964	84.3	88.7	94.7
CQS	92.1	96.2	97.4

Conclusion

The conventional colour rendering index, CIE test colour method, for full colour RGB LED was revised along with two modified versions. Model 3 (CAT02, CIELAB, CIEDE2000) shows stable CRI scores using visual data obtained by the white matching experiment. Additionally, it scores similarly using different test colour sample sets. Therefore, model 3 is suggested as the appropriate colour rendering index for RGB LED lighting.

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Author Biography

Yung Kyung Park received her BA and Master Degree in physics from Ewha Womans University (Korea, 2001, 2003) and MSc in colour science from University of Derby (UK, 2003). Also received a PhD in colour science at University of Leeds (UK, 2009). Her work has focused on the colour appearance of mobile displays. Afterwards she worked as a researcher at Ewha Color Design Research Institute. Currently she is working at Samsung Electronics, LCD R&D centre.