

## A BETTER DESCRIPTION OF METAMERIC EXPERIENCE OF LED CLUSTERS

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We carried out colour matching experiments using colour LED clusters and filtered incandescent lamps. There is considerable difference between the instrumentally determined chromaticities if broad band colours are visually matched with narrow band colours produced by additive mixture of the light of red, green and blue LEDs. The measured  $u',v'$  chromaticity difference could be halved if not the 2° standard colour matching functions (CMFs) are used, but CMFs derived from cone fundamentals.

As a further step the cone fundamental derived CMFs have been modified. The obtained CMFs provide very good agreement between the visual and instrumental matches. These tentative CMFs have to be further evaluated with a larger number of observers, before it can be recommended for general practice.

### Introduction

In an earlier experiment<sup>1</sup> results of Maxwell colour matches have been reported. It was shown that the CIE 1931 colour matching functions (CMFs) do not describe the metameric matches between broad band stimuli and stimuli produced by the additive mixture of the light of red, green and blue LEDs (RGB-LED) well. The differences between the visual and instrumental match increased towards the blue part of the chromaticity diagram. If CMFs derived from the cone fundamentals<sup>2,3</sup> were used, the differences between the visual and instrumental matches could be halved.

In recent years several papers dealt with the question of the validity of Grassmann's laws, and the transformability of primaries (see e.g. <sup>4,5</sup>), the present paper does not wish to question the validity of those papers, it just would like to show what effect a change of the CIE 1931 colorimetric system to a system based on cone fundamentals (or similar) could have for the colorimetry of lights produced by the additive mixture of the light of red, green and blue LEDs of different dominant wavelengths. Two extreme sets of RGB LEDs were used for which the dominant wavelengths were near to the PC (Prime Colour) and the AP (Anti Prime Colour) wavelengths of Thornton's experiments<sup>6</sup>. As test chromaticity we

<sup>1</sup> Csuti P, Schanda J, Colour matching experiments with RGB-LEDs, *Color Res. & Appl.* 33 108-112

<sup>2</sup> CIE Techn. Report: Fundamental Chromaticity Diagram with Physiological Axes - Part 1 Publ. CIE 170-1:2006.

<sup>3</sup> CIE TC 1-36 draft technical report of Chapter 7.3: Development of chromaticity diagrams based upon the principles of the CIE XYZ system (draft 2006).

<sup>4</sup> Brill MH (2006) Towards resolving open questions on the validity of Grassmann's laws. *Proc. ISCC/CIE Expert Symp. '06 - 75 years of the CIE standard colorimetric observer*. Publ. CIE x030:2006. pp.8-12.

<sup>5</sup> Oicherman B, Luo MR, Robertson AR (2006) Test of the transformation of tristimulus space: Forward- and inverse-matrix methods. *Proc. ISCC/CIE Expert Symp. '06 - 75 years of the CIE standard colorimetric observer*. Publ. CIE x030:2006. pp. 30-36.

<sup>6</sup> Thornton WA (1992) Towards a more accurate and extensible colorimetry. Part 1. *Color Res. & Appl.* 17 79-122; Part 2. *Color Res. & Appl.* 17 162-186; Part 3. *Color Res. & Appl.* 17 240-262.

selected that region of the chromaticity diagram, where in the previous experiment the largest colour difference was found between the visual match of the RGB-LED light and a light of the same visual colour produced by broad-band sources.

**Experiment**

The experimental set up was similar for both experiments, i.e. for the PC experiment one half of an approximately 2° x 3° large bipartite visual field, which could be observed binocularly, was illuminated by the light from a filtered incandescent lamp, while the other part of the field was illuminated by the additive mixture of the light of the red, green and blue LEDs (termed RGB LED). For the AP experiment the light of the amber LED had to be additively mixed with the light of the filtered incandescent lamp and this mixture was matched by the light of the other two AP LEDs. Figure 1 shows the relative spectral power distribution of the LEDs used in these experiments.

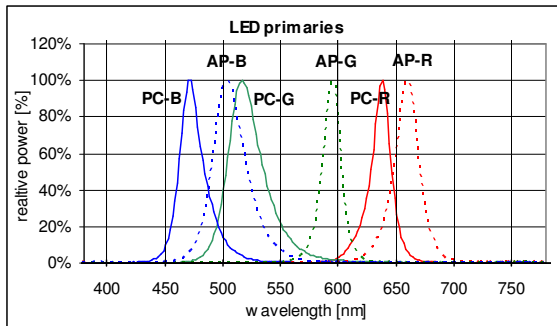


Figure 1: Relative spectral power distribution of the used LEDs, PC refers to the "Prime Colour", AP to the "Anti Prime Colour" set of LEDs

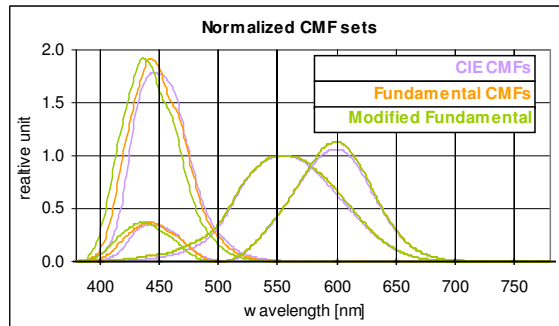


Figure 2: Three sets of CMFs (CIE 2°, Fundamental, Modified Fundamental)

The CIE TC 1-36 tentatively recommended CMFs do not correct all the differences between the instrumental and visual observations. One might contemplate further – based on the non-representative group of observers (five male and two female young observers) used in the present experiments – whether one could further decrease the difference between the instrumental and visual matches by optimizing the CMFs for the present, restricted group of observers. If yes, this could open up the possibility to do such optimization based on a much larger, representative sample of observers to get CIE colorimetry to describe the visual observations of LED colours better. Figure Figure 2 shows the three sets of CMFs, those of the CIE 2° standard colorimetric system,  $\bar{x}_f(\lambda), \bar{y}_f(\lambda), \bar{z}_f(\lambda)$  functions derived from the cone fundamental CMFs of CIE TC1-36, and  $\bar{x}_m(\lambda), \bar{y}_m(\lambda), \bar{z}_m(\lambda)$  modified CMFs, optimized by the help of the present experiment. Figure 3 shows  $u', v'$  chromaticity differences obtained with these three sets of CMFs for the colour matches described in paper<sup>1</sup> and the present experiment.

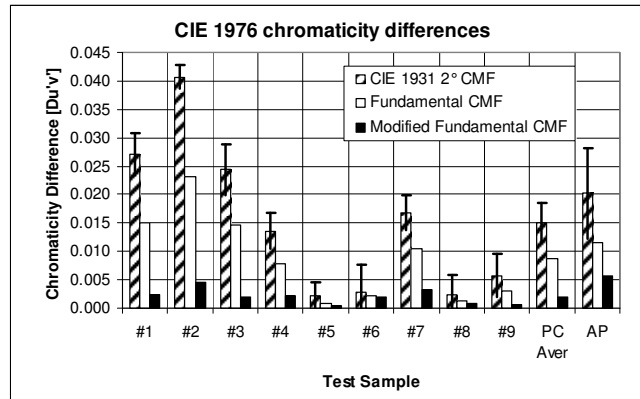


Figure 3: Results of the experiments: #1 – #9 PC, last column AP comparing the different CMF sets; error bars show standard deviation of visual settings.

### Conclusions

Standard colorimetric methods lead to considerable ( $\Delta E_{ab} > 10$ ) differences between visually matching fields. This can hamper the use of LED architectural lighting of the light of a mixture of RGB-LEDs has to match the light produced by traditional light sources. The use of CMFs investigated by CIE TC 1-36 can solve only part of this problem. We have shown that the still remaining discrepancy, which is most pronounced in the blue part of the chromaticity diagram can be largely eliminated by the use of a modified set of CMFs.

Further investigations using a higher number of LED spectra and a more representative set of observers has to be used to get to final recommendations of a new modified set of CMFs.