Experimental Investigation of Distortion of Colour Harmony: A Harmony Distortion Index

Ferenc Szabó, László Antos, Peter Bodrogi, János Schanda; Virtual Environments and Imaging Technologies Laboratory, Department of Image Processing and Neurocomputing, Faculty of Information Technology, University of Pannonia, Veszprém, Hungary

Abstract

This study investigates the distortion of visual colour harmony impression in case of different types of artificial changes among the perceptual attributes of test samples. A set of visual experiments were carried out to investigate the observer's colour harmony impression as a function of artificial distortions. The visual colour harmony impression of a colour combination appearing harmonious under a reference illuminant might decrease if the combination of samples is illuminated by different test light sources, especially RGB LED clusters. A new quantity, the so called Harmony Distortion Index (HDI) is defined to describe the harmony distortion property of light sources.

Introduction

Authors investigated existing colour harmony models[1,2,3] and developed several new predictive formulae[4] to quantify visual colour harmony impression. A Harmony Rendering Index (HRI)[4] based on the harmony predictions of colour harmony formulae for a set of test colour combinations under different illuminants was also developed, to describe light source colour quality. In an earlier experimental study[5], authors came to the conclusion that colour harmony impression decreased significantly by changing the reference light source to a white LED lamp consisting of a cluster of RGB LEDs of unusual spectral power distribution. A possible explanation of this phenomenon was claimed to be that there were very different and non-systematic colour shifts, concerning both magnitudes and directions among the samples[5]. In a previous study[6], several "equivalent" shifts were displayed to 7 observers in order to investigate the authors' "shift-invariance" hypothesis of colour harmony. In case of "equivalent" shifts, each of the three perceived attributes (hue, chroma and lightness) changes to the same extent for all colours of the colour combination. Several "non-equivalent shifts" were also shown to examine the distortion of perceived colour harmony. In this article, these experimental results are analyzed to form a model describing the colour harmony distortion property of light sources.

Experimental Method

To investigate the distortion of visual colour harmony, a series of visual experiments were carried out. Equivalent and non-equivalent distortions were simulated on a calibrated CRT monitor changing hue, chroma and lightness separately (see Figure 1). For "equivalent" shifts, each of the 3 perceived attributes (CIECAM02[7] hue, chroma and lightness) changed to the same extent for all constituent colours of the colour combination. "Non-equivalent shift" means that the 3 perceived attributes change not to the same extent or not to the same direction for the two or three constituent colours of the colour combination. The extent of distortions we applied were 2, 4, 7,

9, 12 CIECAM02 ΔE units. The task of the 7 observers (3 male, 4 female, aged between 22-24) was to evaluate visual colour harmony on a scale from -5 to +5, where -5 means very disharmonious, +5 excellent harmony. Observations were repeated three times, to get significant experimental results. Before the experiments, the observer's colour vision was tested by the Farnsworth-Munsell 100 Hue test.
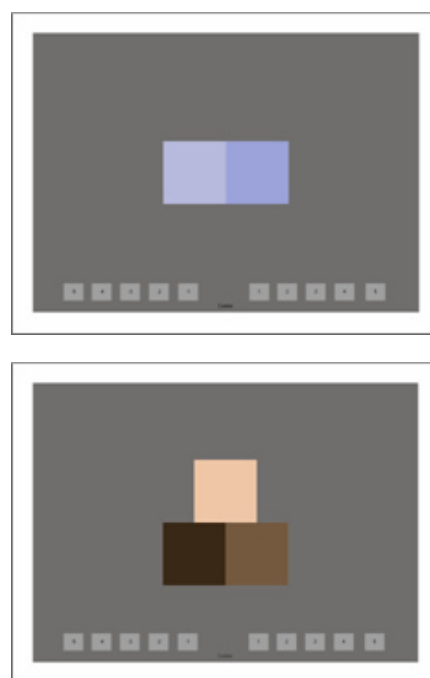

Figure 1.: Experimental images on the CRT monitor in case of two and three colour combinations

Results

From the analysis of visual results, the relation between distortions and perceived colour harmony impression was determined.

As can be seen in Figure 2 distortion of visual colour harmony is different in case of artificial equivalent and non-equivalent distortions. On this Figure, the effect of the size of the artificial distortion can be also seen. In case of "small" distortions, the extent of the artificial distortion is 7 CIECAM02 ΔE units. For "large" distortion, this distortion is 12 CIECAM02 ΔE units.

The main factors which are responsible for the distortion of colour harmony impression were identified as:

1. extent of distortion
2. perceptual attribute

3. a further quantity describing the "equivalent/non-equivalent ratio" of the distortion.
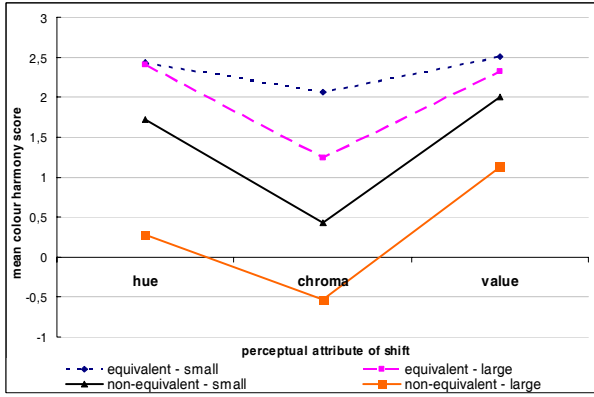
Figure 2.: Distortion of observer's visual colour harmony in case of different type of artificial distortions for two colour combinations.

Figure 5.: Distortion of observers' visual colour harmony impression as a function of artificial chroma distortions. Mean of visual results can be seen with 95% confidence intervals.

As a conclusion of these first results it can be stated that the distortion of visual colour harmony can be predicted with the help of a new metric, which is composed of functions which are good descriptors of the effect of hue, chroma and lightness distortions separately. Mathematical functions were fitted to experimental data to describe the effect of these factors. These functions must be also responsible for predicting the distortion of visual colour harmony as a function of the extent of distortion. Visual results and fitted curves can be seen in Figures 3-5.

As can be seen in Figures 3-5, the decrease of observers' visual colour harmony is significantly higher in case of non-equivalent distortions. From these functions, a universal colour harmony ranking can be constructed.

Harmony Distortion Index

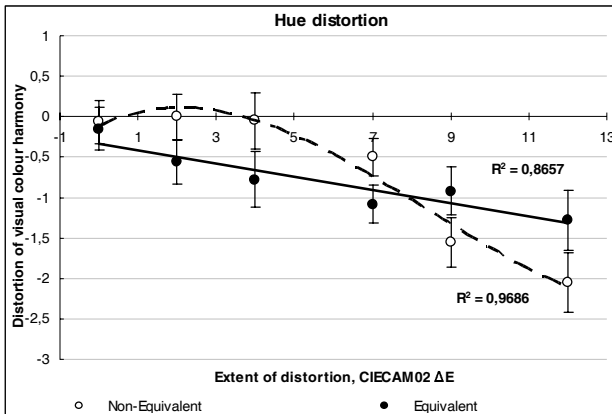From these results a Harmony Distortion Index (HDI) was defined as

Figure 3.: Distortion of observers' visual colour harmony impression as a function of artificial hue angle distortions. Mean of visual results can be seen with 95% confidence intervals.

$$I_{HDI} = 100 - l * \sum_{i=1}^{n} \begin{matrix} s_{Je}\alpha f(\Delta J_{\text{equivalent}}) + \\ s_{Ce}\beta g(\Delta C_{\text{equivalent}}) + \\ s_{he}\chi h(\Delta h_{\text{equivalent}}) + \end{matrix} \tag{1}$$

$$(1-s_{Je})\delta i(\Delta J_{\text{non-equivalent}}) + (1-s_{Ce})\varepsilon j(\Delta C_{\text{non-equivalent}}) +$$

$$(1-s_{he})\phi k(\Delta h_{\text{non-equivalent}})$$

where:

s_{Je} – represents the equivalent part of the distortion along lightness (between 0 and 1)

s_{Ce} – represents the equivalent part of the distortion along chroma (between 0 and 1)

s_{he} – represent the equivalent part of the distortion along hue (between 0 and 1)

$$s_{Je} = \frac{\Delta J_{equivalent}}{\Delta J_{equivalent} + \Delta J_{non-equivalent}}; \tag{2}$$

$$s_{Ce} = \frac{\Delta C_{equivalent}}{\Delta C_{equivalent} + \Delta C_{non-equivalent}};$$

$$s_{he} = \frac{\Delta h_{equivalent}}{\Delta h_{equivalent} + \Delta h_{non-equivalent}}$$
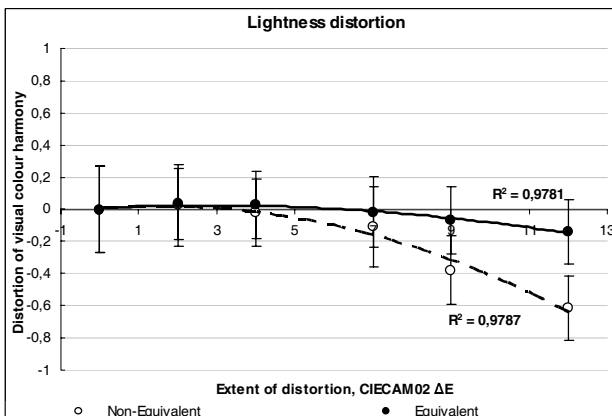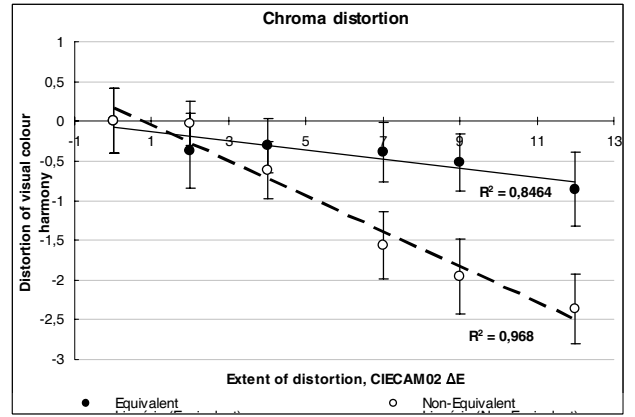

Figure 4.: Distortion of observers' visual colour harmony impression as a function of artificial lightness distortions. Mean of visual results can be seen with 95% confidence intervals.

f, g, h, i, j, k are fitted curves fitted to the visual results (See Figures 3-5),

$\alpha, \beta, \chi, \delta, \varepsilon, \phi$ are suitable constants to scale the different effect of the six types of distortions (equivalent and non-equivalent distortions among the three perceptual attributes) to each other, and

l is a constant to bring the HDI of practical light sources on a usable scale.

The accurate values of the constants are evaluated according to the results of independent visual experiences (see next section).

Testing the model with an independent dataset

The new colour harmony metric was tested with an independent experimental dataset. To do this investigation 10 two-colour combinations were observed in a lighting booth under different illuminants. Light sources were categorized into three groups, according to colour temperature. The level of illumination was set to 170 cd/m^2. Colorimetric properties of light sources can be seen in Table 1.

Table 1.: Colorimetric properties of test light sources.

| #	Name	x	y	CCT
1	Incandescent lamp	0.4631	0.4134	2682
2	White phosphor LED	0.4623	0.4220	2776
3	RGB LED	0.4648	0.4120	2707
4	Compact fluorescent lamp	0.4564	0.4125	2752
5	Halogen lamp	0.3942	0.3960	3835
6	White phosphor LED	0.3923	0.3878	3827
7	RGB LED	0.3916	0.3836	3639
8	Compact fluorescent lamp	0.3953	0.3931	3820
9	D65 simulator	0.3133	0.3221	6555
10	White phosphor LED	0.3139	0.3326	6554
11	RGB LED	0.3080	0.3317	6780
12	Compact fluorescent lamp	0.3196	0.3527	6081
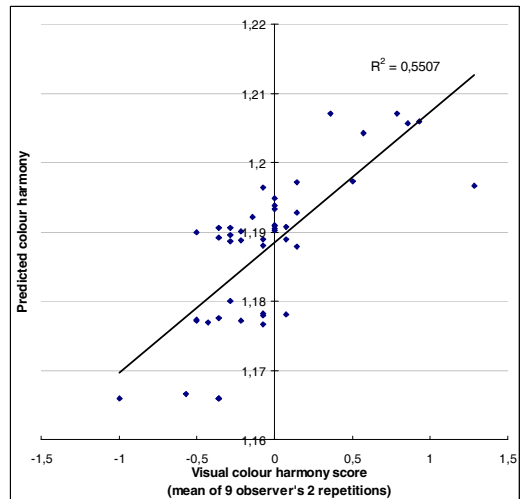
Figure 7.: Correlation of visual colour harmony ranking and predicted colour harmony distortion at 4100K (distortion of 10 two colour combinations under 4 test light sources)
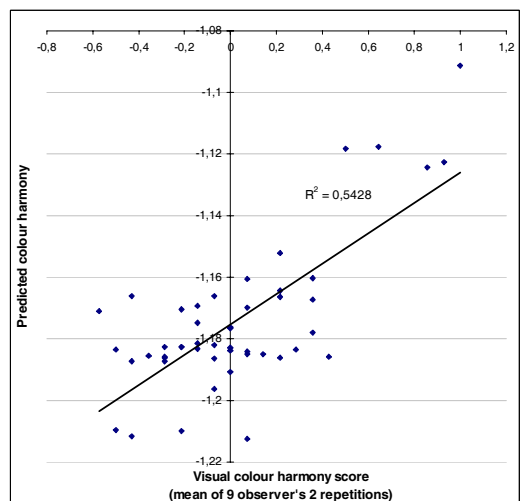

Figure 8.: Correlation of visual colour harmony ranking and predicted colour harmony distortion at 6500K (distortion of 10 two colour combinations under 4 test light sources)
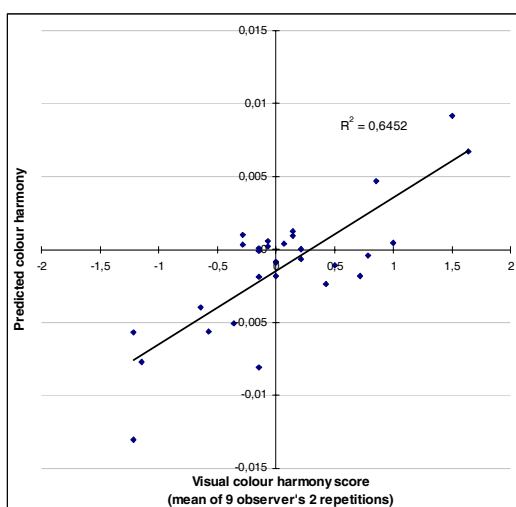
Distortions among perceptual attributes can cause different fall of colour harmony at various colour temperatures of illumination. Hence, weighting factors in Eq(1) can be optimized according to visual results. Figures 6-8 shows the prediction of HDI using different optimized weighting factors at various CCTs. As can be seen in Figures 6-8 there is a significant correlation between HDI and visual results. Further optimization of the model with more light sources is currently underway.

Conclusion

The distortion of colour harmony impression was examined in case of two- and three- colour combinations with the help of artificial distortions of the perceptual attributes of the constituent colours. Relations between distortions and perceived colour harmony were defined. From the accurate mathematical modelling of colour harmony, a new method was developed to describe light source colour quality based on the extent of distortion of colour harmony caused by the test light source. This new Harmony Distortion Index can be compared with

Figure 6.: Correlation of visual colour harmony ranking and predicted colour harmony distortion at 2700K (distortion of 10 two colour combinations under 4 test light sources)

©2008 Society for Imaging Science and Technology

HRI[4] and may contribute to the work of supplementing the current Colour Rendering Index[8] of the CIE.

References

[1] R. Van Nostrand, Munsell: A Grammar of Color, 1969, Reinhold Book Coorporation

[2] A. Nemcsics, Farbenlehre und Farbendynamik, Akadémiai Kiadó, Budapest, 1993.

[3] Web page of RAL Design System: http://www.ral.de/en/ral_farben/farbkarten/ral_design.php

[4] F. Szabó, P. Bodrogi, J. Schanda: Visual Experiments on Colour Harmony: A Model and a Rendering Index (The 26th Session of the CIE 2007, Beijing, China)

[5] F. Szabó, P. Bodrogi, J. Schanda: Comparison of Colour Harmony Models: Visual Experiment with Reflecting Samples Simulated on a Colour CRT Monitor, (CGIV 2006, Leeds, UK)

[6] F. Szabó, J. Schanda, P. Bodrogi: Experimental Investigation of the Distortion of Colour Harmony, (AIC 2007 Colour Harmony Conference 2007, Budapest, Hungary)

[7] Moroney N, Fairchild MD, Hunt RWG, Changjun L, Luo MR, Newman T (2003). The CIECAM02 color appearance model. Proc. IS&T/SID Tenth Color Imaging Conf. pp. 23-27.

[8] Commission Internationale de l'Éclairage, CIE TC 1-62, Colour Rendering of White LED Light Sources, Technical Report, Publication CIE 177:2007.

Author Biography

Ferenc Szabó holds a Masters Degree in Information Technology and a Bachelors Degree in Electrical Engineering from the University of Veszprém, Hungary. He is a PhD student in Information Technology at the University of Pannonia (Veszprém), Faculty of Information Technology, Department of Image Processing and Neurocomputing, Virtual Environment and Imaging Technologies Laboratory. His research topic is colour harmony and colour rendering.

Peter Bodrogi graduated at the Eötvös Loránd University of Budapest, as a physicist, and obtained his PhD degree in information technology. Currently, he is associate professor at the University of Pannonia (Veszprém, Hungary), and an Alexander von Humboldt research fellow at the Technical University of Darmstadt.

János Schanda, physicist, is DSc of the Hungarian Academy of Sciences, professor emeritus of the University of Pannonia (Veszprém, Hungary), and current Vice-President Technical of the International Commission on Illumination (CIE, www.cie.co.at).