Comparison of CQS(Qg) and Optimal Color Volume for the evaluation of Color Saturation

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ABSTRACT

A comparison of the Color Gamut Scale, CQS(Qg), and the Optimal Color Volume (VOLcol) is presented. The optimal color solids are computed using a MATLAB program based on the theoretical maximum gamut of object colors under a given light source, proposed by D. MacAdam in 1935. It was found that the ratio of the optimal color volumes Oc, and the Color Gamut Scale Qg, has almost the same range of variation for real and attainable light sources. Additionally, their correlation coefficient demonstrates very good agreement, validating Qg as a good index for object color saturation.

INTRODUCTION

The color quality of white light sources, specifically in order to get the best trade-off between luminous efficacy and color rendering, is a controversial issue with emerging technologies. Recently, the possibility of tuning virtually any desired spectral power distribution (SPD) for a specific light source with a light engine using clusters of monochromatic and phosphor-based LEDs, demonstrates a huge range of possibilities to obtain a spectral content adapted to a specific lighting application. At this time, light engines are experimental devices and not commercially viable due to high cost, control complexities and other issues, such as luminaire and diffuser design. Davis and Ohno [1], [2] reported that this type of light sources has the capability to enhance the chroma of certain object colors, stating, *"evidence suggests that increases in object chroma, as long as they are not excessive, are not detrimental to color quality and may even be beneficial."* With the intent to quantify this characteristic in white light sources, several proposed metrics have recently emerged. It is quite important to study the "colorfulness," without loss of "naturalness," of object colors in evaluating new metrics. MacAdam, in 1935, proposed the theory of the maximum visual efficiency of colored materials [3], [4], resulting in what we now call the MacAdam limits for optimal colors, and defining the maximum attainable color saturation of a light source for a specific luminance. More recent approaches, such as Qg [1] and GAI [5], calculate a "Gamut Area". In this work, we compare the Qg index and the convex hull volume of the optimal colors calculated for the 121-spectra database used by Davis and Ohno.

METHODS

We have used the 121-spectra database, from the Davis and Ohno work (spreadsheet version 7.5), which includes several commercially-available light sources and standard CIE-illuminants, as well as ideal and attainable spectra obtained using clusters of monochromatic LED and phosphor-based sources. Using the "Fast and accurate model for optimal color computation," proposed by K. Masaoka [6], the boundary of the optimal colors for a specific luminance level was calculated. Since the model take 100 as a maximum value of luminance, 20 optimal colors boundaries were calculated in luminance steps of 5 from 5 to 100, for each SPD of the 121-spectra database. After that, the convex hull volume (VOLcol) of these optimal colors boundaries was calculated. The VOLcol ratio between test light source and its reference light source as defined in CIE-CRI [7] was calculated and named as Oc.

Additional indices such as general Qa, Color fidelity Scale Qf and the Luminous Efficacy of Radiation (LER or K), and some statistics (Table 1) and correlated coefficients (Table 2) were calculated for every parameter evaluated of the spectra database.

RESULTS

In Table 1, we see that values for Qg and Oc are very similar with exception of the maximum value. In this case the maximum value was for spectrum #032, “Ideal primary colors.” This unreal peak explains why the optimal colors volume is quite high, and thus resulting in the maximum Oc. In addition we can see that Qg index is a less sensitive index than Oc when the SPD studied includes an ideal peak. In Table 2, we see that the correlated coefficient for VOLcol and Oc is quite high; otherwise, in the same way, we can say that there is a good agreement between Oc and Qg indexes.

Table 1: Statistics for nine parameters of the 121-spectra database

Statistics	Efficacy	CCT	Duv	CRI	Qa	Qf	Qg	Oc	VOLcol
Max.	517	7507	0.0291	100	100	100	121	167	3.79E+06
Min.	156	1720	0.0000	-47	0	0	0	0	8.18E+02
average	325	3998	0.0034	77	79	77	96	95	2.12E+06
Mediana	333	3465	0.0016	82	82	80	98	95	2.12E+06
Std. Dev.	61	1270	0.0040	21	16	16	16	13	2.96E+05

Table2: Correlation indices calculated for nine parameters of the 121-spectra database

	Efficacy	CCT	Duv	CRI	Qa	Qf	Qg	Oc	VOLcol
Efficacy	1	-0.35841721	0.16526122	-0.4135816	-0.48655689	-0.45976779	-0.35207095	-0.35205258	-0.33909189
CCT		1	0.38004797	0.20111714	0.17505574	0.20773866	-0.03971939	0.13322882	0.20367308
Duv			1	-0.18030185	-0.25909963	-0.18845309	-0.43473854	-0.18501703	-0.17087675
CRI				1	**0.94960137**	**0.96939265**	0.61875746	0.57725795	0.58895496
Qa					1	**0.98315461**	0.73192784	0.60642543	0.61635096
Qf						1	0.60694124	0.52241295	0.53449506
Qg							1	**0.79128674**	**0.78410025**
Oc								1	**0.99194271**
VOLcol									1

CONCLUSION

It was found that Qg (gamut area) index has almost the same range of variation than Oc (optimal colors volume) for real and attainable light sources. In addition there exists a good correlation coefficient between Oc and Qg. Since the Oc index takes considerably more computational time to be evaluated than the Qg index, despite the fast algorithm used, it is clear that there is no loss of information using Qg as a metric to evaluate the object color saturation. These result are validated with the theoretical maximum proposed by MacAdam in 1935.

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