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Influence of Colour Difference over Visibility in Multimedia Projection

S. Masiokas, M. Kriuglaitė
Department of Electrical Engineering, Kaunas University of Technology,
Studentų 48, LT-51368 Kaunas, Lithuania, phone: +370 37 207588,
e-mails: s.masiokas@ktu.lt; miglekriuglaite@yahoo.com

Introduction

In previous papers colour luminance contrast was foregoing. However, objects with the same colour luminance contrast are distinct if they differ in colour. In this paper colour difference ΔE influence over visibility will be discussed when other visibility factors are invariable.

Briefly, colour difference is a distance between two colours in colour body. Prerequisite for this concept is uniform colour space.

In common case, if there was a colour system with, e.g. MNP coordinates, colour difference would be $\Delta E = (\Delta M^2+\Delta N^2+\Delta P^2)^{1/2}$ [1].

XYZ system is unusable as it is not uniform. A change of the same amount in a color value does not produce a change of about the same visual importance. Ideally colour difference of one unit would equal to one visually just noticeable difference (JND). If point of any colour is taken and closest JND points are marked around it, outline of these points will be uneven elipses. Disparity in length indicates the amount of distortion between parts of the diagram [2].

UVW system is more practicable (since 1931 it was held as the main one, though is best only for small colour differences, e.g., for colour reproducing quality of different light sources).

Uniform colour spaces

Two uniform colour spaces CIELAB and CIELUV were simultaneously adopted by CIE to approximate human vision. CIELAB is an opponent colour system. It correlates with a fact that somewhere between the optical nerve and the brain retinal colour stimuli are translated into distinctions between light and dark, red and green, and blue and yellow [2]. CIELAB indicates these all values with three axis *L*, *a*, *b*.

Luminance values run from 0 (black) to 100 (white). The same valuation is used in CIELUV. Luminance or grayscale axis is separate unlike in RGB, CMY, where it depends on relative amounts of the three colour channels. *Y* scale is a uniform scale of luminance with equal steps between each value, but it is not adequate to represent differences that are visually equivalent. Human eye has much less ability to differentiate between degrees of lower values than it does in middle and higher values [2]. *L* values are approximately uniformly spaced, but more indicative of the actual visual differences. Opposing each other colours were set on axis. Like all CIE models this system is device independant and therefore is not restrained by gamut. *Lab* values do not define absolute colors unless the white point is also specified.

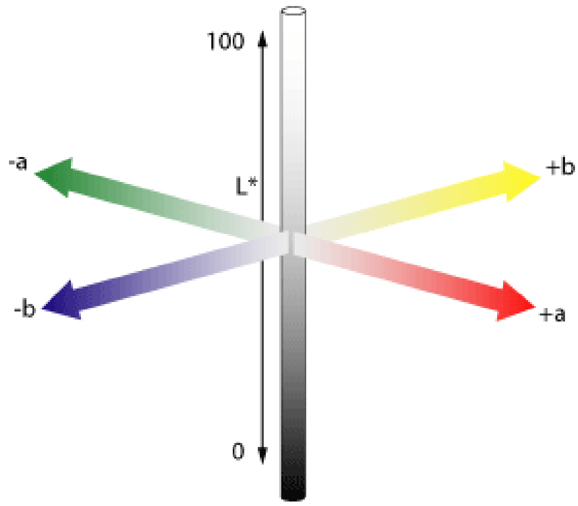

Fig. 1. *L*ab* colour space

The CIELUV system also has three the same orthogonal dimensions. CIELUV is extensively used for applications which deal with colored lights and different light sources. CIELUV chromaticity diagram has elongated the blue-red portion of the diagram and relocated white point to decrease the visual disparity with the green portion.

Another approximately uniform colour space is Munsell system [3]. A correlate of luminance Munsell Value is considered as a vertical axis; Hue consists of five main segments, denoted Red, Yellow, Green, Blue and Purple; Chroma, a correlate of perceived chroma, is represented by the distance of a sample from the vertical axis.

Colour difference variation

First formulas calculated colour difference as the distance between two points in a three-dimensional colour space:

$$\Delta E_{uv} = [(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2]^{1/2}\,, \qquad (1)$$

$$\Delta E_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\,]^{1/2}. \qquad (2)$$

This primitive formula does not evaluate lots of supplementary conditions. It was noticed, that results not always correspond to visual perception, therefore it is not usable for professional evaluation.

CIE improved and declared new colour difference formula ΔE^*_{94}. It gives better correspondance between visual perception and calculated results. There are determinated reference conditions for experimentation [4]:

- samples should be homogenous,
- magnitude of ΔE <5,
- minimum sample separation,
- sample size greater than 4° subtended visual angle,
- light source D_{65}, illuminance – 1000 lx,
- uniform, neutral grey L^* = 50 background field

$$\Delta E_{94} = \left[\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{k_C S_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{k_H S_H}\right)^2\right]^{1/2}, \qquad (3)$$

where k_L, k_C, k_H – parametric factors that describe the effect of change from reference conditions. For reference conditions all of them are equal to 1. In different conditions factors must be recalculated. S_L, S_C, S_H – weighting functions, describing place of a colour in CIELAB colour space. [5]:

$$S_L = 1; \quad S_C = 1 + 0{,}045\, C^*; \quad S_H = 1 + 0{,}015\, C^*. \qquad (4)$$

CIE ΔE_{00}. The CIE ΔE_{00} formula stands as the last in a long series of developments improving the CIELAB formula. It was developed on the basis of experimental data accumulated through a number of different studies [3]. Yet this system is held as the most progressive and accurate, though mathematically complicated. Five spatial wighting correction of luminance, hue, saturation, correction of hue and saturation difference for blue region and factor, changing scale of an a^* axis for calculating differences ir grey region [6]

$$\Delta E_{00} = \left[\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'\Delta H'}{k_C S_C k_H S_H}\right)\right]^{1/2}. \qquad (5)$$

However, ΔE_{00} is not perfect. The biggest imbalance is when hue of colours differs about 180°, i.e. when there is big distance (colour difference) [6]. An ideal colour difference formula should e based on physiological terms of colour difference sensation [4].

Research

Since all these systems are limited in evaluating colour differences and does not give unambiguous solution, they will be used for suggesting most credible recomendations.

Eight pure primal computer colours **W**hite (R255, G255, B255), Blac**K** (R0, G0, B0), **R**ed (R255, G0, B0), **G**reen (R0, G255, B0), **B**lue (R0, G0, B255), **C**yan (R0, G255, B255), **M**agenta (R255, G0, B255), **Y**ellow (R255, G255, B0) were chosen and all possible combinations analysed using different colour difference calculation formula (Table 1). Relative values were taken so that results could be compared and analysed equivalently. Analysis of relative colour differences values cleerly show, that results signally differ for every colour difference system.

Table 1. Research data

	Absolute value				Relative value			
	ΔE_{uv}	ΔE_{ab}	ΔE_{94}	ΔE_{2000}	ΔE_{uv}	ΔE_{ab}	ΔE_{94}	ΔE_{2000}
WK	100	100	100	100	0,36	0,39	0,67	0,90
WR	185	114,5	114,5	45,8	0,67	0,44	0,76	0,41
WG	136,3	120,4	120,4	33,3	0,50	0,47	0,80	0,30
WB	147,2	150	150	64,2	0,54	0,58	**1,00**	0,58
WC	72,6	50,9	50,9	25,5	0,26	0,20	0,34	0,23
WM	143	122,2	122,2	42,2	0,52	0,47	0,81	0,38
WY	107,1	96,9	96,9	30,5	0,39	0,37	0,65	0,27
KR	186,8	117,3	117,3	50,4	0,68	0,45	0,78	0,45
KG	161,7	148,5	148,5	87,9	0,59	0,57	0,99	0,79
KB	134,6	137,7	137,7	39,7	0,49	0,53	0,92	0,36
KC	116,2	104	104	90,5	0,42	0,40	0,69	0,81
KM	150,1	130,3	130,3	56,7	0,55	0,50	0,87	0,51
KY	144,6	137,2	137,2	101,2	0,53	0,53	0,91	0,91
RG	269,5	170,6	71,1	86,6	0,98	0,66	0,47	0,78
RB	250,4	176,3	65,8	52,9	0,91	0,68	0,44	0,47
RC	254	156,5	78,8	71	0,92	0,60	0,53	0,64
RM	172,5	129,5	49,2	42,6	0,63	0,50	0,33	0,38
RY	186,2	114	60,6	64,3	0,68	0,44	0,40	0,58
GB	255	258,7	103,2	83,2	0,93	**1,00**	0,69	0,75
GC	123,3	104,6	39,4	34,5	0,45	0,40	0,26	0,31
GM	274,6	235,6	89	111,4	**1,00**	0,91	0,59	**1,00**
GY	91,3	66,3	25,6	23,4	0,33	0,26	0,17	0,21
BC	143	168,7	86	66,5	0,52	0,65	0,57	0,60
BM	100	58	32,7	32,4	0,36	0,22	0,22	0,29
BY	246,4	235,1	105	103,4	0,90	0,91	0,70	0,93
CM	183,2	156,6	73,3	58	0,67	0,61	0,49	0,52
CY	145	112	51,3	42	0,53	0,43	0,34	0,38
MY	231,5	199,6	84	92,8	0,84	0,77	0,56	0,83

ΔE_{ab} gives Green and Blue combination the highest value, ΔE_{94} – White and Blue. These two are negotiable, meanwhile ΔE_{uv} and ΔE_{2000} puts Green and Magenta to the first place. Empirical practise show that this combination assuredly is not best seen among all analysed samples. This proves that concepts of visibility and colour difference can not be equalized.

It was ascertained in preceding investigation, that KY, KG, KW, KC (0,92-1,00) and BW, BY, KM (0,67-0,76) have the highest colour luminance contrast [7].

These combinations were also evaluated in different colour difference systems and compared to rank of colour luminance contrast in Table 2.

Table 2. Comparison of different systems results

Colour luminance contrast		ΔE_{uv}	ΔE_{ab}	ΔE_{94}	ΔE_{2000}
KY	1	0,53	0,53	0,91	0,91
KG	0,94	0,59	0,57	0,99	0,79
KW	0,93	0,36	0,39	0,67	0,9
KC	0,92	0,42	0,40	0,69	0,79
BW	0,76	0,54	0,58	1	0,58
BY	0,76	0,9	0,91	0,7	0,93
KM	0,67	0,67	0,55	0,50	0,87

Scales of ranks are different in every case and are not close to scale based on colour luminance contrast. Though ΔE_{94} and ΔE_{2000} might be held as less doubtfull.

When there is no luminance difference between sample and reference colours, chromatic constituents become deciding. In that case opposite colours are held to be the most contrasting.

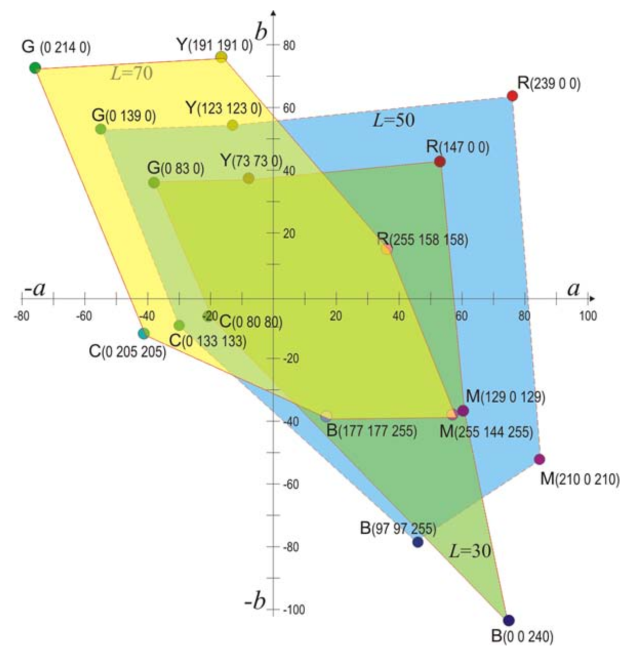

Fig. 2. Cuts of constant luminance planes inCIELAB colour body

Few common cuts for L^*= 30, 50, 75 were analysed the same colours with respective luminance in every plane (Fig. 2). Using Fig. 2, opposite colours may be ascertained. In all planes C is opposite to R, and G, Y are opposite to M, B.

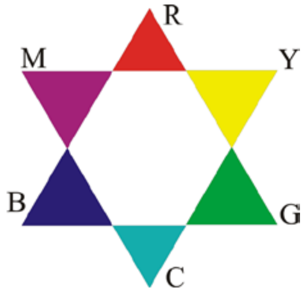

Fig. 3. Opposite and neighbouring colours

Table.3 Relative colour difference values of opposite and neighbouring opposite colours

	Opposite colours			
	ΔE_{uv}	ΔE_{ab}	ΔE_{94}	ΔE_{2000}
GM	**1,00**	0,91	0,59	**1,00**
BY	0,90	0,91	0,70	0,93
RC	0,92	0,60	0,53	0,64
	Neighbouring opposite colours			
RG	0,98	0,66	0,47	0,78
RB	0,91	0,68	0,44	0,47
GM	**1,00**	0,91	0,59	**1,00**
MY	0,84	0,77	0,56	0,83
CM	0,67	0,61	0,49	0,52
CY	0,53	0,43	0,34	0,38

So when there is no luminance different colour wheel can also be used for determining cominations of best visibility. Additionally there neighbouring opposite colours (Fig. 3) which are also held well seen for constant luminance cases. Such combinations are: RG,RB, GM, MY, CM, CY. Colour wheel is analysed according to colour difference in Table 3. Only one GM combination among opposite colours has the highest relative colour difference value. Meanwhile other higest colour differences are among neighouring opposite colours or does not get to this table at all.

Conclusions

1. In any system ΔE does not essiantially show the real colour difference because of very big colour difference.
2. When there is know luminance contrast it is advisable to use opposite colours for best visibility combinations.
3. As criterions for choosing ΔE in multimedia it is advisable to use colour coding, when different colour have particular purpose chosen for coding (e.g., for expressing positive or negatyve emotions, for very important or secondary information or coding particular values).

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Colour luminance contrast between task and background is the most contributory visibility factor in digital projection image, its effect was earlier investigated. Influence of chromatic constituents over visibility is not so significant, but must be also evaluated. Chromatic contrast and colour difference become deciding when colour luminance contrast between task and background is low or equals to zero. It’s topical in case of ambient light, which discolours image on screen. Fundamental colour difference formulas, their particularity of use in uniform colour spaces are discussed in this paper. Primal computer colours combinations of best visibility for positive and negative image are ascertained. Ill. 3, bibl. 7, tabl. 3 (in English; abstracts in English, Russian and Lithuanian).

С. Масёкас, М. Крюглайте. Влияние разности цветов на видимость проекции мультимедий // Электроника и электротехника. – Каунас: Технология, 2010. – № 7(103). – С. 67–70.

Контраст яркости цвета больше всего влияет на видимость цифровой проекции. Его воздействие было исследовано раньше. Влияние цветовых слагаемых не так значительна, однако должна быть исследована. Цветовой контраст и разность цветов становится главными, когда разность яркости между фоном и объектом очень мала или не существует. Это актуально при постороннем цвете, который обесцвечивает изображение на экране. Основные формулы разности цветов, особенности их пpменения, равноконтрастные цветовые системы обсуждены в работе. Установлены лучшие сочетания чистых компьютерных цветов для позитивного и негативного изображения. Ил. 3, библ. 7, табл. 3 (на английском языке; рефераты на английском, русском и литовском яз.).

S. Masiokas, M. Kriuglaitė. Spalvų skirtumo įtaka daugiaterpės projekcijos matomumui // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 7(103). – P. 67–70.

Spalvų skaisčio kontrastas yra skaitmeninės projekcijos matomumui daugiausia įtakos turintis veiksnys. Jo įtaka buvo išnagrinėta anksčiau. Spalvinių dedamųjų įtaka nėra tokia svarbi, tačiau į ją taip pat reikia atsižvelgti. Spalvos kontrastas ir spalvų skirtumas tampa lemiami, kai fono ir objekto tarpusavio skaisčių skirtumas yra labai mažas arba lygus nuliui. Tai aktualu, kai vaizdą ekrane išblukina pašalinė šviesa. Atartos pagrindinės formulės spalvų skirtumui apskaičiuoti, jų naudojimo ypatybės bei lygiakontrastės spalvų erdvės. Nustatyti negatyvaus ir pozityvaus vaizdo geriausio matomumo grynų kompiuterinių spalvų deriniai. Il. 3, bibl. 7, lent. 3 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).