Variation of Perceived Colour Difference Under Different Surround Luminance

Thilan Costa[1(✉)], Vincent Gaudet[1], Edward R. Vrscay[2], and Zhou Wang[1]

[1] Department of Electrical and Computer Engineering, Faculty of Engineering, University of Waterloo, Waterloo, ON N2L 3G1, Canada
{tcosta,vcgaudet,zhou.wang}@uwaterloo.ca

[2] Department of Applied Mathematics, Faculty of Mathematics, University of Waterloo, Waterloo, ON N2L 3G1, Canada
ervrscay@uwaterloo.ca

Abstract. With the wider availability of High Dynamic Range (HDR) Wide Colour Gamut (WCG) content, both consumers and content producers have become more concerned about the preservation of creative intent. While the accurate representation of colour plays a vital role in preserving creative intent, there are relatively fewer objective image and video quality assessment methods that are available which consider the colour quality. This paper will study the effect of surrounding luminance on perception of a colour stimulus, specifically, whether the perceptual uniformity is preserved in colour spaces and colour differencing methods as the surrounding luminance changes. The work presented in this paper provides important information and insight required for the future development of a successful colour quality assessment model.

Keywords: Perceptual uniformity · Delta E 2000 · ICtCp · CIECAM02 · HDR · WCG · Colour quality assessment · Surrounding luminance

1 Introduction

With the popularity of High Dynamic Range (HDR) Wide Colour Gamut (WCG) displays that boast the ability to reproduce content as graded in expensive grading studios, the ability to measure colour fidelity becomes an important topic of interest in the field of image and video quality assessment.

In order to measure fidelity, one requires the means to measure differences in colour in a way that correlates with the perceived difference by the human visual system (HVS). Ideally, a colour difference measure should provide a similar difference value for all colour pairs that are only different by the smallest noticeable perceptual difference for those particular colours (referred to as the *Just Noticeable Difference* (JND)) [10]. A colour space that satisfies this property for all colours represented within the space is called a perceptually uniform colour space [10]. A perceptually uniform colour space is highly desirable for colour

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difference applications in image and video production and distribution since it supplies the foundation to formulate objective quality assessment methods and standards for evaluating degradation of colour.

Additionally, various factors affecting the viewing conditions such as the surround luminance, surrounding colours and ambient luminance, can also affect how a patch of colour would be perceived by the HVS. While the colour difference value may change for different background luminance values, ideally we would prefer the colour space to still be perceptually uniform i.e. for the JND of each colour observed under the same background luminance to remain similar.

Various colour differencing models and methods have been proposed over the years based on approximately perceptually uniform colour spaces. $\Delta E2000$ based on the L*a*b* is such a method that comes recommended by the International Commission on Illumination (CIE) for evaluating colour difference [5]. Then there are are other newer proposed methods based on the IC_tC_p [6] and CIECAM02 colour spaces [7]. CIECAM02 is claimed to also be more perceptually uniform than $\Delta E2000$ [8], while IC_tC_p claims to be more perceptually uniform than them both [9,11].

In this paper, we discuss work performed to evaluate the perceptual uniformity of commonly used colour spaces and colour difference methods under different background luminance levels. This is especially relevant since a particular colour is not usually observed by itself when viewing images and video. In images and video, the colour is surrounded by other colours that could have a lower or higher luminance in comparison to the observed colour. Thus, it becomes important to evaluate the effect of background luminance on the perceptual uniformity of the colour space. We first describe the experimental design, and present the results obtained from the experimental data. Since it is infeasible to consider different surrounding colours with different luminances, our experiment is limited to an achromatic stimulus as the surrounding luminance. The data and insight obtained from this experiment will be used to formulate an objective colour quality assessment method for HDR WCG image and video content.

2 Experiment Design

For this experiment, we sampled colour points from the colours contained within BT 2020 primaries [1,3]. 12 reference colour samples were randomly chosen per luminance level, for a total of 72 reference colours at 6 luminance levels of 0.05, 0.5, 5, 50, 150, and 300 nits. While HDR WCG content supports up to 10,000 nits, the current HDR WCG displays are limited to the 1000 nits range, and the higher luminances are usually used for highlights in an image/frame of video. Thus, a maximum luminance of 300 nits is a realistic choice since a large colour patch would be less likely to be graded to be displayed at higher luminance levels.

The sampling of the colours were performed in the xyY colour space. For each reference colour, 1500 test colour points were sampled at fixed distances from the reference colour (by manually verifying the intra-distance between the points to be far smaller than the perceptual difference, but also such that the furthest point to clearly be perceptually different from the reference colour) along a randomly chosen direction on the xy plane of the xyY colour space, holding the luminance level constant. The colour for the surrounding luminance was chosen to be achromatic, and luminance levels of 0, 0.01, 1, 10, and 100 were chosen for the background.

The test was carried out on a Canon DP-2420 Reference monitor in a dark room with a backlight of approximately 5 nits to reduce eye fatigue. The test procedure is described in the following steps.

- Each reference colour and the furthest sampled test point from the 1500 sampled test points corresponding to the reference colour would be shown on two squares as shown in Fig. 1. The region in which the surrounding luminance will be changed is shown in white in the same Figure. Note that the entire monitor screen was not used to show the same surrounding luminance for this experiment since the peak luminance capability/stability of a display decreases as the pixel arrays on the entire screen is activated. Keeping the activated surround region smaller enables the display luminance to be reliably maintained at the desired value.
- The Canon Reference monitor used in this experiment is not an OLED display that can support black levels at 0 nits. Therefore, the display was covered using non-reflective blackout materials, exposing only the two squares to simulate the 0 nits surround luminance. When the other surround luminance values were displayed, the region outside of the chosen surround luminance region was covered using the blackout materials to keep the surrounding luminance at 0 nits.
- The left or right square will be randomly chosen at the start of each test pair to contain the reference colour, while the other contains the test colour. The test subject would be able to adjust the colour in the test square by navigating through the 1500 samples test points using a slider. When the slider is at the leftmost position, the two squares would look the most different in appearance while the two squares would contain the identical colour at the rightmost position. Subjects are instructed to choose the leftmost position at which the two squares look the same.
- Once the leftmost position is found, the subject would press a button and the next test case would be displayed.
- The test consists of 72 test pairs per set, which takes about 15 minutes to complete. The surround luminance was fixed for the entire set at one of the chosen six luminance levels. Once the set is complete, the test subject would have a five minute break, and the next set is started which would contain the same 72 pairs of colours, but a different surround luminance. Each subject required approximately 2 hours to complete the test with the breaks.

3 Results

There were 30 test subjects in total, and outlier detection was performed to filter the data as defined in BT.500 [4].

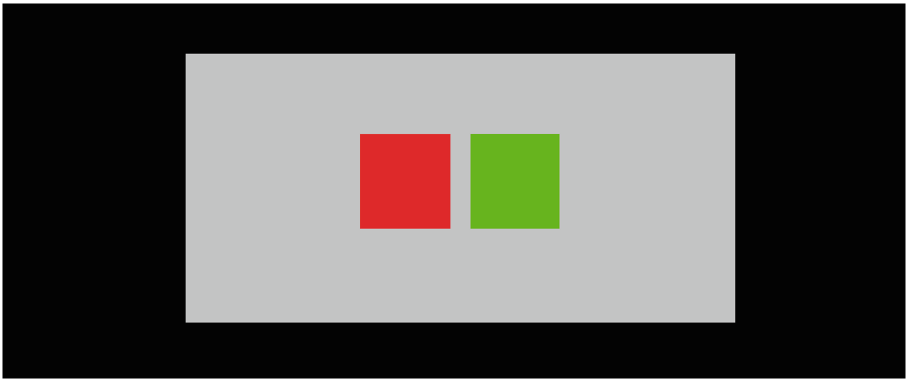

Fig. 1. Test setup for testing the impact of surround luminance on the perception of colour difference.

We then first computed the JND for each test case for each test subject. Then we computed the final JND value for the test case as the average of the JND values for each subject. If the colour space or colour difference method is perceptually uniform, then the variation of the final JND value for each test case should be minimal. Therefore, we evaluate the perceptual uniformity of each colour space using the coefficient of variation (CV) given as follows [2],

$$CV = \frac{\textit{The standard deviation of the final JND values}}{\textit{The mean of the final JND values}}. \quad (1)$$

The CV was computed for each background luminance level, and is reported in Table 1.

Table 1. Coefficient of Variation (CV) measuring perceptual uniformity of the space (lower the CV, better the perceptual uniformity of the space).

Method	0 nits	0.01 nits	1 nits	10 nits	100 nits
ΔRGB	1.083	1.0917	1.0243	0.9969	0.8265
ΔICtCp	0.6057	0.6328	0.5840	0.5438	0.4884
ΔYCbCr	1.0215	1.0269	0.9649	09288	0.7827
ΔE2000	0.7956	0.8444	0.7739	0.7726	0.7555
CIECAM02-UCS	0.7191	0.7864	0.7249	0.6752	0.6768

It appears from the results that the perceptual uniformity of all the colour spaces improve with increasing surrounding luminance. We also see confirmation of previous results [8,9,11] that indicated better performance by IC_tC_p over existing colour spaces, and also the better performance of CIECAM02-UCS over $\Delta E2000$.

4 Conclusions

In this paper, we present an experiment performed to study the perceptual uniformity of prominent colour spaces as the perceived colour stimulus by the HVS is affected by a fixed surround luminance. The results show that the perceptual uniformity of the colour spaces that were tested increases as the surround luminance increases, which is an unintuitive result.

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