HUE CORRECTION IN HDR TONE–MAPPING

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ABSTRACT

The HDR tone–mapping operators have evolved rapidly in recent years. Moreover, the physiology–influenced methods have been researched lately as a separate branch.
Our contribution to this field is the application of hue correction according to the subjective effect referred to as the Bezold–Brücke hue shift. We introduce a mathematical approach for the correction of this shift. The correction is performed in a colour space given by the gamut base colours R,G,B (primaries) and white point. This approach is applied to the traditional physiology–influenced operators.

Index Terms— HDR, colour, hue shift

1. INTRODUCTION

The HDR tone–mapping operators have recently been studied extensively and several dozens of algorithms have emerged in the past few years. Some were intended to provide visually attractive images. Others were meant to render a genuine image, mostly similar to the original scene subjectively observed by human. These operators are often inspired by human visual system (HVS) physiology. Their purpose is to simulate and partly substitute some mechanisms in human vision.

The areas being studied cover photoreceptors modelling [6], local retina adaptation [2] and also photopic (daylight) and scotopic (nocturnal) vision adaptation and the adaptation characteristics in time [1]. Last mentioned method simulates the most of phenomena described in the HVS. The perception of tone–mapped image obviously cannot be perfect. Yet we know that visual pathways transfer several kinds of information separately. Hue is separated from luminance [10] and local contrast from global illumination [9]. Even if only one component's reconstruction quality is increased, it benefits the overall perception. But none of the methods include hue correction according to the Bezold–Brücke hue shift.

The colour shift phenomenon was described by Bezold back in 1873, revealing that two different spectral colours may be perceived as being the same if their luminance differs. Yet the effect was known and used by artists long before him, as R. Pridmore describes in [4]:

> *...However, the old masters (e.g. Michelangelo, The Entombment 1507; Rubens, The Judgement of Paris 1620) regularly show correct or slightly exaggerated B – B hue–shift; for example, yellow – green hues (e.g. lawns, clothes) are greener in shade, yellower in highlight, and yellow – red hues (e.g. skin tones) are redder in shade, yellower in high–light, as the reader may readily observe in real life or photographs.*

Pridmore's measurement in the above mentioned paper [4] was used as input data for the presented work. The effect was measured across three orders of Luminance magnitude, 0.1 – 100 $Cd\cdot m^{-2}$.

The following section describes the application of the hue correction to a state–of–the–art tone–mapping algorithm. The calculation for a given colour space is also explained.

Section 3 describes the testing details and Section 4 summarizes the results.

2. HUE CORRECTION

2.1. Application to the Tone–mapping

The base of used tone–mapping was inspired by Ledda et al. [1]. No adaptation time characteristics were used, only a static image was generated instead.

The time–consuming bilateral filter was computed with our accelerated approach [3]. For a better comparison, we also skipped the sigmoid computation and kept only the photopic and mesopic vision mixing.

The processing schematic is shown in Figure 1. The HDR colour is split into the luminance and hue plus saturation (not HSL, where L means lightness – the luminance carries

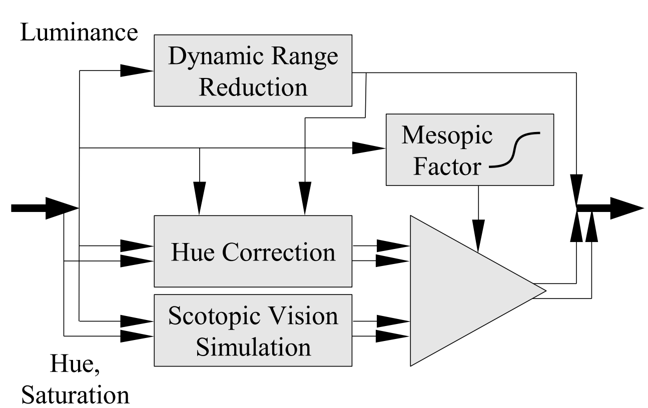

Figure 1: Processing schematic.

the high dynamic range, which is being reduced for display purposes).

Hue and saturation are processed using two different methods. One of them simulates the scotopic colourless vision, while the second involves the hue correction for daylight colour vision (it should be noted, that these boxes include the sigmoid nonlinearity in the original paper).

The mixing of the photopic and scotopic vision is computed by the so–called mesopic factor, described in [8].

2.2. Correction Computing

The important fact is that hue correction needs to exploit both the original luminance and the luminance after the dynamic range reduction. The reason is that the correction effect grows with the original to displayed contrast ratio. The aim is the most genuine sensation of the rendered image. It means that if the monitor was capable of displaying the original dynamic range, no hue correction would have to be applied. The approach is illustrated in Figure 2.

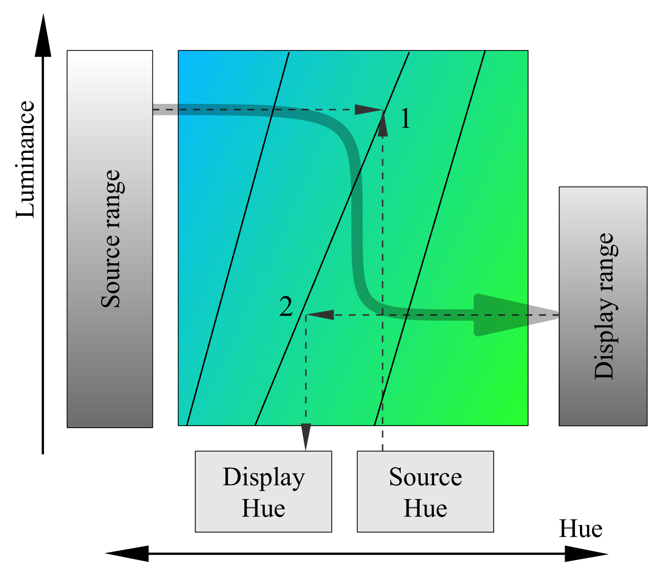

Figure 2: Hue shift processing diagram. The square area is part of the B–B shift chart, the hues at the diagonal lines are perceived as constant. The source luminance and source hue define a position in the chart (1). From this point, the luminance on a display (after tone–mapping) gives the corrected display hue (2).

The curves in the Bezold–Brücke shift chart show the constant subjective hue across the luminance.

For practical purposes, it is necessary to convert the hue values from the used Extended Dominant Wavelength [5] to any practical unit. We should expect that the source image is stored in a RGB colour space given by gamut and white point in CIE (x,y) coordinates.

We use the value hue from HSV and HSL models, yet the L and V values are useless because they do not cover the high dynamic range. We only use *Hue* and *Saturation*, which conserve ratio among *R*, *G* and *B*, but not the absolute values.

In order to fill the conversion table, spectral and extended spectral (purple) coordinates are firstly converted into the RGB for a given gamut and white point. The conversion is demonstrated in Figure 3.

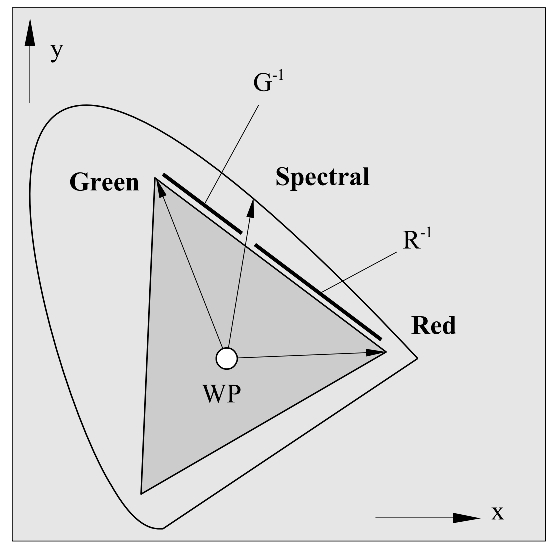

Figure 3: Conversion of spectral CIE coordinates to RGB values for a given gamut.

The **Spectral** coordinates (x,y) and all primaries (**Red**, **Green**, **Blue**) are converted as vectors from the white point (**WP**) position.

The colour must be pure, which means that one of the values must be zero. The values are computed similarly for each of the three arcs, for example, between the **Red** and **Green** vectors the values are gotten by solving

$$\begin{aligned} &B=0, \\ &a\left(R\cdot\overrightarrow{Red}+G\cdot\overrightarrow{Green}\right)=\overrightarrow{Spectral}\,, \end{aligned} \tag{1}$$

Where a is any positive number which does not have to be computed, because only the R:G ratio matters for computing *Hue*.

The correct arc (R-G, G-B or B-R) can be determined as the only one, which gives all values as non–negative.

This gives us the hue conversion table in the units of our specific gamut's *Hue*.

Then, the correction only involves *Hue* and *Saturation* stays unchanged for all corrected colours. This causes corrected colours to circulate around triangles given by a scaled gamut with an unchanged position of the white point (see Figure 4).

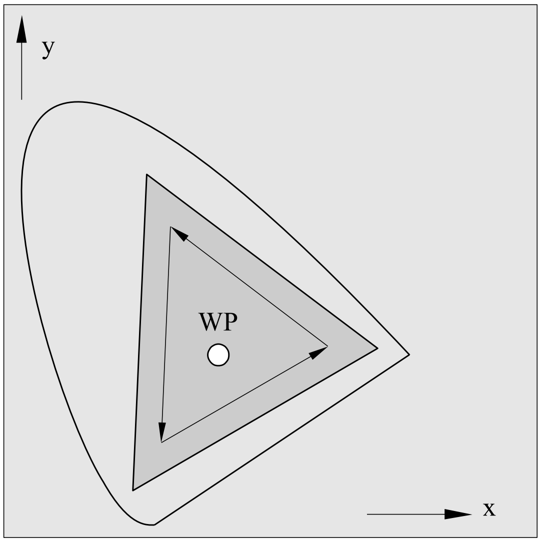

Figure 4:Colour circulation with constant saturation.

It might be objected that the colours should circulate around the scaled locus boundary. This is true, but in practical image processing, colours outside the gamut cannot be displayed anyway. This means that some colours must have *Saturation* changed. *Saturation* would be either saturated, or even decreased below the value lying on the scaled locus. This would surely damage the *Saturation* channel, hence we recommend to conserve at least the *Saturation* corresponding to the gamut edge.

After hue correction, luminance has to be normalised. The changing of the R:G:B ratio also changes luminance because HVS sensitivity is not constant across the visible colours.

The best way is to use the subjectively normalised RGB from the beginning, in the Luminance and *Hue* + *Saturation* splitting. The following formulae give us *Hue* and *Saturation* stored in subjectively normalised RGB values:

$$L = L_R \cdot S_R + L_G \cdot S_G + L_B \cdot S_B , \quad (2)$$

$$R \cdot S_R + G \cdot S_G + B \cdot S_B = 1, \quad (3)$$

Where S_R , S_G and S_B are normalised HVS sensitivities to the colour primaries according to a specific gamut, so that

$$S_R + S_G + S_B = 1. \quad (4)$$

Then, once the RGB values are converted to *Hue* and *Saturation*, *Hue* is corrected and the values are converted back to RGB. We only need to correctly normalise them, so that (3) holds true. This ensures that no luminance change appears as a side effect.

Inverse conversion into the RGB HDR values is then straightforward:

$$\begin{aligned} L_R &= L \cdot R , \\ L_G &= L \cdot G , \\ L_B &= L \cdot B , \end{aligned} \quad (5)$$

The method is demonstrated in Figure 5.

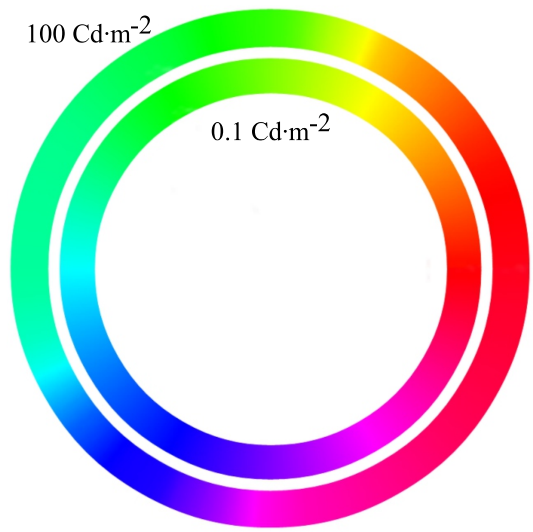

Figure 5: The method demonstration: The hues lying at the same angle in both circles would be perceived as identical for inner circle luminance 0.1 Cd·m^{-2} and outer circle luminance 100 Cd·m^{-2}. Computed using colour space sRGB and white point D65.

3. TESTING

An image with enormous contrast over 1:3000 was captured by multi–exposure for testing. The test image should also contain several constant hues in varying luminance. This was achieved by lighting a set of coloured pencils from one side and letting the other side disappear in the darkness. With these controlled conditions, both the illumination colour and object colour are reasonably constant across the whole luminance range.

Figure 6: Testing scene capture.

The light source was two neutral LEDs (Cree® XLamp® XM-L Neutral White) covered with a framed low–profile soft diffuser, close to the pencil tips (see Figure 6). Apart from the above mentioned light source, the room was darkened.

The first processing (Figure 7 b) includes dynamic range reduction only. It is obvious that if such a massive reduction is needed, the scene lighting and shadows are not easy to read.

The second processing (Figure 7 c) includes hue correction. With such an enormous contrast, the shift is clearly apparent. Orange and pink tones are getting more yellowish with increasing light (O,P). Greens are getting bluer with increasing light and blues greener in the shadows (G,B)

In the third version (Figure 7 d), the scotopic simulation is also applied. The saturation fades in dark shadows and the image gets more readable – the light appears to fade in the image background although the objective luminance doesn't differ much. We can also note that with scotopic vision, blue tones are lighter than red ones (B,R).

4. CONCLUSIONS AND FUTURE WORK

According to our knowledge, Bezold–Brücke correction has not been attempted as a part of HDR tone–mapping so far. This paper presents an implementation of such a correction. In spite of the convincing test, we are aware of several questions and uncertainties.

It is to be told that the Bezold–Brücke effect is still being investigated. We use a study which compares the stimuli isolated on a black background. It might be assumed that our approach will contribute to the displayed image authenticity, yet it has to be admitted that the background colour contribution might be significant and no measurement is available. Future work in this field would include measurement of the hue shift for higher luminance levels and measurement of the background colour influence. The authenticity of the processed images might be also tested by subjective comparison with the image reconstructed via an HDR monitor (as described in [7]).

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6. REFERENCES

[1] P. Ledda, L.P. Santos, A. Chalmers, "A Local Model of Eye Adaptation for High Dynamic Range Images", *Proc. of the International Conference on Computer Graphics, Virtual Reality, Visualisation and Interaction*, AFRIGRAPH '04, pp. 151-160, ISBN: 1-58113-863-6, 2004

[2] F. Durand, J. Dorsey, "Fast Bilateral Filtering for the Display of High-Dynamic Range Images", *Proc. of the Conference on Computer Graphics and Interactive Techniques*, USA, pp. 257-266, ISSN: 0730-0301, 2002

[3] M. Seeman, P. Zemčík, R. Juránek, A. Herout, "Fast Bilateral Filter for HDR Imaging", *J. Vis. Commun. Image R.*, Vol. 23, pp. 12-17, 2012

[4] R.W. Pridmore, "Bezold-Brucke Hue-Shift as Functions of Luminance Level, Luminance Ratio, Interstimulus Interval and Adapting White for Aperture and Object Colors", *Vis. Research*, Vol. 39, Issue 23, pp. 3873-3891, Nov 1999

[5] R.W. Pridmore, "Extension of Dominant Wavelength Scale to the Full Hue Cycle and Evidence of Fundamental Color Symmetry", *Color Res. Appl.*, 18, pp. 47–57, 1993

[6] E. Reinhard, K. Devlin, "Dynamic Range Reduction Inspired by Photoreceptor Physiology", *IEEE Trans. on Visualization and Computer Graphics*, Vol. 11, No. 1, pp. 13-24, 2005

[7] P. Ledda, A. Chalmers, T. Troscianko, H. Seetzen, "Evaluation of Tone Mapping Operators using a High Dynamic Range Display", *ACM SIGGRAPH*, 2005

[8] H.W. Jensen, S. Premoze, P. Shirley, W.B. Thompson, J.A. Ferwerda, M.M. Stark. "Night rendering", technical report, 2000

[9] K. Purpura, E. Kaplan, R.M. Shapley, "Background Light and the Contrast Gain of Primate P and M Retinal Ganglion Cells", *Proc. Natl. Acad. Sci.*, Vol. 85, pp. 4534-4537, Jun 1988

[10] A.M. Derrington, J. Krauskopf, P. Lennie, "Chromatic Mechanisms in Lateral Geniculate Nucleus of Macaque", *J. Physiol.*, 357, pp. 241-265, 1984

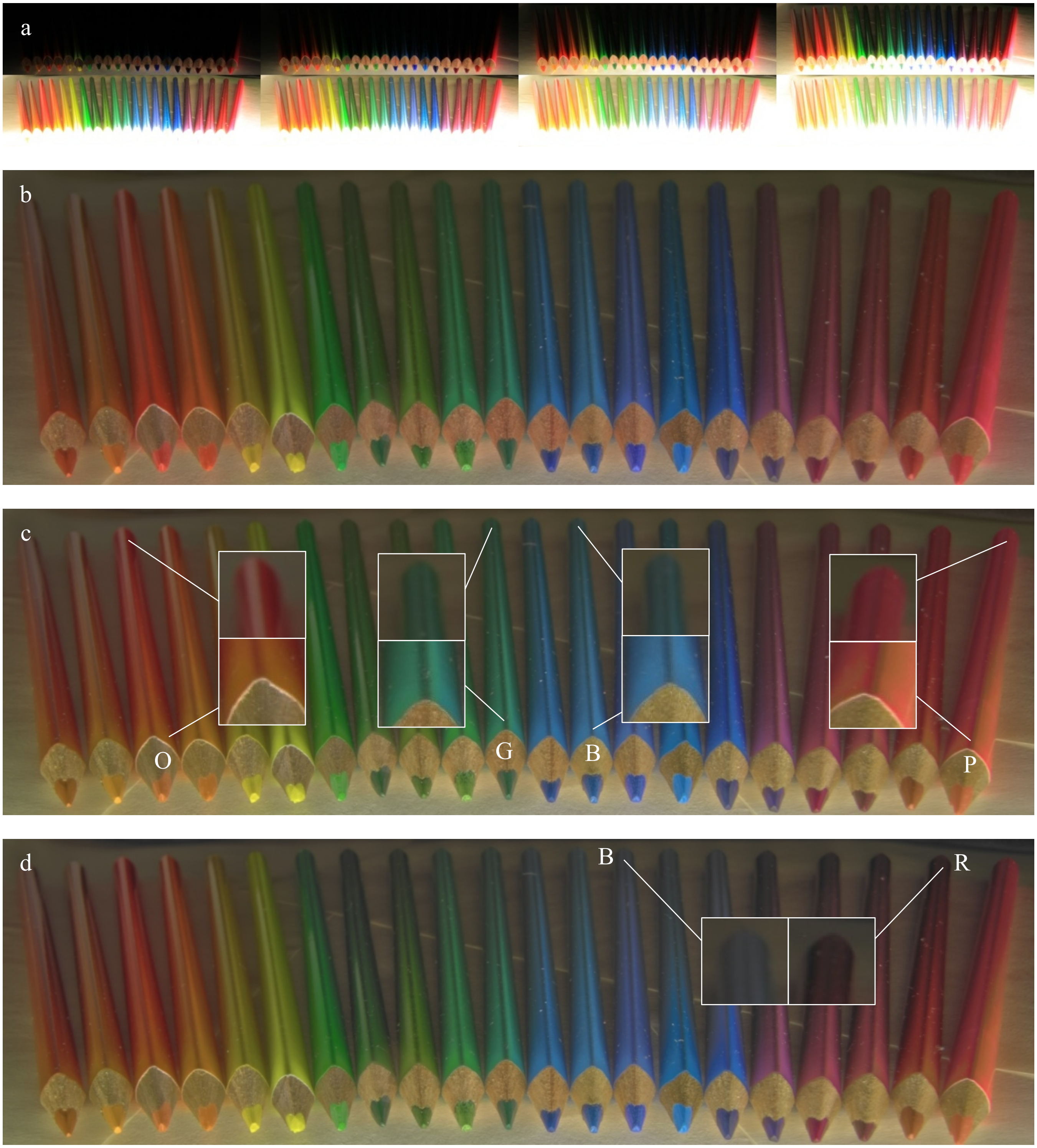

Figure 7: Partial exposures (a) and different HDR processing. Dynamic reduction only (b). Hue correction (c) shows the same colours differently according to the simulated luminance level. Hue correction and scotopic mode simulation (d) – blues appear lighter than reds in the dark. Colour space sRGB and white point D65 were used for all processing.