OPTIMIZING NON CONSTANT LUMINANCE INTO CONSTANT LUMINANCE FOR HIGH DYNAMIC RANGE VIDEO DISTRIBUTION

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ABSTRACT

To improve compression efficiency, pixels are traditionally represented using a luma and two chroma values. Such a representation aims at separating light from color information. Two methods are usually considered for computing luma values: Non-Constant Luminance (NCL) and Constant Luminance (CL). CL equations have been derived from the luminous efficacy of the used gamut color primaries in the light linear domain. NCL applies the same equations but on perceptually encoded values, thus resulting in lower compression efficiency and hue shifts. However, given the higher hardware complexity for implementing CL, the common operational practice in legacy television distribution is to use NCL. In this paper, our motivation is to derive a new set of equations that provides the compression benefits of CL with the lower complexity of NCL for High Dynamic Range video distribution. Results show that the proposed method increases compression efficiency significantly over the NCL approach while maintaining NCL's cost complexity.

***Index Terms*—** HDR, Constant Luminance, Video Compression

1. INTRODUCTION

Traditional pixel representations use a luma and two chroma values for improved compression efficiency. To convert Red, Green and Blue (RGB) values into a luma/chroma decomposition such as $Y'C_BC_R$ [1], two methods are usually considered: Non-Constant Luminance (NCL) and Constant Luminance (CL). CL computes luma coefficients by weighting light linear RGB values whereas NCL applies the same weighting on perceptually encoded RGB values (denoted R'G'B' in this paper). Since the weighing coefficients were derived for the CL case using light linear RGB values [2], using the same coefficients for NCL yields lower compression efficiency and creates color and hue shifts as detailed in the ITU-R Recommendation BT.2246 [3]. However, with conventional Standard Dynamic Range (SDR) technology, images and videos are perceptually encoded at the camera stage using proprietary transfer functions. Thus, access to linear light is not practical most of the time.

A new emerging technology, High Dynamic Range (HDR), can capture and represent the full range of perceptible shadow and highlight information and thus overcomes the main limitations of SDR technology. Furthermore, HDR values correspond to floating point linear light values and thus makes CL implementation possible. Tests on CL and NCL have been conducted in [4] and reported that CL achieves higher compression efficiency.

However the hardware implementation for CL is more complex and diverts from existing infrastructure. The simplicity of NCL is one of the reasons why broadcasters continue to use NCL. However, NCL may not utilize the most optimum weighting of the R'G'B' values, thus we propose in this paper to derive new weighting coefficients of R'G'B' values that provide luma coefficients closer to the CL implementation. These new weighting coefficients close the gap between NCL and CL compression efficiency while keeping the low complexity levels of NCL.

The rest of this paper is organized as follows. Section 2 gives background information about the NCL and CL workflows, along with the related differences between HDR and SDR technology. Section 3 describes our proposed method for optimizing NCL into CL, while compression efficiency is assessed objectively in Section 4. Section 5 concludes this paper and points out future research directions.

2. CONSTANT VERSUS NON-CONTSTANT LUMINANCE

Luminance signal (Y) is derived from a color matching experiment, where a neutral luminance patch is generated by a weighted mixture of three color primaries (usually R, G, B):

$$Y = aR + bG + cB \tag{1}$$

where a, b and c are the weighting coefficients. This is based on the principle that the color of a target light can be matched by a linear combination of three color primaries. This principle is also referred as Grassmann's law [5]. NCL representation adopts the same coefficients to calculate the luma signal (Yn') after the physical RGB signals have been

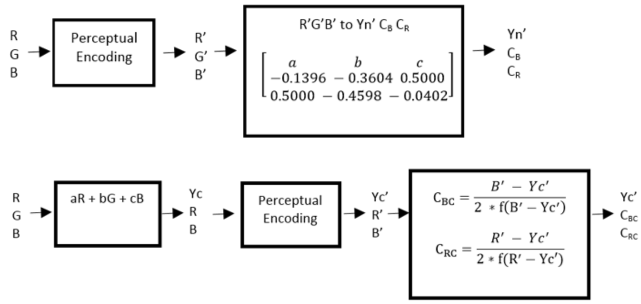


Fig. 1: Workflows of NCL and CL encoding methods.

perceptually encoded (R'G'B'). CL computes the luma (Yc') by applying the perceptual encoding on the physical luminance (Y) signal as shown in Eq. 1. Detailed computational steps for these two workflows are shown in Fig. 1. Note that a, b, and c coefficients depend on the used color gamut (primaries). In this article, we only consider the color gamut defined by the ITU-R Recommendation BT.2020 [1]. The weighting coefficients for the NCL and CL luma computations using the BT.2020 color gamut are as follows: a = 0.2627, b = 0.6780, and c = 0.0593.

The disadvantages of NCL using Yn'C_BC_R representation include color and hue shift, lesser decorrelation of luminance from chrominance information, and error propagation from chroma to luma information (see [6] for more details). Color and hue distortions result from applying perceptual encoding on each R, G and B channel separately. The perceptual transfer function decreases RGB values, which leads to slightly darker pixels and affects the relative ratio between red, green, and blue channels. Thus, a different shade of color is observed. Color and hue shift was not a serious problem with SDR systems due to their limited dynamic range, color gamut, and bit-depth. But with HDR and Wide Color Gamut (WCG) content, these color shifts are much more noticeable. HDR technology [7] can represent the full range of perceptible shadow and highlight information and thus overcomes the main limitations of the SDR technology.

Considering the above-mentioned limitations of NCL, CL was added to the BT.2020 recommendation to transmit "true" luminance and better decorrelation of light intensity (luma) from color information (chroma) [1]. Experiments comparing the CL approach against NCL have been reported in [4] and results show that CL can improve the compression efficiency along with the color quality when compared to traditional NCL representation.

The main drawback of CL is the significantly increased implementation complexity. In the CL case, the chroma values are a function of the difference between luma and B'/R', whereas in NCL this dependency does not exist (see Fig. 1). In the CL post-processing stage, green signal can't be recovered without the help of inverse perceptual encoding, which requires non-linear circuits. Thus, the

Table I: Comparison between Ya' and Yn' based on Yc'

Average Distortion	
$\frac{1}{2^{30}}\sum_{1}^{2^{30}}\|\|Yc' - (dR' + eG' + fB')\|\|^2$	0.0284
$\frac{1}{2^{30}}\sum_{1}^{2^{30}}\|\|Yc' - (aR' + bG' + cB')\|\|^2$	0.0326

hardware implementation for CL is dramatically different from NCL and there is no backward compatibility. Consequently, broadcasting industrials prefer to keep complexity low and explicitly implement NCL encoding scheme. In the case of HDR, since it deals with values that correspond to physical light intensities (measured in cd/m2), the derivation of CL values can greatly be simplified by generating Yc and applying perceptual encoding to Yc, R, and B (see Fig. 1). With SDR, however, access to linear light is not possible due to the proprietary perceptual encoding performed at the camera stage. If broadcasters do not want to change their hardware to CL implementation because of complexity reasons, changing the weighting coefficients of the NCL equation is a much simpler and a more affordable option.

3. PROPOSED METHOD

In order to benefit from the CL compression efficiency without introducing its increased complexity, we propose to derive new coefficients d, e, f to globally minimize the difference between our generated alternative luma (denoted Ya') and the CL luma Yc'. Our optimization problem can, thus, be formulated as follows:

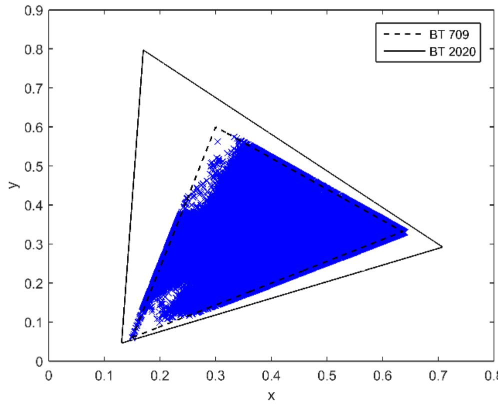
$$Ya' = dR' + eG' + fB' \tag{2}$$

$$J = argmin\, \|Yc' - Ya'\|^2 \tag{3}$$

where d, e, f are between 0 and 1, and the sum of these three parameters is constrained to be equal to 1. This optimization depends on the targeted bit-depth. In this paper we solely focused on 10 bits (around 1 billion R'G'B' code values, 30 bits per pixel).

Solving the optimization problem in (3) for a 10 bits R'G'B' input results in the following coefficients: d = 0.3348, e = 0.4968 and f = 0.1684. Table I reports the average distortion between our computed luma (Ya') and the CL luma (Yc') over all R'G'B' combinations. Table I also reports the distortion between CL (Yc') and the NCL luma (Yn'). We observe that our new coefficients provide a luma closer to that computed using the CL method when considering all R'G'B' combinations.

Note that our new coefficients need to be transmitted in order to reconstruct R', G' and B' channels from Ya'C_BC_R values. One way of achieving this, for example, is to send them via a Supplementary Enhancement Information (SEI) message of HEVC.



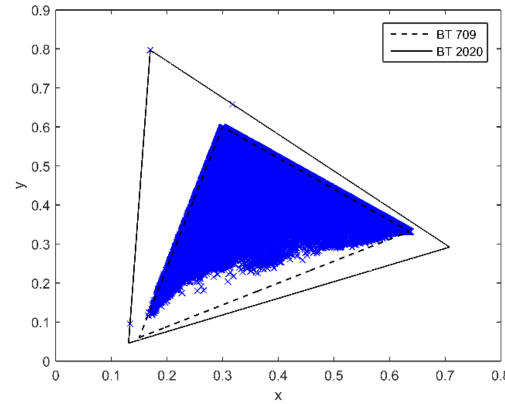


Fig. 2: Chromaticity distribution for Market3 (left) and BalloonFestival (right) [13].

4. RESULTS

To compare the compression efficiency of our approach with the traditional NCL implementation, we encoded 5 HDR video sequences provided in the MPEG Call for Evidence (CfE) for HDR and WCG Video Coding [8]. Four different Quantization Parameters (QPs) were used with HEVC (version HM 16.7) according to MPEG recommendations. Two objective metrics; tOSNR-XYZ and DE100; were computed for each original and decoded frames, using the test model software HDRTools 1.0 [9], and averaged over the whole sequence. The tOSNR-XYZ metric measures the overall PSNR for pixels in the XYZ color space. This metric measures the degradations of the signal when distributed throughout the pipeline. The DE100 metric is a PSNR computed using the CIEDE2000 [10] that predicts the color distortion between two pixels and includes perceptual aspect since it is based on the CIE L*a*b* color space [11].

Table II reports the average bit-rate reduction (in percentage) for the same tOSNR-XYZ value between our method and the NCL one. Bit-rate savings are measured using the Bjontegaard's Delta (BD) Rate [12]. Negative numbers represent bit-rate reduction, thus our method always require a lower bit-rate to achieve the same level of quality according to the tOSNR-XYZ metric. These results suggest that higher compression efficiency is possible due to the better decorrelation achieved by our approach.

Regarding the DE100 metric, all results reported in Table II indicate bit-rate reduction except for the BalloonFestival sequence where our method requires a higher bit-rate. Fig.2 plots the chromaticity distributions for Market3 and BalloonFestival (first frame of each sequence). We find that BalloonFestival has much more deeply saturated green than Market3. This difference in color accuracy can be explained by the fact that our new Green coefficient (e = 0.4968) is lower than that of BT.2020 (b = 0.6780). Thus, deeply saturated green colors will have a higher distortion due to baseband quantization (conversion from floating point to integers).

Table II: Average BD-rate reduction under the same quality

	tOSNR-XYZ	DE100
FireEater2	-7.3%	-3.5%
Market3	-3.1%	-0.8%
BalloonFestival	-6.0%	2.2%
Hurdles	-3.4%	-2.0%
Start	-5.4%	-2.4%
Average	-5.04%	-1.3%

Unfortunately, this will obviously lead to an increased correlation between luma and Green, also explaining the lower color accuracy for the BalloonFestival sequence. This suggests that our method works for HDR content with uniform chromaticity distributions. This result was expected since our optimization was equally important for each R'G'B' combination. Consequently, our method will most likely provide lower compression efficiency for HDR video sequences with many deeply saturated green pixels. It can be argued that for that type of content, the SEI message can be updated to revert to original NCL weighting.

Fig. 3 plots the tOSNR-XYZ compression results for a normal daylight HDR content (BalloonFestival) and a broad daylight video sequence (Start). We observe that our method has a higher tOSNR-XYZ when considering the same bit-rates for both sequences. This result is coherent with the numbers reported in Table II. Fig. 4 plots the DE100 results for the same two sequences. Again the results follow those reported in Table II. An interesting observation is that the DE100 is nearly the same for both techniques, at any chosen QP, and only the bit-rate is different. This difference in bit-rates confirms that a green prominent signal, such as in BalloonFestival, will have a higher entropy because a lesser decorrelation is achieved between the green channel and the luma channel. The contrary is true for the Red, Blue or balanced signals.

These results show that our proposed method successfully increases the compression efficiency of most

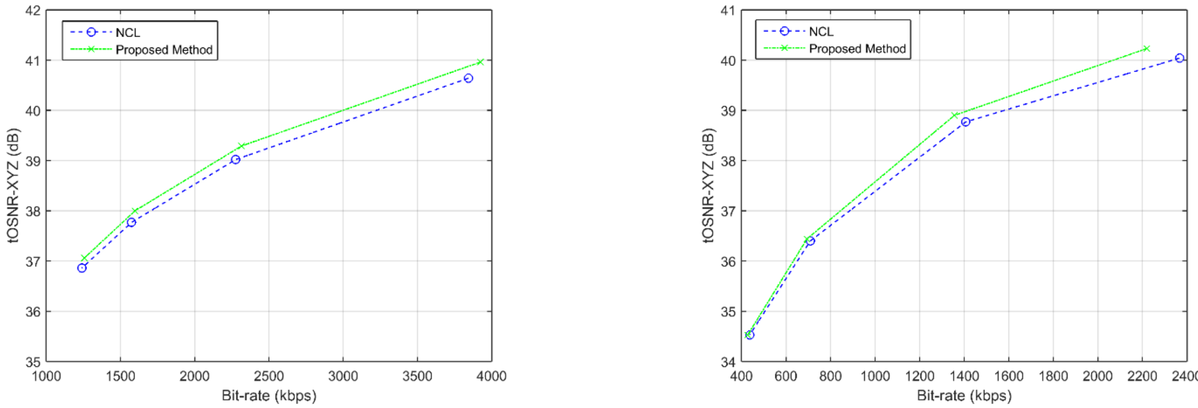


Fig. 3: tOSNR-XYZ for BalloonFestival (left) and Start (right) [13].

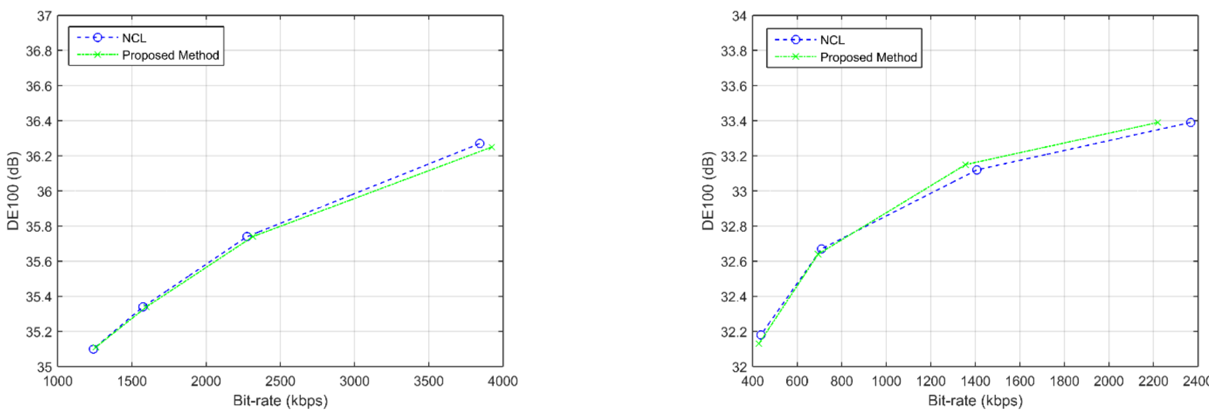


Fig. 4: DE100 for BalloonFestival (left) and Start (right) [13].

content over the NCL approach, without increasing the hardware complexity. New coefficients for R'G'B' are introduced and can be sent with an SEI message. The NCL approach can outperform our method for content with a high amount of green pixels. We expect to observe similar results for content covering the full BT.2020 gamut, with increased compression efficiency for most content apart for the green prominent ones. If the decreased compression efficiency of green content is substantial, the former NCL coefficients can be sent via an SEI message for selected content. Finally, note that transmission of the new coefficients is not included in those compression results. However such a transmission cost is negligible (for example as much as three 32 bits floating point values = 96 bits).

5. CONCLUSION

In this article, we proposed to derive a new set of coefficients for perceptually encoded R'G'B' values to optimize NCL into CL. Compression benefits of CL are provided with low NCL implementation cost. Focus was put on minimizing the difference between NCL luma (Yn') and CL luma (Yc').

The results show that our proposed method has improved compression efficiency and color quality according to tOSNR-XYZ and DE100 metrics. An average of 5.04% bit-rate savings is observed for maintaining the same signal quality in the XYZ color space. An average of 1.3% bit-rate reduction is identified for keeping same color quality in the CIE L*a*b* color space. However, results also show that for content with mostly green pixels, our method can be outperformed by the NCL approach. To compensate for this effect, we proposed to send, via SEI message, the chosen coefficient to generate the luma signal. This paves the way for adaptive weighting coefficients based on the distribution of pixels of a given content. Furthermore, the used chroma scaling coefficients (see Fig. 1) correspond to the NCL implementation and further work to derive new scaling that depends on the chosen weighting coefficients may improve compression efficiency.

Finally, in this paper, we applied objective metrics to measure the quality of HDR content. As there is no standard evaluation method for judging the visual quality of HDR videos, we chose two metrics that are recommended by MPEG. A subjective evaluation should be conducted to assess visually the impact of our new weighting coefficients.

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