A Hybrid Approach for Efficient Color Gamut Mapping

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***Abstract*—Ultra High Definition (UHD) and High Definition (HD) Television standard recommendations support different color gamuts with the HD gamut much smaller than that of the UHD one. To adapt UHD content to the restricted gamut of HD televisions, a process known as gamut mapping is required. This gamut mapping projects out-of-gamut colors inside the targeted color gamut. Gamut mapping can be performed in any color space and using different projection methods. In this paper, we present a hybrid gamut mapping approach which selects one combination of color space and projection method for each UHD color representable. The selection is based on the CIE ΔE2000 metric. Results show improvements in terms of CIE ΔE2000 when comparing original and projected colors over existing methods.**

I. Introduction

With the emergence of Ultra High Definition (UHD) televisions in the consumer electronics market, the production of content in UHD format is becoming more common. In addition to increased pixel resolution (almost 4 times more than High-Definition-HD), UHD technology offers increased displayable color space, a technology known as Wide Color Gamut (WCG).

A gamut is a subset of the visible colors a display can show or a camera can record and is defined by its white point and primaries. Legacy HD television systems only support a small proportion of the color that a human observer can perceive. This portion is described in the ITU-R Recommendation BT.709 [1], more commonly referred to as BT.709 or Rec.709. The ITU-R Recommendation BT. 2020 [2] covers a larger color gamut and is the recommendation used in UHD television systems.

Fig. 1 shows the range of colors covered by the BT.709 and BT.2020, in the CIE 1931 chromaticity plane [3], in comparison with all the visible colors (depicted by the horse-shoe shape). In this chromaticity plane, the BT.709 covers approximately 35.9% of the full visible gamut using 8 bits while the BT.2020 covers 75.8% of that range using 10 bits [4].

Distributing and broadcasting UHD content with wider color gamut such as BT.2020 to HD TVs with a smaller gamut (e.g., BT. 709) requires an adaptation process called gamut mapping. The process of gamut mapping inevitably leads to a loss in the mapped video's color information. Therefore, to ensure an acceptable quality on legacy displays, an efficient gamut mapping process is required before transmission of the content or at the receiver side. The efficiency of gamut mapping depends on the chosen color space and the projection technique. To this end, in this study we propose a hybrid approach that for each color in the BT.2020 gamut chooses a combination of color space and projection technique that yields the minimum possible color error.

II. Proposed Hybrid Gamut Mapping Method

Many color spaces exist with different characteristics, such as perceptual uniformity, hue linearity, etc. Gamut mapping can be performed in any color space and using different projection techniques with different constraints such as hue linearity or minimizing the Euclidian distance from the boundary of the gamut.

The study in [5] shows that among the tested color spaces and projection techniques, the combination of the CIELAB color space and Toward White Point (TWP) projection technique results in the least *average* error. The TWP projects out-of-gamut colors to the intersection between the gamut boundary and the line that connects the source color value to

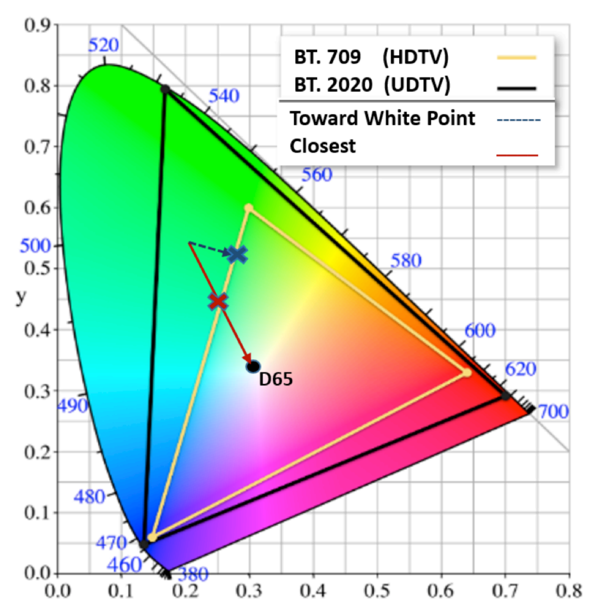

Fig. 1. CIE 1921 xy chromaticity diagram with the BT. 709 and BT. 2020 color gamuts, arrows illustrate Toward White point (TWP) and Closest projection techniques.

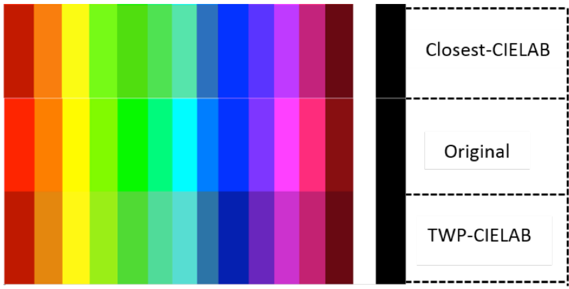

Fig. 2. Visual Comparison of Closest-CIELAB and TWP-CIELAB approaches for gamut mapping from a larger gamut to a smaller one

the white point (see Fig. 1). However, as it can be observed in Fig. 2, for some colors the combination of the CIELAB and the Closest projection method (denoted by Closest-CIELAB) outperform TWP-CIELAB. The Closest projection method maps out-of-gamut colors to a point on the gamut boundary that yields the minimum Euclidian distance between the source and mapped color value (see Fig. 1). In other words, the best overall gamut mapping technique does not yield the lowest distortion for every possible color.

In our hybrid mapping approach, we map each R'G'B' code value of the BT.2020 gamut using 10 bits to BT.709 using 8 its, with the combination of color space and projection technique that results in the minimum error. This method is hybrid in the sense that each color code value can potentially use a different combination of color space and projection technique. The color spaces used in this implementation are xyY [6], Yu'v' [7], Yuv, CIELUV, CIELAB, and IC_aC_b. Note that xyY is not designed with perceptual uniformity in mind, contrary to Yu'v', Yuv, CIELUV, and CIELAB. IC_aC_b is a color space that focuses on keeping hue lines constant. The projection technique utilized in our hybrid approach are TWP and Closest projection.

To select the optimized combination, for each of the 2^{30} combinations of R'G'B' values, we compute the CIE ΔE2000 metric for all combination pairs. Note that our method is generic in the sense that any new color space or projection could be included in our minimization process to achieve even higher gamut mapping accuracy.

III. Results And Discussions

Table I presents the results of the proposed hybrid gamut mapping method. We selected the TWP and CIELAB pair (denoted by TWP-CIELAB) as our point of reference since in [5] it was the combination that resulted in the least average error amongst all the tested combinations.

As it can be observed Mean Error has been reduced using the proposed hybrid gamut mapping method. Also, the percentage of colors with error value of less than one has increased. This is an important aspect since the CIE ΔE2000 metric returns a value greater than 1 only if the difference between the two tested colors is noticeable. The increase in number of colors with error less than 1 means that more colors are mapped below the visible threshold.

Our method can be computed offline and then implemented in a Look-Up Table (LUT). Without any subsampling, the size of this LUT would reach 3.2GB. Further optimization can be achieved by considering only out of gamut values in the LUT. Another possibility for reducing the LUT size is to use an octree-forest approach such as the one in [8] to subsample the number of coefficients used. Such a LUT could be implemented in set top boxes or TVs to guarantee that each color is mapped to a color resulting in the lowest perceptual distortion possible. Please note that these optimization methods were not used in the obtained results.

IV. Conclusions

In this paper we proposed a hybrid gamut mapping technique to convert BT. 2020 color code values to the BT. 709 gamut. A specific application of this method is to adapt UHD content to HD television systems and set top boxes. The results showed that our method reduces the overall error introduced by the mandatory gamut conversion. Our method is practical and easy to be used in set up boxes since it can be implemented as a subsampled 3D-LUT. Assuming that a new color space, projection technique or color metric is designed, the created LUT would only need to be updated to improve its performance.

Table I
Results of the Hybrid Gamut Mapping Approach Versus TWP-CIELAB

Gamut Mapping Method	Mean Error (CIE ΔE2000)	Number of pixels with error < 1
TWP-CIELAB	4.46	340180257
Proposed hybrid approach	4.08	358361835

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