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| *Title:* | **Adaptive Perceptual Quantizer for HDR Video Coding** | | |
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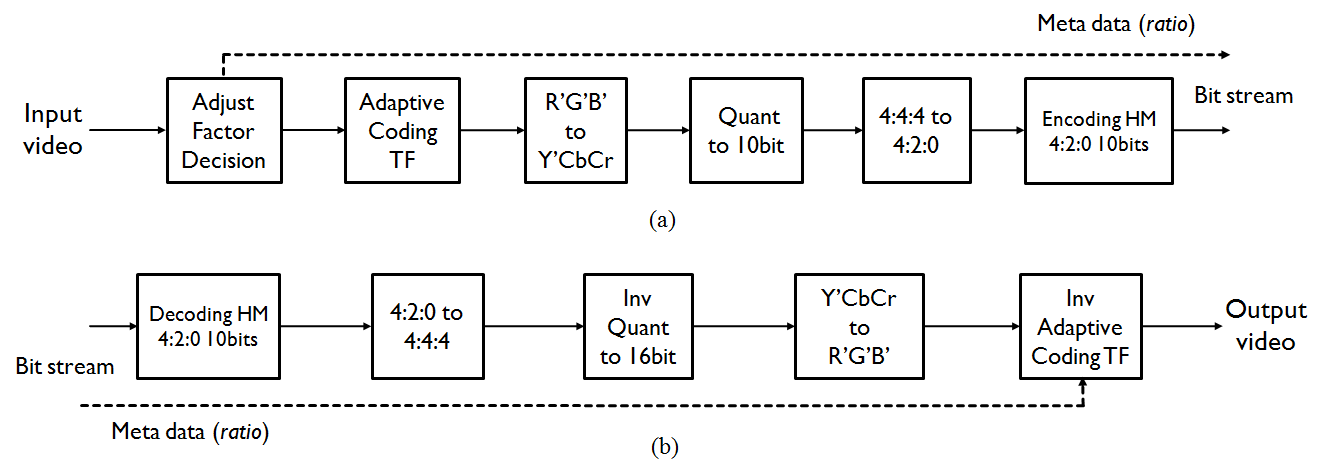
# Abstract

Proposed is an adaptive transform function based perceptual quantizer (PQ) for HDR videos, namely adaptive PQ. Adaptive PQ is to solve the problem that PQ is not adaptive to HDR contents because of using a fixed mapping function from luminance to luma. By introducing a ratio factor derived from the luminance information of HDR content, adaptive PQ maps luminance to luma adaptively according to the content.

# Adaptive PQ

Fig. 1 illustrates the whole framework of HDR video coding based on adaptive PQ [1]. First, we transform the input video sequence from RGB to YCbCr color space, and extract the maximum and minimum luminance of each frame, *Ymax* and *Ymin*. From *Ymax* and *Ymin*, we calculate the adjustment factor *ratio*. Then, we adjust the transfer function (TF) for adaptive PQ based on *ratio*, and perform HDR video coding. Since *ratio* is different for each frame, it is sequentially updated in each frame. To use *ratio* as the metadata for HDR video coding, we add *ratio* in bit stream, more specifically in the Supplemental Enhancement Information (SEI) syntax element. Next, the video sequence is processed by color space conversion from R’G’B’ to Y’CbCr, quantization and chroma down-sampling to get the standard input format, i.e. 10-bit, 4:2:0, non-constant luminance, and Y’CbCr, for HEVC Main 10 coding [2]. The processed sequence is encoded and decoded by HEVC Main 10 Profile. In the decoding part, the decoded sequence is processed by chroma up-sampling, inverse quantization (10bit-to-16bit), color space conversion (Y’CbCr to R’G’B’) [2]. Then, we adjust inverse PQ based on the metadata *ratio*, and perform inverse adaptive PQ for HDR video reconstruction. In inverse PQ [3], the relationship between normalized luma and luminance is given. Let *N* denote the normalized luma, *L* denotes the normalized luminance. We would like to find out the relationship between normalized luminance and JND. Since JND is related to luminance rather than luma, we consider inverse PQ transfer function *f* as follows:

 (1)



**Fig. 1 Whole framework of HDR video coding based on adaptive PQ. (a) Encoding. (b) Decoding.**

where *m*1, *m*2, *c*1, *c*2, and *c*3 are set as 0.1593, 78.8438, 0.8359, 18.8516, and 18.6875, respectively. Because *N* represents the normalized luma,  only when *N*=0. Thus, we simplify (1) for *N*>0 as follows:

 (2)

Let *Ni* and *Ni+*1 denote adjacent normalized luma; *Li* and *Li+*1 denote their corresponding normalized luminance. We have , and the normalized quantization step is a positive constant. Also, we have and . By using the 1st-order Taylor series expansion, we obtain as follows:

 (3)

 (4)

where *f’* means the derivative of *f*. In PQ [3], Barten CSF model [4] shows the relationship between luminance and JND [3], and thus we get the JND, *mt*, from luminance by its inverse representation, i.e. *mt*=1/CSF, as follows:

 (5)

where

 (6)

 (7)

 (8)

where a value *g*1 is related to normalized quantization step Δ*N* because Δ*N* is determined only by bit-depth [5] (the bit-depth is 10 in HEVC Main 10 Profile); therefore, *g*1 is a constant; *g*2(*Ni*) is highly dependent on *Ni*, according to the derivation in [3], which is parallel to the JND, i.e. *g*2(*Ni*) is equal to JND multiplied by a constant of less than 1. In (3), a value *g*3 is only related to the constant parameters [3]. In PQ [3], if the covered luminance range is from 10-6 cd/m2 to 102 cd/m2, then the precision of each luma (i.e. the half-unit distance in the color space) is 0.46 JNDs; if the covered luminance range is from 10-6 cd/m2 to 103 cd/m2, then the precision of each luma is 0.68 JNDs; if the covered luminance range is from 10-6 cd/m2 to 104 cd/m2, then the precision of each luma is 0.9 JNDs. Thus, the precision is closely related to the encoded luminance range. Based on this observation, we obtain a new parameter *ratio* which is determined by the luminance range of the HDR content as follows:

 (9)

where *Ymax* and *Ymin* are the maximum and minimum luminance of the HDR content, respectively, log10(⋅) is the logarithmic function with base of 10. From Eqs. (5)-(8), it can be observed that all parameters of *m*2, *c*1, *c*2 and *c*3 contribute to *g*2(*Ni*), which is parallel to the JND. Thus, if they are adjusted by *ratio*, the perceptual uniformity of PQ is destructed [3][6]. However, since *m*1 only contributes to *g*3, if we use *ratio* to adjust it, the perceptual uniformity of PQ still remains. Moreover, it is adaptive to HDR content. Therefore, we use *ratio* to adjust *m*1, and obtain adaptive PQ as follows:

 (10)

Besides, the corresponding inverse adaptive PQ is obtained as follows:

 (11)

where

 (12)

The parameters of ratio are coded as metadata in the bitstream.

# Experimental Results

We perform experiments in the HEVC test model (HM16.7) Main 10 Profile random access configuration, which uses a hierarchical B picture structure with a Group of Pictures (GOP) size of not larger than 8 frames and the intra period is determined by frame rate [7]. To verify the superiority of the proposed method over PQ, we compare adaptive PQ with Anchor based on PQ which uses HM16.7 and modified HDRTools 0.10 (HDRTools 0.10 with patch files) instead of SuperAnchor v3.2 [7]. For the tests, we use a Workstation with Intel(R) Xeon(R) E5-2640 CPU (2.60GHZ) and 32.00GB RAM running a Windows 7 environment and Microsoft Visual Studio 2013.

We provide Bjøntegaard Delta (BD) rates in comparison with PQ in TABLE I. From TABLE I, it can be observed that adaptive PQ achieves almost the same bit-rate compared with Anchor under the same objective metrics. Because adaptive PQ utilizes quantization intervals more efficiently and has better perceptual uniformity in the luminance range than PQ, adaptive PQ achieves better performance for test sequences of a narrow dynamic range with a dark tone, e.g. *FireEater*, which means adaptive PQ preserves more details, colors, and structural information than PQ. Fig. 2 provides visual quality comparison between PQ and adaptive PQ in *FireEater*. As shown in Fig. 2, adaptive PQ produces clearer details than PQ, while preserving colors better than PQ (see the rectangular regions). Adaptive PQ in Fig. 2(e) effectively preserves color information better than PQ in Fig. 2(b). Moreover, adaptive PQ in Fig. 2(f) successfully reconstructs image details than PQ in Fig. 2(c).

**TABLE I**

**BD Rates of Adaptive PQ in Comparison with PQ**





(a) (b) (c)



(d) (e) (f)

**Fig. 2 Visual quality comparison in *FireEater* with QP=22. (a) Reconstructed HDR frame by PQ. (b) and (c) Enlarged regions of (a). (d) Reconstructed HDR frame by adaptive PQ. (e) and (f) Enlarged regions of (d).**

# Conclusions

We have proposed adaptive PQ for HEVC Main 10 Profile-based HDR video coding. Adaptive PQ is based on PQ, and adaptively maps luminance to luma because it is adjusted according to HDR contents. First, we have extracted the maximum and minimum luminance of the HDR content, and used them to calculate the adjustment factor for coding TF. Then, we have adjusted TF based on the adjustment factor, called adaptive PQ. We have used the adjustment factor as the metadata, and saved it in the SEI syntax element. In comparison with PQ, adaptive PQ utilizes the quantization intervals more efficiently than PQ, which is useful for reducing the quantization distortions. Moreover, adaptive PQ has better perceptual uniformity in the luminance range than PQ, and thus contributes to the color preservation. For test sequences with a narrow dynamic range, adaptive PQ achieves better performance than PQ in terms of detail preservation and color reproduction.

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