SUMMARY

[0008a] According to a first aspect of the present invention, there is provided a method comprising: accessing an input image in a first color space with a first dynamic range; applying a color transformation step to the input image to determine a first output image in a perceptually-quantized IPT (IPT-PQ) color space, the first output image comprising intensity pixel values and chroma components pixel values, wherein the color transformation step comprises applying a non-linear perceptual quantizer function to a function of the input image; applying a color-volume mapping function to the first output image to generate a tone-mapped output image, the tone-mapped output image comprising intensity pixel values and chroma components pixel values, wherein the color-volume mapping function comprises a tone mapping function, a saturation mapping function, and a pixel saturation estimate function, wherein the tone mapping function generates the intensity pixel values of the tone-mapped output image by applying a non-linear mapping to the intensity pixel values of the first output image, wherein the saturation mapping function generates the chroma components pixel values of the tone-mapped output image by adjusting the chroma components pixel values of the first output image based on changes in intensity, wherein the pixel saturation estimate function computes a saturation metric (S) as the sum of squares of the chroma components pixel values of the first output image, wherein the saturation metric is applied to the tone-mapped output image to darken bright saturated colors and to desaturate highly saturated colors, thereby modifying the intensity pixel values and the chroma components pixel values; and applying a detail preservation function to the modified intensity pixel values of the tone-mapped output image to generate intensity pixel values of a filtered tone-mapped output image, the filtered tone-mapped output image comprising the modified chroma components pixel values of the tone-mapped output image.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] An embodiment of the present invention is illustrated by way of example, and not in way by limitation, in the figures of the accompanying drawings and in which like reference numerals refer to similar elements and in which:

[00010] FIG. 1 depicts an example process for the display management of EDR images according to an embodiment of the present invention;

[00011] FIG. 2 depicts an example process for converting input EDR data from an input color space into a perceptually-quantized space according to an embodiment of the present invention;

[00012] FIG. 3 depicts an example process for color volume mapping for EDR images according to an embodiment of the present invention;

[00013] FIG 4 depicts an example process for detail preservation according to an embodiment of the present invention; and

[00014] FIG. 5 depicts an example process for output color conversion according to an embodiment of the present invention.

DESCRIPTION OF EXAMPLE EMBODIMENTS

[00015] Efficient display management (e.g., tone and gamut mapping) of enhanced dynamic range (EDR) images is described herein. In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, that the present invention may be practiced without these specific details. In other instances, well-known structures and devices are not described in exhaustive detail, in order to avoid unnecessarily occluding, obscuring, or obfuscating the present invention.

OVERVIEW

[00016] Example embodiments described herein relate to the efficient display management of EDR images. A display management processor receives an input image with enhanced dynamic range to be displayed on a target display which has a different dynamic range than a source reference display. The input image is first transformed from an input color space (e.g., RGB or YCbCr) into a perceptually-quantized (PQ) color space, preferably the IPT-PQ color space. A color volume mapping function, which includes an adaptive tone-mapping function and an adaptive

Claims:

1. A method comprising:

accessing an input image in a first color space with a first dynamic range;

applying a color transformation step to the input image to determine a first output image in a perceptually-quantized IPT (IPT-PQ) color space, wherein the color transformation step comprises applying a non-linear perceptual quantizer function to a function of the input image;

applying a color-volume mapping function to the first output image to generate a tone-mapped output image, wherein the color-volume mapping function comprises a tone mapping function, a saturation mapping function coupled to the output of the tone mapping function, and a pixel saturation estimate function; and

applying a detail preservation function to the tone-mapped intensity image to generate a filtered tone-mapped intensity image.

2. The method of claim 1, wherein applying the color transformation step further comprises:

removing any non-linear encoding from the input image to generate a linear image;

converting the linear image into an LMS color image; and

applying the non-linear perceptual quantizer (PQ) function to the LMS color image to generate the first output image.

3. The method of claim 2, wherein the non-linear perceptual quantizer function comprises the SMPTE ST 2084 mapping function.

4. The method of claim 1, wherein the tone-mapping function is expressed as a parameterized sigmoidal tone curve function, wherein parameters of the function are determined based on characteristics of a source display and a target display.

5. The method of claim 4 wherein the characteristics of the source display comprise a minimum brightness value and a maximum brightness value for the source display.

6. The method of claim 4, wherein the characteristics of the target display comprise a minimum brightness value and a maximum brightness value for the target display.

7. The method of claim 4, wherein the characteristics of the source display are accessed through received source display metadata.

8. The method of claim 4, wherein the sigmoidal tone function is expressed as

$$I_m = \left(\frac{C_1 + C_2 I_o^{Slope}}{1 + C_3 I_o^{Slope}}\right)^{Rolloff}$$

wherein C_1, C_2, C_3, *Slope*, and *Rolloff* are constants defining the parameters of the tone-mapping function, and for an input I_o, I_m is a corresponding output value.

9. The method of claim 4, wherein parameters of the tone-mapping function are further determined based on a *Brightness* value and a *Contrast* value to adjust overall brightness and contrast of the tone-mapped output image.

10. The method of claim 1, wherein the pixel saturation estimate function computes a saturation metric (S) as the sum of squares of pixel values of the chroma components (P,T) for the first output image.

11. The method of claim 1, wherein the saturation mapping function (f_{SM}) is expressed as

$$f_{SM}(I_o) = I_m - I_o + 1$$

wherein I_m denotes the output of the tone-mapping function, and I_o denotes the intensity of the first output image.

12. The method of claim 1, wherein applying the color-volume mapping function comprises computing:

$I_m = f_I(I_o) * (1 - S * \alpha)$,

$P_m = P * f_{SM}(I_o) * (1 - S * \beta)$,

$T_m = T * f_{SM}(I_o) * (1 - S * \beta)$,

where S denotes an output of the pixel saturation estimation function, α and β denote input weights, $f_T(I_o)$ denotes the tone-mapping function, $f_{SM}(I_o)$ denotes the saturation mapping function, I_o denotes intensity pixel values of the first output image, P and T denote pixel values of chroma components of the first output image, and I_m, P_m, and T_m denote pixel values of color components of the tone-mapped output image.

13. The method of claim 1, wherein applying the detail preservation function further comprises computing:

$$D = I_o - I_m,$$

$$B = F(D,H),$$

$$Ex = F(B,Hx),$$

$$Ey = F(B,Hy),$$

$$E = (|Ex| + |Ey|) * W_{MSE} + (1 - W_{MS}),$$

$$I_{mf} = I_o - B - E * (D - B)$$

where $F(D,H)$ denotes applying to image D a filter with kernel H, I_o denotes intensity pixel values of the first output image, I_m denotes the tone-mapped intensity image, I_{mf} denotes the filtered tone-mapped intensity image, B denotes the output of a blur filter, Ex denotes the output of a horizontal edge-detection filter, Ey denotes the output of a vertical edge-detection filter, and W_{MSE} and W_{MS} are weights.

14. The method of claim 13, wherein the E output value is further clamped to be between 0 and 1.

15. The method of claim 13 wherein the kernel H comprises a 5x11 Gaussian filter with standard deviation equal to 2.

16. The method of claim 13 wherein the kernel H comprises a low-pass filter.

17. The method of claim 12, wherein the values of $(1 - S * \alpha)$ and $(1 - S * \beta)$ are clamped to always be larger than zero.

~~18. An apparatus comprising a processor and configured to perform any one of the methods recited in claims 1-17.~~

~~19. A non-transitory computer-readable storage medium having stored thereon computer-executable instruction for executing a method in accordance with any of the claims 1-17.~~

Claims:

1. A method comprising:

accessing an input image in a first color space with a first dynamic range;

applying a color transformation step to the input image to determine a first output image in a perceptually-quantized IPT (IPT-PQ) color space, the first output image comprising intensity pixel values and chroma components pixel values, wherein the color transformation step comprises applying a non-linear perceptual quantizer function to a function of the input image;

applying a color-volume mapping function to the first output image to generate a tone-mapped output image, the tone-mapped output image comprising intensity pixel values and chroma components pixel values,

wherein the color-volume mapping function comprises a tone mapping function, a saturation mapping function, and a pixel saturation estimate function,

wherein the tone mapping function generates the intensity pixel values of the tone-mapped output image by applying a non-linear mapping to the intensity pixel values of the first output image,

wherein the saturation mapping function generates the chroma components pixel values of the tone-mapped output image by adjusting the chroma components pixel values of the first output image based on changes in intensity,

wherein the pixel saturation estimate function computes a saturation metric (S) as the sum of squares of the chroma components pixel values of the first output image, wherein the saturation metric is applied to the tone-mapped output image to darken bright saturated colors and to desaturate highly saturated colors, thereby modifying the intensity pixel values and the chroma components pixel values; and

applying a detail preservation function to the modified intensity pixel values of the tone-mapped output image to generate intensity pixel values of a filtered tone-mapped output image, the filtered tone-mapped output image comprising the modified chroma components pixel values of the tone-mapped output image.

2. The method of claim 1, wherein applying the color transformation step further comprises:

removing any non-linear encoding from the input image to generate a linear image;

converting the linear image into an LMS color image; and

applying the non-linear perceptual quantizer (PQ) function to the LMS color image to generate the first output image.

3. The method of claim 2, wherein the non-linear perceptual quantizer function comprises the SMPTE ST 2084 mapping function.

4. The method of claim 1, wherein the tone-mapping function is expressed as a parameterized sigmoidal tone curve function, wherein parameters of the function are determined based on characteristics of a source display and a target display.

5. The method of claim 4, wherein the characteristics of the source display comprise a minimum brightness value and a maximum brightness value for the source display.

6. The method of claim 4, wherein the characteristics of the target display comprise a minimum brightness value and a maximum brightness value for the target display.

7. The method of claim 4, wherein the characteristics of the source display are accessed through received source display metadata.

8. The method of claim 4, wherein the sigmoidal tone function is expressed as

$$I_m = \left(\frac{C_1 + C_2 I_o^{Slope}}{1 + C_3 I_o^{Slope}} \right)^{Rolloff}$$

wherein C_1, C_2, C_3, *Slope*, and *Rolloff* are constants defining the parameters of the tone-mapping function, and for an input I_o, represented by an intensity pixel value of the first output image, I_m is a corresponding output value, represented by the corresponding intensity pixel value of the tone-mapped output image.

9. The method of claim 4, wherein parameters of the tone-mapping function are further determined based on a *Brightness* value and a *Contrast* value to adjust overall brightness and contrast of the tone-mapped output image.

10. The method of claim 1, wherein the saturation mapping function is expressed as

$$f_{SM}(I_o) = I_m - I_o + 1$$

wherein I_m denotes the output of the tone-mapping function, and I_o denotes the intensity pixel values of the first output image, and

wherein applying the color-volume mapping function comprises computing:

$I_m = f_T(I_o) * (1 - S * \alpha)$,

$P_m = P * f_{SM}(I_o) * (1 - S * \beta)$,

$T_m = T * f_{SM}(I_o) * (1 - S * \beta)$,

where *S* denotes the saturation metric generated by the pixel saturation estimation function, α and β denote input weights, $f_T(I_o)$ denotes the tone-mapping function, $f_{SM}(I_o)$ denotes the saturation mapping function, I_o denotes the intensity pixel values of the first output image, *P* and *T* denote the chroma components pixel values of the first output image, I_m denotes the pixel values of the tone-mapped output image, and P_m and T_m denote the color components pixel values of the tone-mapped output image.

11. The method of claim 10, wherein the values of $(1 - S * \alpha)$ and $(1 - S * \beta)$ are clamped to always be larger than zero.

12. The method of claim 1, wherein applying the detail preservation function further comprises computing:

$D = I_o - I_m$,

$B = F(D, H)$,

$Ex = F(B, Hx)$,

$Ey = F(B, Hy)$,

$E = (|Ex| + |Ey|) * W_{MSE} + (1 - W_{MS})$,

$I_{mf} = I_o - B - E * (D - B)$

where *F(D,H)* denotes applying to image *D* a filter with kernel *H*, I_o denotes intensity pixel values of the first output image, I_m denotes the intensity pixel values of the tone-mapped output image, I_{mf} denotes the intensity pixel values of the filtered tone-mapped output image, *B* denotes the output of [[the]]a blur filter, Ex denotes the output of [[the]]a horizontal edge-

detection filter, Ey denotes the output of [[the]]a vertical edge-detection filter, and W_{MSE} and W_{MS} are weights.

13. The method of claim 12, wherein the *E* output value is further clamped to be between 0 and 1.

14. The method of claim 12, wherein the kernel *H* comprises a 5x11 Gaussian filter with standard deviation equal to 2.

15. The method of claim 12, wherein the kernel *H* comprises a low-pass filter.

16. An apparatus comprising a processor and configured to perform any one of the methods recited in claim 1.

17. A non-transitory computer-readable storage medium having stored thereon computer-executable instruction for executing a method in accordance with claim 1.