AN INTEGER TONE MAPPING OPERATION FOR HDR IMAGES EXPRESSED IN FLOATING POINT DATA

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ABSTRACT

This report proposes a new tone mapping operation which is implemented in integer input and integer output. A tone mapping operation (TMO) generates a low dynamic range (LDR) image from a high dynamic range (HDR) image. Since pixel values of an HDR image are generally expressed in a floating point data format, e.g. RGBE, OpenEXR, a TMO is also implemented in floating point calculations in conventional approaches. However, it requires huge memory resources, even though a resulting LDR image is expressed in simple integer. We perform a TMO with integer input and integer output to reduce memory resources. It is experimentally confirmed with PSNR and contrast evaluations that the proposed method offers LDR images of visually high quality comparable to the conventional method.

Index Terms— high dynamic range, image signal, tone mapping, integer operation

1. INTRODUCTION

Recently, high dynamic range (HDR) images have been spreading rapidly from the field of photographic and computer graphics, to the other fields such as medical imaging and car-mounted camera. On the contrary, the next generation display devices which can accept so wide range of dynamics of pixel values in HDR images are not popular yet. Therefore, a tone mapping operation (TMO) is important to reduce dynamic range of HDR images so that is can be treated with conventional display devices.

So far, various investigations have been done on TMOs. Most of those were concentrated on finding a tone mapping function suitable for human visual system [1–4]. Recently, some reports dealt with reducing communication cost combining with data compression technologies [5–8]. Unlike those previous reports, this report discusses on 'resources' of a TMO such as memory space or computational cost for light implementation of tone mapping.

In general, it is important to reduce memory space and computational cost in image processing, including tone mapping we are discussing here. Heavy demand for computation is continuously increasing, e.g. large variety of color depth, huge size of images and resolution of displaying devices. Therefore, it is still necessary to consider how to implement signal processing under limited resources for economic reason, even though faster machines appear in the future. Especially, a TMO requires heavy resources, since it is generally composed of 'floating point' operations for an HDR data format such as RGBE and OpenEXR [2]. In this report, we implement a TMO with 'integer' operations.

A fast and flexible TMO has been proposed in [9]. Visibility and contrast were simply controlled with a single parameter. However it does not directly contribute to reducing resources. A global tone mapping in [1, 2] has been widely used due to its simplicity. However, a function for this TMO is limited to a specific one. Moreover, a function itself is just a part of whole TMO.

Unlike those conventional approaches, our method is based on 'integer' operations of tone mapping for reduction of memory resources. Considering not only a function itself but also whole procedure of a TMO, we try to resolve the essential problem on high demand of resources.

In our method, any kind of functions can be utilized as a global tone mapping. It offers almost the same result of tone mapping as a conventional method under reduced resources of computation. We show that memory resources are reduced by our method. As a result, it enables 8 bit integer operation. We also confirm that the proposed method offers high quality of tone mapped images comparable to a conventional method.

2. PHOTOGRAPHIC TONE REPRODUCTION

Procedure of a tone mapping is described as below. It generates an integer low dynamic range (LDR) image from a floating-point HDR image. Fig. 1 illustrates one of well-known tone mapping procedures [1]. Firstly it calculates world luminance $L_w(p)$ of a pixel p as

$$L_w(p) = 0.27R(p) + 0.67G(p) + 0.06B(p), \tag{1}$$

where $R(p)$, $G(p)$, and $B(p)$ are floating-point RGB values of the input HDR image. Next, the scaled luminance $L(p)$ is calculated by

$$L(p) = k \cdot \frac{L_w(p)}{\bar{L}_w}, \tag{2}$$

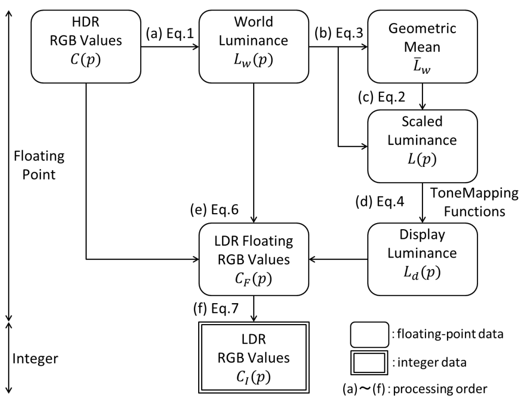

Fig. 1. Photographic Tone Reproduction

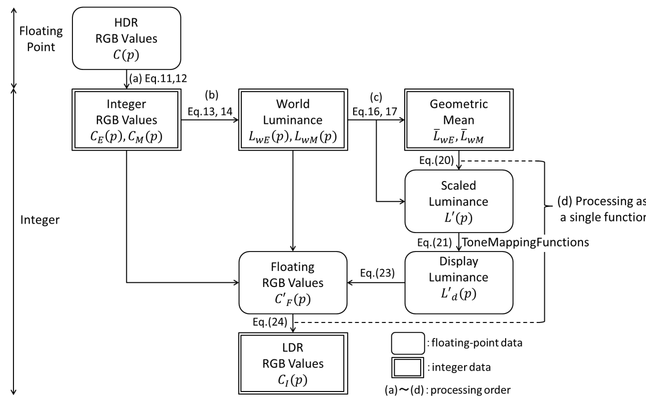

Fig. 2. Proposed method outline

where $k \in [0, 1]$ is a parameter called "key value." $\bar{L}_w$ denotes geometric mean of the world luminance $L_w(p)$. It is defined as

$$\bar{L}_w = \exp\left(\frac{1}{N}\sum_p \log_e\left(L_w(p)\right)\right), \tag{3}$$

where N is the total number of pixels in the input HDR image. Note that Eq. (3) has singularity due to zero value of $L_w(p)$. It is avoided by introducing a small value in [1]. However, its arbitrariness is not negligible for pixel values in a floating point format, since its pixel value is also small. Therefore, in this report, we include nonzero values only in the geometric mean. Next, display luminance $L_d(p)$ is computed with a tone mapping function $y()$ as

$$L_d(p) = y(L(p)), \tag{4}$$

where Reinhard's global operator [1] is specified as

$$y_{\text{Reinhard}}(L(p)) = \frac{L(p)}{1 + L(p)}. \tag{5}$$

Finally, floating-point LDR pixel value $C_F(p)$ is derived as

$$C_F(p) = L_d(p) \cdot \frac{C(p)}{L_w(p)}, \tag{6}$$

where $C(p) \in \{R(p), G(p), B(p)\}$ is the RGB value of input HDR image, and $C_F(p) \in \{R_F(p), G_F(p), B_F(p)\}$. Moreover, 8-bit integer LDR value $C_I(p)$ is generated as

$$C_I(p) = \text{round}\left(C_F(p) \cdot 255\right), \tag{7}$$

where $\text{round}(x)$ rounds x to the nearest integer value and $C_I(p) \in \{R_I(p), G_I(p), B_I(p)\}$.

It should be noted that each procedure in Fig. 1 outputs pixel value in 'floating point' data except the final output $C_I(p)$. Therefore this 'floating point' tone mapping operation requires huge memory resources, e.g. memory space and bit depth.

3. PROPOSED METHOD

3.1. Proposed Method Outline

The proposed method suits HDR images in a variety of formats such as the RGBE and the OpenEXR [2]. In our method, the HDR image data is transformed to integer values based on the HDR image format. After that, the integer data are tone mapped according to the flow shown in Fig. 2.

3.2. Floating Point Pixel Value

This report deals with the RGBE format as an example of floating point data format of HDR images. It uses 32 bits per pixel in total. It consist of 8 bit common exponent and 8 bit mantissa for each RGB channel [2]. Its exponent $F_E(p)$ and mantissa $F_M(p)$ for floating-point value $F(p)$ are calculated by

$$F_E(p) = \left\lceil \log_2 F(p) + 128 \right\rceil, \tag{8}$$

$$F_M(p) = \left\lfloor F(p) \cdot 2^{136 - F_E(p)} \right\rfloor, \tag{9}$$

where $0 \leq F_E(p) \leq 255$ and $0 \leq F_M(p) \leq 255$. In the equation above, $\lceil x \rceil$ rounds x to the nearest integer greater than or equal to x, and $\lfloor x \rfloor$ rounds x to the nearest integer less than or equal to x. In this format, the original floating point value $F(p)$ is represented as

$$F(p) = \frac{F_M(p) + 0.5}{256} \cdot 2^{F_E(p) - 128}. \tag{10}$$

3.3. New Tone Mapping Procedure

Fig. 2 illustrates diagram of the proposed method. Unlike the conventional method in Fig. 1, all the values except the original input $C(p)$ are expressed as integers. Therefore it is expected to reduce the resources.

The proposed method converts the original HDR pixel in floating point value into 'integer' at the first stage. The common exponent, $C_E(p)$, and each RGB value mantissa, $C_M(p)$, are converted as

$$C_E(p) = \lceil \log_2\{\max(R(p), G(p), B(p)\} + 128\rceil\,, \quad (11)$$

$$C_M(p) = \left\lfloor C(p) \cdot 2^{136 - C_E(p)} \right\rfloor\,, \quad (12)$$

where $0 \leq C_E(p) \leq 255$, $0 \leq C_M(p) \leq 255$, and $C_M(p) \in \{R_M(p), G_M(p), B_M(p)\}$. If $\max\left(R(p), G(p), B(p)\right) < 10^{-38}$, this method sets $C_E(p) = C_M(p) = 0$ [2]. And if $C_M(p) = 256$, this method sets $C_M(p) = 255$. Next, the integer values pair for world luminance $L_w(p)$ is calculated; exponent $L_{w_E}(p)$ and mantissa $L_{w_M}(p)$ of world luminance $L_w(p)$ are given as

$$L_{w_E}(p) = \lceil \log_2(ML(p) + 0.5) + C_E(p) - 8\rceil\,, \quad (13)$$

$$L_{w_M}(p) = \left\lfloor (ML(p) + 0.5) \cdot 2^{C_E(p) - L_{w_E}(p)} \right\rfloor\,, \quad (14)$$

$$ML(p) = 0.27 R_M(p) + 0.67 G_M(p) + 0.06 B_M(p), \quad (15)$$

where $0 \leq L_{w_E}(p) \leq 255$ and $0 \leq L_{w_M}(p) \leq 255$. If $C_M(p) = 256$, this method sets $C_M(p) = 255$. Next, integer valued geometric mean is calculated; exponent $\bar{L}_{w_E}(p)$ and mantissa $\bar{L}_{w_M}(p)$ of geometric mean $\bar{L}_w$ are derived as

$$\bar{L}_{w_E} = \lceil AL_{w_M} + AL_{w_E} - 8\rceil\,, \quad (16)$$

$$\bar{L}_{w_M} = \left\lfloor 2^{AL_{w_M} + AL_{w_E} - \bar{L}_{w_E}} \right\rfloor\,, \quad (17)$$

$$AL_{w_E} = \frac{1}{N} \sum_p L_{w_E}(p), \quad (18)$$

$$AL_{w_M} = \frac{1}{N} \sum_p \log_2\left(L_{w_M}(p) + 0.5\right)\,, \quad (19)$$

where $0 \leq \bar{L}_{w_E} \leq 255$ and $0 \leq \bar{L}_{w_M} \leq 255$. Here, $\bar{L}_{w_E}$ and $\bar{L}_{w_M}$ are computed by only non-zero $L_{w_E}(p)$'s. Then, scaled luminance $L'(p)$ is restored as a floating-point value by

$$L'(p) = k \cdot \frac{L_{w_M}(p) + 0.5}{\bar{L}_{w_M}} \cdot 2^{L_{w_E}(p) - \bar{L}_{w_E}}. \quad (20)$$

Display luminance $L'_d(p)$ is given by

$$L'_d(p) = y'\left(L'(p)\right). \quad (21)$$

For example, tone mapping function $y'()$ which corresponds to Eq. (5) is

$$y'_{\text{Reinhard}}\left(L'(p)\right) = \frac{L'(p)}{1 + L'(p)}. \quad (22)$$

Finally, floating-point LDR RGB value $C'_F(p)$ is calculated as

$$C'_F(p) = L'_d(p) \cdot \frac{C_M(p) + 0.5}{L_{w_M}(p) + 0.5} \cdot 2^{C_E(p) - L_{w_E}(p)}, \quad (23)$$

where $C'_F(p) \in \{R'_F(p), G'_F(p), B'_F(p)\}$. The final LDR image is obtained by rounding $C'_F(p)$ to integer values by

$$C_I(p) = \text{round}\left(C'_F(p) \cdot 255\right). \quad (24)$$

Outputs of Eqs. (20), (21), and (23) are floating-point values, but Eqs. (20), (21), (23), and (24) can be implemented as a single function as shown in Fig. 2. However, it is necessary to further break down ideally.

As we have shown above, the proposed method is implemented with 'integer' input and 'integer' output. It contributes to reduce memory resources as confirmed in the next section.

4. EXPERIMENTAL RESULTS

This section compares the proposed and the conventional [1] method using HDR images in RGBE format. All floating point values are computed and stored in double precision format. Eq. (5) is used as the tone mapping function.

4.1. LDR Image Comparison

LDR image produced by the proposed and the conventional [1] method are subjectively compared from the viewpoints of visual quality, the peak signal-to-noise ratio (PSNR), and the maximum error. Figure 3 shows LDR images. It indicates that it is impossible for human eyes to distinguish these two images.

Table 1 shows PSNR and the maximum error of RGB values for 32 HDR images in which LDR images produced by the conventional method are used as reference images. From Table 1, the worst PSNR was observed to be 49.7 dB and the maximum error was 4. It can be concluded that these two

Conventional Method | Proposed Method

Fig. 3. LDR Image Comparison (It is impossible to distinguish these two images.)

Table 1. PSNR and Maximum Error Results

Image	PSNR[dB]	Error	Image	PSNR[dB]	Error
1	57.2	1	17	60.9	1
2	61.7	1	18	63.8	1
3	60.2	1	19	49.7	4
4	60.7	1	20	57.0	1
5	61.7	1	21	60.5	1
6	56.8	1	22	57.2	1
7	60.8	1	23	59.7	1
8	57.2	1	24	60.7	1
9	58.5	1	25	54.1	2
10	62.4	1	26	57.8	1
11	58.9	1	27	59.4	1
12	53.6	2	28	58.1	1
13	62.4	1	29	58.1	1
14	57.3	1	30	56.5	1
15	60.5	1	31	60.9	1
16	59.7	1	32	57.0	1

Table 2. Contrast Comparison

Image	Edge content based contrast [10]		Relative Entropy [11]	
	conventional	proposed	conventional	proposed
1	3.46	3.48	0.099	0.099
2	9.89	9.89	0.033	0.033
3	6.37	6.38	0.007	0.007
4	6.37	6.38	0.021	0.021
5	7.83	7.83	0.011	0.011
6	4.64	4.65	0.010	0.010
7	10.55	10.55	0.033	0.033
8	9.99	9.99	0.014	0.014
9	12.09	12.09	0.027	0.027
10	3.94	3.94	0.004	0.004
11	5.06	5.08	0.018	0.018
12	6.76	6.76	-0.014	-0.014
13	6.19	6.18	0.029	0.029
14	7.19	7.18	0.025	0.025
15	4.75	4.75	0.011	0.011
16	3.85	3.87	0.011	0.011

methods are objectively comparable. It should be noted that pixel values sometimes exceed the range representable by the HDR image format in the tone mapping procedure, even the proposed method takes account into HDR image format in converting floating point values into integers. Therefore LDR images produced by the proposed method are slightly different from those by the conventional method. However the errors are too small to affect the subjective visual quality.

4.2. Comparison on Contrast

Contrast of images is one of very important factors for evaluating image quality [10–13]. Therefore we evaluate the contrast for LDR images with two metrics [10, 11] as below. Table 2 shows a result of contrast evaluation. It shows that the proposed method with integers keeps the contrast equivalent to the conventional method with double precision floating point values. In another metric [12], the result was similar.

4.3. Comparison on Memory and Bit Depth

Table 3 summarizes memory resources required to store data in the TMO. It indicates that the proposed method significantly reduces memory resources comparing to the conventional method. The memory resources to store data are reduced from 192 to 32 bit/pixel (16.7 %) at maximum by the proposed method. When we pay attention to bit depth of individual input and output, the conventional method requires 64 bit (double precision) for each input-output in the TMO. On the contrary, the proposed method requires only 8 bit (integer) for each input-output, since all integer input-output are in the range from 0 to 255. The bit depth for each input-output is also reduced from 64 to 8 bit (12.5 %) by the proposed method.

Table 3. Memory Comparison

Input/Output Data	Memory	
	Conventional	Proposed
HDR RGB values	192 bit/pixel	32 bit/pixel
World Luminance	64 bit/pixel	16 bit/pixel
Geometric Mean	64 bit	16 bit
Scaled Luminance	64 bit/pixel	-
Display Luminance	64 bit/pixel	-
LDR Floating RGB values	192 bit/pixel	-
LDR integer RGB values	24 bit/pixel	24 bit/pixel

5. CONCLUSION

In this report, we proposed an efficient integer operation for tone mapping of HDR images expressed in a floating point data format. Our method replaces floating point pixel value data in the conventional method with integers. It was confirmed that the memory resource were reduced to 16.7 % at maximum and that the bit depth for individual input-output was reduced to 12.5 %. It contributes to reduce memory resources of a tone mapping operation. It was also confirmed that there is almost no difference in LDR images between the proposed method and the conventional method with evaluations based on PSNR and contrast metrics.

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