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LETTER

A Unified Tone Mapping Operation for HDR Images Expressed in Integer Data

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SUMMARY This letter considers a unified tone mapping operation (TMO) for HDR images. The unified TMO can perform tone mapping for various HDR image formats with a single common operation. The integer TMO which can realize unified tone mapping by converting an input HDR image into an intermediate format is proposed. This method can be executed efficiently with low memory and low performance processor. However, only floating-point HDR image formats have been considered in the method. In other words, a long-integer which is one of the HDR image formats has not been considered in the method. This letter applies the method to a long-integer format, and confirm its performance. The experimental results show the proposed method is effective for an integer format in terms of the resources such as the computational cost and the memory cost.

key words: *high dynamic range, tone mapping, integer*

1. Introduction

High dynamic range (HDR) images are increasingly being used in many fields: photography, computer graphics, medical imaging, and others. In contrast, display devices which can express the pixel values of HDR images are not popular yet. Therefore, the importance of a tone mapping operation (TMO) which generates an LDR image from an HDR image is growing.

An integer TMO approach which deals with resource reduction was proposed in [1], [2]. The method in [1] treats a floating-point number as two 8-bit integer numbers which correspond to a exponent part and a mantissa part, and it applies tone mapping to these integer numbers separately. The method can be executed with low memory and low computational cost. However, this integer TMO approach is designed for the RGBE format; its performance is not guaranteed for other formats. In [2], the intermediate format was introduced, and the integer TMO was extended for it. By using the intermediate format, it can be applied to other formats such as the OpenEXR [3] and the IEEE754 [4]. Nevertheless, in [2], only floating-point HDR image formats are used as input images; a long-integer which is one of the HDR image formats is not considered.

The aim of this letter is to construct a unified TMO which is a general purpose TMO for various HDR image formats with a single common operation. To achieve it, it is necessary to apply a common operation to various formats including a long-integer.

This letter applies the method in [2] to a long-integer format, and confirms its efficacy. The proposed unified TMO can treat all possible HDR image formats including both floating-point data and integer data. The experimental results shows the proposed method is more effective for an integer format in terms of resources such as computational cost and memory cost.

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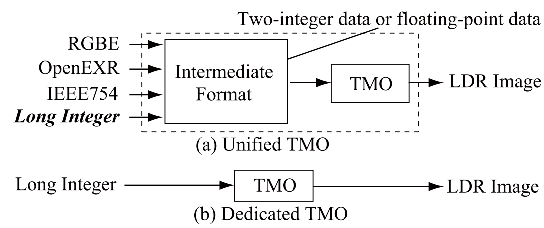

Fig. 1 The scheme of a unified tone mapping operation.

2. Unified TMO

Figure 1 shows the scheme of a unified tone mapping. In (a), various input HDR image formats are converted to an intermediate format, and then a TMO for the intermediate format is applied. Thus, (a) is a unified method which can process various HDR image formats using a single common TMO. On the other hand, in (b), each input HDR image format is processed by a TMO dedicated to each format. Although this method is simple, it can not be used as a unified TMO because it has exclusive use of the integer format. This letter focuses on the TMO (a) including the long-integer as the input HDR image format.

3. Proposed Method

3.1 Intermediate Format

This letter considers two types of an intermediate format; the IEEE754 format [4] and the intermediate format which proposed in [2]. In this section, the proposed intermediate format is described.

Figure 2 shows the bit allocation of the intermediate format. The format with 8-bit exponent part and 8-bit mantissa part is selected in this letter. About the bit length of the

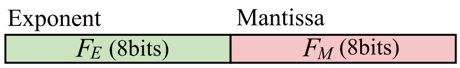

Fig. 2 The bit allocation of the proposed intermediate format.

intermediate format is discussed in [2].

The encode functions which yield the exponent part F_E and the mantissa part F_M of each RGB channel F are defined as

$$F_E = \lceil \log_2 F + 128 \rceil, \quad F_M = \left\lfloor F \cdot 2^{136-F_E} \right\rfloor, \tag{1}$$

On the other hand, the decode function which yields the original RGB value from the intermediate format is defined as

$$F = (F_M + 0.5) \cdot 2^{F_E - 136}. \tag{2}$$

3.2 Integer TMO for the Intermediate Format

The integer TMO converts the input and output data of each process to two integer data. It defines new processes and replaces each tone mapping process by them. These new processes are composite functions, and it is composed of the functions of the intermediate format (Eq. (1) and Eq. (2)) and the processes of the Reinhard's TMO [5]. Note that this technique of the integer TMO works well by using the intermediate format. The technique does not work well for the IEEE754 format because it has denormalized numbers as well as the OpenEXR [6].

In [2], only floating-point HDR image formats are considered in the integer TMO. This letter applies the integer TMO for long-integer format.

4. Experimental and Evaluation Results

In this section, measurements of PSNR and SSIM [7] of the resulting LDR images, the processing time of tone mapping, and evaluation of memory usage were carried out. These experiments and evaluation compared the proposed method with fixed-point arithmetic, the IEEE754 method with floating-point arithmetic, and the integer dedicated method with fixed-point arithmetic. The proposed one was the integer TMO with the Reinhard's operator [2], the IEEE754 method was the Reinhard's TMO with a 64-bit IEEE754 floating-point format, and the integer dedicated method was the Reinhard's TMO with a 16-bit integer format, respectively. All of the methods was implemented in C-language. The HDR images in a 16-bit long integer format were used.

Table 1 shows the maximum, minimum, and average PSNR, and the average SSIM. This experiment used the resulting LDR image of the IEEE754 method as a true value because it was executed with most plenty resources. The integer dedicated method gave high PSNR and SSIM values because it is designed for integer format. On the other hand, the proposed method also gave a high SSIM value.

Table 1 The maximum, minimum, and average PSNR and the average SSIM of the methods. 73 HDR images were used in this experiment.

	PSNR [dB]			SSIM
	Max	Min	Average	
Integer dedicated	91.76	49.91	60.10	0.9993
Proposed	66.56	50.39	55.84	0.9985

Table 2 The memory usage of the methods. This table shows the memory usage in each process in [2], [5].

	Memory usage [bytes]		
	IEEE754	Integer dedicated	Proposed
An HDR image	$A \times B \times 24$	$A \times B \times 6$	$A \times B \times 6$
World luminance	$A \times B \times 8$	$A \times B \times 4$	$A \times B \times 2$
Geometric mean	8	4	2
Table	–	393216	1024

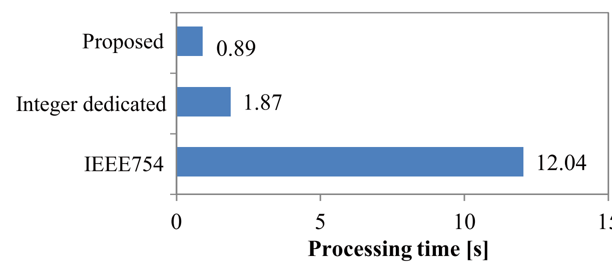

Fig. 3 The processing time of the methods. This experiment applied tone mapping for HDR images with 512×768 pixels in the integer format using each method.

Although the PSNR values were slightly lowered, they were still sufficiently high values.

Table 2 shows the memory usage of each calculation when the size of the input HDR image is $A \times B$ pixels. The proposed method and the integer dedicated method used the pre-calculated tables in order to calculate with fixed-point arithmetic. However, they are sufficiently small as compared with the image data. The memory usage which depends on the image size is 75% and 20% less than the IEEE754 double precision method, and the integer dedicated method, respectively.

Figure 3 shows the processing time of the methods. This experiment was carried out on PXA270 ARM Processor 624 MHz and 128 MB RAM. The methods with fixed-point arithmetic were processed more quickly because the processor does not have a floating-point unit (FPU). The proposed method with fixed-point arithmetic was 13.53 and 2.10 times faster than the IEEE754 double precision method and the integer dedicated method, respectively.

From the above results, these experiments and evaluation confirmed that the proposed method is more effective for a long-integer format.

5. Conclusion

This letter has proposed the unified TMO including a long-integer format. The method tries to convert a long-integer number into the floating-point number, and treat it as two 8-bit integer numbers which correspond to its exponent part and mantissa part. The memory usage of the method is reduced by using these short integer numbers. Moreover, the method with fixed-point arithmetic can be executed fast on a processor without an FPU. The experimental and evaluation results have confirmed that the method can be executed with fewer resources than the other methods, while it offers high accuracy of tone mapping.

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