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Research Article

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Tone Mapping Algorithm for HDR Image using SAD Weighted Guided Image Filter

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Abstract In this paper, tone mapping algorithm using the sum of absolute difference (SAD) weighted guided image filter is proposed. The weight which guided image filter includes in this paper can be obtained by using SAD in local window. In conventional algorithm, it has high computational complexity and causes halo artifacts. However, proposed algorithm which uses SAD weighted guided image filter reduces processing time and halo artifacts. The proposed algorithm reduces processing time and shows good subjective and objective image quality measure at the same time.

Keywords Tone mapping, HDR image, guided image filter, weighted guided image filter

Introduction

High dynamic range (HDR) image can express elaboratively as it can cover a wide range of light intensity. Dynamic range means the ratio between the largest and the smallest light intensity in the image. The dynamic range of human vision is 100,000:1 considering visual adaptation. On the other hand, the dynamic range of display device which most consumers use is 1,000:1 [1]. Because of the difference of dynamic range, traditional display devices can't display HDR image properly. To display HDR image through traditional display devices, the process of dynamic range compression is inevitable. However, in the process of linear compression, it causes loss of information. To solve this problem, many compression algorithms which minimize the loss of information during compression process have been developed [2-4].

Tone mapping is the process which compresses the HDR image to low dynamic range (LDR) image. By using tone mapping, consumers can see the HDR contents through LDR display devices. There are two kinds of tone mapping. One is global tone mapping and the other is local tone mapping. Global tone mapping is the technique which applies the same process to each pixel regardless of their neighbors, such as [2-3]. As using the same process to all pixels, it is simple but can lose high-frequency components such as edges. Local tone mapping is the technique which considers the local property of the pixels [4]. This technique can preserve high-frequency components more than global tone mapping but it is complex and can cause halo artifacts.

The HDR image can be divided into base layer and detail layer. The base layer is the homogenous region which contains the flat area and detail layer contains a high-frequency component which expresses details of the image. When the dynamic range is compressed, it is efficient to compress the base layer and preserve the detail layer. As base layer is insensible to human vison, human hardlydetect the loss of information of the base layer. By summing the compressed base layer and preserved detail layer, the result of compressed dynamic range and preserved detail can be obtained. The decomposition process is performed by using the edge-preserving smoothing filter. Weighted least squares (WLS) filter [5] and guided image filter (GIF) [6] are typical examples of the edge-preserving smoothing filter. WLS filter reduces halo artifacts but it has high computational complexity. So, it takes long processing time. On the other hand, GIF takes short processing time as it is simple but it causes halo artifacts. To reduce halo artifacts in the result of GIF, weighted guided image filter (WGIF)

[7] has been proposed. It reduces halo artifacts, but calculating weight takes a long time and the detail is less preserved than GIF.

In this paper, tone mapping algorithm using SAD WGIF is proposed. This algorithm can reduce halo artifacts as same as a conventional algorithm which uses or WGIF but it also reduces processing time by using another weight. This weight can be obtained by using SAD in the local window. The proposed algorithm also enhances details by using Laplacian image sharpening.

The Composition of this paper is as follows. In Section II, the conventional algorithm is introduced including GIF and WGIF. The proposed tone mapping algorithm which uses SAD weighted guided image filter is presented in Section III. Section IV shows experimental results and discussion of the algorithms. Finally, the conclusion of this paper is presented in Section V.

Conventional algorithm

In this section, conventional tone mapping algorithm which uses WGIF is introduced [8]. The conventional algorithm reduces halo artifacts and improves subjective quality. As the proposed algorithm is based on WGIF, the introduction of GIF and WGIF is also covered in this part.

A. Guided image filter

GIF makes output image q_i by using guidance image I_i. This filter includes the guidance image features into input image. The output image $q_i$is the linear transformation of the local window in the guidance image. The linear transformation can be expressed like Equation (1).

$$q_i = a_k I_i + b_k, \forall i \in \omega_k \quad (1)$$

where a_k and b_k are linear transformation coefficients between the output image q_i and guidance image I_i. Coefficient a_k and b_k are selected which minimize cost function. Equation (2) is the cost function of GIF [9], [10].

$$E(a_k, b_k) = \sum_{i \in \omega_k} ((a_k I_i + b_k - p_i)^2 + \varepsilon a_k^2) \quad (2)$$

where parameter ε is regularization parameter. To minimize the cost function, coefficient a_k and $b_k$can be obtained as,

$$a_k = \frac{\frac{1}{|\omega|}\sum_{i \in \omega_k} I_i p_i - \mu_k \bar{p}_k}{\sigma_k^2 + \varepsilon} \quad (3)$$

$$b_k = \bar{p}_k - a_k \mu_k \quad (4)$$

where μ_k and σ_k^2 are averages of local window and variance, respectively. Also $|\omega|$ is the number of local window's pixel and $\bar{p}_k$ is average of local window in input image.

The guidance image can be selected input image itself or another image which has the same size. As the guidance image is identical to the input image, numerator of Equation (3) is equal to σ_k^2. If center pixel k is located on the edge, the value of σ_k^2 is large and ε can be disregarded. Output q_i is close to guidance image as the value of a_k is close to 1 so the edge can be preserved. On the contrary, when the center pixel k is located on the flat area, the value of σ_k^2 is small and the ε can't be disregarded. The value of a_k is close to 0 so the output q_i loses the feature of guidance image and be smoothed.

To apply the coefficients to the linear transformation, an averaging technique is used [11]. At last, output image q_i can be presented as Equation (5).

$$q_i = \bar{a}_i \mathrm{I}_\mathrm{i} + \bar{b}_i \quad (5)$$

where $\bar{a}_i$ and $\bar{b}_i$ mean averages of a_k and b_k, respectively.

B. Weighted guided image filter

To reduce halo artifacts which appear in results of GIF and WGIF have proposed. Edge-aware weighting is used in WGIF which can be expressed as Equation (6).

$$\Gamma_G(k') = \frac{1}{N}\sum_{k=1}^{N} \frac{\sigma_I^2(k') + \rho}{\sigma_I^2(k) + \rho} \quad (6)$$

where $\sigma_I^2(k')$ means variance of local window which the center pixel is k in the guidance image I_i and ρ means $(0.001 \times \text{dynamic range})^2$ which is small constant value. When pixel k' is on the edge, $\sigma_I^2(k')$ will be large so the weight will be large. On the contrary, when pixel k' is on the flat area, the weight will be small. By including this weight to cost function, the edge region can be detected precisely. This accuracy can reduce halo artifacts.

Cost function including edge aware weighting is presented in Equation (7). Coefficient $\hat{a}_k$ and $\hat{b}_k$ which minimize the cost function is

$$\hat{E}(\hat{a}_k, \hat{b}_k) = \sum_{i \in \omega_k} \left(\begin{matrix} (\hat{a}_k I_i + \hat{b}_k - p_i)^2 \\ + \frac{\varepsilon}{\Gamma_G(k)} \hat{a}_k^2 \end{matrix} \right) \quad (7)$$

$$\hat{a}_k = \frac{\frac{1}{|\omega|}\sum_{i \in \omega_k} I_i p_i - \mu_k \bar{p}_k}{\sigma_k^2 + \frac{\varepsilon}{\Gamma_G(k)}} \quad (8)$$

$$\hat{b}_k = \bar{p}_k - \hat{a}_k \mu_k \quad (9)$$

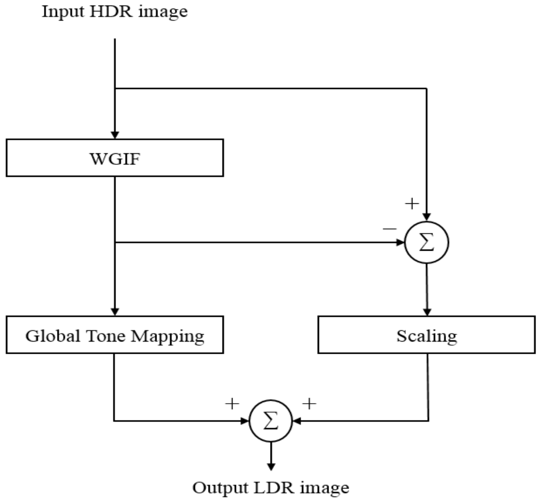


Figure1: Flowchart of the conventional tone mapping algorithm

where $\Gamma_G(k)$ means edge aware weighting. As the weight is located on the denominator of ε part, the denominator of Equation (8) is changed on each pixel. When center pixel k is on the edge, coefficient $\hat{a}_k$ is closer to 1 and closer to 0 when on the flat region. As same as original guided image filter, average of coefficient is used in linear transformation.

C. Tone mapping algorithm using WGIF

The procedure of tone mapping algorithm using WGIF is presented in Fig. 1. At first, the input image is brought to log domain which matches to human visual features. Input imagec omes to the blurred image as result of WGIF. This blurred image is a base layer and the difference of base layer and original input image is detail layer. The base layer is compressed by using global tone mapping algorithm and detail layer is enhanced by using Laplacian sharpening. At last, compressed base layer and enhanced detail layer is combined. To visualize the output, it uses gamma correction [12].

As the dynamic range of base layer is wide, the compression process is necessary to reduce dynamic range. Global tone mapping is used to compression of base layer. In the conventional algorithm, Equation (10) is used [2].

$$\hat{L}(p) = \log(a) + L_b(p) - \bar{L}_h - \log(1 + a\exp(L_b(p) - \bar{L}_h)) \quad (10)$$

$$a = 0.18 * 4^{\frac{2\bar{L}_h - L_h^{\min} - L_h^{\max}}{L_h^{\min} - L_h^{\max}}} \quad (11)$$

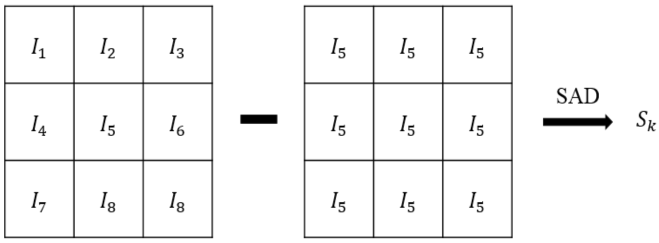


Figure 2: Weight calculation in 3 x 3 local window

where value a is a key value of overall brightness. $\bar{L}_h$ and L_b means average brightness value in log domain and pixel brightness value of base layer in log domain respectively. $L_h^{\min}$ and $L_h^{\max}$ means minimum and maximum brightness value of input image in log domain. Compression process is performed through Equation (10). By using exponential function, Equation (10) can be expressed in intensity domain as Equation (12).

$$\hat{Y}_b(p) = \frac{aY_b(p)}{\bar{Y}_h + aY_b(p)} \quad (12)$$

where Y_b and $\bar{Y}_h$ mean intensity domain of base layer and average brightness of input image in intensity domain. Detail enhancement is performed by scaling 1.5 to detail layer.

Proposed Algorithm

D. WGIF using sum of absolute difference

In this paper, SAD WGIF is proposed which uses different weight from edge aware weighting. The weight which proposing in this paper is calculated by using SAD of the local window which a center pixel is k and the window which fills with a center pixel value. Fig. 2 shows the example of SAD when the local window size is 3x3 and Equation (13) shows calculation of weight. The weight W_s can be obtained as follows

$$W_s(k') = \frac{S_{k'}}{\bar{S}_k} \quad (13)$$

where $\bar{S}_k$ means the average of S_k in the image. When the center pixel k is located on the edge region, as SAD is large in edge area, the weight is larger than 1 and when on the flat region, smaller than 1. Since calculation of SAD has lower computational complexity than variance, processing time can be reduced.

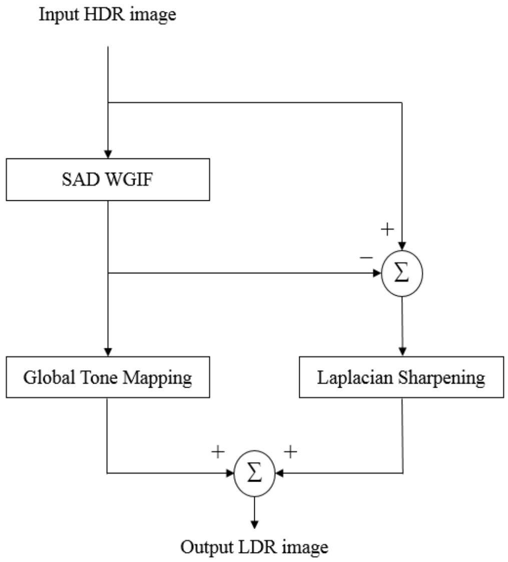


Figure 3: Flowchart of the proposed tone mapping algorithm

E. Tone mapping algorithm using SAD WGIF

Proposed algorithm is similar to conventional tone mapping algorithm [8] which uses WGIF but it uses SAD WGIF. Also, it uses global tone mapping which can stand human visual property. The procedure of proposed algorithm presents in Fig. 3. Input image in log domain is decomposed into base layer and detail layer by using SAD WGIF. Compression of base layer is performed by using adaptive logarithmic mapping [3] and enhancement of detail layer is applied to Laplacian image sharpening [12]. Finally, gamma correction is performed to make final output.

As log function reflects the property of human visual response, the adaptive logarithmic mapping is used for global tone mapping. This mapping uses the advantage of base 2 logarithmic mapping in dark region and base 10 logarithmic mapping in bright region adaptively. Equation (14) is the mapping which uses the base 2 to 10 adaptively.

$$\hat{L}_b(x) = \frac{L_{max}}{100\log_{10}(1+L_{b,max})} \frac{\log(1+L_b(x))}{\log\left(2+8\left(\frac{L_b(x)}{L_{b,max}}\right)^{\alpha}\right)} \quad (14)$$

$$\alpha = \frac{\log(\beta)}{\log(0.5)} \quad (15)$$

where L_{max} and L_b mean maximum brightness of display device and brightness of base layer, respectively.

To enhance detail layer considering neighbor pixels, Laplacian image sharpening is applied to detail layer. Laplacian of 4 directions is presented in Equation (16). Applying Laplacian to detail layer, enhanced detail layer can be obtained as Equation (17).

$$\nabla^2 L_d(x,y) = L_d(x+1,y) + L_d(x-1,y) + L_d(x,y+1) + L_d(x,y-1) - 4L_d(x,y) \quad (16)$$

$$\hat{L}_d(p) = L_d(p) + c[\nabla^2 L_d(p)] \quad (17)$$

where x and y mean the location of pixel and value c is constant value which is smaller than 0. L_d is intensity value of detail layer.

Experimental Results and Discussion

The experiment is performed in PC condition of Windows7 64 bit Intel Core i7-4770K CPU@ 3.50GHz. The window size is 7x7 and ε is set to 0.16 to evaluate the performance of conventional and proposed algorithm. In proposed algorithm, β and c are set to 0.85 and -0.3 respectively. Gamma value is set to 1 in gamma correction. Memorial, Belgium, Office, CoffeeShop, CarWall and KitchenWindow are used for test image in experiment.

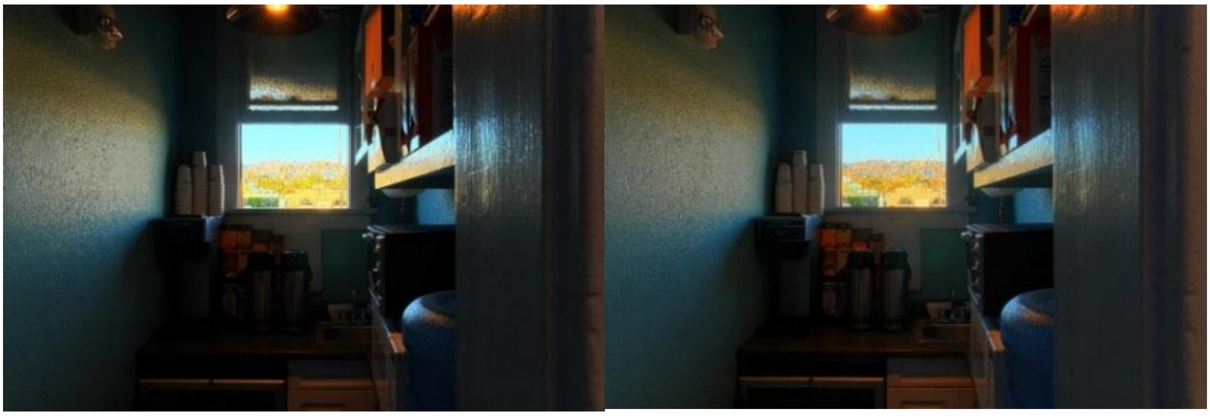
Fig. 4 is the image photographed in indoor which has bright regions in the window part. The conventional algorithm [8] has less detail, especially outside of the window. On the other hand, the proposed algorithm preserves details of the outdoor. This feature can be detected in Fig. 5. The Bright region, such as window part, is preserved in proposed algorithm. Since adaptive logarithmic mapping stands the response of human visual property, the proposed algorithm presents the remarkable output in the dark region. This can be observed in the indoor region of Fig. 4 and the ceiling region of Fig. 5. The output images of algorithms which use a different filter are presented in Fig. 6. The upper row is Belgium tone mapped images and the lower row is regions of interest (ROI) which size is 200 pixels by 200 pixels of each upper row images. Halo artifacts which can be observed in the white pillar in ROI of GIF output are reduced in the results of WGIF and SAD WGIF. In the ROI, proposed filter has more clear details than WGIF. The proposed filter reduces halo artifacts and preserves details at the same time.

Table 1: Comparison of TMQI and processing time

HDR image	TMQI		Processing time				
	Conventional	*Proposed*	*GIF (sec)*	*WGIF (sec)*	*Proposed (sec)*	*vs GIF (%)*	*vs WGIF (%)*
Memorial	0.7875	**0.7949**	82.83	127.06	86.92	104.94	68.41
Belgium	**0.8112**	0.7963	164.00	254.76	171.34	104.48	67.26
Office	**0.7585**	0.7555	533.59	849.98	563.54	105.61	66.30
CoffeeShop	0.7472	**0.7565**	1,073.92	1,669.47	1,142.50	106.39	68.43
CarWall	0.7362	**0.7483**	2,026.49	3,217.59	2,111.80	104.21	65.63
KitchenWindow	0.7251	**0.7324**	2,091.22	3,254.54	2,213.74	105.86	68.02
Average	0.7610	0.7640	995.34	1,562.23	1,048.31	105.25	**67.34**

Objective quality measurement and processing time are presented in Table 1. For objective quality measurement, tone mapped image quality index (TMQI) [13] is used in experiments. TMQI considers preservation of structural fidelity and statistical naturalness of the result. In Memorial, CoffeeShop, CarWall and KitchenWindow, proposed algorithm has better TMQI score than conventional algorithm. However, since Laplacian sharpening makes the image unnatural, proposed algorithm has a low score in Belgium and Office.

Comparing WGIF and SAD WGIF, SAD WGIF takes less time than WGIF. Proposed filter saves 32.66% in average than a conventional filter. This is because the calculation of variance which the conventional filter uses contains square operation. On the contrary, proposed filter has only subtraction operation in SAD which takes less time than square and multiplication operation.



(a) Conventional algorithm (b) Proposed algorithm

Figure 4: Tone mapped KitchenWindow images

(a) Conventional algorithm (b) Proposed algorithm

Figure 5: Tone mapped Memorial images

(a) GIF (b) WGIF (c) SAD WGIF

Figure 6: Comparing each filter which uses in proposed algorithm

Conclusion

This paper proposes a tone mapping algorithm using SAD WGIF. The proposed algorithm uses SAD WGIF which reduces processing time and improves image quality. SAD WGIF obtains its weight by using SAD in the local window which takes less time operation of variance. It reduces 32.66% in average than conventional algorithm. Also, proposed algorithm has the objective quality which has 0.003 better score in TMQI than conventional algorithm. The output image of proposed algorithm preserves details than conventional algorithm.

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