High dynamic range image enhancement technology based on guided image filter

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Abstract: The focal plane size of modern CCD/CMOS camera is getting bigger and bigger, that is to say, more and more pixels have been integrated on the focal plane array. Under this advance in technology, people can take a picture with higher resolution and higher dynamic range. The image contains much more information of the real world. A serious problem of dealing with such kind of image is that, although the image has high dynamic range, people cannot display all the information of it. Certain technologies have been applied on modern cameras to solve this problem, but they still have some defects. A novel high dynamic range image enhancement algorithm was raised, which used the guided image filter to separate the image and deal with the detail layer as well as the base layer. The high frequency information needs to be enhanced to highlight the detail of the image on the detail layer. Meanwhile, the base layer controls the gray scale contrast which also needs to be processed with certain strategy. The color saturation can be controlled by both two layers. The raw high dynamic range image can be enhanced both through the detail layer and the base layer to improve its digital detail, gray scale rearranging and the color contrast. Detailed analysis of the procedure and figure demonstration were illustrated to show the ability of this algorithm.

Key words: guided image filter; high dynamic range; detail enhancement; gray scale adjustment

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利用导向滤波的宽动态范围图像增强技术

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摘 要: 随着现代 CCD 和CMOS 相机阵列尺寸的增大,越来越多的像素被集成到焦平面阵列上。基于该项技术可以获取更高分辨率和更宽动态范围的图像,该图像包含了更多真实的细节信息。然而,在处理这种图像的时候,尽管图像具有宽动态范围,但是却无法显示图像的所有有用信息。一些技术已经被用于先进的相机以解决上述问题,但它们还是存在或多或少的缺点。因此,提出了一种新的宽

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动态范围图像增强算法。该算法使用导向图像滤波器对图像进行分割,然后同时处理被分割的基频层以及细节层。通过增强高频信号来突出细节层中图像的细节，同时使用策略处理基频层以控制灰度对比度。颜色饱和度可以通过两个层一起控制。通过细节层和基频层来增强原始宽动态范围图像,提高数字细节、灰度自适应以及颜色对比度。对算法进行了详细的分析。图像仿真示例显示该算法性能可靠。
关键词：导向图像滤波器； 宽动态范围； 细节增强； 灰度自适应

0 Introduction

Modern high-quality CCD or CMOS cameras are able to produce images with a very wide dynamic range. To our knowledge, even the pixel number of the cameras on the smart cell phone can reach up to a million level. Such amount of pixel number can give a great description of the real-world scene. But at the same time, any CCD or CMOS camera which is working under the visible light spectrum has to be equipped with a highly manufactured optical lens. So, sometimes strong daylight will cause the image over-exposed, and thus makes the image lack of details. To solve this problem, people have developed many sophisticated algorithms, and some of them have been applied in the real photo devices. For example, the iphone cameras are added a function of "HDR" in their photo software. The "HDR" function can process the over-exposed picture and give the information back which is hiding behind the strong daylight. In order to reduce the dynamic range that is acceptable for the display system and make the output image pleasing for human observer, a novel high dynamic range(HDR) image enhancement algorithm is proposed in this paper.

When dealing with the image captured in the visible light spectrum, dynamic range compression (DRC) is often a useful method to please the human eye[1]. Such methods have been widely investigated and a number of visualization techniques have been proposed in literature. We often consider that the information stored in the HDR images is correspond to the observable luminance or radiance in the real world. This is quite different to the traditional digital image displayed on the monitor or stored in the printer. So the HDR images are sometimes considered as "related to the scene". This concept is raised to distinguish the traditional digital images that are "related to the device" or "related to the output". In the meantime, traditional image processing of the digital image is often focused on the human visual system to encode. This type of encoding is usually called "gamma correction". Traditional gamma correction is a widely used for contrast enhancement owing to its simplicity and the convenience of displaying images in real-time system. But as for the HDR image, it can only be part of the processing procedure because of the massive data stored in the HDR image. Modern HDR image processing is raised by Paul Debevec at 1997. He described a method of acquiring HDR image by taking pictures towards the same scene with different exposure strategies, and finally formed a HDR image. After that, many researchers participated in the study of acquiring, compressing and displaying of HDR image, and make this technology useful in the daily life. Nowadays, the study of processing HDR image has been focused on some primary fields, such as de-noising[2-4], tone-mapping[5], and displaying[6-7]. For example, as for de-nosing of HDR image, local Laplacian filters of edge-aware method[4] and total variation (TV)[2] method are applied. These kinds of method are concentrated on avoid unnecessary smoothing of the radiance field and preserving the high frequency edge information of the image. As for tone-mapping, algorithms like spatially adaptive histogram equalization[7], tone-mapping based on retinex[5] are proposed to develop from standard definition to high definition in terms of resolution. As for displaying, halo and clipping prevention and light detection/color appearance models for HDR images are raised to make the image fits for the conventional displaying devices[7].

In this paper, we propose a new HDR image processing method based on a local linear image filter–the Guided filter[8]. We focus on how to effectively enhance the HDR image by highlighting the detail information of the raw data, which can greatly improve the visual effects for the observers. And at the meantime, we focus on how to effectively compress the total image gray level which will work in with the enhancement procedure to combine the bright and dark scene comfortable for the human eyes. The main purpose of the newly raised algorithm is to separate the original HDR image into two layers called the detail layer which contents most of the high frequency information of the raw data, and the base layer which contents the energy and the low frequency information of the raw data. We calculate the main difference of the value of the base layer to acquire the delta value to form the gamma curve. We set the new gamma curve to adjust the contrast of the base layer, and set the gain coefficient to adjust the fluctuation of the high frequency detail of the detail layer. A new gray scale transferring index will be calculated after the procedure mentioned above and it will be applied to the raw data to finish the HDR adjustment. We compare our algorithm with a widely applied method established in the MATLAB to test and approve the effectiveness of the proposed one.

1 Principle of the newly raised algorithm

As mentioned by He et al[8], the guided image filter(GIF) can be widely used in computer vision and graphics, which is not only do a great job in edge-preserving but also can be computed easily. Followed and inspired by our latest work on the detail enhancement of infrared thermal images[9] and BF & DDE raised by Zuo et al[10], we design our processing diagram as shown in Fig.1. First we apply a logarithmic calculation of the raw HDR image to adjust the gray value in order to ease the following calculation process. Then we conduct the GIF on the raw HDR image to separate the image into two layers, that is the detail layer and the base layer. We choose the base layer to calculate the delta coefficient and use it as the foundation of the upcoming calculated new gamma adjusting curve. When the new gamma curve has been determined, the new HDR gray level can be achieved by applying the new gamma curve on the base layer and the adjusted detail layer. We form the new gray scale transferring coefficient by the new HDR gray level and the raw HDR gray level and finish the HDR image enhancement of the whole process. The procedure is very easy and very convenient for computation. Detailed processing description will be given in the following chapters.

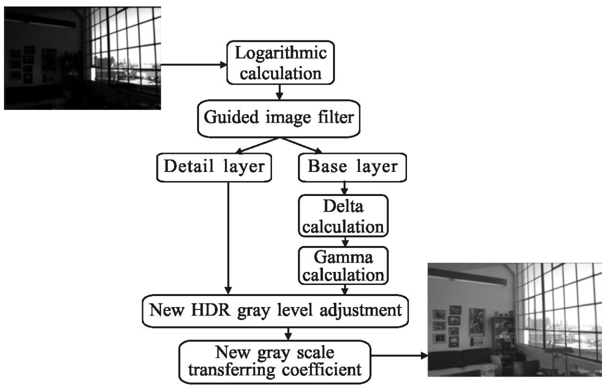


Fig.1 Block diagram of the newly raised algorithm

2 Process of the newly raised algorithm

In this section, we will descript our whole process procedure step by step to illustrate the effects of our algorithm. Since the GIF is the key to our algorithm, we first give a fast review on how the GIF works.

2.1 Guided image filtering process

The expression of GIF is given by He et al [8] as follows:

$$I_{\text{gif}}(i,j)=\sum_{(i',j')\in w_{i,j}} W_G(i',j')I_{\text{in}} \tag{1}$$

where the notation $(i',j')\in w_{i,j}$ indicates that (i',j') are pixels in a filter window that centered at the pixel (i,j); $W_G(i',j')$ is the kernel weights function which can be used as the weighting coefficient to enhance the details. The kernel weights can be explicitly expressed by:

$$W_G(i',j')=\frac{1}{|w|^2}\sum_{\substack{(i',j')\in w_{ij}\\(i'',j'')\in w_{ij}}}\left(1+\frac{(I_{\text{in}}(i'',j'')-\mu_{i',j'})(I_{\text{in}}(i',j')-\mu_{i',j'})}{\sigma_{i',j'}+\varepsilon}\right) \tag{2}$$

where w is the number of pixels in the window $w_{i,j}$, a square window of a radius r; $\mu_{i',j'}$ and $\sigma_{i',j'}$ are the mean and variance of in I_{in}; $w_{i',j'}$ is a regularization parameter to describe the smoothing level of the filter. The linear model of this filter output can be shown as follows:

$$I_{\text{gif}}(i,j)=\frac{1}{|w|}\sum_{(i',j')\in w_{i,j}}(a(i',j')I_{\text{in}}(i',j')+b(i',j')) \tag{3}$$

Here, $a(i',j')$ and $b(i',j')$ are linear coefficients assumed to be constant in $w_{i',j'}$. They can be given by:

$$a(i,j)=\frac{\frac{1}{|w|}\sum_{(i',j')\in w_{i,j}}I_{\text{in}}(i',j')G(i',j')-\mu_{i,j}\overline{I_{\text{in}}(i',j')}}{\sigma_{i,j}+\varepsilon} \tag{4}$$

$$b(i,j)=\overline{I_{\text{in}}(i',j')}-a(i,j)\mu_{i,j} \tag{5}$$

From Eq.(3), (4) and (5), we can get the output value of the GIF. As He at al[13] mentioned, because of the linear coefficients are varying spatially, ∇I_{gif} is no longer the scaling of ∇I_{in}. Since the linear coefficients are the output of an average filter, their gradients should be much smaller than those of I_{in} near strong edges. In this situation we can still have $\nabla I_{\text{gif}}\approx\bar{a}\nabla I_{\text{in}}$. It means that abrupt intensity changes in I_{in} can be mostly maintained in I_{gif}. The edge -preserving property can be seen from the equations above: if a pixel is in the middle of a "high variance" area, its value will be unchanged. Meanwhile, if it is in the middle of a "flat patch" area, its value becomes the average of the pixels nearby. The parameter ε becomes the criterion of "flat patch" and "high variance". When the patches′ variance (σ^2) is much smaller than ε, they will be smoothed. On the contrary, those with variance much larger than are preserved. The parameter ε and the window size codetermine the capability of detail extraction. Figure 2 shows some examples of the detail extraction when the parameter ε has been chosen the different values.

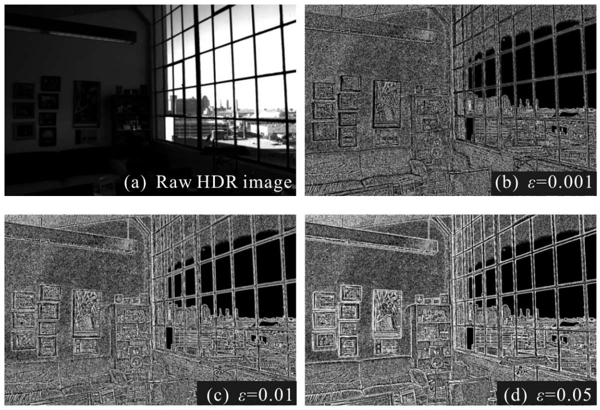


Fig.2 Examples of detail extraction of GIF

One major character of HDR image is that it contains much more details than the traditional digital image. Although some weak details will be hidden because of the over-exposure of the CCD/CMOS that we cannot observe very clearly in the raw image, we can still distinguish them out with the GIF.

2.2 Base layer processing strategy

Many HDR processing or displaying methods are focused on how to adjust the over-exposure problem by fitting curves under different gray scale levels in the single picture. These methods are much like the multi-threshold histogram-equalization processing. Others are focused on the tone-mapping methods of HDR images [2]. Here in the newly raised algorithm, we focus on a new strategy of dealing with the base layer to adjust the gray level of the HDR image. As mentioned above, after the GIF, the detail layer of HDR image has been separated out from the raw image. We can easily acquire the base layer by subtracting the detail layer from the raw image as follows:

$$I_B(i,j)=I_{\text{in}}(i,j)-I_D(i,j) \tag{6}$$

where $I_B(i,j)$ represents the base layer; $I_D(i,j)$ represents the detail layer. Since we have separated out the detail layer of the HDR image by choosing the satisfying ε, there will be only the energy of the raw image and the low frequency information remains in the base layer. That is to say, the energy scale in the base layer is the determination of the whole brightness and darkness of the raw image. We subtract the detail layer by using the same ε chosen in Fig.2 and get the following base layers shown in Fig.3.

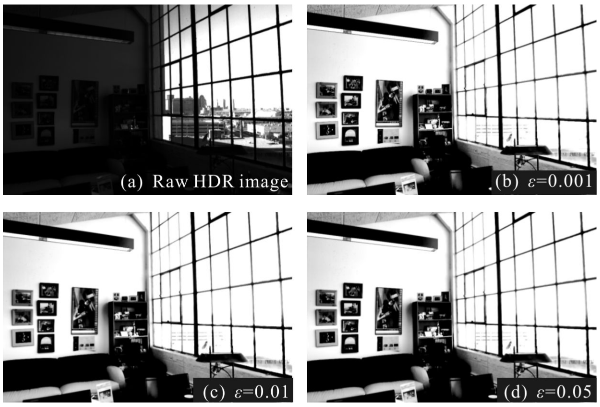


Fig.3 Base layer demonstration with the same ε

The detail of an image is the high frequency signal which contains very weak energy of the raw image. So as we can see from Fig.3, although the ε is changing, the energy of the image is not reduced. The only variation is that the image becomes blurry. From Fig.3 we know that, the brightness and darkness adjustment must be done with the base layer. If we can successfully adjust the original energy distribution of the raw image, we can greatly improve the image quality of the HDR image combined with the detail layer enhancement.

In our research, we recognize that the gray value difference of the base layer must be acquired. We define the delta value as the following equation:

$$\Delta_d=\max(I_B(i,j))-\min(I_B(i,j)) \tag{7}$$

where the parameter Δ_d represents the difference between the maximal gray value $\max(I_B(i,j))$ of the base layer and the minimal gray value $\min(I_B(i,j))$. The Δ_d tells us the biggest gray value difference of the HDR image we are dealing with. It is the basic characterization of the dynamic range of the HDR image. The following adjustment is based on the calculation of this parameter.

After the calculation of the delta, we use it to form a new gamma value in order to adjust the energy of the base layer. Since every HDR image has the different gray scale, we use the following equation to calculate the gamma value:

$$\gamma_g=\log(C_{\text{contrast}})/\Delta_d \tag{8}$$

where γ_g represents the specific gamma value to each calculated Δ_d. The parameter C_{contrast} is a pre-set value used to modify the gamma calculation. Usually the value of C_{contrast} is given in the range of [5,200] depends on the selection of Δ_d and the human observation. In this paper, the value of C_{contrast} is chosen according to the experimental environment. The following table is a summary of gamma γ_g and Δ_d we used in this paper.

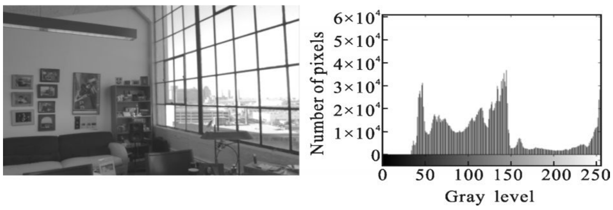
We have run some simulation according to Tab.1 to check out the gray level contrast stretching effect of the base layer. We predict that a satisfying contrast stretching will rearrange the image energy into a wide scale, which will demonstrate in the histogram.

Tab.1 Selection of gamma γ_g and delta according to the parameter under different C_{contrast}

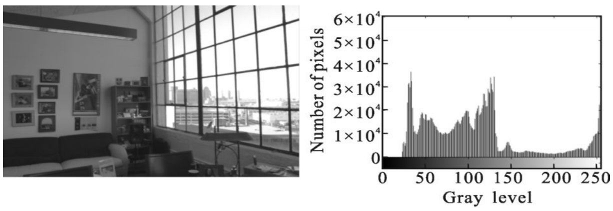
	C_{contrast}=12		C_{contrast}=24		C_{contrast}=48		C_{contrast}=56	
	γ_g	Δ_d	γ_g	Δ_d	γ_g	Δ_d	γ_g	Δ_d
ε=0.001	0.3136	3.4412	0.4011	3.4412	0.4886	3.4412	0.5080	3.4412
ε=0.01	0.3249	3.3216	0.4155	3.3216	0.5062	3.3216	0.5263	3.3216
ε=0.05	0.3324	3.2464	0.4251	3.2464	0.5197	3.2464	0.5385	3.2464

Figure 4 is an illustration of the base layer gray level stretching according to Tab.1.

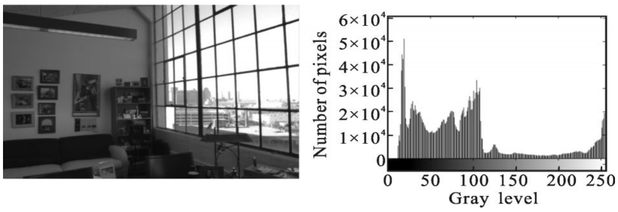
In Fig.4, we can find out that, according to Eq.8, the changing of C_{contrast} will bring in a new gamma value. When we apply the new gamma value onto the base layer, it will effectively adjust the gray scale and stretch it into a wider range in the histogram. Since gamma is a logarithmic value, it will affect the base layer gray scale according to its original curve shape. That is to say, the region of low gray value will change rapidly following the gradient of the gamma curve, and the region of high gray value will change slowly. From Fig.4 we know that, this is because we do not want to over enhance the detail to make the image looks over sharp. 1.4 is just fulfill our needs to enhance the image detail. Also we can see from Fig.4, with the growth of the $C_{contrast}$, the histogram keeps varying in the low gray value region, which makes the contrast of the base layer bigger and bigger. In our research, we choose the value of $C_{contrast}$ as 24 to acquire the best enhancement of the chosen image. The upcoming demonstration in the next chapter is under different value of $C_{contrast}$ and gamma due to the different delta of other chosen image.



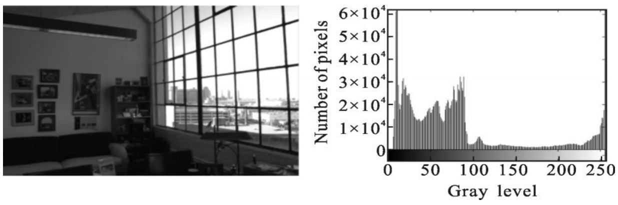
(a) $C_{contrast}$=12, ε=0.01, γ_g=0.3249



(b) $C_{contrast}$=24, ε=0.01, γ_g=0.415 5



(c) $C_{contrast}$=48, ε=0.01, γ_g=0.506 2



(d) $C_{contrast}$=56, ε=0.01, γ_g =0.526 3

Fig.4 Base layer gray level stretching demonstration

2.3 Gray scale transferring and displaying

After the gray scale rearrangement of the base layer and the detail extraction of the detail layer, we can calculate the new gray level. Since we deal the raw image with the GIF and separate it into two layers, we have to combine the two adjusted layers into a new image, and use it to calculate the gray scale transferring coefficient to accomplish the displaying of the color image. The combination of the two adjusted layers follows the next equation:

$$I'(i,j)=10[\gamma_g I_B(i,j)+G\cdot I_D(i,j)] \tag{9}$$

where $I'(i,j)$ represents the newly combined image; G represents the gain coefficient which controls the detail fluctuation of the detail layer. For the tested image, the G is set as 1.4. Once we get the adjusted image $I'(i,j)$, the gray scale transferring coefficient can be calculated with $I'(i,j)$. This approach is to adjust the RGB weighting of the original color. If we are dealing with a pure gray image, it will not be necessary to conduct this approach. The gray scale coefficient can be calculated very easily as follows:

$$S=I'(i,j)/I_{in}(i,j) \tag{10}$$

And the color adjustment can be done with the gray scale coefficient S as follows:

$$I_{color}'(i,j,x)=S\cdot I_{in}(i,j,x) \tag{11}$$

where the parameter represents the RGB channel of the color image. We test the effect of our algorithm and compare it to the tone-mapped function in the Matlab software to give a demonstration in the following figures.

It can be seen from Fig.5, both methods can achieve good effects on HDR image. But our algorithm has the advantage of higher color contrast and detail enhancement. As mentioned above, the detail gain coefficient has been set as 1.4. From Fig.5 we know that, this is because we do not want to over enhance the detail to make the image looks over sharp. 1.4 is just fulfill our needs to enhance the image detail. The color saturation of Fig.5(c) is better than Fig.5 (b) under human observing. The color contrast of Fig.5(c) appears much vivid than Fig.5(b). We keep on giving another demonstration of different HDR image to show the results of our algorithm as follows.


(a) Original HDR image　　(b) Matlab tone-mapped image

(c) Proposed algorithm demonstration

Fig.5 Comparison of the Matlab function and our algorithm with C=12, ε=0.01, γ_g=0.3249, G=1.4

In Fig.6 we can see that, though the Matlab tone-mapped image can display the houses region much bright, but the cloud region is enduring the over-exposed problem. But in our algorithm, the color saturation and color contrast are much better than Fig.6 (b). Meanwhile, let us lay our eyes on the cloud region, it can be found that the detail of clouds is enhanced than the raw image and Fig.6(b), which makes our algorithm much effective than the matlab function.


(a) Raw image　　(b) Matlab tone-mapped image

(c) Proposed algorithm demonstration

Fig.6 Results demonstration under C=12, ε=0.01, γ_g=0.3249, G=1.4

3 Conclusion

In this paper, a novel high dynamic range image enhancement algorithm based on the guided image filter is raised. This algorithm can separate the raw image into two layers and conduct certain image processing correspondingly. We conduct the detail enhancement and the gray scale contrast adjustment at the same time on the two layers, and finally use a transferring coefficient to combine the adjusted layers back together to generate a new HDR image. Experimental results show that our algorithm has the advantage of better detail enhancement, better color contrast and better color saturation. All the improvements make the HDR image much suitable for human observation.

References:

[1] Gonzalez R C, Woods R E. Digital Image Processing [M]. 2nd ed. New Jersey: Prentice Hall, 2003: 27–47.

[2] Rameshan R M, Chaudhuri S, Velmurugan R. High dynamic range imaging under noisy observations[J]. ***Image Processing* (*ICIP*), *IEEE***, 2011: 11–14.

[3] Dedrick E, Lau D. A Kalman-filtering approach to high dynamic range imaging for measurement applications [J]. ***Image Processing*, *IEEE***, 2011, 21(2): 527–536.

[4] Paris S, Hasinoff S W, Kautz J. Local Laplacian filters: edge-aware image processing with a Laplacian pyramid [J]. ***ACM Trans Graph***, 2011, 49(17): 67–75.

[5] Kim Kyungman, Bae Jonghyun, Jaeseok Kim. Natural hdr image tone mapping based on retinex [J]. ***Consumer Electronics*, *IEEE***, 2011, 57(4): 1807–1814.

[6] Im J, Paik J. Spatially adaptive histogram equalization for single image-based ghost-free high dynamic range imaging [J]. ***Journal of Arts and Imaging Science***, 2014, 1(1): 55–58.

[7] Yukihiro Bandoh, Qiu Guoping, Masahiro Okuda, et al. Recent advances in high dynamic range imaging technology [J]. ***Image Processing*(*ICIP*)**, 2010: 3125–3128.

[8] He Kaiming, Sun Jian, Tang Xiaoou. Guided image filtering [J]. ***Computer Vision, Lecture Notes in Computer Science***, 2010, 6311: 1–14.

[9] Liu N, Zhao D X. Detail enhancement for high-dynamic-range infrared images based on guided image filter [J]. ***Infrared Physics and Technology***, 2014, 67: 138–147.

[10] Zuo C, Chen Q, Liu N. Display and detail enhancement for high-dynamic-range infrared images [J]. ***Opt Eng***, 2011, 50 (12): 127401.