A Novel High Dynamic Range Compression with Detail Refinement
(高動態範圍影像壓縮上細微修整之演算法)

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Abstract

When capturing scene in a real world, traditional display devices would encounter a problem of representing high contrast. It is because the part in the dimmest region or in the brightest region is almost invisible. The causes of this invisible part can be ascribed to two limits—the brightness adaptation of eye and the architecture of display devices. To overcome this problem, tone reproduction algorithms have been designed to clamp the contrast and conform to human visual system.

In this paper, we proposed a new algorithm for tone reproduction problems. This new algorithm is based on the level set method and Barladian's algorithm; we modify the integrated algorithm with adding three more steps. These three steps are: adaptive gain control, dodging-and- burning, and local contrast enhancement. In experimental our algorithm reproduced images not only visibly represents in low dynamic range, but also conserves and reveals more details.

Key word: Tone reproduction, Adaptive gain control, dodging-and-burning, High dynamic image(HDR), Human visual system(HVS).

1. Introduction

Recently, the digital cameras (DC) become popular electronic consumer commodities. People can use it to make any digital image by themselves. The limits of eye and display device lead to the bottleneck in representing completely. If there is a scene with high contrast, the detail in the shadow region or brightest region must be hidden on the display device. To overcome these problems of displaying, tone reproduction algorithms were proposed to reproduce a displayable image conformed human visual system (HVS).

In general, tone reproduction algorithm can be classified into two categories. These two categories are tone reproduction curve and tone reproduction operator. Tone reproduction curve transforms the high dynamic range image to low dynamic range with an invariable mapping function as a curve. It means that the pixels with the same luminance will be mapped to the same results. However, the second one is different with tone reproduction curve. Tone reproduction operator, transforms the high dynamic range image to low dynamic range according to its locality. Thus, although pixels have the same luminance, they may be mapped to distinct luminance within different locality.

In this paper, we describe a new tone reproduction algorithm to reproduce the image conforming to real-world scene that we can see. Our proposed algorithm based on integrating the level set method and Barladian's algorithm with further modification. This modification includes three steps as adaptive gain control, dodging-and-burning, and local contrast enhancement. The reproduced image by proposed algorithm not only can be display with low dynamic range but also preserves fine details.

This paper is organized as follows: section 2.introduces the related background and previous works. Section 3, explains the proposed algorithm. Section 4, demonstrating the experimental results and comparison with other methods. Finally, presents the conclusion and future works.

2. Related works

How to map the large range of intensities found in an HDR image into the limited range generated by a conventional display device is the fundamental problem. To introduce previous tone reproduction algorithms clearly, we classify algorithms into two categories. They are tone reproduction curve and tone reproduction operator.

2.1 Tone Reproduction curves

In 1993, **Tumblin** and **Rushmeier** [6] proposed a high dynamic range compression algorithm to make the display brightness match the real-world brightness closely. The algorithm was mainly based on a mathematics model of the human visual system that included light-dependent visual effects. The reason for using this model was for its low complexity.

Ward Larson, **Rushmeier** and **Piatko** [15] introduced a new tone reproduction method in 1997. This method used the new histogram adjustment technique which was based on the population of local adaptation luminance in a scene. This method modified a luminance histogram, and discovered clusters of adaptation levels. It efficiently mapped scene value to display values with preserving local contrast visibility. The imperfections are used to further affect visibility and appearance to simulate the natural scene.

Tumblin, **Hodgins**, **J. K.**, and **Guenter** [8], in 1999, accounted two methods for display high contrast images. And some models introduced in the paper were widely used in latest methods. Among these models, the most important ideal belonged to the tone reproduction curves was to get the adaptive values of scene and the other of display. For example, both of **Ashikhmin** [1] in 2002 and **Boris Barladian** [2] in 2004 applied these adaptation models to strengthen their methods.

2.2 Tone Reproduction operators

In Siggraph 2002, **Reinhard, Stark, Shirley and Ferwerda** [12] proposed a method that combine the global tone reproduction curve with local band-pass filter. This technique is able to solve the problem that exist underexposed or overexposed regions in a scene. Reinhard's method initially maps the scene luminance to the smaller range that suitable for displaying. It is only rely on the average of luminance which was scalable in logarithmic domain. Then, this new operator enhances the contrast with automatic dodging-and- burning.

The Low Curvature Image Simplifier (LCIS) method is also a tone mapping operator. It is proposed by **Tumblin and Turk** [7] in **1999**. It is applies anisotropic diffusion to separate input scene image into boundary and smooth shading in each level of hierarchy. The boundary and smooth shading have their own weighting Value. The final result is the integration of the boundaries and smooth shadings that are multiplied by its weighting value in each level.

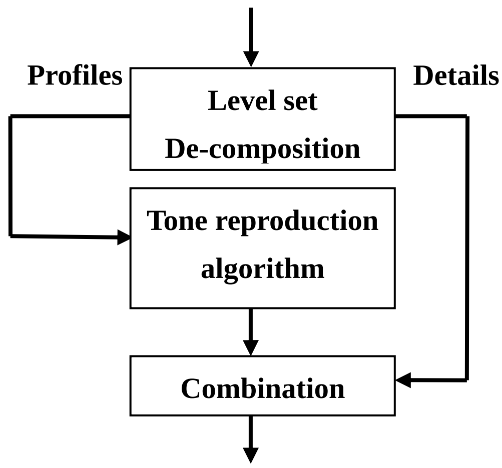
Fattal, Lischinski and Wermann [13] addressed a method of **Gradient Domain High Dynamic Range Compression** in Siggraph 2002. Their algorithm is based on the simple observation. Their idea is to identify large gradients at various scales, and attenuate their magnitudes without changing their direction unaltered, then reduced high dynamic range image from the attenuated gradient field.

3. Proposed Algorithm

3.1 Basic Structure

To create this operator we took substantial inspiration from level set method and Barladian's algorithm. The former is applied for dividing the image into profiles partition and details partition from the beginning. The advantage of level set method is preserving the detail of image then it is better with brighter region. The latter transforms the luminance of profiles partition from the high dynamic range to the low dynamic range. The basic flowchart is shown in figure 1.

Input scene image



Output
display image

Figure 1: Flow chart of basic structure.

3.2 The Level Set Method

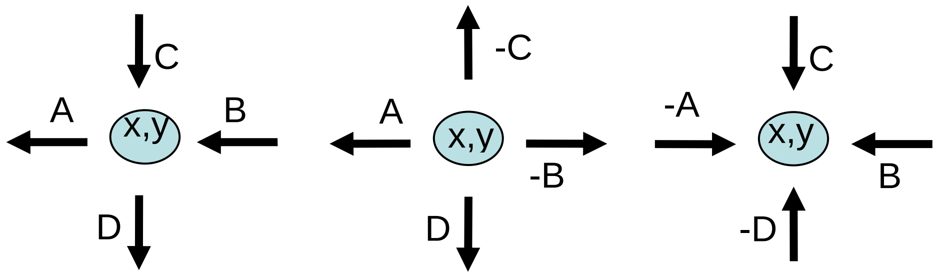
The LCIS method over preserves details and makes too much noise. To overcome this problem, **Ruifeng Xu and Sumanta N. Pattanaik** [14]**,** in 2003, proposed a level set method that applies the ideal of anisotropic diffusion. Initially the basic formula describe with partial differential equation (PDE) in motion of the surface as in equation (1):

$$I_t + F(\kappa)|\nabla I| = 0 \qquad (1)$$

where, I is the luminance value at (*x*, *y*), t is the time constant, I_t is the derivation over time, ∇I is the first order partial derivation over *x* and *y*. $F(\kappa)$ is the moving speed, κ is surface curvature at point (*x*, *y*). Equation (1) can be rewritten as the numerical solution below:

$$I_{xy}^{n+1} = I_{xy}^{n} - \Delta t[\max(F_{xy},0)\nabla^{+} + \min(F_{xy},0)\nabla^{-}] \qquad (2)$$

I_{xy}^{n}, I_{xy}^{n+1} mean the luminance of the point (x, y) at



(a) Four direction (b) Positive flux ∇^+ (c) Negative flux ∇^-

Figure 2: Three expressions under different condition with equations A to B(a) original directions (b) directions of positive flux ∇^+ (c) directions of negative flux ∇^-.

step *n, n+1* respectively Δt is the time step. ∇^+ is the positive flux, ∇^- is the negative flux, and F_{xy} is the flux speed. In equation (2), the magnitude of the detail depends on the flux and its speed F.

Figure 2 shows the concept of flux. In figure 2(a) specifies the meaning of formulas that from A to D in which roughly considered as the four direction flux in level set. It can be said that they are the four directions of the subtraction with the luminance. Figure 2 (b) expresses the four directions of positive flux. The four directions of negative flux are shown in figure 2(c).

According to equation (2), positive and negative flux never exists at the same time. The curvature will decide the speed of the flux, and then the latter will decide weather the positive or the negative flux to appear. The correlation with four different cases for curvature, speed F and flux can be shown in the Figure 3. The curvature is assumed to be negative; therefore positive flux is switched on. The detail formed by speed and flux also became to negative.

From another point of view, because of ∇^+ was negative, the luminance at the point (x, y) was considered that it is smaller than the surrounding pixels.

If the detail is decomposed under this condition, the value of the detail must be a negative value rationally. And under the contrary condition, the detail value must be a positive value. For this reason that has been evident to know how detail is decomposed. After decomposing details, the information remained from the image was called profile. The profile is low frequency information. And instead of compressing original image, it is more valid to get better result by compressing profile image with the same tone mapping curve.

3.3. Robust Parameter Estimation for Tone Mapping Operator

This algorithm based on integrating the revised Tumblin-Rushmeier tone reproduction operator and one of Reinhard's formulas. In 1960 and 1966, Stevens and Stevens offered an example operator based on the supra-threshold brightness measurements, and they claimed that an elegant power-law relation exists between luminance (*L*), adaptation luminance (L_a), and perceived brightness *B*:

$$B = C_0\left(\frac{L}{L_a}\right)^r \tag{3}$$

L is luminance in cd/m^2, *B* is brightness in brils, L_a is adaptation luminance in cd/m^2, $C_0 = 0.3698$ is a constant due to measurement units, and r is the contrast sensitivity which is an exponent depends on adaptation luminance(L_a).

In 1999, Tumblin and Rushmeier were guided by equation (3), and provided another new thought. They used two instances of equation (3) to convert scene luminance to display luminance. One instance was the perceived brightness of the display B_d and the other instance was the perceived brightness of the scene (real-world) B_w, then B_d was set to equal to B_w. The equation has been described below:

$$B_w = C_0\left(\frac{L_w}{L_{wa}}\right)^\gamma = B_d = C_0\left(\frac{L_d}{L_{da}}\right)^\gamma \tag{4}$$

L_{wa} is the real-world adaptation luminance, and L_{da} is the display adaptation luminance. For solving L_d and arranging equation (4) the account of following equation was given:

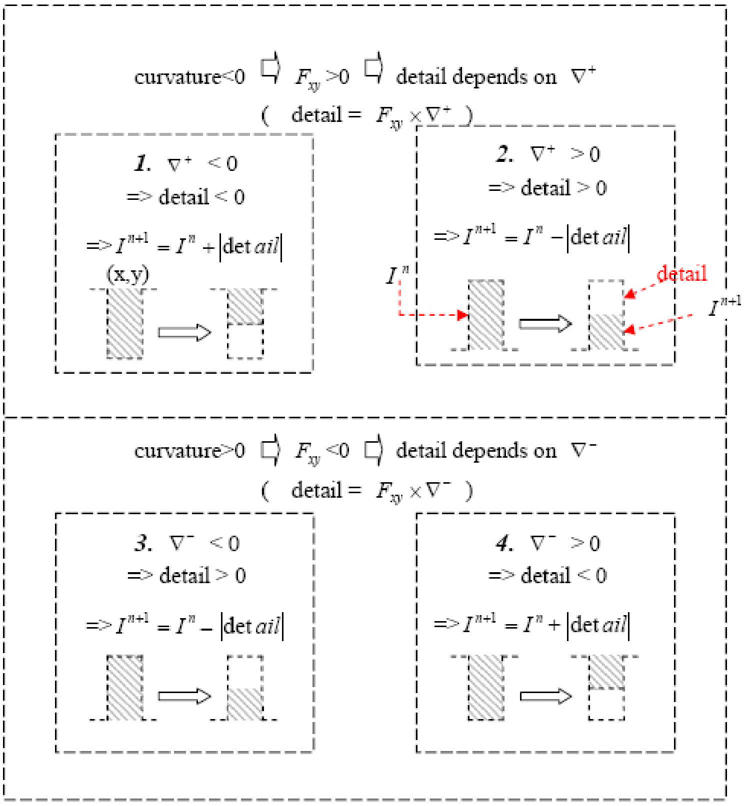


Figure 3: Four conditions for explaining decomposition of detail.

$$L_d = L_{da}\left(\frac{L_w}{L_{wa}}\right)^{\left(\frac{\gamma_w}{\gamma_d}\right)} \tag{5}$$

However, this simple model has an anomaly that may come into existence unexpectedly. All mid-range scene luminance are mapped to mid-range display luminance near L_{da}, thus the display appears a uniform gray in shadow scenes where contrast sensitivity is low. Therefore Tumblin and Rushmeier suggested that a function to remove this anomaly. The function is $m(L_{wa})$ that applied as a new scale factor term based on the scene adaptation luminance (L_{wa}). When it increases from starlight to the threshold of eye damage, the corresponding display luminance should grow steadily from display minimum to maximum. The $m(L_{wa})$ is varying with the same log-linear expression Stevens used to find contrast sensitivity r in equation (9). If L_{wa} values smaller than 100 cd/m^2, the changes in m match changes in contrast sensitivity, and cause minimum scene luminance to map precisely to the minimum display luminance. Above 100cd/m^2, reaching minimum display luminance requires scene luminance further below (L_{wa}). Hence, the revised tone reproduction operator proposed by Tumblin and Rushmeier is given:

$$L_d = m(L_{wa}) \cdot L_{da}\left(\frac{L_w}{L_{wa}}\right)^{\left(\frac{\gamma_w}{\gamma_d}\right)} \tag{6}$$

The function $m(L_{wa})$ also depends on the C_{max} which is the maximum available display contrast (30 to 100 typical), and $m(L_{wa})$ is given in equation (7).

$$m(Lwa) = (\sqrt{C_{\max}})^{(\gamma wd-1)} \tag{7}$$

where

$$\gamma_{wd} = \left[\frac{\gamma_w}{1.855 + 0.4\log(L_{da})}\right] \tag{8}$$

Stevens' contrast sensitivity is given:

$$\gamma(L_a) = \begin{cases} 2.655 & for L_a > 100cd/m^2 \\ 1.855 + 0.4\log_{10}(L_a + 2.3*10^5) & otherwise \end{cases} \tag{9}$$

The revised tone reproduction operator leads to fine result in general cases. But it still makes the part of scene values to be outside of displayable range probably. Thus, Barladian applied second method that formularized by Reinhard et al. [Reinhard 2002] as the following equation:

$$L_{df}(x,y) = \left(\frac{L_d(x,y)\left(1 + \frac{L_d(x,y)}{L^2_{fwhite}}\right)}{1 + L_d(x,y)} \right) \qquad (10)$$

where the L_{white} is the smallest luminance value that is mapped to pure white. By solving following two equations, the L_{fwhite} will be obtained by following equations:

$$Ld_{white} = m(L_{wa}) * L_{da} * \left(\frac{L_{white}}{L_{wa}}\right)^{(\frac{\gamma w}{\gamma d})} \qquad (11)$$

$$L_{dwt} = \left(\frac{Ld_{white}\left(1 + \frac{Ld_{white}}{L^2_{fwhite}}\right)}{1 + Ld_{white}} \right) \qquad (12)$$

Equation (11) is the revised Tumblin- Rushmeier tone reproduction operator, and Barladian applies L_{white} in substitution for L_w. If L_{dwt} is given, solving for L^2_{fwhite} leads to the following equation:

$$L^2_{fwhite} = \frac{Ld^2_{white}}{\left|(L_{dwt} - 1) \cdot Ld_{white} + L_{dwt}\right|} \qquad (13)$$

As long as L_{fwhite} is obtained, if it integrates equation (6) with equation (10), the full algorithm of Barladian's is constructed.

3.4 New method of tone mapping operator

The proposed algorithm improves the result with keeping details and enhancing contrast. The flow chart of proposed algorithm is shown in figure 5. The first step of proposed algorithm is adaptive gain control, to keep the detail in the bright region with a smaller L_{dwt} value. Then put the automatic dodging-and-burning operator into equation (10). Finally, before recomposing low dynamic range profiles with details, it attached the local contrast enhancement to the transformed profiles.

However, it differs from the general local contrast enhancement. The enhancement of the proposed method mainly depends on the details information that decomposed previously. Instead of depending on standard deviation, the enhancement of proposed method not only intensifies the contrast well, but also reduces the traditional halo-effect.

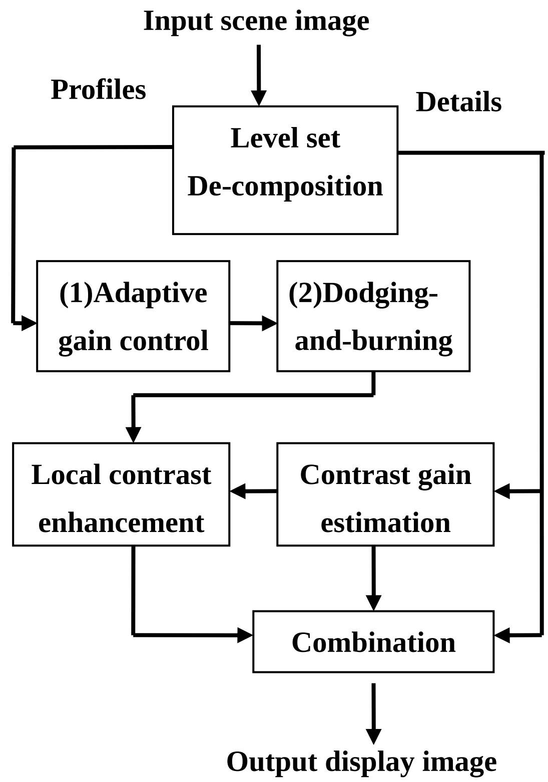


Figure 5: The flow chart of proposed algorithm

3.4.1 Adaptive Gain Control

The proposed algorithm provides a revised curve according to the analysis, and reforms the Barladian's curve. The result will be improved to more conform to the real-world scene.

3.4.2 Proposed curve

Figure 7 shows the curves of Barladian's algorithm and the proposed curves. Figure 7(a) is the curve of Tumblin-Rushmeier's curve. Figure 7(b) is Reinhard's curve. Figure 7(c) is the Barladian's curve. After transforming by Tumblin-Rushmeier's curve, Barladian applies Reinhard's curve to transform again.We consider the curve of the Barladian's algorithm, figure 7(d) shows the modified curve, and figure 7(e) is the original Reinhard's curve. Figure 7(f) is the integrated curve that the proposed algorithm wants to obtain. The proposed algorithm modifies the Tumblin-Ruhmeier's equation is below:

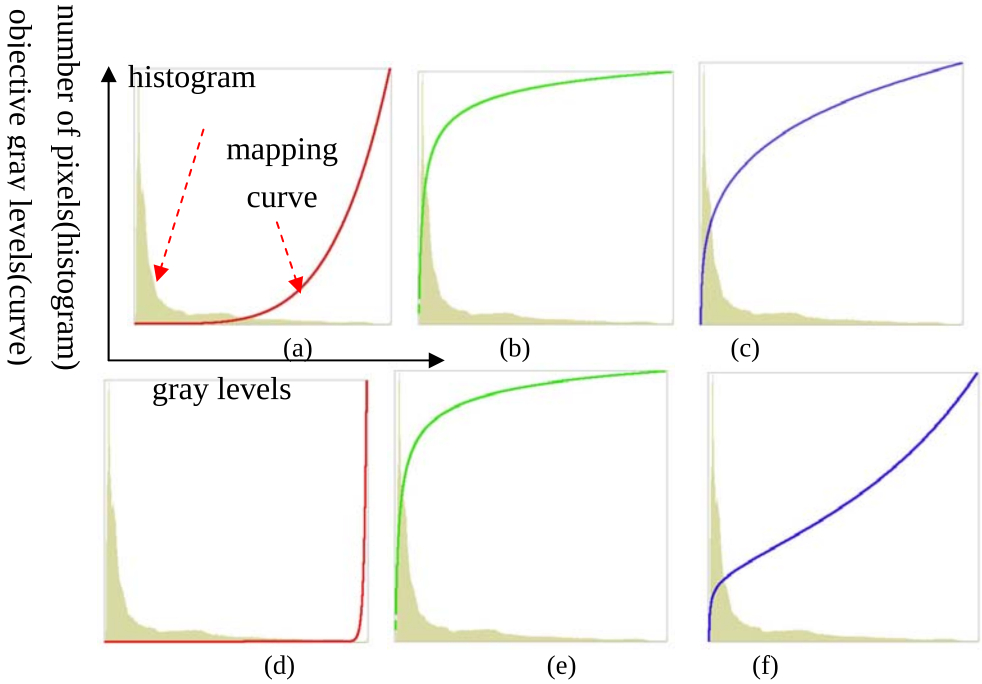


Figure 7: Compare with Barladian's algorithm and proposed algorithm (a)-(c) Barladian's algorithm (d)-(f) proposed algorithm. (a) Tumblin-Ruchmeier's curve (b) Reinhard's curve (c) Barladian's curve (d) modified curve with adaptive gain control (e) Reinhard's curve (f) proposed curve.

$$L_d = m(L_{wa}) \cdot L_{da} \left(\frac{L_w}{L_{wa} - k \cdot L_w} \right)^{\left(\frac{\gamma_w}{\gamma_d}\right)} \quad (14)$$

where k is the parameter that determines the magnitude of the gain. By specifying different k, we can get different shape of the curves. When adaptive gain control process is under the same condition, the greater k leads to the sharper gain. In the other hand, if the range of the bright region is broader, it needs the shaper gain to reveal the bright detail. For that reason, it needs a greater k. The proposed algorithm provides two parameters to determine the adaptive gain control. We make these two parameters as an adaptive range and adaptive quantity.

Adaptive quantity is a number of pixels that are considered as the pixels in the brighter region. Adaptive range is the number of bins that counted from the end of the histogram, and the sum of pixels in these bins satisfies the adaptive quantity. We formulate such concept as following equation (15).

$$r = \arg \min_{1 \le r < n,\, f(r) > \frac{1}{q} \cdot N} \left[f(r) = \sum_{i=1}^{r} H'_{n-i} \right] \quad (15)$$

where $\frac{1}{q} \cdot N$ is the adaptive quantity and q is always given by user. N is the number of total pixels in the current image. N is the number of the total bins in the histogram. H'_{n-i} is the number of pixels in the *n-i*$_{th}$ of the histogram, and these pixels are all with detail value greater than 0.03. The purpose of counting with H'_{n-i} instead of original histogram is to reduce the noise efficiently and make the adaptive gain control more precise. Therefore, when r is smaller, it means that there are many pixels are concentrated in the narrow range of the bright gray levels. In other words, there is a wider and brighter region in the image, and it need sharp gain to reveal the details in such region. In the contrary, there is a little bright region with few pixels, and it needs slight gain. However, it is reasonable that if r is located on the middle of histogram, there are still many pixels in the bright region. It needs a sharper gain. Thus, the k should be greater than the half of maximum k. basing on such variation of k; the proposed algorithm applied bias function to determine k. Because that the variation of k is similar with the behavior of the bias function. The precise detail has been described as equations below:

$$k = bias_b \left(\frac{(H_{size} - r)}{H_{size}} \times K_{\max} \right) \quad (16)$$

$$K_{\max} = \frac{0.9 \cdot Lwa}{L_{\max}} \quad (17)$$

Proposed algorithm let K_{max} follow the equation (17) to avoid the over strengthening of the gain. In fact, the bias function was first presented by Perlin and Hoffert as a density modulation function. The bias function is a power function, and it remaps an input value to a higher or lower value over the unit interval with parameter *b*. The bias function is given:

$$bias_b(s) = s^{\left(\log(b) / \log(0.5)\right)} \quad (16),$$

we suggested that the value of b is 0.6.

3.4.3 Dodging-and-Burning

The adaptive gain control could reserves the details in bright region well, but it leads to another situation. That is the reduction of the contrast in the shadow region. It is due to that the extension of the bright region reduces the contrast in the shadow region. We use the method of dodging-and-burning to improve this problem. This local method has been proven that it enhance contrast efficiently.

Reformulated the equation (10) as below:

$$L_{df} = \left(\frac{L_d\left(1+\dfrac{L_d}{L_{fwhite}^2}\right)}{1+L_d'}\right) \quad (17),$$

we applied simple low-pass filter to perform dodging-and-burning. To reduce halo effect, the proposed algorithm applies moderate low-pass filter as given:

$$L_d'(x,y) = \frac{L_d(x,y) + (filter_{lowpass}(L_d(x,y)))}{2} \quad (18)$$

3.4.4 Enhance local contrast with detail information

After processing with adaptive gain control and dodging-and-burning, HDR images have been transformed to low dynamic range and kept fine contrast, but will occur losing details in the result. Therefore, the proposed algorithm applies local contrast information further enhance contrast and details. In general the local contrast enhancement is formulated in equation (19).

$$f(i,j) = m_x(i,j) + G(i,j)\left[x(i,j) - m_x(i,j)\right] \quad (19)$$

$f(i,j)$ is the enhanced value of point(x, y), $m_x(i,j)$ is the local mean, $G(i,j)$ is the contrast gain, and $x(i,j)$ is the original pixel value of point(i, j).

The contrast gain of local contrast enhancement is controlled by standard deviation generally. However, with tone reproduction, it not only leads to deep contrast but also produces halo effect.

Especially the pixels located on the edge will obtain great values of standard deviation. Then, the contrast gains of these pixels also grow to greater with the halo effect. Besides, the other artifact, over emphasizing contrast, will also exist in the same time. To reduce these artifacts, we using detail information as contrast gain to enhance local contrast. Actually, directly using detail information to control contrast gain is not enough to reduce halo effect. It is still necessary to arrange detail information to further reduce halo effect.

We formulated contrast gain function as follows:

$$\text{if} \quad detail(x,y) \geq 1 \quad \begin{cases} \text{if } (detail(x,y) > mean^+) \\ \quad CG = scaler^+ \cdot \left[detail_{max} - detail(x,y)\right] \\ \text{else} \\ \quad CG = detail(x,y) \end{cases}$$

(20)

$$\text{if} \quad detail(x,y) < 1 \quad \begin{cases} \text{if } (detail(x,y) < mean^-) \\ \quad CG = scaler^- \cdot \left[detail(x,y) - detail_{min}\right] \\ \text{else} \\ \quad CG = \left|detail(x,y) - 1\right| + 1 \end{cases}$$

(21)

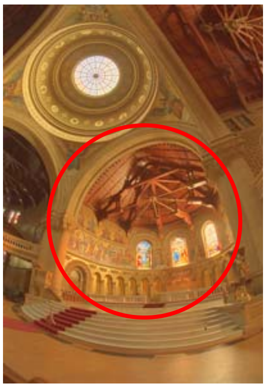
where $detail(x,y)$ is detail value of point(x,y), $mean^+$ is the mean of details which details value are equal to or greater than 1, $mean^-$ is the mean of details which details value are smaller than 1 , CG is the contrast gain. Besides, $scaler^+$ and $scaler^-$ are scale factors to lead the contrast gain to be zero when a point(x,y) has maximum detail or minimum detail. $scaler^+$ and $scaler^-$ are designed as following equations:

$$scaler^+ = \frac{mean^+}{detail_{max} - mean^+} \quad (22)$$

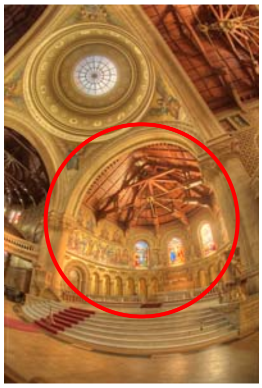
$$scaler^- = \frac{mean^-}{detail_{min} - mean^-} \quad (23)$$

4. Experimental Results

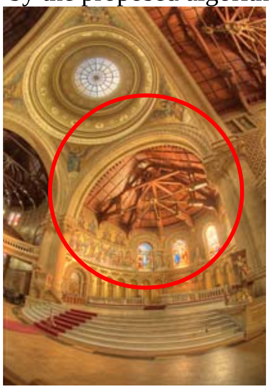
In this section, we represent the results of proposed algorithm. We not only applied previous HDR images, but also applied other RAW images that we captured additionally. The difference between HDR and RAW images is that a HDR image provides



(a) by the proposed algorithm.



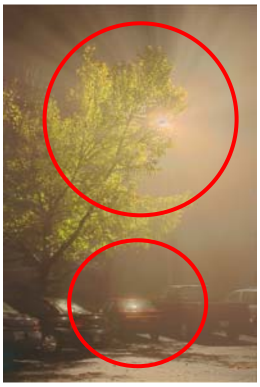
(b) by Fattal's Gradient Domain algorithm.



(c) by Druand's algorithm.

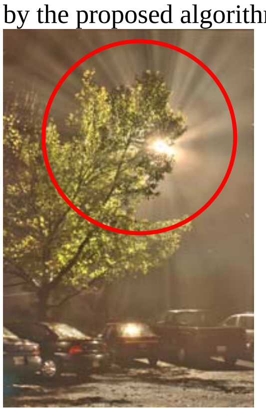
(d) by Reihard's algorith.

Figure 8: Comparison with other methods of Memorial church.



(a) by the proposed algorithm.

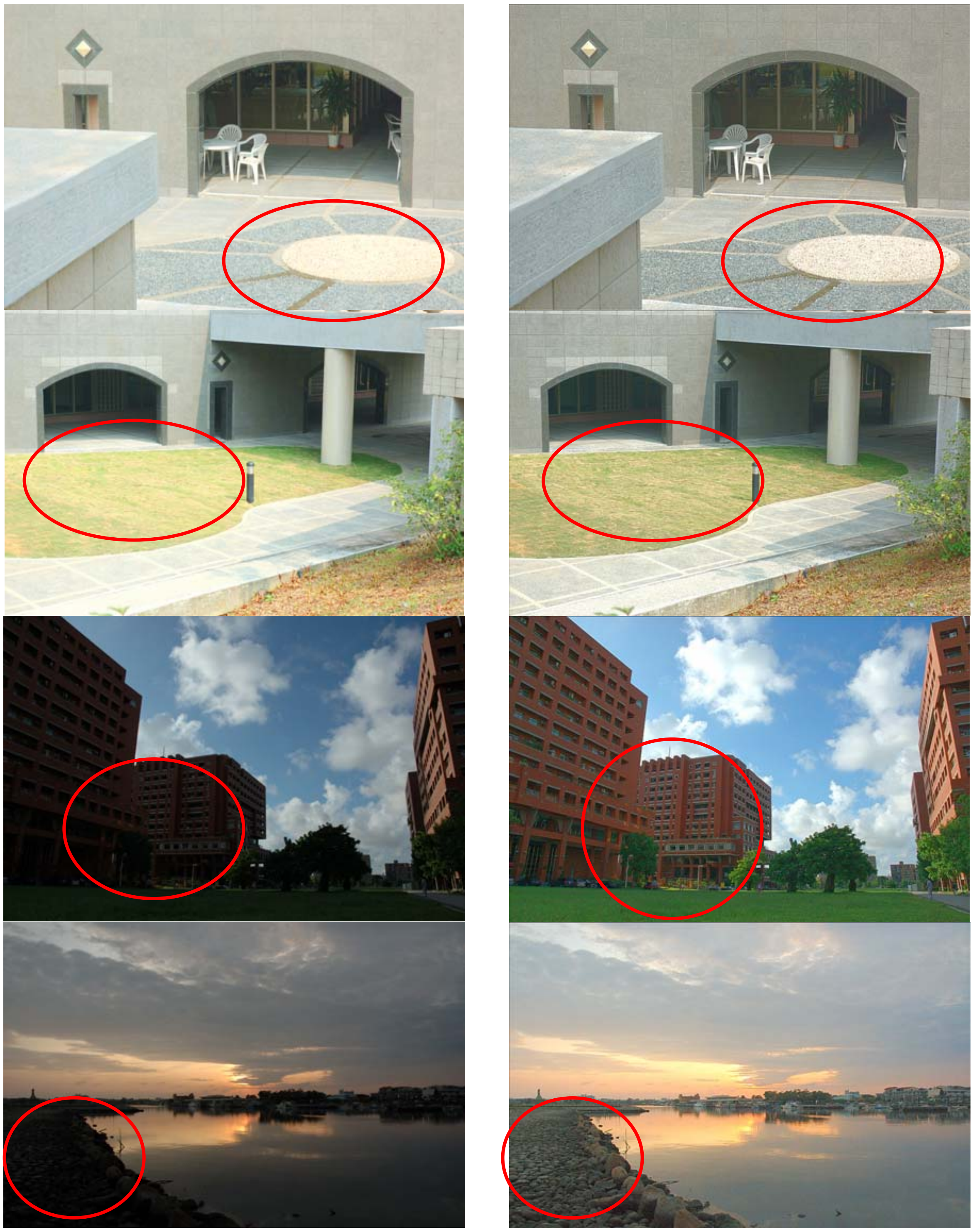
(b) by Fattal's Gradient Domain algorithm.



(c) by Druand's algorithm.

(d) by Reihard's algorith.

Figure 9: Comparison with other methods of Memorial church.



(a) by linear operator. (b) by proposed algorithm.

Figure 10: The effect of resulting images by proposed algorithm is exactly batter then by linear operator. (the format of all images is in 12 bits taken by Nikon D70.)

32bits float points each channel of RGB. A RAW image provides 16 bits integer each channel of RGB. These experimental RAW images were captured by Nikon D70 and AF-S DX Nikker ED 18-70mm F3.5 - 4.5G (IF). Generally the image format captured by Nikon D70 is 12 bits NEF format what is Nikon's privately compressive RAW format. We transform that to 16 bits RAW format for convenience.

Finally, following experimental results are separated into three parts. First, we took 32 bits images and 16 bits images to compare with the results of Barladian's algorithm. Second, we compared with others methods in this part. Finally we show others results of proposed algorithm.

Figure 8 compares the proposed algorithm with other methods of Memorial church. The result image is smoother with other algorithms as the remark region. In figure 9 the detail information is clearer with another method, as the street light and the car. Figure 10 shows the effect of resulting images by proposed algorithm is exactly batter then by linear operator.

5. Conclusion

In this paper, we proposed algorithm is based on three steps to compress HDR image. There are adaptive gain controls, dodging-and-burning, and local contrast enhancement. The advantages of proposed algorithm are: intuitive and efficient, reserve details and enhance contrast well, and low and unobvious halo effect.

The proposed algorithm improves the result with keeping details and enhancing contrast. The function of adaptive gain control is to keep the detail in the bright region. The automatic dodging-and-burning operator enhances the contrast in the shadow region. Finally, before recomposing low dynamic range profiles with details, it attached the local contrast enhancement to the transformed profiles.

According to the experimental, our algorithm reproduced images not only visibly represents in low dynamic range, but also conserves and reveals more details. Therefore, it can be said that the proposed algorithm efficiently compresses high dynamic range images and preserves good contrast and details.

6. Acknowledgments

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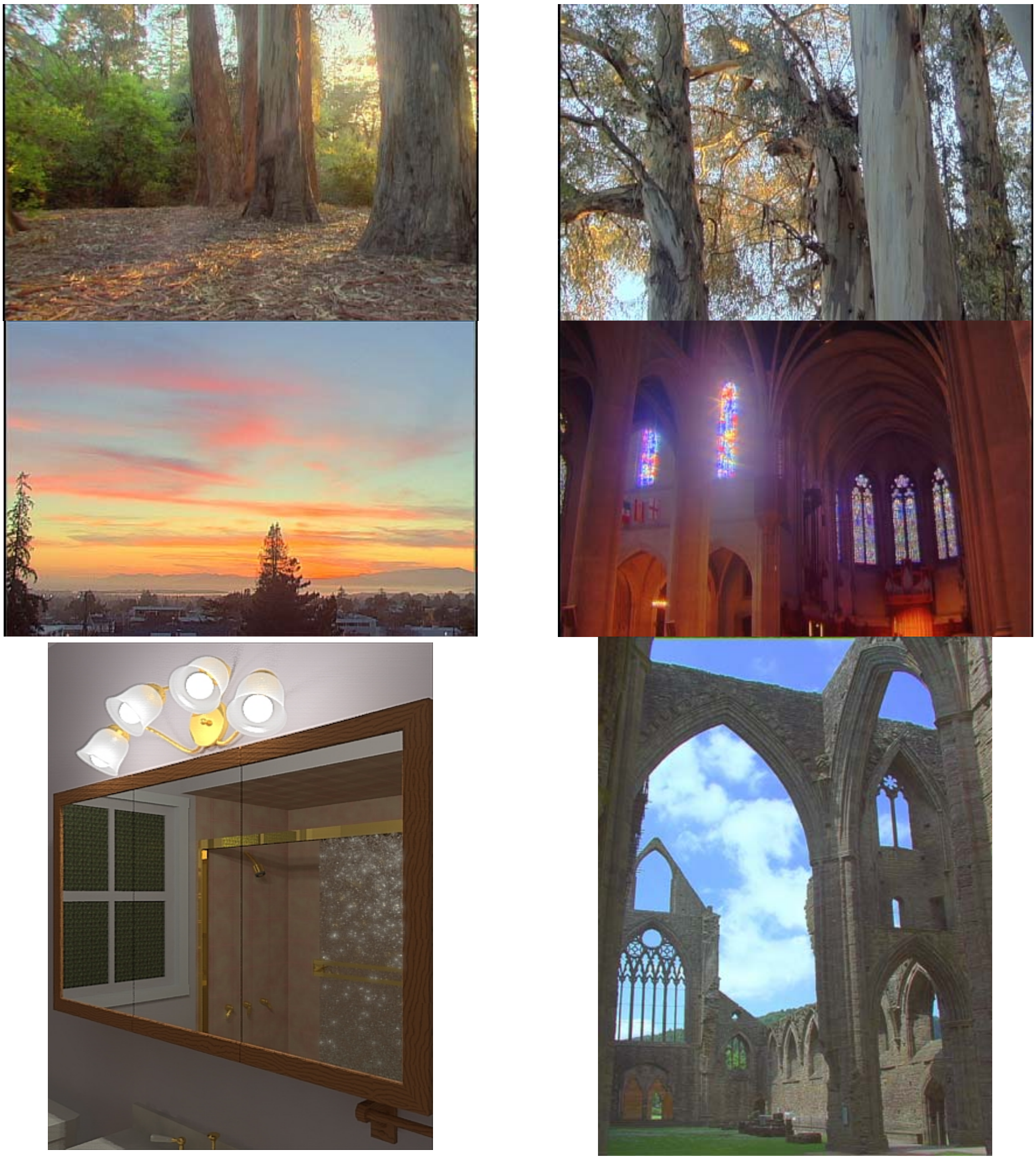

Figure 11: More experimental results.