Extending Dynamic Range of Two Color Images under Different Exposures

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Abstract

We present a method of extending the dynamic range of an picture with two different exposure images. Since pictures under different exposure times show different scene dynamic ranges, if we make use of the visible information of each different exposure image, we can recover a high dynamic range image which contains what cannot be visualized by an auto-exposure time.

In this method, we did not follow the ordinary fusion methods which were based on multi-layered or radiance map based approach of multiple images. Instead, we used the filling method of undesirable regions of an auto-exposure picture, preserving its overall image quality.

Our filling method uses the gradient information of the visible regions and recovers the saturated regions by the energy minimization approach. The results show that our fusion method is simple and practical to make a HDR image, if we have two proper exposure images.

1. Introduction

Many commercial cameras have a limited sensor dynamic range. When a picture is captured by these cameras, the result, sometimes, showed under- or over-exposure regions that degraded the overall image quality. Since the camera has its own response characteristics for light, it is impossible to capture the full dynamic range of the natural scene as intended. To solve this problem, many researchers carried out the studies of HDR imaging system using hardware techniques. In recent years, however, because of the widespread use of commercial digital cameras which show good image quality, they tried to solve HDR imaging problem by software techniques.

The exposure time is useful information to make an effective HDR camera, because different exposure times show different dynamic range characteristics of an imaging system. Mann and Picard [6] presented a method of fusing different exposure pictures. They used the principle of *Wyckoff* film which has multiple light sensitivity layers and made a fusion image using the general film response curve. Debevec et al. [2] showed that the original scene radiance map can be recovered from several different exposure images, presenting the camera radiometric calibration method.

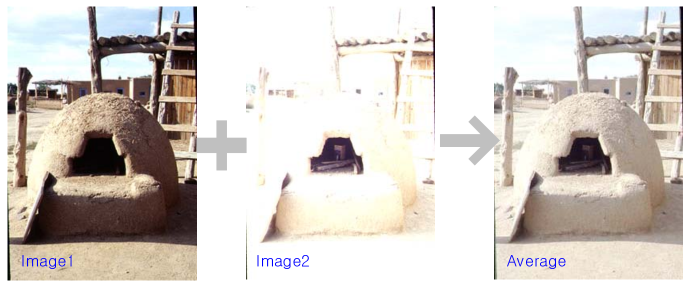

Figure 1. Left: Auto-exposure Middle: Higher exposure Right: The averaging of two images(image1 and image2)

This method made possible the reconstruction of a 32-bit full dynamic range map. Based on this work, many researchers presented various compression methods to display in 8-bit compatible devices. For example, there were filtering technique [3], gradient technique [4] and global operator [7] technique etc.. These methods showed how to compress a given high dynamic range image but did not show how to handle multiple images without the radiometric calibration technique. While the radiance map based approach showed a high image quality and realized the high dynamic information of the scene, it must pass through computationally complex processing. Most of all, it must use multiple pictures to get a high quality radiance map.

Bogoni [1] presented an effective fusion method of multiple images. He used the pyramid technique, which is similar to the weighted average of each layer according to edge visibility. However, our method takes a different approach

0-7695-2128-2/04 $20.00 (C) 2004 IEEE

to do the same work. Since each different exposure image has different visible regions according to their dynamic range, we tried to make use of the best visible information of each image and fill the invisible (over- or under-exposure) regions of an auto-exposure picture, preserving its good image quality (color and overall intensity levels).

Our two-exposure image approach is useful when an auto-exposure picture was captured as in Fig.1. In this case, the photographer wants to visualize dark inside regions, preserving other regions and our method can support his concern without other redundant exposure pictures.

In the remainder of the paper, we will explain how our fusion method can recover Fig.1 with only two color pictures. In Section 2, we will describe the basic concepts of getting the saturation mask, recovering invisible regions and making color layers. In Section 3, we will brief a scheme to solve the difference equation and show our results. In Section 4, we will discuss our method and the extension works.

2. Problem statement

If we usually take a picture, as shown in Fig.1, we cannot capture the inside of a house which is invisible under a short exposure time, but when we set the camera exposure time longer, the inside regions become visible while the other regions are saturated. Because of the capability of the camera sensor, this situation can always happen when taking a picture of the natural scene. The simple image fusion method is to take the average of two images pixel by pixel [6] and in the view of HDR imaging, this approach [5] was used. While simple, this approach can produce several undesirable side effects, including reduced contrast and degraded color characteristics.

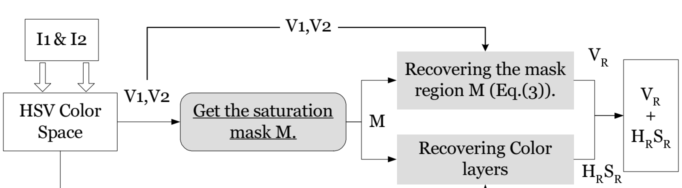

Figure 2. Overall procedure

Next, how can we exploit the visible information of each image and combine them, preserving original color characteristics and avoiding the degradation of its details in visible regions?

Our method needs two different exposure pictures. In Fig.2, we define the intensity layer of one input image I_1 as the base image V_1 which was captured by an auto-exposure and the one of the other exposure I_2 as V_2 which was captured under a different exposure time and contains the visible information corresponding to under- or over-exposure regions of V_1. The color layers of each image are denoted by H_1S_1 and H_2S_2.

The first main step of our method is to find the mask of under- or over-exposure regions of V_1. For this, we use 2D histogram of V_1 and V_2, and make a saturation mask M. Then, we recover the missing intensities in V_R and the color layers, H_R and S_R. Because the initial layer V_R consists of the original intensity layer V_1 except the mask region M, recovering the final layer V_R is to fill the mask regions with the boundary conditions V_1 and the gradient information of V_2 and the color layer H_R and S_R are simple composite layers of two input color layers $H_{1,2}$ and $S_{1,2}$, according to the mask M.

In following section, detailed descriptions will be presented.

2.1. Getting the saturation region mask

Assuming that two images are registered, we can obtain 2D histogram of two images V_1 and V_2 whose vertical or horizontal projection is the histogram of each image. 2D histogram shows which image is darker and at which intensity level the image starts to become saturated.

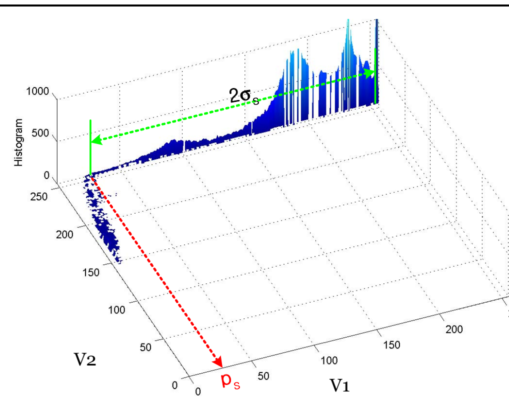

Figure 3. 2D Histogram

Analyzing Fig.3, we know that V_2 is brighter than V_1 and below the intensity level p_s of V_1, the invisible regions in V_1 is clearer in V_2. Thresholding below level p_s in V_1, we obtain the saturation mask M in Fig.4(a) which depicts where the undesirable contrast regions are in V_1 by black. If we directly exploit the intensities of V_2 to merge two images like in Fig.4(b), the result image, as expected, has discrete boundaries that do not satisfy the continuity condition with adjacent intensities. Therefore, we should take a measure to recover lost intensities constraint on the boundary condition of the black mask, which will be explained in the following section.

2.2. Filling in the saturation regions

The basic idea is to fill in black mask regions of V_1, preserving the visible information of V_2. For this, we exploit the gradient $\mathbf{G}_2 = \nabla V_2$ of the visible regions denoted by $\mathcal{D}$ in Fig.4(a). Then, we obtain the following mathematical expression:

$$\iint_{\mathcal{D}} F(V_R, \nabla V_R)dxdy = \iint_{\mathcal{D}} \alpha|\mathbf{G}_2(x,y) - \nabla V_R(x,y)|^2 + (1-\alpha)|V_2(x,y) - V_R(x,y)|^2 dxdy. \quad (1)$$

The first term recovers missing intensities $V_R(x,y)$ from the gradient information, $\mathbf{G}_2$ and the second term provides the likelihood information to guide the intensity levels of the recovered $V_R(x,y)$ so that its levels would not be grown up out of the desirable image range. If $\alpha = 1$, the recovered $V_R(x,y)$ is the 2-dimensional integration of $\mathbf{G}_2$ with the boundary condition V_1 and if $\alpha = 0$, the result is the simple replacement as in Fig.4(b). Therefore, our objective function aims for the image fusion that satisfies the boundary conditions within the range of original contrasts of V_2.

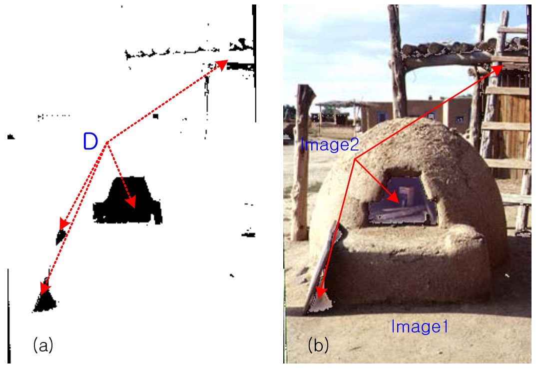

Figure 4. (a) the mask (b) the simple fusion: intensities at the mask boundaries are not matched

According to *Variational principle*, we can derive Euler-Lagrange equation minimizing the integral in Eq.(1)

$$\frac{dF}{dV} - \frac{\partial}{\partial x}\frac{\partial F}{\partial V_x} - \frac{\partial}{\partial y}\frac{\partial F}{\partial V_y} = 0 \quad (2)$$

which become the following equation:

$$\alpha\nabla \cdot \nabla V + (1-\alpha)V = \alpha\nabla \cdot \mathbf{G}_2 + (1-\alpha)V_2. \quad (3)$$

Because the gradient information is the relative difference between pixels based on the neighbors, if the gradient information of invisible regions are known, it is possible to recover the desirable intensities depending on their neighborhood values (the boundary conditions). More detailed derivation can be found in [4].

2.3. Handling color space

We use V component of HSV color space for the intensity reconstruction by Eq.(3) and to reconstruct the color fusion image in HSV space, we should make the other layers, H and S. Then, how can we extract the color components of the saturation regions? Since the saturation regions lost their color characteristics, we must get the color information from the visible regions of the other image. H and S components of the average of input color images can be the solution of our color layer. However, in order to reduce the effect of saturated colors (white or black), we apply the following concept.

- We assume that H and S components are similar between two images except for the saturation regions. Therefore, H and S components of the saturation regions can be extracted from the corresponding visible regions of the other image.

Replacing the saturated H and S components by the layers of the visible regions, we made the final fusion image with two images.

3. Implementation and experimental results

There are various methods to solve Eq.(1) with the boundary condition. For our implementation of Eq.(3), we will briefly mention the numerical solution.

- $\nabla^2 V$ and $\nabla \cdot \mathbf{G}_2$ used the forward and backward difference schemes.
- *Successive Over Relaxation* method was applied.
- The basic iterative difference equation is obtained by rearranging Eq.(3). Here, we experimentally set α to about $0.8 \sim 0.9$.

Fig.5 and Fig.6 show experiments for under- and over-exposure cases. Fig.5(b) is an ordinary outdoor picture where the inside of an igloo is not visible and Fig.6(b), an indoor picture where the outside of a door is not visible. These situations always occur when using a commercial digital camera. Fig.5(a) and Fig.6(b) are the other images to combine. These images have the visible information for the region of interest, respectively. The results show that this method can combine two different visual information effectively, preserving the overall image quality of the base image.

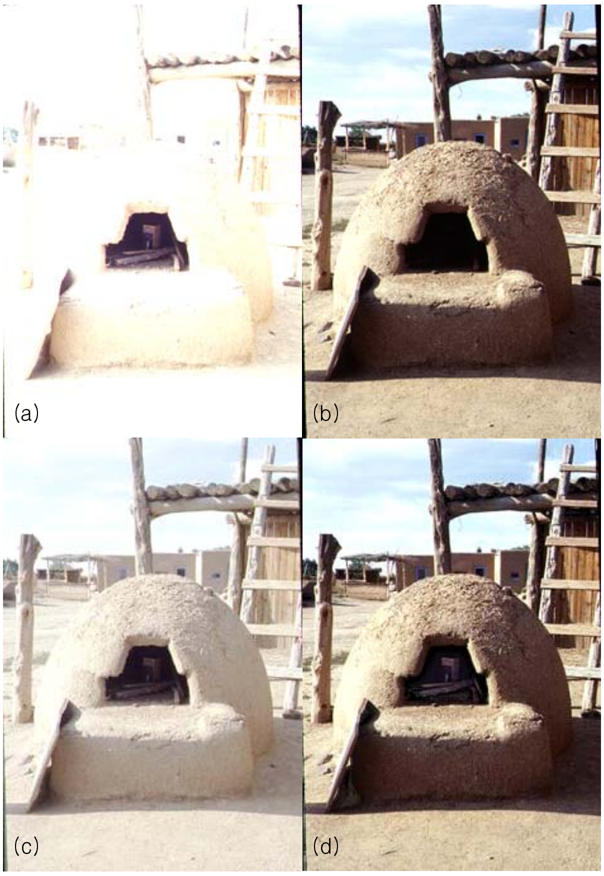

Figure 5. Under-saturated case: (a),(b) two input images under different exposures (c) the averaging of two images (d) our result

4. Discussions and Conclusions

We present the image fusion method by energy minimization. This method uses two color images under different exposures and makes a fusion image based on the iterative scheme. Since we use the gradient information as the texture of under- or over-exposure regions and the likelihood information constraint on the recovered intensity levels, we can easily recover the missing intensities appropriate to the boundary conditions. This fusion method is simple and useful when the picture cannot realize details in bright and dark regions, because it needs only one image under a different exposure which contains what is missing from an auto-exposure image.

As an extension to the work, it is necessary to find a "proper" exposure time automatically according to scene conditions. If our method is adaptible to hardware implementation and it is possible to find the proper exposure time to combine, the photographer can easily take a picture by a commercial camera without being concerned about over- or under-exposure regions shown in Fig.5,6 and this two-exposure approach is practical compared to the multiple-exposure approach.

Figure 6. Over-saturated case: (a),(b) two input images under different exposures (c) the averaging of two images (d) our result

References

[1] L. Bogoni. Extending dynamic range of monochrome and color images through fusion. In *Proc. International Conference on Pattern Recognition*, volume 3, pages 7 –12, 2000.

[2] P. E. Debevec and J. Malik. Recovering high dynamic range radiance maps from photographs. In *In Proc. ACM SIGGRAPH*, Aug. 1997.

[3] F. Durand and J. Dorsey. Fast bilateral filtering for the display of high-dynamic-range images. In *In Proc. ACM SIGGRAPH*, pages 257–266, 2002.

[4] R. Fattal, D. Lischinski, and M. Werman. Gradient domain high dynamic range compression. In *Proc. ACM SIGGRAPH*, pages 249–256, 2002.

[5] M. D. Grossberg and S. K. Nayar. High dynamic range from multiple images: Which exposures to combine? In *In Proc. ICCV Workshop on Color and Photometric Methods in Computer Vision*, Oct. 2003.

[6] S. Mann and R. Picard. Being 'undigital' with digital cameras: Extending dynamic range by combining differently exposed pictures. Technical Report TR-323, M.I.T. Media Lab Perceptual Computing Section, Boston, Massachusetts, 1994. Also appears, –IS&T 48th annual conference, Cambridge, Massachusetts, May 1995.

[7] E. Reinhard, M. Stark, P. Shirley, and J. Ferwerda. Photographic tone reproduction for digital images. In *In Proc. ACM SIGGRAPH*, pages 267–276, 2002.