Exposure Fusion Algorithm for Scenes with an Extremely High Dynamic Range

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***Abstract*—Nowadays, high dynamic range imaging techniques are often applied for outdoor applications that may encounter scenes with an extremely high dynamic range. In such scenes, a halo can be produced by gradient reversal, and color information is easily damaged. In this paper, we propose an exposure fusion algorithm that does not suffer from any artifacts in extremely high dynamic range scenes. Using the HSV color model, gradient reversal is suppressed in the Value component, and color information is preserved in the other components. Experimental results show that these two artifacts are effectively avoided, and all of the scene's details are preserved.**

***Keywords* – High dynamic range, exposure, halo, HDR, HSV.**

I. INTRODUCTION

Currently, complementary metal-oxide semiconductor sensors and charge-coupled devices are widely used in the digital imaging field. These common sensors are cheap, and work well with high-end image processing techniques. However, scenes with a high dynamic range (HDR) cannot be described sufficiently well by a single image. To overcome this inherent limitation of these sensors, HDR imaging techniques using multiple different exposure images have been studied. Researchers have attempted to depict HDR scenes with a low dynamic range (LDR) capture device, and represent them on standard dynamic range (SDR) display devices, such as on a monitor or when printed.

In photography field, most existing algorithms focus on improving image quality by applying local adaptation and maximizing the image contrast [1]-[4]. These methods produce pleasing images for general HDR scenes, but the local adaptation can cause a halo effect. Nowadays, HDR imaging techniques are used in autonomous and outdoor applications [5]. In these applications, the dynamic range can be extremely high, such as when a vehicle passes through a tunnel, which can worsen the problem of the halo. Several HDR algorithms have been proposed to suppress this halo [6], [7]; however, extremely high dynamic ranges can also lead to color artifacts. Moreover, a Poisson solver is generally needed to convert an image from the gradient domain to the spatial domain. Therefore, there is a need for artifact-free HDR imaging techniques that can be applied to scenes with an extremely high dynamic range.

In this paper, we propose an exposure fusion algorithm that produces an artifact-free SDR image. We use the HSV (Hue, Saturation, Value) color model, as this makes it easy to manipulate intensity and color information separately. Input LDR images are added to the Value component, and compressed with a single curve to avoid gradient reversal. In the Hue and Saturation components, color information is obtained from a weighted blend of input exposure images. Because the color information of the high- and low-intensity pixels is damaged by the saturation and noise, respectively, the weights are determined by how close the Value component of each exposure image is to the median value. The Hue and Saturation components of the composed image are then extracted to give the final exposure fusion Hue and Saturation values. Additionally, the proposed algorithm does not require surrounding pixel information when synthesizing the SDR image.

The remainder of this paper is arranged as follows. In Section II, we discuss existing HDR imaging techniques, before describing our proposed algorithm in detail in Section III. Section IV presents our experimental results, and a discussion of our work is given in Section V.

II. RELATED WORK

HDR imaging techniques can be categorized as either global operators or local operators. A global operator reduces the dynamic range of a scene using the corresponding pixel's intensity and global quantity. Generally, such techniques have a low computational cost, but cannot preserve details when the scene's dynamic range is extremely high. For example, Drago et al. [8] suggested a logarithmic mapping based on the human visual system, but the biased radiance distribution in this method can damage important visible details. Reinhard et al. [9] proposed a photoreceptor model by applying a sigmoidal function. Because global operators reduce the dynamic range by applying the same curve, they are suitable for medium dynamic ranges and real-time processing applications. Additionally, they do not produce a halo effect, because no local adaptation is used.

Local operator techniques reduce the dynamic range adaptively using a local adaptation calculated from the corresponding pixel and surrounding pixels. Adaptive compression gives good performance, but local adaptation causes a halo to appear near high-contrast regions, and requires information about surrounding pixels. For example, Rahaman et al. [1] proposed

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a retinex algorithm based on the human visual system, and Reinhard et al. [2] suggested a photographic tone reproduction that uses a zone system. Both of these approaches preserve scene details better than global operators, but the use of local adaptation creates a halo. In addition, several exposure fusion algorithms [3], [4] have been proposed that create a fused image as the weighted summation of input LDR images. The weights for each image are determined by measuring how well the pixel is exposed. Applying different weights for each pixel can introduce gradient reversal effects, and the unwanted halo can persist.

Several algorithms have been developed to prevent the appearance of a halo. Fattal et al. proposed a tone-mapping method [6] that manipulates images in the gradient domain, and Song suggested a probabilistic exposure fusion technique [7]. These algorithms preserve scene details using local adaptation while simultaneously suppressing the halo in the gradient domain. However, they require a Poisson solver to convert an image from the gradient domain to the spatial domain.

III. PROPOSED ALGORITHM

When the dynamic range of a scene is extremely high, it is hard to both preserve color information and prevent gradient reversal while synthesizing the SDR image. In the proposed model, we handle these two problems separately by employing the HSV color model. The Value component is used to preserve scene information and avoid gradient reversal, while the Hue and Saturation components obtain color information from a weighted summation of input exposure images. Fig. 1 shows a block diagram of the proposed algorithm.

A. Value Component

Humans perceive an image's visual information as the difference in intensity between a corresponding pixel and its neighborhood pixels. In this paper, we call the difference in the Value component the *gradient value*. This is calculated as follows:

$$\Delta G = V(\mathbf{p}+\mathbf{d}) - V(\mathbf{p}), \tag{1}$$

where p is an image coordinate and $\mathbf{p}+\mathbf{d}$ indicates the coordinates of a neighboring pixel of $\mathbf{p}$.

Existing local operators calculate the local adaptation level using surrounding gradient information to improve the efficiency with which the dynamic range is compressed, and reproduce each pixel's intensity according to its local adaptation level. Therefore, even when two pixels have the same intensity, the results can be different—this causes the halo. In contrast, existing global operators compress the dynamic range of a scene using a one-to-one mapping, regardless of the illuminance distribution. This prevents gradient reversal, but yields poor results when the scene's dynamic range is high or the illuminance distribution is concentrated in a certain range.

To overcome these problems, both gradient information and the intensity relation should be considered at the same time. Moreover, ranges containing lots of information should be less compressed, while others should be more compressed to describe HDR scenes with SDR images. The proposed scheme synthesizes the Value component as follows.

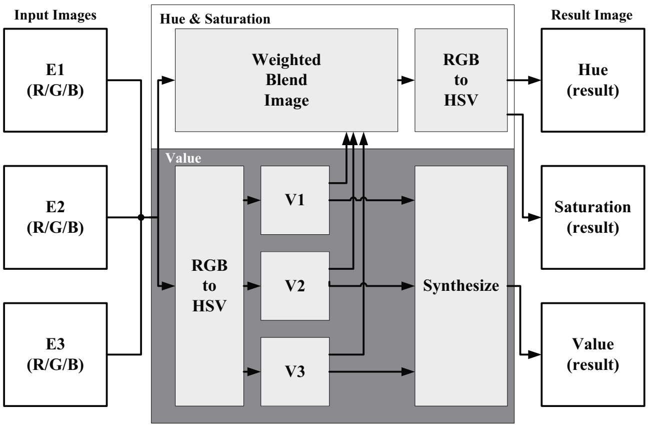

Figure 1. Block diagram for proposed HDR exposure fusion model

Step 1. Reconstruct the HDR pixel map containing the whole scene information from input LDR images. The map is reconstructed as follows:

$$V_{\text{pseudo}}(\mathbf{p}) = \mathrm{V}_1(\mathbf{p}) + \mathrm{V}_2(\mathbf{p}) + \mathrm{V}_3(\mathbf{p}), \tag{2}$$

where V_k is the Value component for each exposed image.

Step 2. Compress the HDR pixel map to the range $[0, 1]$ as follows:

$$V(\mathbf{p}) = f(V_{\text{pseudo}}(\mathbf{p}), max(V_{\text{pseudo}})). \tag{3}$$

The compression function f in (3) can be any non-decreasing function $f : [0, c] \rightarrow [0, 1]$, where $c \geq 0$. The second term is a global characteristic for a scene with a maximum value of V_{pseudo}. The simplest compression function is $f(x, range) = \frac{x}{range}$. This retains all scene information from the input LDR images, but other compression functions achieve better results. In our experiments, we use the following compression function:

$$f(x, range) = \frac{x + \alpha}{\beta \cdot range}, \tag{4}$$

where α is a constant value for increasing the minimum intensity of the HDR pixel map, and β is constant value that maps the HDR pixel map to $[0, 1]$. Simulations have shown that the optimal values of α and β are 0.15 and 1.2, respectively. Equation (4) causes the intensity distribution to be concentrated in the center, which is effective when a scene's illuminance distribution is biased toward low or high dynamic ranges in a certain region.

Equation (2) implies three major features. Basically, the HDR pixel map contains all of the visual details within a scene as represented by the input LDR images. If one or more input images contain scene details and have a non-zero gradient value, then the HDR pixel map also has a non-zero gradient value. Second, if a certain range does not contain any information, the gradient value is zero. Thus, the HDR pixel map represents only the range that contains information.

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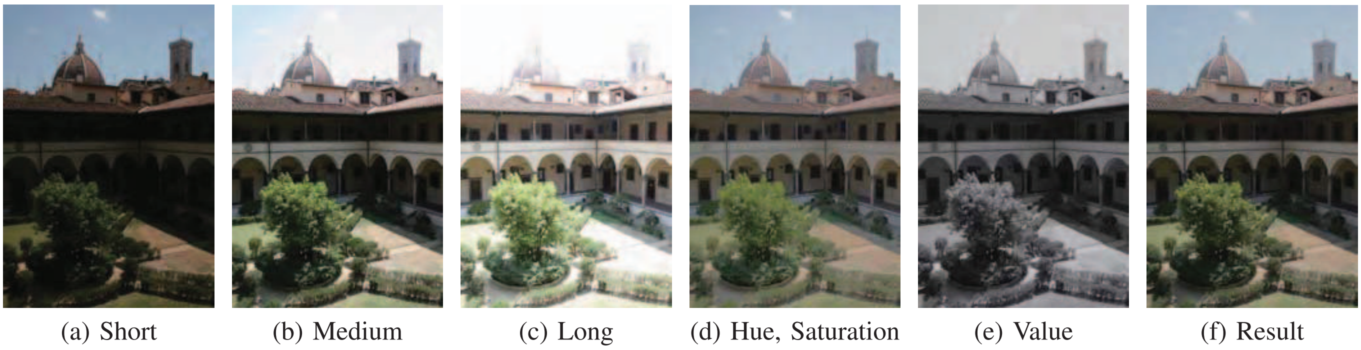

Figure 2. Example images for our proposed model. (a)–(c) input LDR images taken with different exposures, (d) weighted blend image to extract Hue and Saturation components, (e) synthesized Value component containing all information about the scene, and (f) fused result of proposed model. Image courtesy of Bartomiej Okonek.

This is the main reason that the proposed algorithm performs well when the scene's dynamic range is extremely high. Third, our method does not introduce gradient reversal, because each exposure image has the same weight for every pixel, and the compression function is a non-decreasing one-to-one correspondence.

B. Hue and Saturation Components

When the intensity of a pixel is close to the median value for all pixels, the color information is reliable. When the pixel intensity is low, the quantization error in the RGB color model and noise degrade the color information more than when the pixel intensity is high. However, when the pixel intensity is too high, color information can be damaged by saturation. In the proposed algorithm, the Hue and Saturation components are obtained from a weighted blend of the input LDR images. This blend image is constructed as $\sum_{k=1}^{3} w_k E_k / \sum_{k=1}^{3} w_k$, where E_k is the RGB image for each exposure image and w_k is given by:

$$w_k = \begin{cases} V_k(1-V_k) & \text{if } 0.1 < V_k < 0.9, \\ 0.1 & \text{otherwise.} \end{cases} \tag{5}$$

After composing the blended image in the RGB color model, the Hue and Saturation components are extracted by converting from RGB to HSV.

Fig. 2 illustrates the procedure of the proposed scheme. Fig. 2(a)–(c) shows images captured at three different exposures by an LDR capture device, and Fig. 2(d) shows the weighted blend image. Fig. 2(e) is the synthesized Value component, and Fig. 2(f) shows the final result.

IV. EXPERIMENTAL RESULTS

For our experiments, we selected a scene whose dynamic range is extremely high. Three LDR images of this scene are shown in Fig. 3. The long exposure image in Fig. 3(a) illustrates indoor information well, whereas the short exposure image in Fig. 3(c) is better for illustrating outdoor information.

In Fig. 4, the results given by the proposed algorithm are shown alongside those from three other algorithms. To compare with a global operator, the result using the method of Reinhard et al. [9] is shown in Fig. 4(a). To compare with a local operator that uses local adaptation, we show the image processed by a trial version of the PhotomatrixPro commercial software in Fig. 4(b). To compare with a local operator that uses local adaptation and halo prevention techniques, the image produced using the method of Song et al. [7] is shown in Fig. 4(c). Finally, Fig. 4(d) shows the result given by our proposed algorithm.

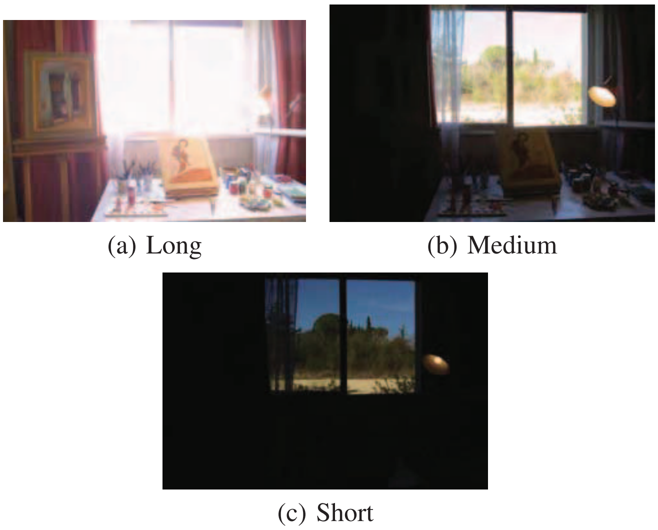

Figure 3. Three input LDR images taken with different exposure settings. Image courtesy of www.hdrsoft.com

For each image in Fig. 4, we compare the three main observation points inside the boxes. Box A is an example of a high contrast region in which a halo effect might be produced, and box B is the region in which artifacts may be produced by the lamp. The region in box C is intended to show the effects of color artifacts. Because the global operator does not produce a halo, no such effect can be observed in box A of Fig. 4(a). However, this image exhibits artifacts around the lamp in box B, as well as color artifacts in the upper right corner of box C.

In contrast, the result in Fig. 4(b) using a local operator has

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(a) Image processed by Reinhard et al. [9].

(b) Image processed by PhotomatrixPro.

(c) Image processed by Song et al. [7].

(d) Image processed by the proposed algorithm.

Figure 4. Experimental results from various algorithms. Input images are shown in Fig. 3.

no artifacts in boxes B and C, but a halo can be observed near the window in box A. In Fig. 4(c), we see that the second local operator effectively suppresses the halo in box A, and displays better visual contrast than the other images. However, artifacts are observed in boxes B and C. In Fig. 4(d), which shows the resulting image produced by the proposed algorithm, there are no artifacts in the scene, although there is less contrast than in Fig. 4(c).

Thus, our method successfully synthesizes the SDR image without any artifacts, and simultaneously preserves all of the scene details.

V. CONCLUSION

In this paper, we have presented an exposure fusion algorithm that is appropriate for outdoor applications. We focused on finding an operator that does not produce artifacts in scenes with extremely high dynamic ranges and has a low computational cost. Using the HSV color model, we prevented the appearance of color artifacts and halos. Our proposed model preserves all scene information using an HDR pixel map in the Value component, and preserves color information by blending input exposure images in the Hue and Saturation components. Moreover, our algorithm does not require information about surrounding pixels. From our experiments, it is clear that our method effectively suppresses halo effects, and uses all information from scenes with extremely high dynamic ranges.

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REFERENCES

[1] Z. Rahman, D.J. Jobson, G.A. Woodell, "Retinex processing for automatic image enhancement," *J. Electron. Imag.*, vol. 13, no. 1, pp. 100-110, Jan. 2004.

[2] E. Reinhard, M. Stark, and P. Shirley, "Photographic Tone Reproduction for Digital Images," *ACM Trans. Graph.*, vol. 21, no. 3, pp. 267-276, Jul. 2002.

[3] A. Goshtaby, "Fusion of multi-exposure images," *Image Vision Comput.*, vol. 23, no. 6, pp. 611-618, Feb. 2005.

[4] A. Varkonyi-Koczy, A. Rovid, and T. Hashimoto, "Gradient-Based Synthesized Multiple Exposure Time Color HDR Image," *IEEE Trans. Instrum. Meas.*, vol. 57, no. 8, pp. 1779-1785, Aug. 2008.

[5] Lapray, Pierre-Jean, H. Barthelemy, and G. Dominique, "HDR-ARtiSt: an adaptive real-time smart camera for high dynamic range imaging," *J. Real-Time Image Process.*, Jan. 2014. doi:10.1007/s11554-013-0393-7.

[6] R. Fattal, D. Lischinski, and M. Werman, "Gradient-domain High Dynamic Range Compression," *ACM Trans. Graph.*, vol. 21, no. 3, pp. 249-256, Jul. 2002.

[7] M. Song, D. Tao, C. Chen, J. Bu, J. Luo and C. Zhang, "Probabilistic exposure fusion," *IEEE Trans. Image Process.*, vol. 21, no. 1, pp. 314-357, Jan. 2012.

[8] F. Drago, K. Myszkowski, T. Annen and N. Chiba, "Adaptive logarithmic mapping for displaying high contrast scenes," *Comput. Graph. Forum (Proc. Eurographics),* vol. 22, no. 3, pp. 419-426, Nov. 2003.

[9] E. Reinhard and K. Devlin, "Dynamic Range Reduction Inspired by Photoreceptor Physiology," *IEEE Trans. Vis. Comput. Graphics,* vol. 11, no. 1, pp. 13-24, Jan.-Feb. 2005.