A MULTI-EXPOSURE IMAGE FUSION ALGORITHM WITHOUT GHOST EFFECT

Jaehyun An, Sang Heon Lee, Jung Gap Kuk and Nam Ik Cho

Seoul National University, Institute of New Media & Communication San 56-1,
Shilim-Dong, Gwanak-Gu, Korea

ABSTRACT

This paper proposes a new multi-exposure fusion algorithm for HDR imaging. The advantage of the fusion based method is that it does not actually generate HDR images so that the compression to LDR is also not needed. However, the conventional exposure fusion suffers from ghost effects when there are moving object or hand trembling because the output is just a weighted sum of multiple exposure input images. In order to alleviate this problem, we propose two kinds of weights in addition to the conventional weights that reflect the contrast, saturation and well-exposedness. The first is the weight that removes the pixels that can cause ghost effects, based on the observation that pixels near the boundary of moving objects often violate the rule that more highly exposed pixel have higher intensity level. The second is to reduce the weight when the correlation between an exposed image and the reference image is low. Experimental results show that the proposed method removes the ghost effectively, and yield less artifacts than the conventional methods.

Index Terms— Ghost, Exposure Fusion, High dynamic range imaging

1. INTRODUCTION

The dynamic range of most commercial image sensors and display devices are not high enough to faithfully reproduce the natural scene. Although the exposure is adjusted according to the brightness of the scene, dark pixels or saturated pixels are inevitable in many cases due to the limited dynamic range of the input/output devices. Hence there have been many researches on reproducing a scene with high dynamic range (HDR) on a display with low dynamic range (LDR). Basically, they require multiple images with different exposures on the same scene, and they can be roughly classified into the HDR generation/compression methods [1] - [2], and the image fusion methods [3] - [4]. The HDR generation methods usually find the camera response function (CRF) from the multiple exposure images and generate an HDR image based on the estimated CRF. Then the HDR image is compressed to the LDR of given display devices. In the fusion methods, the output is obtained as a weighted average of input images considering the contrast, saturation and well-exposedness. Since the fusion methods do not require the estimation of CRF and the pixel data are manipulated in the LDR, they are more efficient than the CRF estimation methods in terms of computational complexity.

The state-of-the-art image fusion methods introduced above generate quite pleasing results when a scene is multiply captured without hand-trembling and also without moving objects in the scene. If not, ghost effect is inevitable as shown in the left column of Fig. 3. Hence there have also been many researches to alleviate the ghost effects in the HDR generation/compression methods. For example, weighted variance of pixel [5] or the local entropy energy [6] are used for the fusion with less ghost effects. But they fail to remove the ghost when there is a moving object with less textures. Khan et al [7] used a motion detection algorithm to detect the pixels in the moving object and manipulate them accordingly. But this approach requires many computations and requires the assumption that the number of pixels in the background is larger than that of the object. There is also a patch based method [8] where the Poisson blending is performed for removing the boundary discontinuity. This removes the ghost successfully, but some visible seams remain if the difference of brightness among the neighboring patch is large.

This paper proposes a new method for the fusion of multiple exposure images without the ghost effects. The proposed method is based on the state-of-the-art exposure fusion [3], where the output is a weighted sum of multiple exposure images. We propose a new weight generation method that can alleviate the ghost effect, based on the photometric relation of the input images and also the zero mean normalized cross correlation (ZNCC) factor between the given and reference image. Experimental results show that the proposed method robustly composites multi-exposure images in any circumstance without ghost problem.

2. REVIEW OF EXPOSURE FUSION

The conventional exposure fusion creates the output as a weighted sum of multiple exposure images, where the weights are designed to reflect the quality of the image at each pixel : contrast, saturation and well-exposedness. Contrast is computed by applying a Laplacian filter to the grayscale version of each image, and saturation is computed as the stan-

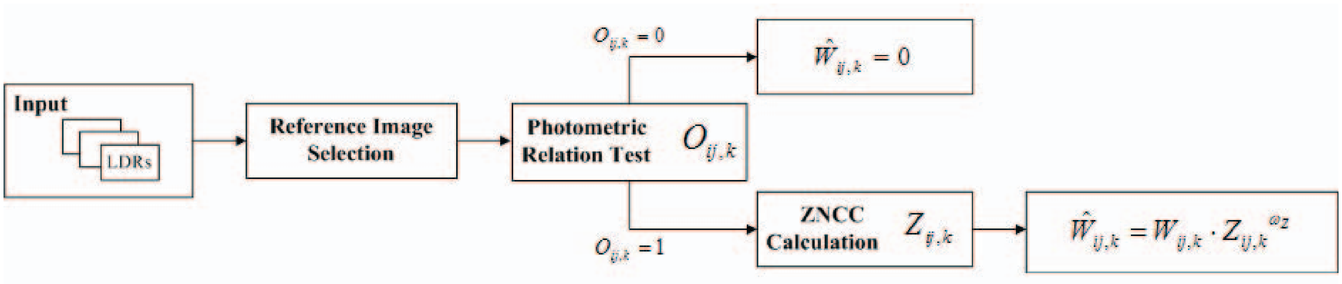


Fig. 1. Block diagram of the proposed method.

dard deviation within the R, G and B channel at each pixel. Finally the measure of well-exposedness gives more weight to pixel when its value is around the center of the dynamic range. The weighted map for each image is calculated by using these measures as

$$W_{ij,k} = \left(C_{_{ij,k}}\right)^{\omega_C} \times (S_{ij,k})^{\omega_S} \times (E_{ij,k})^{\omega_E} \quad (1)$$

where ij is the pixel position and k means the k-th exposure image and C, S and E represent contrast, saturation and well-exposedness respectively, and ω_C, ω_S and ω_E mean correponding weighting factors. Then, blending is performed at multiple resolutions using a pyramidal image decomposition [9].

3. PROPOSED WEIGHT MAP ADJUSTMENT FOR GHOST REMOVAL

The proposed method removes ghost by decreasing the weight value for a pixel when it is likely to cause ghost effect. Fig. 1 shows block diagram of the proposed method. First, we select a reference image from multi-exposure images. Since the purpose of exposure fusion is to minimize saturated region in the composite image, we select an image with the least saturated pixels as the reference image. Then we adjust the weight for each pixel by using a photometric relation and ZNCC.

3.1. Weight adjustment by photometric relation

By the reciprocity law, total exposure X of the film or sensor is represented by

$$X = E \times \Delta t \quad (2)$$

where the E means the irradiance and Δt means exposure time. Then a pixel value Z in LDR image is represented as

$$Z = f(X) \quad (3)$$

where f indicates a nonlinear CRF, which is generally a monotonic increasing function. Thus we have an inequality from photometric relation as

$$Z_1 < Z_2 \quad when \quad \Delta t_1 < \Delta t_2 \quad (4)$$

where Z_1 and Z_2 mean pixel value related with exposure time Δt_1 and Δt_2 respectively. When there are moving objects or hand trembling while taking multiple exposure photos, there occurs ghost pixels where the above inequality condition is not satisfied. In this case, the weight is set to be zero to eliminate this pixel in fusion procedure. We test this condition in the patch level and define a binary map $O_{ij,k}$ as

$$O_{ij,k} = \begin{cases} 0 & when \quad M_{ij,k} \geq 1 \\ 1 & otherwise \end{cases} \quad (5)$$

where the $M_{ij,k}$ means number of pixels which violate photometric relation in each patch containing the pixel.

3.2. Weight adjustment by ZNCC

Although the ghost effect is much alleviated by the above weight adjustment, there are some pixels that satisfy photometric relation but can cause the ghost. Hence we have to suppress these pixels by defining another weight adjustment based on the ZNCC, which is the similarity of two patterns as

$$Z_{ij,k} = \frac{\sum_{(i,j)\in W} D_{ref}(i,j) \cdot D_k(i,j)}{\sqrt[2]{\sum_{(i,j)\in W} D_{ref}(i,j)^2 \cdot \sum_{(i,j)\in W} D_k(i,j)^2}} \quad (6)$$

where

$$D_{ref}(i,j) = I_{ref}(i,j) - \bar{I}_{ref}(i,j) \quad (7)$$

$$D_k(i,j) = I_k(i,j) - \bar{I}_k(i,j)\,. \quad (8)$$

In the above equation, I_{ref} and I_k mean the reference image and the k-th exposure image respectively. We modify the weight by using the ZNCC as

$$\hat{W}_{ij,k} = \begin{cases} 0 & when \quad O_{ij,k} = 0 \\ W_{ij,k} \cdot Z_{ij,k}{}^{\omega_Z} & when \quad O_{ij,k} = 1 \end{cases} \quad (9)$$

where ω_Z means the weighting factor for the ZNCC.

4. EXPERIMENTAL RESULTS

We evaluate the proposed algorithm with various multi-exposure image sequences, including the image used in [8].

(a) (b) (c)

Fig. 2. Performance of proposed quality measures. (a) Only pixel order term, (b) Only ZNCC term, (c) Joint term

All results are obtained by using an 11×11 patch for photometric relation test and a 33×33 patch for ZNCC calculation. The weight factors of quality measure are $\omega_C = 1$, $\omega_S = 1$, $\omega_E = 1$ and $\omega_Z = 50$ for all the experiments. Fig. 2 shows the effect of the proposed weight adjustments where Fig. 2 (a) and Fig. 2 (b) show fusion results with weight adjustment by photometric-relation only and ZNCC only respectively. The results show that each method can not remove ghost perfectly. Fig. 2 (c) shows that the joint consideration of two measures can eliminate ghost successfully. Fig. 3 shows some cropped images of final fusion image. The conventional exposure fusion [3] produces high quality images, but it suffers from ghost problem around the moving parts. However the proposed method generates high quality LDR image without ghost. We also compare results with other ghost elimination algorithm. But since there has been no ghost-removal algorithm in the case of fusion based methods, we compare the results with ghost-removal algorithm based on the CRF estimation [8]. The results of [8] (middle column of Fig. 3) show ghost-free high quality LDR images, but they suffer some disturbing artifacts while the proposed method does not have such artifacts. The full-resolution results and more experimental results are available in [10].

5. CONCLUSIONS

We have proposed a new fusion based HDR imaging method, where the output is the weighted sum of multiple exposure images. The weights for the fusion are decided based on the contrast, saturation and well-exposedness in the conventional image fusion method. In addition to this, we consider the removal of pixels that can cause the ghost effect in designing the weight. Specifically, we define a weight that are forced to be zero when a pixel violates photometric relation that a more highly exposed pixel should have higher intensity level, and also another weight based on the correlation between the images. The experiments show that the proposed method removes ghost effectively, and show less artifacts that are found in the existing methods.

6. ACKNOWLEDGEMENT

This research was supported by the MKE(The Ministry of Knowledge Economy), Korea, under the ITRC(Information Technology Research Center) support program supervised by the NIPA(National IT Industry Promotion Agency) (NIPA-2010-(C1090-1011-0003))

7. REFERENCES

[1] Paul E. Debevec and Jitendra Malik, "Recovering high dynamic range radiance maps from photographs," *SIGGRAPH '97*, pp. 369–378, 1997.

[2] K. Devlin, "A review of tone reproduction techniques," *Technical Report CSTR-02-005, Computer Science*, 2002.

[3] Tom Mertens, Jan Kautz, and Frank Van Reeth, "Exposure fusion," *Proceedings of Pacific Graphics 2007*, pp. 382–390, Nov 2007.

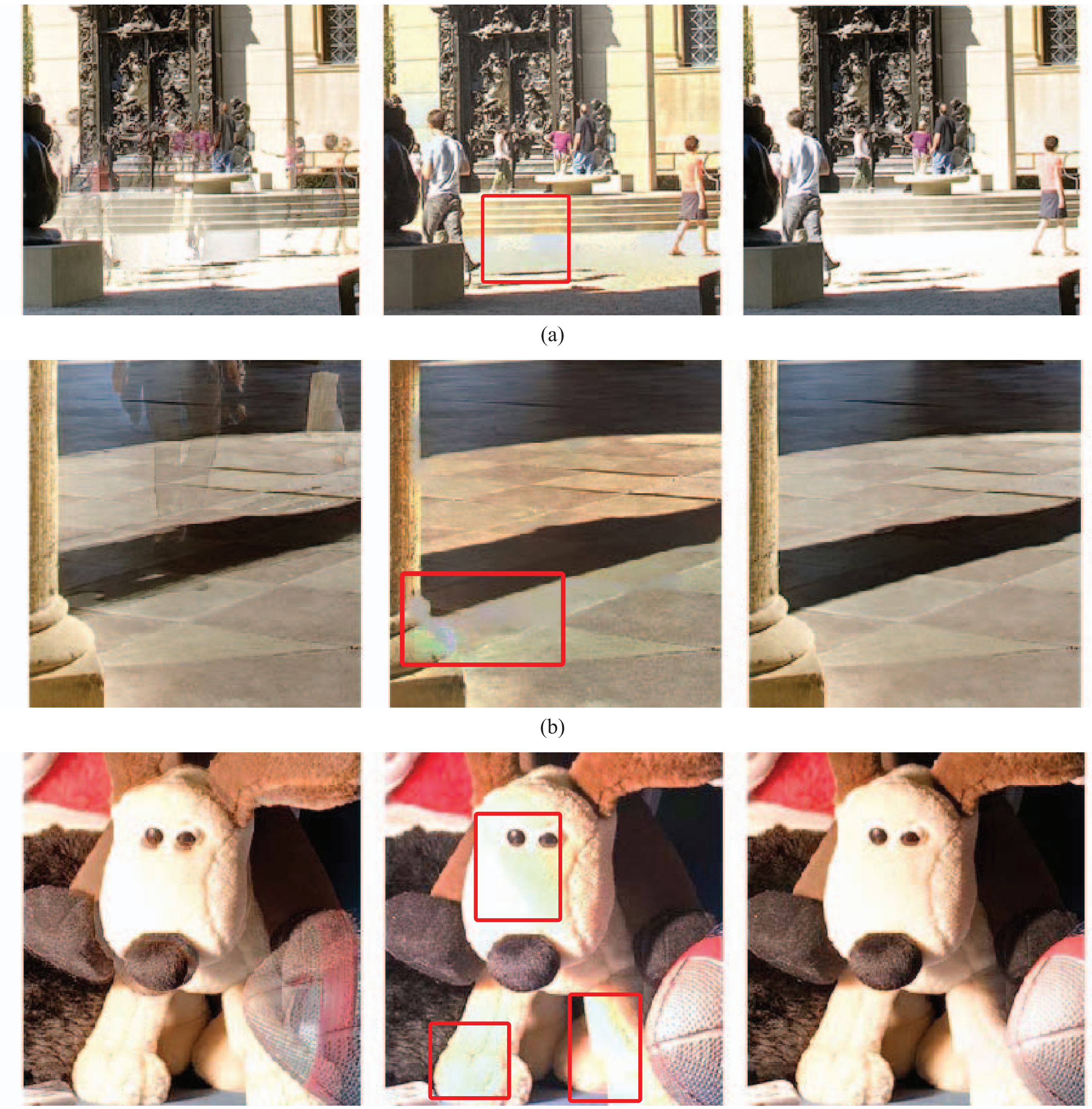
[4] A. Goshtasby, "Fusion of multi-exposure images," *Image and Vision Computing*, pp. 23:611–618, 2005.

[5] E. Reinhard, G. Ward, P. Debevec, and S. Pattanik, "High dynamic range imaging : Acquisition, display, and image based lighting," *Morgan Kaufmann*, 2005.

[6] K. Jacobs, C. Loscos, and G. Ward, "Automatic high dynamic range image generation for dynamic scenes," *IEEE Computer Graphics and Applications*, vol. 28, pp. 84–93, Mar 2008.

[7] E. A. Khan, A. O. Akyuz, and E. Reinhard, "Robust generation of high dynamic range images," *Proc. Int. Conf. Image Processing*, pp. 2005–2008, Oct 2006.

[8] O. Gallo, N. Gelfand, W. Chen, M. Tico, and K. Pulli, "Artifact-free high dynamic range imaging," *Proc. Int. Conf. Computational Photography*, April 2009.



(a)

(b)

(c)

Fig. 3. Experimental results. (a) Sculpture garden sequence (b) Arch sequence (c) Puppets sequence. Left column means results of [3], middle column means results of [8] where color distortion is observed in the red box, and right column means results of the proposed method

[9] P. Burt and T. Adelson, "The laplacian pyramid as a compact image code," *IEEE Transactions on Communication*, vol. COM-31, pp. 532–540, 1983.

[10] *http://cni.snu.ac.kr/~jhahn/ICASSP2010/ghostfree.html*.