Bilateral Filter Based Compositing for Variable Exposure Photography

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Abstract

Compositing a scene from multiple images is of considerable interest to graphics professionals. Typical compositing techniques involve estimation or explicit preparation of matte by an artist. In this article, we address the problem of automatic compositing of a scene from images obtained through variable exposure photography. We consider the High Dynamic Range Imaging (HDRI) problem and review some of the existing approaches for directly generating a Low Dynamic Range (LDR) image from multi-exposure images. We propose a computationally efficient method of scene compositing using edge-preserving filters such as bilateral filters. The key challenge is to composite the multi-exposure images in such a way so as to preserve details in both brightly and poorly illuminated regions of the scene within the limited dynamic range.

Categories and Subject Descriptors (according to ACM CCS): Computer Graphics [I.3.3]: Picture/Image Generation—Computer Graphics [I.4.3]: Enhancement—Computer Graphics [I.4.9]: Applications—

1. Introduction

Variable exposure photography involves the capture of multiple snapshots of the same scene with different exposure time settings of the camera maintaining a constant aperture. One simple example is that of auto-exposure bracketing (AEB) available with the digital cameras. Primary application of variable exposure photography is to composite the multiple exposed images in order to capture the entire dynamic range of the scene in a single image. High Dynamic Range Imaging (HDRI) techniques [RWPD05] address the generation of such a composited image by expanding the dynamic range of the resultant HDR image. HDRI methodologies require the estimation of camera response function (CRF), use standards like OpenEXR and radiance RGBE for encoding, and employ tone reproduction for display and printing purposes.

Alternatively, there are approaches which aim at compositing multi-exposure images without extending the dynamic range of the final image. The objective is to produce an image which looks like a tone-mapped HDR image without going through the typical HDRI process mentioned above. The resultant LDR image generated using these methods for a specific scene can be encoded directly in common 8-bit/channel encoding formats. Our contribution in this paper is to design an appropriate novel method based on bilateral filter to composite multi-exposure images which has marked advantages over the already existing methods. The advantages include ease of implementation, quality of compositing, and the robustness against noise. The complete design of the problem, results, and comparisons with other methods are described in later sections.

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2. Digital Compositing

Digital compositing involves computing a weighted average of the input images to properly reproduce a desired scene ([Bri99], [PD84], [Bli94]).

2.1. Compositing and HDRI Methodology

Though we consider here compositing of the pixel intensity values, the compositing involved in HDRI generation process is quite different. In HDRI, compositing is done on the irradiance values rather than the pixel intensity values ([DM97], [MP95]). The first step in HDRI is to recover the

CRF which maps intensity values to irradiance values, from the differently exposed images using the knowledge of relative shutter speeds ([DM97], [MN99]). The certainty function which is derived from the CRF then forms the matte to perform compositing on the irradiance values. The HDR image, thus obtained, requires tone reproduction for it to be displayed in normal display devices.

2.2. Image Domain Compositing

Compositing performed directly on image intensity does not lead to the generation of HDR image, but leads to the generation of an LDR image. These methods do not require any knowledge of the camera parameters. The method by Goshtasby is a block based approach which cannot handle object boundary and hence leads to artifacts while fusing multi-exposure images [Gos05]. There are two methods at present which perform better compositing: matte-less compositing [RC07] and exposure fusion [MKR07].

The proposed method is quite similar to the work of [MKR07] in the sense that we do generate an explicit α-matte for compositing and different from that of [RC07] as we do not perform any optimization. However, we do not work at different scales [MKR07], but do use the concept of local contrast [RC07] in a completely different way by defining it in terms of spectral components using a bilateral filter. Any filtering based approach suffers degradation at the edges. The edge-preserving property of the bilateral filter allows us to retain excellent properties at the edges. We demonstrate that we can get much better results using the proposed technique.

3. Bilateral Filtering

Bilateral filtering introduced by Tomasi and Manduchi in 1998 [TM98] is a non-linear technique which employs product of a Gaussian kernel in the spatial domain and a Gaussian kernel in the intensity. This makes the filtering operation edge preserving and only the fine textures present in the image are smoothed out.

Let $f(x,y)$ be the image which needs to be operated by a bilateral filter. Let G_{σ_s} be the 2-D Gaussian spatial kernel and G_{σ_r} be the 1-D Gaussian range kernel (on the intensity values). If we denote the bilateral filtered image by $f^{BF}(x,y)$, the bilateral filtering operation is as shown below.

$$f^{BF}(x,y) = \frac{\sum_{y'}\sum_{x'} f(x',y')G_{\sigma_s}(x-x',y-y')G_{\sigma_r}(f(x,y)-f(x',y'))}{\sum_{y'}\sum_{x'} G_{\sigma_s}(x-x',y-y')G_{\sigma_r}(f(x,y)-f(x',y'))} \quad (1)$$

$$G_{\sigma_s}(x,y) = \exp\left(-\frac{(x^2+y^2)}{2\sigma_s^2}\right) \quad (2)$$

$$G_{\sigma_r}(a) = \exp\left(-\frac{a^2}{2\sigma_r^2}\right)$$

where (x',y') correspond to the neighborhood of pixel location (x,y), σ_s denotes the extent of the spatial kernel and σ_r denotes the minimum amplitude to be defined as an edge.

Any direct implementation of the bilateral filter is computationally expensive. Emergence of fast algorithms such as the one by Paris and Durand [PD06] have increased the utility of bilateral filtering in a variety of computational photography applications ([BPD06], [FAR07], [ED04], [DD02]).

4. Proposed Method

The fundamental goal of compositing is to obtain mattes for the input images so that the final image has the desired features. The mattes are obtained using a function called matting function which enables one to generate appropriate matte for a given input image. It is mandatory that the matting function must be a function of the input image itself or its features for automatic compositing approach.

The desired qualities for the matting function for solving HDR problem in non-irradiance domain is that the final image must have proper contrast, well-exposedness and should not have saturation in the upper and lower intensity values [MKR07]. For a particular pixel location, the matting function must assign higher weights for intensity values from those images which have higher contrast, are well-exposed and have minimal saturation. We will now design our matting function based on bilateral filtering keeping these criteria in mind.

Our objective is to composite multiple differently exposed images into a single image which is as close as possible to the original scene. Bilateral filtering serves our purpose in the design of appropriate mattes to achieve this task. Consider a gray scale image and the bilateral filtered version of the same image. The strong edges in the image are preserved while weak edges or textures are completely smoothed out. If we calculate the difference between the input image and the bilateral filtered image, it would only have weak edges or texture information which are crucial for compositing purposes.

Weak edges and textures in images are the first casualty whenever under (or over) exposure takes place. These weak edges are lost locally. Hence they serve as ideal markers to detect over (or under) exposure. If at a given location, the weak edges are relatively strong, compared to the rest of observations, this region in that particular observation should be given a higher weight while compositing. This is the motivation behind this work.

Consider K multi-exposure images. We design our matte as the function of the difference image as shown below.

$$\alpha_m(x,y) = \frac{(C + |f_m(x,y) - f_m^{BF}(x,y)|)}{\sum_{n=1}^{K}(C + |f_n(x,y) - f_n^{BF}(x,y)|)} \quad (3)$$

where $\alpha_m(x,y)$ is the matting function, $f_m(x,y)$ are the multi-exposure images, $f_m^{BF}(x,y)$ are the corresponding bilateral filtered images, and C is a real number (assigned a value of 70 in this study). The composited image is given by $\widehat{f}(x,y) = \sum_{m=1}^{K} \alpha_m(x,y) f_m(x,y)$, $\sum_{m=1}^{K} \alpha_m(x,y) = 1$. The parameter C has two roles to play. It prevents numerical instabilities at homogeneous regions. It can also be used as a possible tuning parameter if certain interactivity is desired by an user.

5. Implementation

The implementation of the designed algorithm is quite straight forward. We use the approximate bilateral filter by Paris and Durand [PD06]. For an image $f(x,y)$ of size $M \times N$, we use the following functions to obtain σ_s and σ_r which represent the standard deviations for spatial and range Gaussian functions, respectively, in a bilateral filter.

$$\sigma_s = K_1 \times min(M,N) \tag{4}$$

$$\sigma_r = K_2 \times (max(f(x,y)) - min(f(x,y))) \tag{5}$$

where K_1 and K_2 are positive real constants. We vary K_1 and K_2 to obtain varying amount of smoothing and to vary the threshold for retaining edges, and they are assigned the values of 1 and $\frac{1}{10}$, respectively, in this study.

One way to implement our algorithm for color images is to operate on R,G, and B channels separately. Alternately, one can work in the CIELab space and work on the L channel alone for each image to obtain the respective matte. This matte can then be used to composite L,a,b channels. This approach would reduce the computation time marginally as only one bilateral filtering operation needs to be performed per image. The results are found to be quite similar to that when R, G, and B channels are processed separately to generate the mattes.

Figure 1 shows our approach for the L channel corresponding to one of the multi-exposure images. The bilateral filtered image (Figure 1(b)) shows that the small textures of the original image (Figure 1(a)) have been removed by the operation while the strong edges are preserved. The difference image in Figure 1(c) shows that the the lost details due to bilateral filering can be recovered. This provides the motivation for deciding upon the weighting function α_m for our approach.

In an Intel Xeon machine with 4GB of RAM, exposure fusion method [MKR07] takes 107 seconds while our method takes 160 seconds to composite a set of 9 RGB images of size 2464×1632 each using Matlab. We do not consider the matte-less compositing approach [RC07] for comparison as it takes much longer to composite these images.

6. Results

We test the performance of the proposed scheme on a scene captured under variable exposure. We ensure that the scene

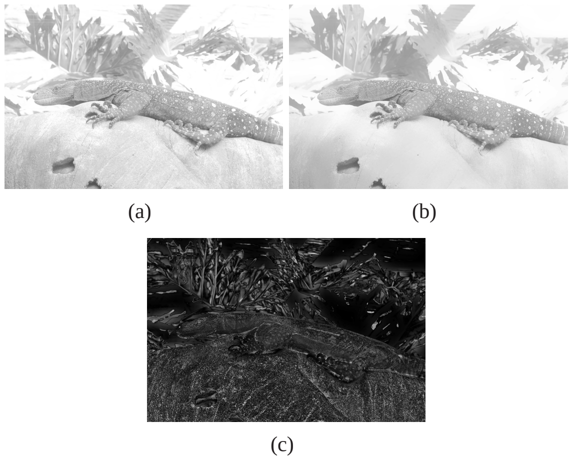
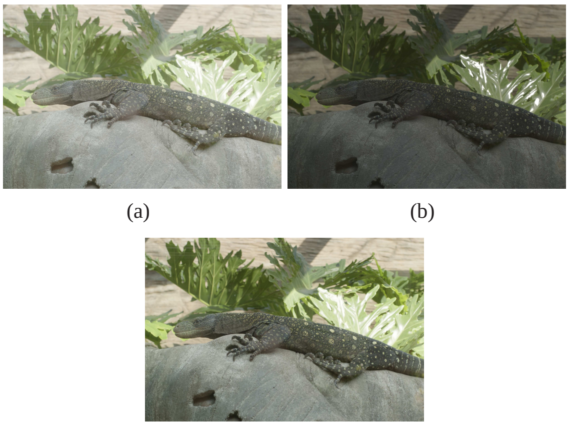


Figure 1: *(a) L-Channel of one of the multi-exposure images (L), (b) after bilateral filtering (L^{BF}), and (c) the difference image ($|L - L^{BF}|$). Image intensities are scaled for display purpose. (*Data Courtesy: *Erik Reinhard, University of Bristol.)*

has both brightly and poorly illuminated regions. This would imply that the scene has a high dynamic range and it cannot be captured using a single photograph. This requires us to capture images of the scene through variable exposure photography. The captured images will span the entire dynamic range of the scene.

Compositing results for the proposed approach, bilateral HDR compression [DD02], and exposure fusion [MKR07] are shown in Figure 2. For bilateral HDR compression, we used gamma adjustment as 1, σ_r as 2.94, σ_s as 3.06, and base contrast as 3.08 which gave the best result visually. Equally weighted quality measures ($\omega_C = \omega_E = \omega_S = 1$) are used for exposure fusion as this setting yielded better results. Visual inspection of the results reveal that the proposed approach (Figure 2(c)) produces image that has more contrast compared to that of the exposure fusion (Figure 2(a)) and bilateral HDR compression (Figure 2(b)). Compositing results in Figure 3 show that the exposure fusion produces appreciably over-exposed regions in the outdoor while our approach produces slightly under-exposed regions in the indoor.

Aydin *et al.* [AMMS08] have developed a metric which can generate a distortion map by comparing two images having different dynamic ranges.We assume that the LDR images are shown in a typical LCD display with maximum luminance 100 and gamma 2.2. We also assume that for all the LDR images, the viewing distance is 0.5 metres and the number of pixels per visual degree is 30. Significance of the choice of these parameters can be found in [AMMS08]. The distortion maps in Figure 4 for the images in Figure 2 show that the amplification of visible contrast (blue), loss of visible contrast (green) and reversal of visible contrast (red) are the least using the proposed approach.



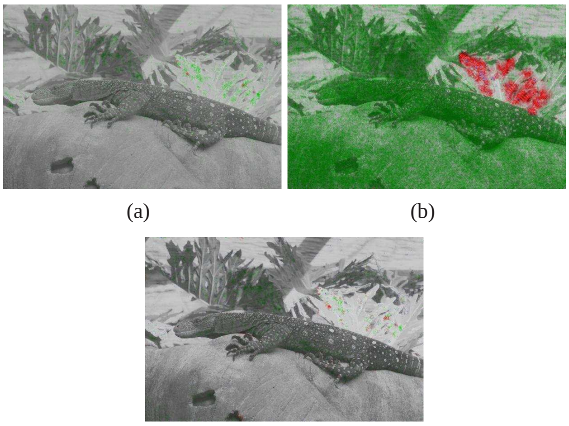
(a) (b)

(c)

Figure 2: *Results using (a) Exposure Fusion [MKR07], (b) Bilateral HDR Compression [DD02], and (c) Proposed approach.*

(a) (b)

Figure 3: *Compositing results using (a) Exposure Fusion [MKR07], (b) Proposed approach (*Data Courtesy: *Tom Mertens, Hasselt University.)*



(a) (b)

(c)

Figure 4: *Computed distortion maps for (a) Exposure Fusion [MKR07], (b) Bilateral HDR Compression [DD02], and (c) Proposed approach.*

7. Conclusions and Future Directions

Bilateral filtering based compositing approach is a novel approach to composite multi-exposure images obtained by techniques like auto exposure bracketting (AEB). The performance of our approach is shown to be better than other methods presently available for compositing such images. The implementation of our approach is very simple and is very fast. Our approach being a non-iterative one, there are no convergence issues as in the case of matte-less compositing [RC07]. Also, our approach does not require one to decompose the image into various scales as in the case of exposure fusion. The algorithm can be extended to other applications in vision and graphics where automatic matting and compositing are required.

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