SINGLE IMAGE BRIGHTENING VIA EXPOSURE FUSION

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ABSTRACT

It is very challenging to capture images via cell phone cameras in low-lighting conditions due to possible motion blur, especially for a high dynamic range (HDR) scene. In this paper, a new single image brightening algorithm is introduced to support capturing an image with a small exposure time and a small ISO value for a low-lighting scene. There are negligible motion blur and over-exposed pixels in the captured image while both details in the darkest regions and the brightness of the image are reduced. The proposed algorithm is applied to brighten the under-exposed regions and to enhance details of the under-exposed regions with negligible increment on the brightness of the brightest areas. The proposed algorithm can also be adopted to brighten an image captured for an HDR scene at day time but with dark objects.

1. INTRODUCTION

It is challenging for a photographer to tune available camera parameters in order to optimize image capture in low-lighting conditions by using most cameras, especially by cell phone cameras. Three adjustable parameters are the camera aperture, the exposure time, and the ISO value. Among them, the latter two are widely adjusted to capture an image in low-lighting conditions. An image can be captured via a long exposure time and a small ISO value. The captured image is clean but it is blurred [1]. To reduce/avoid the blurring, a short exposure time and a large ISO value is usually chosen to capture an image in low-lighting conditions. The captured image is sharp but it is noisy [1]. Meanwhile, both methods have a limitation to capture high dynamic range (HDR) scenes [2, 3] because of the possible saturation [4]. Recently, new methods were proposed to capture multiple images such as a set of noisy images [1], a set of differently exposed images [2], a pair of flash and non-flash images [5], a pair of noised and blurred images [6], etc. Although all these methods could be adopted to capture clean and sharp images, their complexity is an issue.

An attractive method for capturing an image for a low-lighting scene, especially for a low-lighting HDR scene is to use a small exposure time and a small ISO value. There is negligible or even no motion blur in the captured image due to the small exposure time. Furthermore, there are negligible or even no saturated pixels in the captured image because of the small ISO value. Clearly, the capturing method is attractive for cell phone imaging because motion blur is an issue for low light cell phone imaging. However, details in the darkest regions of the scene are not captured well, and the image is also darker because the product of the exposure time and the ISO value is smaller. It is thus desired to design an algorithm to brighten the captured image.

Inspired by the exposure fusion algorithm in [7, 8, 9], a simple but efficient algorithm is introduced in this paper to increase the brightness of the image and to enhance the details in the under-exposed regions. Three virtual differently exposed images are first generated from the image. The brightest areas of the captured scene are well-exposed in the darkest image, the darkest regions of the scene are well-exposed in the brightest one, and other parts of the scene are well-exposed in the middle one. Intuitively, the three differently exposed images can be fused via the algorithms in [7, 8, 9]. Unfortunately, neither the algorithm in [7] nor the algorithm in [9] preserves details and color in the brightest regions of the image well. Even though this problem is solved by the algorithm in [8], the relative brightness among regions is changed if none of the input images capture well certain regions of an HDR scene and the fused image might not always be visual pleasing. In addition, the complexity of the algorithms in [7, 9] could be an issue for mobile devices because all color components are fused via a multiple-scale method. A new exposure fusion algorithm is introduced in a simplified CIELAB color space to fuse the three virtual differently exposed images. Only one color component is fused via a multi-scale method while the other two components are fused via a single-scale method. The proposed fusion algorithm is thus simpler than the algorithms in [7, 9], and can run on smart phones in real time. Experimental results show that the proposed algorithm can brighten the under-exposed regions of the captured image and enhance the details of the under-exposed regions with negligible increment on the brightness of the brightest areas. The proposed algorithm can also be adopted to brighten an image captured for an HDR scene at day time but with dark objects. It is thus attractive for both low-lighting imaging and HDR imaging on mobile devices with limited computational resource such as cell phones. It is worth noting that a similar idea was adopted in [10] to convert a low dynamic range image into an HDR image.

The rest of this paper is organized as follows. A simple brightening algorithm is introduced in Section 2. Experimental results are given in Section 3 to verify the proposed algorithm. Finally, conclusion remarks are listed in Section 4.

2. SINGLE IMAGE BRIGHTENING

A novel image brightening algorithm is designed in this section. Three virtual differently exposed images are first generated from an input image which is captured via a small exposure time and a small ISO value. A simple algorithm is then designed to fuse the three virtual differently exposed images in a new color space to produce the brightened image.

2.1. Generation of Virtual Differently Exposed Images

Unlike the set of differently exposed images in [7, 8, 9], there is only one input image Z. Three virtual differently exposed images are generated from the image Z. The first image $\hat{Z}_1$ is generated

(a) (b) (c) (d)

Fig. 1. An image captured at day time but with dark human subjects and its three virtual differently exposed images.

by using a non-decreasing function to brighten the under-exposed regions of the image Z as well as a global factor to increase the brightness of the whole image Z with negligible increment on the brightness of the brightest areas. The image $\hat{Z}_1$ is produced as

$$\hat{Z}_{1,c}(p) = Y(p)(1 + \exp^{-14Y^{1.6}(p)})Z_c(p), \tag{1}$$

where c is the color channel and $Y(p)$ is the luminance component of the pixel $Z(p)$. The image $\hat{Z}_1$ can be further brightened by using a global factor to increase the brightness of the whole image $\hat{Z}_1$ with negligible increment on the brightness of the brightest areas.

The second and the third images are generated by multiplying $\hat{Z}_1$ by two constants $\frac{5\gamma}{8}$ and $\gamma(> \frac{8}{5})$ as follows:

$$\hat{Z}_{2,c}(p) = \frac{5(256 - \bar{y})}{32}\hat{Z}_{1,c}(p), \tag{2}$$

$$\hat{Z}_{3,c}(p) = \frac{256 - \bar{y}}{4}\hat{Z}_{1,c}(p), \tag{3}$$

where $\bar{y}$ is the average value of the luminance components of all under-exposed and well-exposed pixels in the image Z.

It is shown in Fig. 1 that details in the under-exposed regions of the image in Fig. 1(a) are more visible in the brightest image $\hat{Z}_3$ in Fig. 1(d). With the three virtual differently exposed images, the brightest areas are well-exposed in the image $\hat{Z}_1$, the darkest regions are well-exposed in the image $\hat{Z}_3$, and other parts are well-exposed in the image $\hat{Z}_2$. After three virtual differently exposed images are generated, they will be fused together to produce the final image. It is necessary to preserve both details and color in the brightest regions of the input image Z well in the final image. A new exposure fusion algorithm will be introduced to achieve the objective in the next subsection.

2.2. Fusion of Differently Exposed Images in a New Color Space

A simplified CIELAB color space is firstly introduced as follows:

$$\left\{ \begin{array}{l} \tilde{Z}_{i,1}(p) = \Psi(\check{Z}_{i,2}(p)) - 32 \\ \tilde{Z}_{i,2}(p) = 2(\Psi(\check{Z}_{i,1}(p)) - \Psi(\check{Z}_{i,2}(p))) \\ \tilde{Z}_{i,3}(p) = \Psi(\check{Z}_{i,2}(p)) - \Psi(\check{Z}_{i,3}(p)) \end{array} \right. , \tag{4}$$

where $\check{Z}_{i,1}(p)$, $\check{Z}_{i,2}(p)$, and $\check{Z}_{i,3}(p)$ are computed as

$$\left\{ \begin{array}{l} \check{Z}_{i,1}(p) = \frac{126\hat{Z}_{i,1}(p)+79\hat{Z}_{i,2}(p)+51\hat{Z}_{i,3}(p)}{256} \\ \check{Z}_{i,2}(p) = \frac{45\hat{Z}_{i,1}(p)+208\hat{Z}_{i,2}(p)+3\hat{Z}_{i,3}(p)}{256} \\ \check{Z}_{i,3}(p) = \frac{3\hat{Z}_{i,2}(p)+253\hat{Z}_{i,3}(p)}{256} \end{array} \right. , \tag{5}$$

and the function $\Psi(z)$ is defined as

$$\Psi(z) = \left\{ \begin{array}{ll} 16z^{0.5}; & \text{if } z \geq 64 \\ z + 64; & \text{otherwise} \end{array} \right. . \tag{6}$$

With the simplified CIELAB color space, a simple exposure fusion algorithm can be designed. Unlike the exposure fusion algorithms in [7, 9] which fuse all color components via a multi-scale algorithm, only the color component $\tilde{Z}_{i,1}(p)$ is fused via the following multi-scale algorithm:

$L\{\tilde{Z}_{i,1}(p)\}^l$ and $G\{W_i(p))\}^l$ are Laplacian pyramid of image $\tilde{Z}_{i,1}$ and Gaussian pyramid of weight map W_i, respectively. Here, the value of $W_i(p)$ is determined by the value of $\tilde{Z}_{i,1}(p)$. Pixel intensities in the different pyramid levels are blended as

$$L\{\tilde{Z}_1^{(f)}(p)\}^l = \sum_{i=1}^{3}[L\{\tilde{Z}_{i,1}(p)\}^l G\{W_i(p))\}^l]. \tag{7}$$

The pyramid $L\{\tilde{Z}_1^{(f)}(p)\}^l$ is collapsed to produce the final color component $\tilde{Z}_1^{(f)}(p)$. The other two color components are fused together via a single-scale method as follows:

$$\tilde{Z}_c^{(f)}(p) = \frac{\sum_{i=1}^{3} W_i(p)\tilde{Z}_{i,c}(p)}{\sum_{i=1}^{3} W_i(p)}; \ c = 2, 3. \tag{8}$$

The final image is computed as

$$\left\{ \begin{array}{l} Z_1^{(f)}(p) = \frac{601\Psi^{-1}(\hat{Z}_1^{(f)}(p)) - 227\Psi^{-1}(\hat{Z}_2^{(f)}(p)) - 118\Psi^{-1}(\hat{Z}_3^{(f)}(p))}{256} \\ Z_2^{(f)}(p) = \frac{-130\Psi^{-1}(\hat{Z}_1^{(f)}(p)) + 364\Psi^{-1}(\hat{Z}_2^{(f)}(p)) + 22\Psi^{-1}(\hat{Z}_3^{(f)}(p))}{256} \\ Z_3^{(f)}(p) = \frac{2\Psi^{-1}(\hat{Z}_1^{(f)}(p)) - 4\Psi^{-1}(\hat{Z}_2^{(f)}(p)) + 259\Psi^{-1}(\hat{Z}_3^{(f)}(p))}{256} \end{array} \right. , \tag{9}$$

where the function $\Psi^{-1}(z)$ is the inverse function of $\Psi(Z)$. The values of $\hat{Z}_1^{(f)}(p)$, $\hat{Z}_2^{(f)}(p)$, and $\hat{Z}_3^{(f)}(p)$ are

$$\left\{ \begin{array}{l} \hat{Z}_1^{(f)}(p) = 2(\tilde{Z}_1^{(f)}(p) + 32) + \frac{\tilde{Z}_2^{(f)}(p)}{2} \\ \hat{Z}_2^{(f)}(p) = 2(\tilde{Z}_1^{(f)}(p) + 32) \\ \hat{Z}_3^{(f)}(p) = 2(\tilde{Z}_1^{(f)}(p) + 32) - \tilde{Z}_3^{(f)}(p) \end{array} \right. . \tag{10}$$

Obviously, the proposed exposure fusion algorithm is simpler than the exposure fusion algorithms in [7, 9]. Therefore, the proposed algorithm is friendlier to mobile devices with limited computational resource such as cell phones.

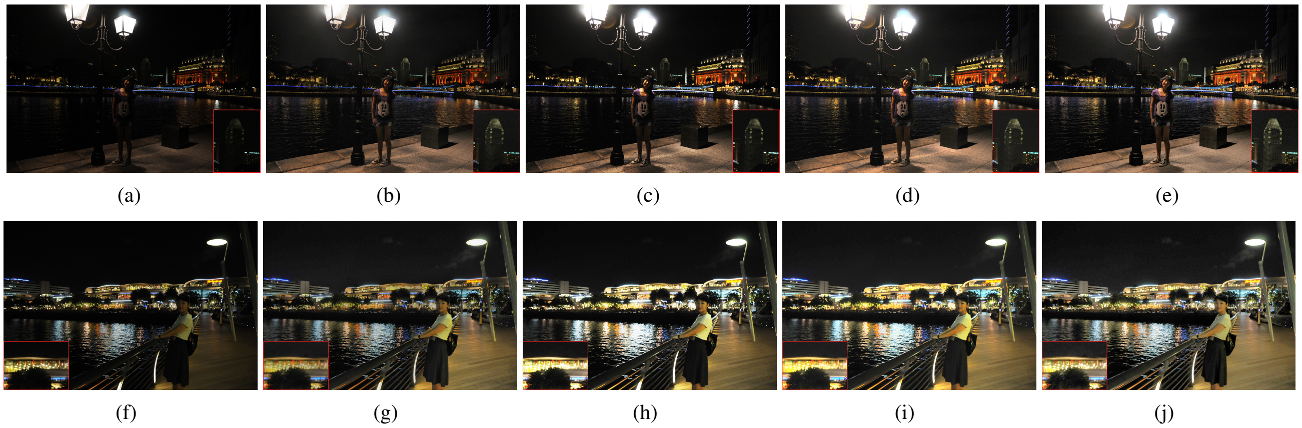

Fig. 2. Comparison of different image enhancement algorithms. (a, f) low-lighting images; (b, g) brightened images by the brightening algorithm [12]; (c, h) brightened images by the Photoshop CS5; (d, i) brightened images by the algorithm in [10]; (e, j) brightened images by the proposed algorithm.

Fig. 3. Images with dark objects and their enhanced images. (a, c) images with dark objects; (b, d) brightened images by the proposed algorithm.

3. EXPERIMENTAL RESULTS

In this section, experimental results are provided to verify the efficiency of the proposed brightening algorithm and the proposed exposure fusion algorithm. Readers are invited to view to the electronic version of the full-size figures and zoom in these figures in order to better appreciate the differences among images.

3.1. Brightening of Low-lighting Images

The proposed brightening algorithm is compared with the brightening algorithm in [10], the brightening algorithm in [12], and the brightening algorithm in the Photoshop. The brightness of images is adjusted to the maximal level by the Photoshop CS5. It is illustrated in Fig. 2 that 1) the brightness of all brightened images is increased and the details in under-exposed regions are indeed enhanced; 2) the global contrast is preserved well by the Photoshop CS 5 but the brightest regions of the images produced by the Photoshop CS5 are saturated even though the images are not as bright as those image produced by the other algorithms; and 3) saturation of the brightest regions is overcome by the algorithm in [12] while the global contrast is not preserved as well as the other algorithms. As a result, the brightened images by the algorithm in [12] look a bit flattened. The brightened images by the algorithm in [12] are darker than the brightened images by the proposed method. Color is slightly distorted by the algorithms in [12], for example the color of the white cloth in Fig. 2(f) is changed. The algorithm in [10] brightens the images well except slightly over color saturation and loss of fine details. The brightening algorithm in the Photoshop is the simplest, and followed by the proposed algorithm, the brightening algorithm in [12], and the brightening algorithm in [10]. It should be pointed out that noise in the under-exposed regions is amplified by all the brightening algorithms.

3.2. Brightening of Day-time Images with Dark Objects

Despite that sophisticated metering techniques are equipped on cameras, it remains a challenge for users to take well-exposed images, especially in presence of backlighting. Dark objects could appear when photos are taken for human subjects in a scene with the backlit. The proposed brightening algorithm is applied to brighten dark objects in two images that are captured at day time. It is shown in Fig. 3 that the darkest regions are brightened without increment on the brightness of the brightest regions.

3.3. Capturing of Images for HDR Scenes

The proposed capturing method could be an efficiency way to capture an image for an HDR scene. Since only one image is captured, neither camera movement nor moving objects is an issue for the proposed method while both of them are challenging problems for differently exposed images based methods in [13, 14] as shown in Fig. 4. In addition, the proposed brightening algorithm would neither change the color tone of the input images nor produce unrealistic effects in the final photographs. On the other hand, an image with a higher quality is produced by using multiple differently exposed images as shown in Figs. 5 and 6 if the HDR scene is static and its dynamic range is very high.

Fig. 4. Comparison of different HDR imaging methods. (a,b,c) three differently exposed images; (d) an image by the algorithm in [13]; (e) an image by the algorithm in [14]; (f) an image by the proposed brightening algorithm with the input image as in Fig. 4(b). Image courtesy of Jacques Joffre.

Fig. 5. The brightened image of the image in Fig. 6(b)

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In the remaining part of this section, the proposed exposure fusion algorithm is compared with the exposure fusion algorithm in [7] which is possibly the best exposure fusion algorithm from both complexity and image quality points of view and the exposure fusion algorithm in [8].

3.4. Comparison of Different Exposure Fusion Algorithms

All the proposed exposure fusion algorithm and the exposure fusion algorithms in [7, 8] are used to fuse two sets of differently exposed images, one for a day-time HDR scene and the other for a night HDR scene. It is shown in Fig. 6 that both the algorithm in [8] and the proposed algorithm preserve both detail and color in the brightest regions better than the algorithm in [7]. The relative brightness is changed by the algorithm in [8] if certain regions of an HDR scene are not well exposed. As a result, the fused image might not be visually pleasing. The algorithm in [8] is the simplest. The proposed algorithm is slightly simpler than the algorithm in [7] in the sense that only one color channel is fused via a multi-scale method in the proposed algorithm.

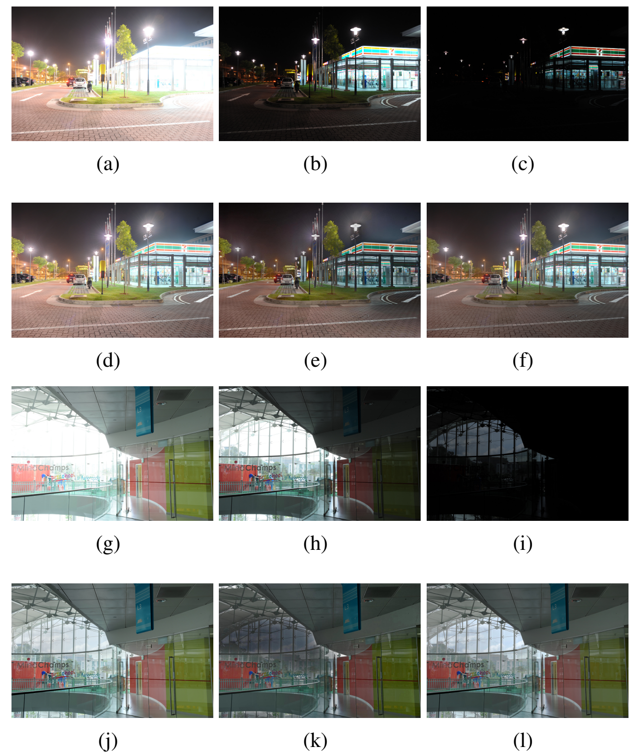

Fig. 6. Comparison of the proposed exposure fusion algorithm with the exposure fusion algorithms in [7, 8]. (a)-(c) and (g)-(i) two sets of differently exposed images; (d,j) fused images by the algorithm in [7]; (e,k) fused images by the algorithm in [8]; (f,l) fused images by the proposed algorithm.

4. CONCLUSION AND DISCUSSION

A simple algorithm is proposed to brighten a single input image and to enhance details in its under-exposed regions. The proposed brightening algorithm can be applied to support capturing an image in low-lighting conditions with a small exposure time and a small ISO value. The proposed algorithm is friendly to mobile devices with limited computational resource. In addition, the proposed algorithm is also useful for high dynamic range imaging. Only one image is captured via a small exposure time and a small ISO value. Neither camera movement nor moving objects is an issue for the proposed method while both of them are issues for multiple differently exposed images based methods in [15, 16, 17, 18]. An interesting problem for the proposed brightening algorithm is how to avoid amplifying noise in the darkest regions when details in the darkest regions are enhanced. This problem will be investigated in our future research.

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