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Single image-based spatially adaptive dynamic range extension using combined color-channels transmission map

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ABSTRACT

In this paper, a novel dynamic range extension method is presented by detecting under-exposed regions and performing spatially adaptive contrast enhancement. More specifically, a combined color-channels transmission (CCT) map is proposed to detect low-contrast regions, and spatially adaptive gain computation is used to enhance the contrast of the under-exposed regions. As a result, the proposed method can extend the dynamic range of a single input image by changing the brightness of under-exposed regions with preserving the brightness of background. Moreover, the proposed method requires less computational load than existing multiple frames-based high dynamic range (HDR) imaging methods without color distortion. For these reasons, the proposed method can be applied to various imaging devices, such as mobile phone cameras, compact digital cameras, and video surveillance systems.

1. Introduction

The human eye can perceive the luminance up to 10,000 cd/m^2 from real world scenes having a very wide dynamic range whereas practical digital image acquisition and display devices have a significantly reduced dynamic range [1]. Moreover, the dynamic range of a natural scene could be as high as 10^9:1 whereas commercial imaging devices can only provide a limited dynamic range of 800:1 [2]. For these reasons, conventional digital imaging devices can present only a partial region of the dynamic range, and thus the acquired image is subject to be under- or over-exposed as shown in Fig. 1. Therefore, a dynamic range extension method for enhancing the contrast is required.

The most popular contrast enhancement method is standard histogram equalization (SHE). Despite its simplicity, SHE cannot avoid under- or over-exposure and color distortion because it globally changes brightness [3]. For overcoming this problem, a number of modified versions have been proposed. Kim proposed bi-histogram equalization (BHE) that separates the input histogram into two sub-histograms using the mean of intensity [5]. Similarly, Wan et al. proposed dualistic sub-image histogram equalization (DSIHE) [6], which separates the input histogram into two sub-histograms using the median of intensity values. However, these methods cannot provide the higher degree of brightness preservation and contrast enhancement if histogram distribution is concentrated in a particular region. Chen and Ramli proposed recursive mean-separate histogram equalization (RMSHE) that recursively separates the input histogram into sub-histograms using the mean [7]. Major drawback of the RMSHE is the indefinite processing time since it depends on the number of separated histograms. Kim and Paik proposed gain-controllable clipped histogram equalization (GC-CHE) [8], which adaptively controls the maximum value of the histogram and the intensity transformation function by clipping histograms. Although these histogram equalization methods can enhance the contrast with preserving brightness, they can neither avoid color distortion nor extend the dynamic range. The most popular dynamic range extension method is the fusion of multiple images with different exposures [9]. However, this method requires at least two low dynamic range (LDR) images and results in ghost artifacts because of motions in the scene. For removing motion-induced ghost artifacts, several methods have been proposed. Im et al. proposed an elastic registration-based high dynamic range (HDR) imaging method that aligns LDR images using iterative affine transformations [10]. However, this method can compensate only global motion and requires high computational load because of the iterative processing. For compensating both global and local motions, Im et al. also proposed a single image-based ghost-free HDR imaging method [11], which generates two virtually different-exposure LDR images from a single input image using weighted histogram separation. However, this method still results in color distortion. Several methods used a dark channel prior to extend the dynamic range [3,4]. Such

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0030-4026/

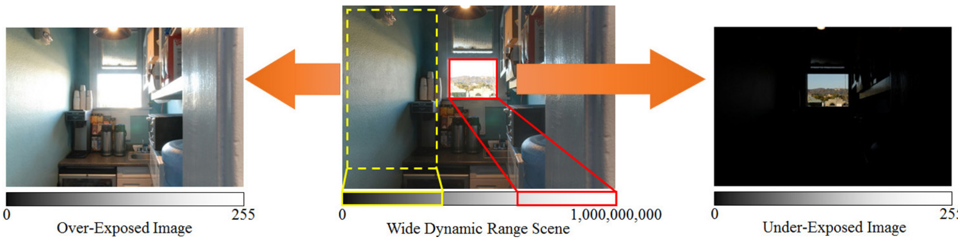

Fig. 1. Differently exposed and a wide dynamic range images.

methods extract the under-exposed region using dark channel prior, and then enhance the contrast of the under-exposed region with preserving the background. The concept of the dark channel prior is that in most non-sky patches, at least one color channel has some pixels whose intensity are very low and close to zero. It means that not only under-exposed regions but also particular color regions have very low intensity. Therefore, it may contain background in the extracted region, which results in the loss of details.

The image acquisition model for the reduced dynamic range environment is shown in Fig. 2. In order to extend the dynamic range, the proposed method detects the under-exposed regions using the combined color-channels transmission (CCT) map, and the brightness of such detected regions are changed for enhancing the contrast. Because the CCT map indicates the amount of light source that arrives from the scene to the image sensor, the brightness of the under-exposed regions can be adjusted in the spatially adaptive manner.

The flowchart of the proposed algorithm is shown in Fig. 3. The proposed method consists of two steps including: (i) generation of the CCT map and (ii) gain computation for enhancing the contrast of under-exposed regions. The proposed method can extend the dynamic range without ghost artifact because it can represent details in both background and foreground regions by enhancing the contrast of under-exposed regions in the spatially adaptive manner.

The rest of the paper is organized as follow. The CCT map-based dynamic range extension is presented in Section 2, experimental results are given in Section 3, and Section 4 concludes the paper.

2. Combined color-channels transmission map-based contrast enhancement

Usually the image is acquired by combining atmospheric light and reflectance from the surface of a subject, and can be expressed as [12]

$$g(x,y) = A(1 - t(x,y)) + f(x,y)a \cdot t(x,y), \tag{1}$$

where g represents the acquired image, A atmospheric light, t the transmission map, and f the subject. Based on the image acquisition model shown in Fig. 2, atmospheric light directly enters the image

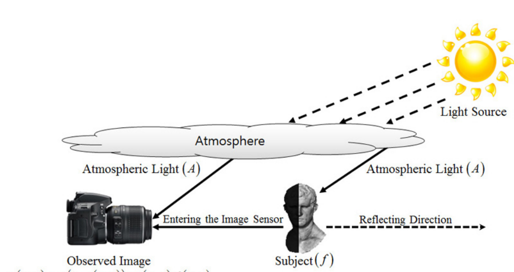

Fig. 2. The image acquisition model for the reduced dynamic range condition.

sensor, and the reflecting surface of the subject is opposite to the image sensor. Therefore, the subject's region becomes darker in the acquired image, and close to zero as

$$f^c(x,y) \approx 0, \quad c \in \{R, G, B\}, \tag{2}$$

where c represents a color channel. The modified histogram equalization and HDR imaging are popular methods for overcoming this problem. However, the modified histogram equalization method may change the pixel intensity, which does not belong to the under-exposed region because it refers only the intensity distribution. On the other hand, the HDR imaging requires the acquisition of multiple differently exposed LDR images, and the ghost artifact occurs when the LDR images are fused with relative motions among images. In order to overcome these problems, the proposed method changes the brightness of the under-exposed regions, and enhances contrast of the under-exposed regions with preserving the brightness of the background. In order to do so, the proposed method extracts the under-exposed regions using the CCT map, which indicates the amount of light entering the image sensor. The small value of transmission map means that less light enters the image sensor, and it can be considered as under-exposed region. This approach is similar to dark channel prior-based backlighting compensation (DCPBLC) methods [3,4], where the dark channel prior is used for dehazing or defogging [12]. The dark channel prior assumes that, in most non-sky patches, at least one color channel has some pixels whose intensity are very low and close to zero. It means that not only the under-exposed regions but also the pure color regions have very low intensity. Fig. 4 shows the example of this case. In the input image, the sky region contains pure colors such as red and blue as shown in Fig. 4(a). The transmission map using the dark channel prior is shown in Fig. 4(b). The color-coded transmission map is shown in Fig. 4(c). The red region needs to be enhanced, whereas the blue region preserves the original brightness. Because a pure color has high value in only one or two channels, it belongs to the under-exposed region as shown in Fig. 4(c).

In order to accurately extract only under-exposed regions, the proposed method generates the transmission map in each color channel as

$$t^c(x,y) = 1 - \frac{g^c}{A^c} + \frac{f^c(x,y)}{A^c} t^c(x,y), \quad c \in \{R, G, B\}, \tag{3}$$

where the atmospheric light A is defined as the maximum intensity in each color channel. As mentioned above, the intensity of the subject's region is close to zero since the reflecting surface is opposite to the image sensor. Therefore, Eq. (3) can be redefined as

$$t^c(x,y) = 1 - \frac{g^c}{A^c}, \quad c \in \{R, G, B\}. \tag{4}$$

The transmission map of each color channel is shown in Fig. 5. The high and low intensity values respectively represents the under-exposed and brightness preserving regions in the input image. The sky region in the red channel transmission map is darker than other transmission maps because of the sunset color. It means that even if the region is not under-exposed, it can be regarded as under-exposed region as the color channel. Therefore, the proposed