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Adaptive contrast enhancement using edge-based lighting condition estimation

Chan Young Jang [a], Suk-Ju Kang [b], Young Hwan Kim [a,*]

[a] Department of Electronics and Electrical Engineering, Pohang University of Science and Technology (POSTECH), Pohang 37673, Republic of Korea
[b] Department of Electrical Engineering, Sogang University, Seoul 04107, Republic of Korea

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ABSTRACT

This paper proposes a new approach to image contrast enhancement that improves the perceptual visual quality by considering the lighting condition and minimizing the structural distortion to a tolerable level. The proposed method consists of the following two major steps: lighting condition estimation and contrast enhancement processes. In the first step, the proposed method estimates the lighting condition by calculating the dynamic range along the edges of the image. In the second step, the method adaptively adjusts the luminance by considering both the estimated lighting condition and the order of luminance levels in order to improve the perceptual visual quality. In addition, the method properly reduces the structural distortion. Experimental results show that the proposed method improved the perceptual visual quality of various images by increasing the average structural fidelity, enhancement performance measure, entropy, and tone-mapped image quality index by up to 11%, 133%, 16%, and 11%, respectively, compared to the benchmark methods.

1. Introduction

With the recent improvement of imaging device technologies, the imaging devices can capture natural scenes that possess a high dynamic range (HDR) [1]. However, HDR images remain incapable of being displayed in display devices that are designed to display low dynamic range (LDR) images [1]. Therefore, in order to display them properly, HDR images are commonly converted into LDR images using tone mapping algorithms [1–3].

Tone mapping algorithms, which map a wide luminosity range onto a relatively narrow brightness range, cannot avoid generating poor contrast regions, which results in the poor visual quality [4]. Fig. 1(a) shows an HDR image having the high perceptual visual quality in both regions A and B. However, the LDR image in Fig. 1(b) has poor contrast regions C and D, which produce the low perceptual visual quality. Regions C and D correspond to regions A and B, respectively. To improve the perceptual visual quality, enhancing the contrast of poor contrast regions in the LDR image is necessary. Therefore, many contrast enhancement algorithms that compensate for the contrast in poor contrast regions have been proposed to improve the perceptual visual quality [5–8].

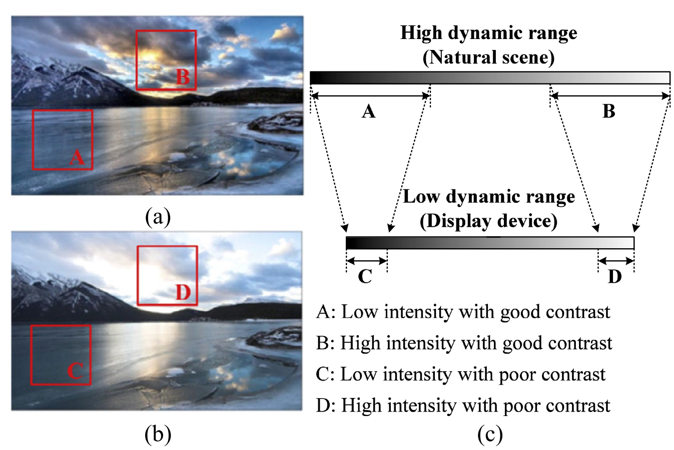

Fig. 1. Tone mapping operation that converts an HDR image into an LDR image: (a) HDR image, (b) LDR image, and (c) tone mapping operation.

Multi-scale retinex color restoration (MSRCR) has been proposed to improve the perceptual visual quality. This method extracts the illumination, which represents the effect of lighting sources, and removes it from the original image to obtain an output image. Therefore, this method increases the perceptual visual quality of the poor-contrast image that was generated under the uniform lighting condition such as fog, haze, and other unusual

* Corresponding author. Fax: +82 54 279 5933.
E-mail address: youngk@postech.ac.kr (Y.H. Kim).

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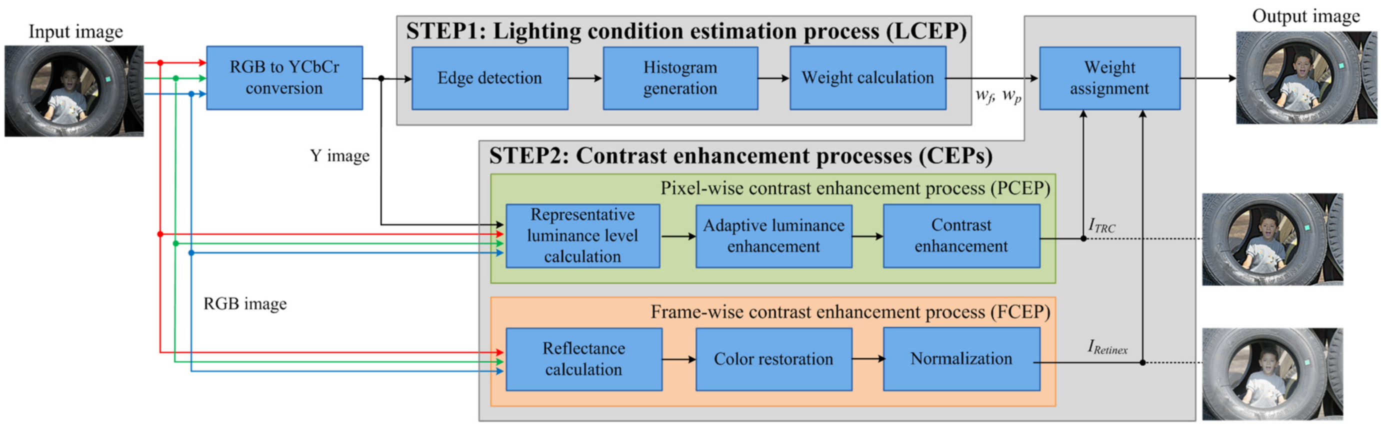

Fig. 2. Overall architecture of the proposed adaptive contrast enhancement algorithm.

weather conditions [5]. However, it adjusts the luminance without considering the order of luminance levels (OLL), which represents the ascending or descending order of pixel values and is closely correlated with the irradiance. Therefore, the processed image can be severely distorted when this method changes the OLL considerably. For example, this method usually causes a halo artifact, which is unwanted halos surrounding an object in the enhanced image [9]. In addition, it causes a graying-out, which represents the low chroma [10]. Therefore, the adaptive and integrated neighborhood dependent approach for nonlinear enhancement (AINDANE) was proposed to compensate for both the halo artifact and graying-out of MSRCR [6]. AINDANE consists of two enhancement stages: adaptive luminance enhancement and adaptive contrast enhancement. In the adaptive luminance enhancement stage, AINDANE adjusts the luminance of each pixel depending on the luminance level that corresponds to the degree of darkness in the image. Next, it enhances the contrast by adjusting the luminance of each pixel compared to that of neighboring pixels in the adaptive contrast enhancement stage. This method improves the perceptual visual quality of poor contrast regions having low luminance that were generated under uniform and non-uniform lighting conditions. However, this method cannot properly compensate for poor contrast regions having high luminance. Therefore, the methods of space-variant luminance map (SVLM) and parallel nonlinear adaptive enhancement (PNAE) were proposed to improve the perceptual visual quality of poor contrast regions having both high and low luminance [7,8]. These methods adjust the luminance of each pixel using the gamma curve or mapping function, then enhance the contrast by modifying the luminance of each pixel compared to that of neighboring pixels. These methods improve the perceptual visual quality of poor contrast regions having high and low luminance that were generated under the non-uniform lighting condition. However, these metrics do not consider the illumination of uniform lighting condition that produces the poor contrast in the whole image. Thus, they cannot properly improve the perceptual visual quality of the image generated under the uniform lighting condition. In summary, existing contrast enhancement algorithms cannot properly improve the perceptual visual quality by adjusting the luminance without considering the lighting condition in the original image.

In this paper, we propose an adaptive contrast enhancement algorithm based on the estimated lighting condition to improve the perceptual visual quality, and minimize the structural distortion to a tolerable level. The proposed method consists of a lighting condition estimation process (LCEP) and contrast enhancement processes (CEPs). In the first process, the proposed method estimates the lighting condition through the calculation of the dynamic range along the edges of the image. The weights are then calculated based on the estimated lighting condition. In the second step, pixel-wise contrast enhancement process (PCEP) and frame-wise contrast enhancement process (FCEP) are performed to improve the perceptual visual quality. Finally, an output image is obtained through the weighted sum of the images derived from PCEP and FCEP.

The remainder of this paper is organized as follows. In Section 2, we describe the proposed contrast enhancement algorithm. In Section 3, we present experimental results and evaluate the performance of the proposed method. Finally, we conclude this paper in Section 4.

2. Proposed method

2.1. Motivation of the proposed method

The lighting condition of poor-contrast images may be uniform or non-uniform. In the case of uniform lighting, the poor-contrast image generally has/poor contrast on the whole image. On the other hand, in the case of non-uniform lighting, the poor-contrast image has poor contrast locally on an image. Therefore, it is natural to enhance the contrast with different methods, depending on the lighting conditions. However, AINDANE [6] attempts to enhance the contrast without considering the lighting condition of the input image. Therefore, this method may degrade the image quality. For example, AINDANE may degrade the quality of an input image with good local-contrast, as it enhances the pixel luminance globally, independently of lighting condition. Furthermore, AINDANE uses only one parameter to enhance the pixel luminance during the luminance enhancement step. Thus, it is difficult to properly enhance the pixel luminance of a local image region which has poor contrast. In addition, AINDANE only increases the pixel luminance in the luminance enhancement step rather than increasing or decreasing the pixel luminance as necessary. Therefore, it may degrade the contrast as the output image becomes brighter overall. In order to enhance the image appropriately, the proposed algorithm first estimates the lighting condition of the input image. In the case of non-uniform lighting, the proposed method adaptively increases or decreases the luminance of each pixel based on the local luminance information. In the case of uniform lighting, the proposed method calculates the illumination of the input image and eliminates the illumination in order to improve the globally poor contrast. Fig. 2 shows the overall architecture of the proposed contrast enhancement algorithm. First, the weights for CEPs are determined based on the estimated lighting condition, which is calculated using the dynamic range along to the edges. Second, both PCEP and FCEP are performed by properly preserving the OLL of the original image. Next, the output image is generated by the weighted sum of the result images of CEPs.