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Adaptive height-modified histogram equalization and chroma correction in YCbCr color space for fast backlight image compensation☆

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ABSTRACT

Automatic exposure controls in commercially available cameras often encounter difficulties in capturing scenes with backlight luminance which dominates the entire image. An Adaptive Height-Modified Histogram Equalization (AHMHE) algorithm is proposed as a compensation technique for backlight images. It simultaneously enhances contrast in both the dark and the bright areas without creating regions of degraded local contrast. Moreover AHMHE is an adaptive algorithm: thus it requires minimal user input, and its reduced computational requirement makes it suitable for real-time application. In addition to AHMHE, a chroma correction technique was applied to chroma components in the YCbCr color space to produce more vivid color images. A series of subjective and index evaluations were conducted to measure the resultant image quality improvements by the AHMHE and the chroma correction algorithms.

1. Introduction

Most digital cameras have features like auto-exposure, auto-focus and auto-white balance that enable users to take reasonable looking pictures under various lighting conditions. However, these features are generally ineffective under backlight conditions when sunlight or fluorescent light over-illuminates the background relative to the main object in the focal region. Therefore there is a need for robust backlight compensation in digital camera design. Typically the exposure time is adjusted by the camera to capture details of the bright areas. When this happens to a backlight image, the backlighted region saturates the entire image, as pixel intensity in the bright area approaches the high end of the camera dynamic range. An illustration of this problem is shown in Fig. 1. In the backlight image, typically the bright area contains the background while the dark area contains the main object. To capture desirable images, it becomes important to determine how much luminance compensation should be added to the dark region so as to enhance contrast in the main object of the photograph. In other words, the challenge is to enhance the contrast of the dark area without degrading contrast in the bright region.

It is common to represent the color by hue, saturation and intensity, and it's been observed that human eyes are most sensitive to intensity among these components [1]. To achieve the backlight compensation in color images, contrast enhancement techniques in terms of brightness would be most effective. In addition, a saturation enhancement technique is needed to produce more vivid and colorful images. Hue, on the other hand, is preserved in the resultant images to maintain the same color from the original images.

2. Histogram equalization for contrast enhancement

There are many approaches for enhancing the contrast of images [2–9]. Techniques using histograms are most common in the contrast problem [2–6]. Among these, Histogram Equalization (HE) is the most popular method due to its simplicity and effectiveness [2]. HE uses histogram information of the image and turns them into images with uniform histogram distributions. However, this technique is less effective when the contrast characteristics vary drastically across the image as in backlight conditions. That is the bright area becomes saturated in the resultant image due to the compensation taken place in the dark area, as shown in Fig. 2. Moreover, the resultant image may have regions of decreased local contrast. This is because HE only uses global information (from the whole image) and does not consider local information of luminance variation within neighborhoods of each pixel.

To overcome these shortcomings, the Bin Underflow Bin Overflow Histogram Equalization (BUBO HE) algorithm was proposed [3]. BUBO HE prevents sharp up-swings in the mapping function to limit the compensation level and compensate the regions of having low intensity by minimizing the slope in the mapping function. However,

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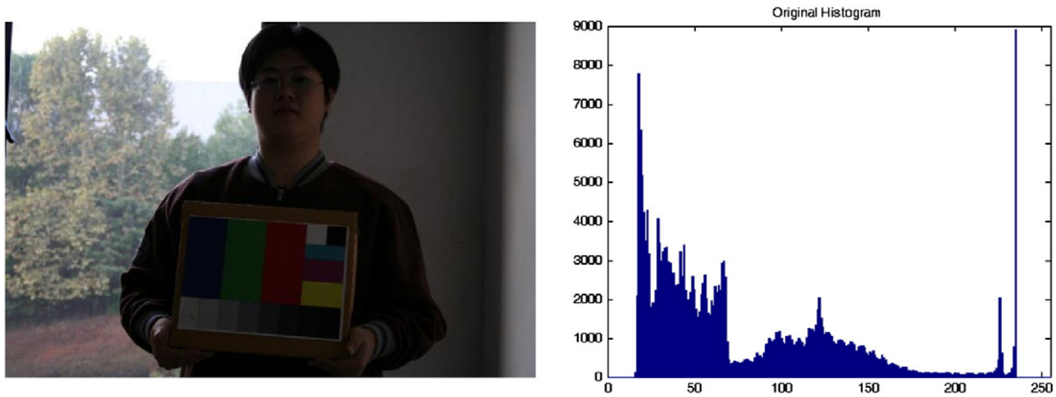

Fig. 1. Example of backlight image and its luminance histogram.

some parts of the mapping function that are controlled by threshold become a straight line, as shown in Fig. 3. Therefore the details of the resultant image in those parts become less distinguishable between pixel neighborhoods. Additionally this method does not address the decreased local contrast problem.

Adaptive HE (AHE) overcomes the decrease in the local contrast by generating a mapping function for each pixel from the histogram in the surrounding window [4]. Although this method improves the local contrast, it requires significant increase in computations. The Contrast Limited Adaptive Histogram Equalization (CLAHE) algorithm and AHE with a temporal filtering method were proposed to reduce the computational burden by a block unit process [5,6]. These methods first divide images into blocks and calculate the mapping functions of those blocks. To remove the borders of the block, the mapping function is interpolated between neighborhood blocks. To facilitate the visualization of local details, the block size must be small, however, small blocks increase the computational requirements. Thus, there is a tradeoff between the enhancement of local details and the computational loads in these methods. In addition to this short-coming, CLAHE does not use the whole dynamic range of the histogram, as shown in Fig. 4. This causes decrease in the contrast and leaves foggy images.

These methods using the histogram can be classified into two types [10]. The first type can be classified as Global Histogram Equalization (GHE) method including the HE and the BUBO HE. The second class can be termed as the Local Histogram Equalization (LHE) approaches including the AHE, the CLAHE, and the AHE with temporal filtering. As it can be inferred from the labels, these methods can be differentiated by the influence range of their mapping functions. The GHE type methods are simple and fast using look-up tables, however, they may result in regions of decreased local contrast. The LHE type results in images with good local contrasts. However, they require high computational loads.

This paper proposes an alternative algorithm termed "Adaptive Height-Modified Histogram Equalization (AHMHE)" for improving visual qualities in backlight images. The AHMHE enhances the contrast in both dark and bright areas while minimizing regions with decreased local contrast. While addressing the local contrast problem, the AHMHE maintains very low computational complexity comparable to those of the GHE types. Therefore, this processing has potentials for real-time imaging applications. From our initial trials of the method, the associated processing time compared well with the other methods commonly used for real-time imaging applications. From the cases studied here, it seems to be capable of producing high contrast in all parts of resultant images. Moreover, the AHMHE is an adaptive algorithm, which requires no external input. Fig. 5 outlines the overall operations performed by the AHMHE.

The AHMHE process is divided into three parts. The first step develops the mapping function using adaptively height-modified histograms through power operations. The second step enhances the local contrast by considering the relationships between adjacent pixels. In this step, we define the Local Contrast Map by difference operations of Luminance (Y) components with blurred Y. Detailed procedures are explained in the next section. The final step is the chroma correction to get vivid color images by considering the luminance change.

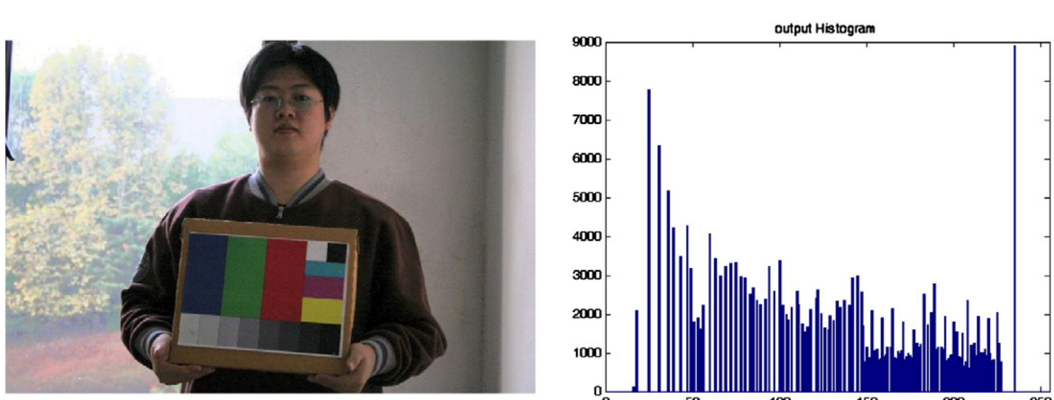

Fig. 2. HE resultant image and its luminance histogram.