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Image contrast enhancement using entropy scaling in wavelet domain

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A B S T R A C T

In this paper, we present an entropy-based contrast enhancement method in the wavelet domain. The proposed method is used in the HSI color space. The low-frequency coefficients in the wavelet domain are modified by the global histogram-based approach. The high-frequency coefficients are scaled by magnifying the entropy of the contrast defined in the wavelet domain. The contrast of the intensity component is enhanced first. Then, the saturation component of the HSI color space is linearly scaled by using the enhanced intensity component. Simulation results show that the image enhancement performance obtained by using the proposed algorithm is superior to the performance of the existing methods. In particular, the proposed approach can reveal the details and color information of low-light images without any post-processing.

1. Introduction

Contrast enhancement is a common and important task for image processing, pattern recognition and computer vision. Image contrast enhancement processes consist of a collection of techniques that seek to improve the visual appearance of an image or to convert the image to a form better suited for analysis by a human or a machine [1]. The histogram modification-based approaches are representative contrast enhancement methods. These technologies can simply preserve or change the background intensity, and modify the image histogram to obtain an enhanced image. However, histogram modification-based algorithms usually result in excessive contrast enhancement, which in turn gives the processed image an unnatural look and creates visual artifacts [2]. Various methods have been proposed to overcome the demerits of histogram modification-based approaches. Starting with bi-histogram equalization methods [3,4], improved enhancement technologies are presented to obtain a more visually-pleasing or informative image in the spatial domain [5–8]. Transform domain approaches [9,10] for contrast enhancement have been reported to improve the image quality by manipulating the transform coefficients that are mapped to the image intensities.

Another popular contrast enhancement technology called the direct method [11], establishes the criterion of contrast measurement and enhances the image by improving the contrast measurement. Thus far, many contrast measurements have been defined in the spatial domain [11,12] and the transform domain [13–15]. Direct enhancement methods can obtain an improved image contrast or visually-pleasing high-frequency components by using various contrast measures. However, some of the direct methods still suffer from noise amplification, under-enhancement, and over-enhancement which should not be generated by an ideal contrast enhancement algorithm

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[16]. Therefore, noise reduction algorithms [17–19] are often included in direct enhancement methods.

In 1991, an entropy-based contrast enhancement algorithm [20] has been presented using the magnification of the entropy of the pixels of a gray image. The basic idea of this algorithm is to enhance the contrast by transforming the global entropy. Recently, a spatial entropy-based image contrast enhancement method [21] has been reported. The cumulative distribution function for the entropy of an image is mapped to the uniform distribution function instead of the cumulative distribution function of the image pixels. To achieve both local and global contrast enhancement at the same time, this algorithm is combined with transform-domain coefficient weighting. The contrast enhancement method in [20] is one of the direct methods. On the other hand, the method presented in [21] is one of the histogram modification-based approaches. The concept of entropy is applicable to both the popular image contrast enhancement methods.

Recently, combined contrast enhancement methods that have the advantages of the histogram modification-based approaches and the direct methods in the discrete cosine transform (DCT) domain [12–14] and the discrete wavelet transform (DWT) domain [15–18] have been reported. In these algorithms, the AC coefficients are scaled followed by modifying the DC coefficients to enhance the image contrast. In 2014, a variational model of perceptually inspired color correction based on the wavelet representation for contrast enhancement [22] is introduced. However, this method has a lot of parameters, therefore, occasional failure cases such as color breakage and under- or over-enhancement according to the badly selected parameter sets. In this paper, we introduce an entropy-based contrast enhancement algorithm by exploiting both the direct method and the histogram-based approach in the wavelet domain. While maintaining the advantages of entropy-based methods, we present a new contrast enhancement algorithm by modifying low-frequency coefficients based on histogram modification, and by scaling high-frequency coefficients using entropy magnification.

The proposed method is used in the HSI color space. First, the intensity component, I, is transformed to the wavelet domain. The contrast measurement is defined on the basis of the ratio of the high-pass wavelet coefficients to the low-pass wavelet coefficients in the corresponding spatial location. The brightness and the contrast of the background component are improved by the modified wavelet low-pass coefficients by using a well-known histogram modification-based enhancement algorithm. The high-pass coefficients are updated by magnifying the entropy for the changed contrast measurement due to the brightness enhancement. The saturation component, S, in the wavelet domain is modified by the enhanced I component. In this paper, we use the linear relationship between S and I. That is, the S component is increased according to the increased I component, and vice versa. The hue component, H, is not altered in our algorithm because changing H means changing the color itself. Through experiments, we can see that the proposed method can achieve both globally and locally enhanced results. In particular, the proposed method can reveal the detail information of images very well and is effective for low-light image enhancement. Further, the proposed method achieves good results in various performance metric comparisons, and does not require an additional noise reduction process unlike the other direct contrast enhancement methods.

The rest of this paper is organized as follows. In Section 2, we briefly review the contrast enhancement methods in the transform domain. The proposed entropy-based contrast enhancement in the wavelet domain is presented in Section 3. Section 4 shows the experimental results obtained by using the proposed approach, and Section 5 presents the conclusions of this study.

2. Transform domain enhancement by coefficient scaling

There are many possible definitions of contrast. Almost all definitions represent the contrast as a ratio of the luminance change to the mean background luminance. Two definitions, namely the Michelson formula and the Weber fraction, have been commonly used for measuring the contrast of test targets [23]. In the transform domain, the DC coefficients can represent the mean background luminance, whereas the AC coefficients are considered the luminance change. Therefore, a local contrast measurement can be defined as the ratio of the AC coefficient to the DC coefficient in many transform-domain approaches [13–19].

For a given image, one of the popular contrast definition is as follows.

$$C(m,n)=\left|\frac{T_{AC}(m,n)}{T_{DC}(m,n)}\right|, \tag{1}$$

where $C(m,n)$ denotes a local contrast measurement at a location (m,n) in the transform domain, and $T_{AC}(m,n)$ and $T_{DC}(m,n)$ represent the AC coefficient and the DC coefficient of a well-known transform such as DCT or DWT, respectively. In this scheme, contrast enhancement is generally achieved by scaling $T_{DC}(m,n)$ and $T_{AC}(m,n)$ as follows.

$$T^{E}_{DC}(m,n)=\kappa_{DC}(m,n)T_{DC}(m,n), \tag{2}$$

$$T^{E}_{AC}(m,n)=\kappa_{AC}(m,n)T_{AC}(m,n), \tag{3}$$

where $T^{E}_{DC}(m,n)$ and $T^{E}_{AC}(m,n)$ denote the scaled DC coefficient and AC coefficient, respectively. $\kappa_{DC}(m,n)$ and $\kappa_{AC}(m,n)$ represent the scaling factor of the DC coefficient and AC coefficient, respectively. The scaling process results in $\kappa_{AC}(m,n)/\kappa_{DC}(m,n)$ times the contrast of the original image [15].

In recent years, transform domain methods have been developed on the basis of coefficient scaling in order to achieve enhanced contrast measurement. In [14], the DCT coefficients were separated into the illumination (DC coefficients) and reflectance (AC coefficients) components. The DC coefficients were adjusted on the basis of the Retinex theory [24] to compress the image dynamic range. To enhance the contrast, the AC coefficients were modified