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Brightness preserving based on singular value decomposition for image contrast enhancement

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ABSTRACT

This paper proposes a modification of the low contrast enhancement techniques that are based on the singular value decomposition (SVD) for preserving the mean brightness of a given image. Although the SVD-based techniques enhance the low contrast images by scaling its singular value matrix, they may fail to produce satisfactory results for some low contrast images. With the proposed method, the weighted sum of singular matrices of the input image and its global histogram equalization (GHE) image is calculated to obtain the singular value matrix of the equalized image. Simulation results show that the proposed method preserves the image brightness more precisely and enhances it with relatively negligible visual artifacts. It outperforms the conventional image equalization such as GHE and local histogram equalization (LHE), as well as the SVD techniques that based on scaling its singular value both qualitatively and quantitatively.

1. Introduction

The purpose of image enhancement is to improve the image quality so that the processed image is better than the original image for a specific application or set of objectives. There are many image enhancement methods have been proposed [1–14]. The global histogram equalization (GHE) method is one of the most popular contrast enhancement techniques. GHE is a simple and effective technique to transform a narrow histogram by spreading and stretching the dynamics range of an input image to achieve overall contrast enhancement. The local histogram equalization (LHE) method on the other hand, [4,5] can enhance the overall image contrast more effectively, but its computational complexity is much higher due to its use of fully overlapped sub-blocks. However, both GHE and LHE without any modification usually result in excessive contrast enhancement, which in turn give the processed image an unnatural look and create visual artifacts which make them not very well suited for some applications (e.g., display-processing). To overcome this drawback of conventional HE, many methods have been proposed in the literature [1–6] such as brightness preserving bi-histogram equalization (BBHE) [1] and brightness preserving dynamic histogram equalization (BPDHE) [7,8].

BBHE divides the histogram of an input image into two sub-histograms (segments) using the mean intensity as threshold and then each sub-histogram is equalized independently. The first is the histogram of intensities that are less than the mean intensity; the second is the histogram of intensities that are greater than the mean intensity. Another similar approach namely dualistic sub-image histogram equalization (DSIHE) has also developed, in which histogram segmentation was based on the median intensity value [9]. These methods may result into ineffective dynamic range expansion, thereby resulting in poor contrast enhancement of the processed image. To overcome this drawback, the Dynamic HE (DHE) [10] and BPDHE methods have been proposed. DHE expands the segments of the histogram to a new dynamic range by using the original dynamic range and the number of pixels in the corresponding segment. BPDHE method partitions the histogram based on the local maximum of the smoothed histogram. However, before applying the histogram equalization, it maps each partition to a new dynamic range. Since any changes in the dynamic range will change the mean brightness, the processed image intensity at the final stage need to be normalized. Although these methods are visually more pleasing than HE, they cannot adjust the level of enhancement.

On the other hand, singular value decomposition (SVD) based techniques have been proposed to enhance the low contrast images and to overcome the limitations associated with the HE methods [11–14]. SVD can be utilized on the pixel domain such as singular value equalization (SVE) technique [11] as well as the frequency

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domain of an image as in [12,13]. SVE technique [11] is based on equalizing the singular value matrix of the image pixels, which contains the intensity information of a given image, obtained by SVD. The technique in [12] decomposes a low contrast input image into the four frequency subbands by using DWT and estimates the singular value matrix of the low–low subband image. This technique called (DWT–SVD) reconstructs the enhanced image through the inverse discrete wavelet transform (IDWT). The performance of this technique has been compared with that of the GHE, LHE, BPDHE, and SVE techniques, and the test results show the superior visual quality of DWT–SVD over the others. Moreover, the technique based on the discrete cosine transform and singular value decomposition (DCT–SVD) [13] was also proposed to enhance the low-contrast satellite images. It should be mentioned that the SVD-based techniques enhance the low contrast images by scaling its singular value matrix. Although these techniques may preserve the mean brightness better than HE techniques, they may fail to produce better contrast enhancement.

In this paper we propose a modification of the SVD-based techniques which not only overcomes the shortfalls of the HE methods which tend to introduce unnecessary visual artifacts but this modification also alleviates the weakness existing in the SVD-based techniques. Unlike the existing SVD-based techniques, the proposed method preserves the natural appearance of the images while avoiding intensity saturation problem by calculating the weighted sum of singular matrices of the input image and its global histogram equalization (GHE) image to obtain the singular value matrix of the equalized image. Hence, the resultant image not only will have a good contrast but also it will have a natural appearance. The rest of the paper is organized as follows: the proposed contrast enhancement technique is explained in Section 2. Simulation results are presented in Section 3. The concluding remarks are given in Section 4.

2. Proposed technique

Singular value decomposition (SVD) has been used for feature extraction, compression, and face recognition [15] as well as for the enhancement of the low contrast images [11,12]. In [11], SVD is used to deal with an illumination problem and hence to enhance the low contrast images. SVD of an image can be represented as a matrix in the form of:

$$I = U_I \Sigma_I V_I^T \tag{1}$$

where U_I and V_I are orthogonal square matrices known as hanger and aligner, respectively, and the Σ_I matrix contains the sorted singular values on its main diagonal. The singular value matrix represents the intensity information of the image and hence any modifications on the singular values will alter the intensity of the input image. Therefore, the SVD can be used for image equalization. The SVD uses the ratio of the largest singular value of the generated normalized matrix, with mean zero and variance of one, over a normalized image which can be calculated according to

$$\xi = \frac{\max\left(\Sigma_{N(\mu=0,\,var=1)}\right)}{\max(\Sigma_I)} \tag{2}$$

where $\Sigma_{N(\mu=0,\,\mathrm{var}=1)}$ is the singular value matrix of the synthetic intensity matrix. This coefficient can be used to generate an equalized image using

$$E_{\mathrm{equalized}I} = U_I \left(\xi \Sigma_I\right) V_I^T \tag{3}$$

where $E_{\mathrm{equalized}I}$ denotes the equalized image I. In SVE, the new singular value matrix $\bar{\sum}_I$ of the equalized image is obtained by scaling up the singular values of the input image (Σ_I) using the correction coefficient ξ which is obtained as:

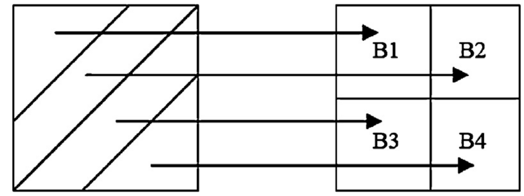

Fig. 1. Mapping of the DCT coefficients into 4 blocks.

$$\xi = \frac{\max(\Sigma\hat{I})}{\max(\Sigma_I)} \tag{4}$$

where $\Sigma\hat{I}$ is the singular matrix of the processed image using the GHE since the mean brightness of the histogram-equalized image is always the mid-gray level regardless of the mean of the input image.

In the DWT–SVD technique [12], an input image is decomposed into the four frequency subbands by using DWT and ξ is calculated as

$$\xi = \frac{\max(\Sigma_{LL\hat{I}})}{\max\left(\Sigma_{LL_I}\right)},$$

where Σ_{LL_I} and $\Sigma_{\mathrm{LL}\hat{I}}$ are the low–low (LL) singular value matrices of the input image and the output of the GHE, respectively. The new LL subband image $\left(\mathrm{L\bar{L}}_I\right)$ is then obtained by:

$$\mathrm{L\bar{L}}_I = U_{\mathrm{LL}_I}\left(\xi \sum\nolimits_{\mathrm{LL}_I}\right) V_{\mathrm{LL}_I}^T \tag{5}$$

The enhanced image is obtained by applying IDWT into the new LL $\left(\mathrm{L\bar{L}}_I\right)$, LH, HL, and HH subands to generate the resultant equalized image.

With the DCT–SVD method [13], the two-dimensional DCT transform is applied to the whole low contrast input image as well as to its GHE equalized version. The obtained DCT coefficients from both images are mapped from the lowest to the highest frequency coefficients in a zigzag scan order into four quadrants labeled B1, B2, B3, B4 such that each quadrant has the same number of DCT coefficients. This process is depicted in Fig. 1. The quadrant B1 is similar to the LL subband of the DWT–SVD method while B2, B3, and B4 are similar to HL, LH, and HH subbands, respectively. The SVD is then applied to the quadrant B1 of the two images and the singular values in quadrant B1 of the low contrast image is modified. The modified DCT coefficients in B1 and the other three quadrants are mapped back to their original positions. Finally, the inverse DCT is applied to produce the enhanced image. The flow chart of both the DWT–SVD and DCT–SVD methods is illustrated in Fig. 2.

This mechanism of contrast enhancement by scaling the singular values could fail to produce satisfactory results for some low contrast images especially for the images with mid-range of brightness The reason behind that is ξ for that images is close to 1 and in this case the difference between the new singular value matrix $\bar{\sum}_I$ of the equalized image and $\sum_I$ is very small. Hence the intensity of the input image doesn't change significantly.

To overcome this problem in this paper, the new singular value matrix $\bar{\sum}_I$ of the equalized image can be modified to include the singular matrix of the input image and the singular matrix of the output image of the GHE. $\bar{\sum}_I$ is represented as the weighted sum of both $\sum_I$ and $\Sigma\hat{I}$ and can be written as:

$$\bar{\sum}_I = 0.5\left(\xi \Sigma_I + \frac{1}{\xi}\Sigma\hat{I}\right) \tag{6}$$