Image Contrast Enhancement Using Singular Value Decomposition for Gray Level Images

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Abstract− In this letter analysis the satellite images by using discrete wavelet transform and singular value decomposition. The input image is decomposes into the four frequency subbands by using DWT and estimates the singular value matrix of the low–low subband image and then it reconstructs the enhanced image by applying inverse DWT. The technique is compared with conventional image equalization techniques such as standard general histogram equalization and local histogram equalization as well as state-of-the-art techniques such as brightness preserving dynamic histogram equalization. The experimental results show the superiority of the proposed method over conventional methods.

Key words− Discrete wavelet transform, Image equalization, satellite image contrast enhancement.

I. INTRODUCTION

In many applications such as geosciences studies, astronomy, and geographical information systems the satellite images are used. One of the most important quality factors in satellite images comes from its contrast. Contrast enhancement is frequently referred to as one of the most important issues in image processing. Contrast is created by the difference in luminance reflected from two adjacent surfaces. In visual perception, contrast is determined by the difference in the color and brightness of an object with other objects. Our visual system is more sensitive to contrast than absolute luminance; therefore, we can perceive the world similarly regardless of the considerable changes in illumination conditions. If the contrast of an image is highly concentrated on a specific range, the information may be lost in those areas which are excessively and uniformly concentrated. The problem is to optimize the contrast of an image in order to represent all the information in the input image.

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There have been several techniques to overcome this issue [1]–[4], such as general histogram equalization (GHE), local histogram equalization (LHE) and brightness preserving dynamic histogram equalization (BPDHE) [5].

In many image processing applications, the GHE technique is one of the simplest and most effective primitives for contrast enhancement [7], which attempts to produce an output histogram that is uniform [8]. One of the disadvantages of GHE is that the information laid on the histogram or probability distribution function (PDF) of the image will be lost. Demirel and Anbarjafari [9] showed that the PDF of face images can be used for face recognition; hence, preserving the shape of the PDF of an image is of vital importance. The state-of-the-art technique BPDHE is obtained from dynamic histogram specification [10] which generates the specified histogram dynamically from the input image. Singular value decomposition (SVD) of an image, which can be interpreted as a matrix, is written as follows:

$$A = U_A \Sigma_A V^T{}_A \quad (1)$$

where U_A and V_A are orthogonal square matrices known as hanger and aligner, respectively, and the Σ_A matrix contains the sorted singular values on its main diagonal. The idea of using SVD for image equalization comes from this fact that Σ_A contains the intensity information of a given image [11].

In our earlier work [6] and [9], SVD was used to deal with an illumination problem. The method 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

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

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

$$\Xi_{\mathrm{equalized}A} = U_A\,(\xi\Sigma_A)\,V_A^T \quad (3)$$

where $\Xi_{\mathrm{equalized}A}$ is representing the equalized image A. This task is eliminating the illumination problem. Nowadays, wavelets have been used quite frequently in image processing. They have been used for feature extraction [12], de-noising [13], compression [14], face recognition [15], and satellite image super-resolution [16]. The decomposition of images into different frequency ranges permits the isolation of the frequency components introduced by “intrinsic deformations”

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or "extrinsic factors" into certain subbands [17]. This process results in isolating small changes in an image mainly in high frequency subband images. Hence, discrete wavelet transform (DWT) is a suitable tool to be used for designing a post invariant face recognition system. The 2-D wavelet decomposition of an image is performed by applying 1-D DWT along the rows of the image first, and, then, the results are decomposed along the columns. This operation results in four decomposed subband images referred to as low–low (LL), low–high (LH), high–low (HL), and high–high (HH). The frequency components of those subband images cover the frequency components of the original image.

In this letter, we have proposed a new method for satellite image equalization which is an extension of SVE, and it is based on the SVD of an LL subband image obtained by DWT. DWT is used to separate the input low contrast satellite image into different frequency subbands, where the LL subband concentrates the illumination information. That is why only the LL subband goes through the SVE process, which preserves the high-frequency components (i.e., edges). Hence, after inverse DWT (IDWT), the resultant image will be sharper with good contrast. In this letter, the proposed method has been compared with the conventional GHE, LHE and BPDEH. The results indicate the superiority of the proposed method over the after mentioned methods.

II. PROPOSED IMAGE CONTRAST ENHANCEMENT

There are two significant parts of the proposed method. The first one is the use of SVD. As it was mentioned, the singular value matrix obtained by SVD contains the illumination information. Therefore, changing the singular values will directly affect the illumination of the image; hence, the other information in the image will not be changed. The second important aspect of this work is the application of DWT. As it was mentioned in Section I, the illumination information is embedded in the LL sub band. The edges are concentrated in the other sub bands (i.e., LH, HL, and HH). Hence, separating the high-frequency sub band and applying the illumination enhancement in the LL sub band only will protect the edge information from possible degradation. After reconstructing the final image by using IDWT, the resultant image will not only be enhanced with respect to illumination but also will be sharper.

The general procedure of the proposed technique is as follows. The input image A is first processed by using GHE to generate $\hat{A}$. Then, both of these images are transformed by DWT into four sub band images. The correction coefficient for the singular value matrix is calculated by using the following equation:

$$\zeta = \frac{\max(\Sigma_{LL\hat{A}})}{\max(\Sigma_{LLA})} \tag{4}$$

where Σ_{LLA} is the LL singular value matrix of the input image and $\Sigma_{LL\hat{A}}$ is the LL singular value matrix of the output of the GHE. The new LL image is composed by

$$\overline{\Sigma}_{LLA} = \zeta \, \Sigma_{LLA}$$
$$\overline{LL}_A = U_{LLA}\overline{\Sigma}_{LLA}V_{LLA} \tag{5}$$

Now, the $\overline{LL}_A$, LH_A, HL_A, and HH_A sub band images of the original image are recombined by applying IDWT to generate the resultant equalized image $\overline{A}$

$$\overline{A} = IDWT\left(\overline{LL}_A, LH_A, HL_A, HH_A\right) \tag{6}$$

In this letter, we have used the 'Harr' wavelet function. In the following section, the experimental results and the comparison of the after mentioned conventional techniques are discussed.

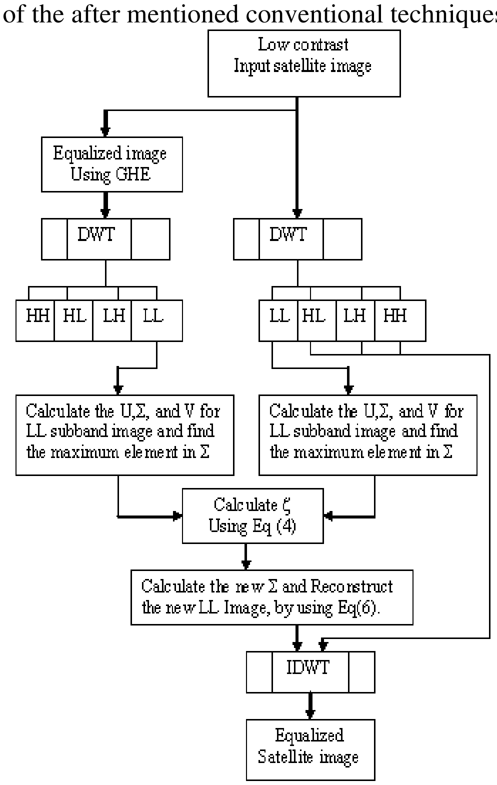

Fig.1. Detailed steps of the proposed equalization technique

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

Figs. 2(a), 3(a), and 4(a) show the low-contrast images taken from several aerospace and geosciences resources. These images have been equalized by using GHE [Figs. 2(b), 3(b), and 4(b)], LHE [Figs. 2(c), 3(c), and 4(c)], BPDHE [Figs. 2(d), 3(d), and 4(d)] and the proposed equalization technique [Figs. 2(e), 3(e), and 4(e)]. The quality of the visual results indicates that

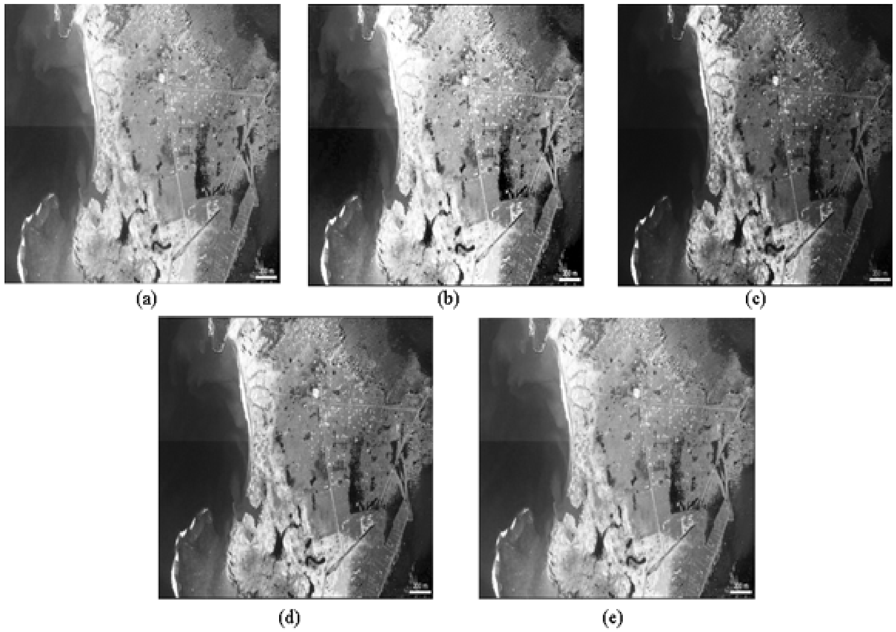

Fig. 2. (a) Original low-contrast image, (b) GHE, (c) LHE, (d) BPDHE, and (e) the proposed technique.

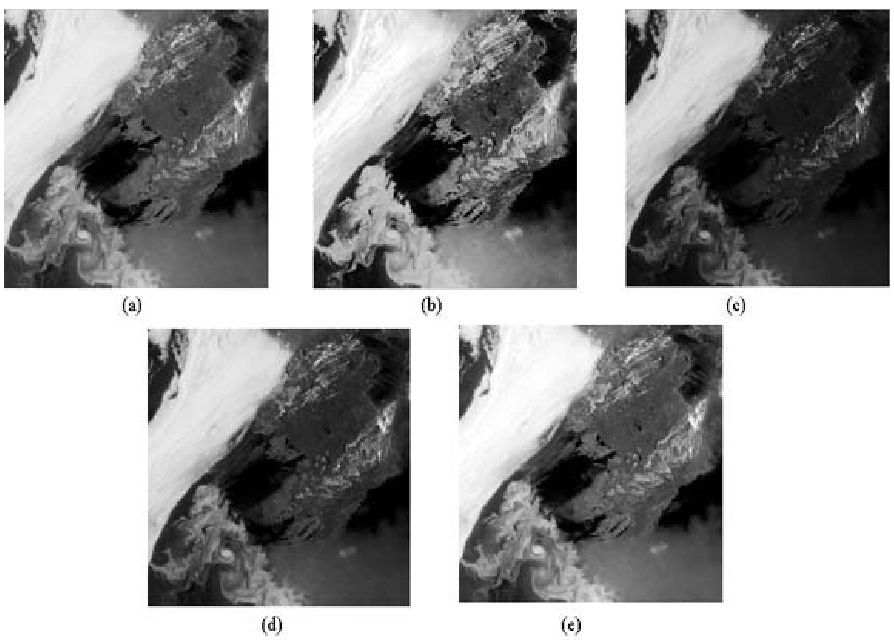

Fig. 3. (a) Original low-contrast image, (b) GHE, (c) LHE, (d) BPDHE, and (e) the proposed technique.

the proposed equalization technique is sharper and brighter than the one achieved by GHE, LHE, and BPDHE.

Experiments have been performed on over 100 randomly selected images from various sources which confirmed the qualitative results. In order to support the qualitative conclusions on the superiority of the proposed method, a quantitative analysis is required. However, when the ground truth that represents the original image is missing, a quantitative error analysis on the enhanced image is not possible. In an attempt to estimate the quantitative performance, we propose to analyze the estimated Gaussian distribution of the enhanced images which are modeled by using the calculated mean (μ) and standard deviation (σ) of the output images.

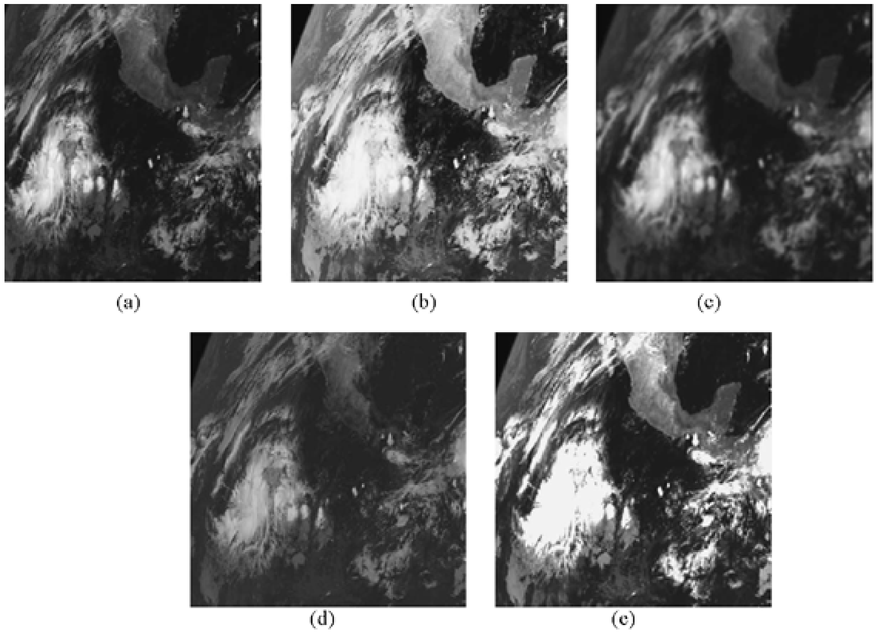

Fig. 4. (a) Original low-contrast image, (b) GHE, (c) LHE, (d) BPDHE, and (e) the proposed technique.

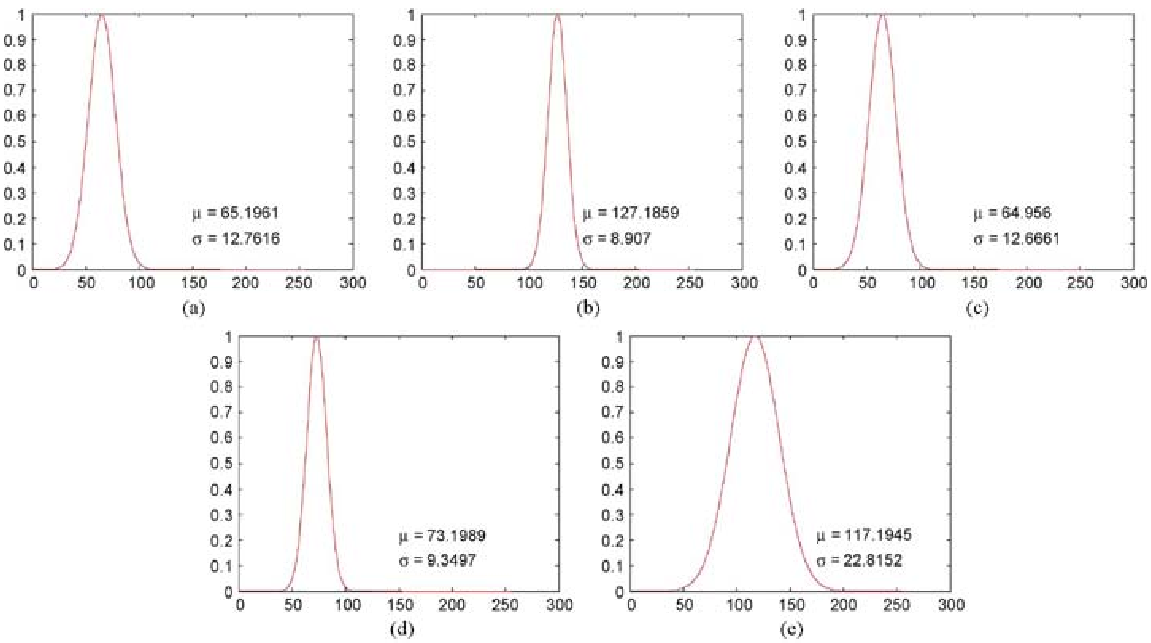

Fig. 5. Estimated Gaussian distribution for Fig. 4(a)-(e), respectively.

Any pixel of an image can be considered as a random variable with a distribution function. According to the central limit theorem, the sum of a sequence of random variables tends to have a Gaussian distribution [18]. In line of this assumption; Fig. 5 shows the Gaussian distributions of the images used in Fig. 4. The table 1 shows the corresponding mean values of original image, GHE, LHE, BPDHE and the proposed method and the chart is drawn. It is clear from these distributions that the estimated Gaussian functions of the GHE and the proposed method have means which are close to the ideal mean (μ=128) for the gray level range [Fig. 4(b) and (e) with μ = 127.19 and 117.19 respectively]. However, the estimated Gaussian distribution of the proposed method covers a wider gray level range [Fig. 5(e)]; that is why it has better illumination. Thus, this analysis supports the qualitative observation that the proposed method over performs the conventional techniques.

Table 1

	Methods	Mean value
1	Original image	65.1961
2	GHE	127.186
3	LHE	64.956
4	BPDHE	73.1989
5	The proposed technique	117.195

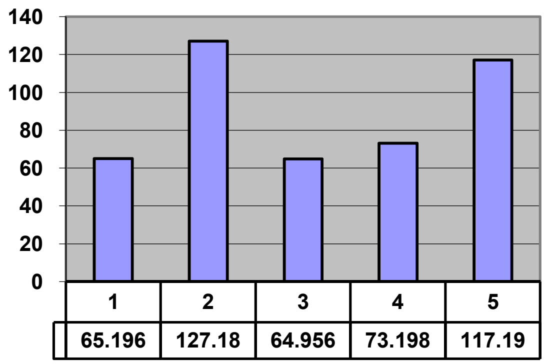

Fig. 6. The comparison chart

IV. CONCLUSION

In this letter, a new satellite image contrast enhancement technique based on DWT and SVD was proposed. The proposed technique decomposed the input image into the DWT subbands, and, after updating the singular value matrix of the LL subband, it reconstructed the image by using IDWT. The proposed technique mean value was compared with the GHE, LHE and the state-of-the-art technique BPDHE in chart. The visual results on the final image quality show the superiority of the proposed method over the conventional methods and the state-of-the-art technique.

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