An Improved Method for Contrast Enhancement of Real World Hyperspectral Images

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Abstract. This paper proposed an improved method for contrast enhancement of real world hyperspectral images. The proposed method consists of two stages: In first stage the poor quality of image is processed by adaptive histogram equalization in spatial domain and in second stage the output of first stage is further processed by adaptive filtering for image enhancement in frequency domain. Simulation and experimental results on benchmark real world hyperspectral image database demonstrates that proposed method provides better results as compared to other state-of-art contrast enhancement techniques such as alpha rooting (AR), multi contrast enhancement (MCE), multi-contrast enhancement with dynamic range compression (MCEDRC), brightness preserving dynamic fuzzy histogram equalization (BPDFHE). Proposed method performs better for different dark and bright real world hyperspectral images by adjusting their contrast very frequently. Proposed method is simple and efficient approach for contrast enhancement of real world hyperspectral images. This method can be used in different applications where images are suffering from various contrast problems.

Keywords: Adaptive Histogram Equalization, real world hyperspectral image, Image processing, Contrast Enhancement.

1 Introduction

The contrast enhancement techniques are commonly used in various applications where subjective quality of image is very important. The objective of image enhancement is to improve visual quality of image depending on the application circumstances. Contrast is an important factor for any individual estimation of image quality. It can be used as controlling tool for documenting and presenting information collected during examination.

The contrast enhancement of image refers to the amount of color or gray differentiation that exists between various features in digital images. It is the range of the brightness present in the image. The images having a higher contrast level usually display a larger degree of color or gray scale difference as compared to lower contrast level. The contrast enhancement is a process that allows image features to show up more visibly by making best use of the color presented on the display devices.

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During last decade a number of contrast enhancement algorithms have been developed for contrast enhancement of images for various applications. Histogram equalization [1], global histogram equalization [2], local histogram equalization [3], adaptive histogram equalization and contrast limited adaptive histogram equalization [4]-[5], other histogram equalization based algorithms [6]-[14] and other contrast enhancement methods [15][16] have been proposed by various researchers. One of the most widely used algorithms is global histogram equalization, the basic idea of which is to adjust the intensity histogram to approximate a uniform distribution. It treats all regions of the image equally and, thus often yields poor local performance in terms of detail preservation of image.

The outline of this paper is as follows. Section 2 describes literature review. Section 3 describes proposed method for contrast enhancement of real world hyperspectral images. Section 4 gives simulation results and discussions to demonstrate the performance of proposed method. Finally, conclusion is drawn in section 5.

2 Literature Review

The existing contrast enhancement techniques for mobile communication and other real time applications is fall under two broad categories that is contrast shaping based methods and histogram equalization based methods [1]. These methods are derived from digital image processing. These methods may lead to over-enhancement and other artifacts such as flickering, and contouring. The contrast shaping based methods are work by calculating an input-output luminance curve defined at every luminance level. The shape of the curve must depend on the statistics of the image frame being processed. For example, dark images would have a dark stretch curve applied to them. Although contrasts shaping based methods are the most popular methods used in the consumer electronics industry but they cannot provide a localized contrast enhancement which is desirable. For example, when a dark stretch is performed, bright pixels become brighter. However, a better way to enhance darker images is to stretch and enhance the dark regions, while leaving brighter pixels untouched [1, 17].

A very popular technique for contrast enhancement of image is histogram equalization technique [3, 1, 2]. A histogram equalization is a technique that generates gray map which change the histogram of image and redistributing all pixel values to be as close as possible to user specified desired histogram. This technique is useful for processing images that have little contrast with equal number of pixels to each the output gray levels. The histogram equalization (HE) is a method to obtain a unique input to output contrast transfer function based on the histogram of the input image which results in a contrast transfer curve that stretches the peaks of the histogram (where more information is present) and compresses the troughs of the histogram (where less information is present) [1]. Therefore it is a special case of contrast shaping technique. As a standalone technique, histogram equalization is used extensively in medical imaging, satellite imagery and other applications where the emphasis is on pattern recognition and bringing out of hidden details. Thus histogram equalization results in too much enhancement and artifacts like contouring which is unacceptable in consumer electronics [4, 5]. During last decade a number of techniques have been proposed by various researchers to deal with these problems. In [10], the histogram is divided into two parts based on the input mean and each part is equalized, separately. This preserves the mean value of image to a certain extent. In [7], each peak of the histogram is equalized separately. An adaptation of HE, termed as contrast limited adaptive histogram equalization (CLAHE) [5] divides the input image into a number of equal sized blocks and then performs contrast limited histogram equalization on each block. The contrast limiting is done by clipping the histogram before histogram equalization. This tends to tone down the over enhancement effect of histogram equalization and gives a more localized enhancement. However it is much more computationally intensive than histogram equalization. If the blocks are non-overlapping, an interpolation scheme is needed to prevent blocky artifacts in the output picture. Therefore overlapping blocks can solve this problem (every pixel is replaced by the histogram equalization output using a neighborhood) but it is more computationally intensive than using non-overlapping blocks. So the CLAHE also requires a field store. Finally one more contrast enhancement method that is homomorphic filter is proposed in spatial domain [1]. In this filter images normally consist of light reflected from objects. The basic nature of the image may be characterized by two components: (1) the amount of source light incident on the scene being viewed, and (2) the amount of light reflected by the objects in the scene but this method does not provide good image quality [4]. Another method is histogram specification (HS) which takes a desired histogram by which the expected output image histogram can be controlled [1]. However specifying the output histogram is not a smooth task as it varies from image to image.

Since past few years various researchers have also focused on improvement of histogram equalization based contrast enhancement techniques such as mean preserving bi-histogram equalization (BBHE) [10], dualistic sub-image histogram equalization (DSIHE) [14] and minimum mean brightness error bi-histogram equalization (MMBEBHE) [18]. The BBHE separates the input image histogram into two parts based on input mean. After separation, each part is equalized independently. This method tries to overcome the brightness preservation problem. The DSIHE method uses entropy value for histogram separation. The MMBEBHE is the extension of BBHE method that provides maximal brightness preservation. Though these methods can perform good contrast enhancement, but they also cause more annoying side effects depending on the variation of gray level distribution in the histogram. Therefore, recursive mean-separate histogram equalization (RMSHE) [8] is proposed which provides better contrast results over BBHE. This algorithm is the improvement in BBHE. However, it also has some side effects. In [15] Hassan and Norio is proposed new approach for contrast enhancement using sigmoid function. The objective of this new contrast enhancer is to scale the input image by using sigmoid function. However this method is also having some side effects. In order to improve the performance of above mentioned algorithm, exact histogram specification (EHS) [9] is used for contrast enhancement of images. In order to provide better result another technique named as brightness preserving dynamic fuzzy histogram equalization (BPDFHE) is proposed [12]. This technique is the modification of the brightness preserving dynamic histogram equalization technique to improve its brightness preserving and contrast enhancement abilities while reducing its computational complexity. This technique uses fuzzy statistics of digital images for their representation and processing. Therefore, representation and processing of images in the fuzzy domain enables the technique to handle the inexactness of gray level values in a better way which results in improved performance. In [15] Celik and Jahjadi proposed contextual and variational contrast enhancement for image. This algorithm enhances the contrast of an input image using interpixel contextual information. This algorithm uses a 2-D histogram of the input image constructed using a mutual relationship between each pixel and its neighboring pixels. A smooth 2-D target histogram is obtained by minimizing the sum of frobenius norms of the differences from the input histogram and the uniformly distributed histogram. The enhancement is achieved by mapping the diagonal elements of the input histogram to the diagonal elements of the target histogram. This algorithm produces better enhanced image results as compared to other existing state-of-the-art algorithms. On the other hand various researchers also proposed many algorithms for contrast enhancement in DCT based compressed domain such as alpha rooting (AR) [6], multi contrast enhancement (MCE) [13], Multi contrast enhancement with dynamic range compression (MCEDRC) [11] and wavelet based domain (ACEWD) [19].

3 Proposed Method

The proposed method consists of two stages: In first stage the poor quality of image is process by adaptive histogram equalization in spatial domain and in second stage the output of first stage is further processed by adaptive filtering for image enhancement in frequency domain. The proposed method is abbreviated as Adaptive Contrast Enhancement Based on Histogram Equalization (ACEBHE). The model of proposed method is shown in Fig. 1. A two dimensional original image is denoted by a function f(x, y). The amplitude of ‘f’ at spatial coordinates (x, y) is a positive scalar quantity whose physical meaning is determined by the source of image. When an image is generated from a physical process, its values are proportional to energy radiated by a physical source such as electromagnetic waves and infrared waves. As a consequence, f(x, y) must be non zero and finite. The two dimensional function f(x, y) may be characterized by two components: (i) The amount of source illumination incident on the scene being viewed (ii) The amount of illumination reflected by objects in scene. First one is called illumination component and it is denoted by i(x, y) and second one is called reflectance component and it is denoted by r(x, y).

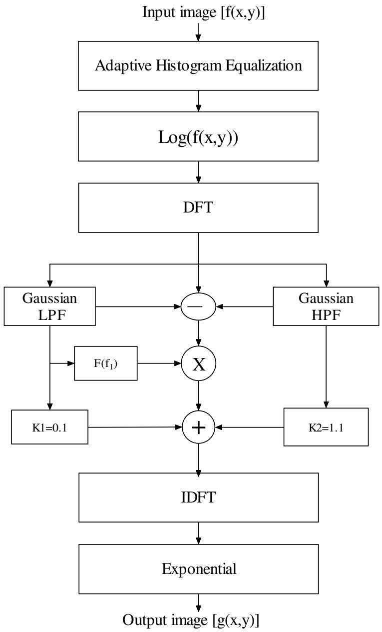


Fig. 1. Block diagram of proposed Adaptive Contrast Enhancement Based on Histogram Equalization

These two components are combined as a product to form two dimensional function f(x,y). Therefore it is given by

$$f(x,y)=i(x,y)*r(x,y)$$

The nature of i(x,y) is determined by illumination source, and r(x,y) is determined by the characteristics of the imaged objects. The function f(x,y) cannot be used directly to operate separately on the frequency components of illumination and reflectance because the Fourier transform of the product of two function is not separable. However if we define

$$z(x,y)=\ln[f(x,y)]=\ln[i(x,y)]+\ln[r(x,y)]$$

Then

$$F\{z((x,y)\}=F\{\ln[f(x,y)]\}=F\{\ln[i(x,y)\}+F\{\ln[r(x,y)]\}$$

The illumination component of two dimensional images is characterized by slow spatial variation, while the reflectance component tends to vary abruptly, particularly at the junction of dissimilar components. These characteristics lead to associating low frequencies of the Fourier transform of the logarithm of an image with illumination and the high frequencies with reflectance. A good deal of control can be gained over the illumination and reflectance components by defining a filter function that affects low and high frequency components of the Fourier transform in different ways. The filter function should be such that it tends to decrease the contribution made by the low frequencies (illumination) and amplify the contribution made by high frequencies (reflectance). The net result is simultaneous dynamic range compression and contrast enhancement. In our method we have suppressed the low frequency components by 90% and increased the clearly visible high frequency components by 110%. Therefore the hidden frequency components are locally enhanced depending on illumination of that particular region. The hidden frequency components are convolved with the function $F(f_l)$ where F is defined as

$$F(f_1)=1+kf_1$$

Where the value of k is different for each 17x17 block

Now the modified high frequency components, low frequency components, and hidden frequency components are added together to give new enhanced two dimensional images in the frequency domain. After that inverse discrete Fourier transform is taken to get the enhanced image in spatial domain. Finally, as z(x,y) was formed by taking the logarithm of the original image f(x,y), the inverse (exponential) operation yields the desired new enhanced image.

3.1 Implementation of Proposed Method

Step(1): Read the input image.
Step(2): Convert input image into gray scale image if it is color image.
Step(3): Apply adaptive histogram equalization algorithm.
Step(4): Find DFT of output from Step(3)
Step(5): Perform adaptive filtering for image enhancement.
Step(6): Find IDFT after adaptive filtering operation.
Step(7): Find exponential of IDFT from Step(6)

4 Simulation Results and Discussions

In order to demonstrates the performance of proposed ACEBHE method, it is tested on different gray scale real world Hyperspectral images with dimension Ml×M2 (=512×512) [20]. In order to obtain simulation and experimental results of proposed ACEBHE method and other existing algorithms, MATLAB software (MATLAB 7.6, release 2008a) is used. Therefore, two experiments have been conducted on different gray scale real world hyperspectral images. In the first experiment the quality metrics is presented and in the second experiment visual quality of image has been presented. In order to judge the performance of proposed ACEBHE method the quality parameters such as measure of enhancement (EME) and measure of enhancement factor (EMF) are the automatic choice for the researchers. Therefore, a better value of EME and EMF implies that the visual quality of the enhanced image is good. The measure of enhancement (EME) and measure of enhancement factor (EMF) are defined in equation (3) and equation (4) respectively for gray scale real world

Hyperspectral images. These image quality metrics are used to compare the performance of proposed ACEBHE method and other existing contrast enhancement techniques such as Alpha Rooting (AR) [6], Multi contrast enhancement (MCE) [13], Multi-contrast enhancement with dynamic range compression (MCEDRC) [11], Brightness preserving dynamic fuzzy histogram equalization (BPDFHE) [12]. The real world hyperspectral images used for experimental tests are available on the website http://vision.seas.harvard.edu/hyperspec/explorei.html

The measure of enhancement (EME) [17, 21] of image I(i, j) with dimensions Ml×M2 pixels is defined as:

$$EME_{k_1 k_2} = \frac{1}{k_1 k_2} \sum_{l=1}^{k_1} \sum_{k=1}^{k_2} \left[20 * ln\left(\frac{I_{max,k,l}}{I_{min,k,l}} \right) \right] \tag{3}$$

where an image (I) is divided into $k_1 \times k_2$ blocks, $I_{max,k,l}$ and $I_{min,k,l}$ are the maximum and minimum values of the pixels in each block.

The measure of enhancement factor (EMF) between output image and input image is defined as:

$$EMF = \frac{\text{EME of output image}}{\text{EME of input image}} \tag{4}$$

4.1 Experiment 1

In this experiment the performance of proposed ACEBHE method is tested on different gray scale real world Hyperspectral images. The performance of proposed ACEBHE method and many existing contrast enhancement techniques has been evaluated for image1 and image2 in terms of quality parameters such as measure of enhancement (EME) and measure of enhancement factor (EMF). For image1, and image2, the performance of proposed ACEBHE method has been compared with many existing contrast enhancement techniques. The measure of enhancement (EME), measure of enhancement factor (EMF) and CPU processing time of proposed ACEBHE method and many existing contrast enhancement techniques for image1, and image2 have been given in Table 1. It can be noticed from Table 1 that the proposed ACEBHE method provides better results as compared to other state-of-art contrast enhancement techniques.

4.2 Experiment 2

In order to perform the superiority of proposed ACEBHE method another experiment has been conducted on different gray scale real world Hyperspectral images. This experiment visualizes subjective image enhancement performance, the enhanced contrast of image1 and image2 have been compared with result of proposed ACEBHE method and many existing contrast enhancement techniques. The visual contrast enhancement results of proposed ACEBHE method and many existing contrast enhancement techniques have been given from Figure 2 to Figure 3. Therefore, it can be noticed from Figure 2(B) to Figure 2(F), and Figure 3(B) to Figure 3(F) that proposed ACEBHE method gives better contrast enhancement results as compared to other existing contrast enhancement techniques.

Table 1. Comparative performance of different methods and gray-scale image

Method / Parameters	AR	BPDFHE	MCEDRC	MCE	PROPOSED ACEBHE
image1.tif					
EME(Original)	10.22	10.22	10.22	10.22	**10.22**
EME(Output)	10.88	17.77	10.64	12.84	**20.12**
EMF	1.06	1.74	1.04	1.26	**1.97**
CPU Time (second)	0.38	0.23	1.75	0.38	**2.74**
image2.tif					
EME(Original)	2.47	2.47	2.47	2.47	**2.47**
EME(Output)	2.77	3.36	2.52	3.02	**4.89**
EMF	1.12	1.36	1.02	1.22	**1.98**
CPU Time (second)	0.38	0.19	1.77	0.38	**0.85**

(A). Original image

(B). Output result of AR

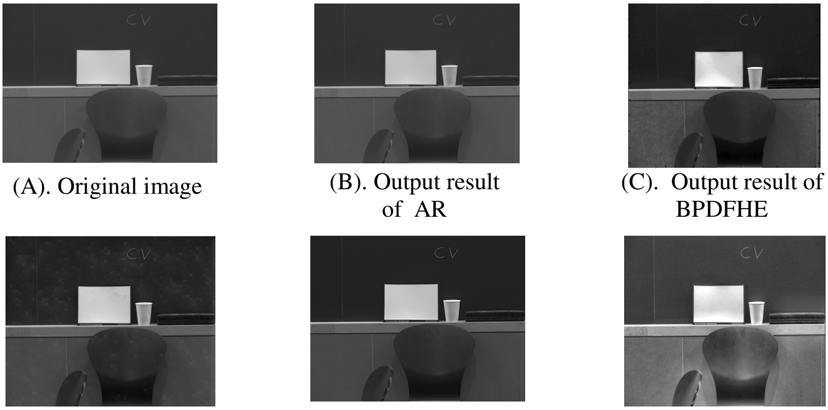
(C). Output result of BPDFHE

(D). Output result of MCEDRC

(E). Output result of MCE

(F). Output result of ACEBHE Method

Fig. 2. Visual Enhancement results of different algorithms for image1. tif



(A). Original image

(B). Output result of AR

(C). Output result of BPDFHE

(D). Output result of MCEDRC

(E). Output result of MCE

(F). Output result of ACEBHE Method

Fig. 3. Visual Enhancement results of different algorithms for image2.tif

5 Conclusion

In this paper an improved contrast enhancement method was proposed for image enhancement purpose for various applications. This method was tested on different gray scale real world Hyperspectral images. The qualitative and subjective enhancement performance of proposed ACEBHE method was evaluated and compared to other state-of-art contrast enhancement techniques. The performance of proposed ACEBHE method was evaluated and compared in terms of EME, EMF and Execution time. The simulation results demonstrated that the proposed ACEBHE method provided better results as compared to other state-of-art contrast enhancement techniques for different gray scale real world Hyperspectral images. The visual enhancement results of proposed ACEBHE method were also better as compared to other state-of-art contrast enhancement techniques. Therefore, proposed ACEBHE method performed very effectively for contrast enhancement of gray scale real world Hyperspectral images. The proposed ACEBHE method can also be used for many other images such as remote sensing images, electron microscopy images and even real life photographic pictures suffer from poor contrast problems during its acquisition.

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