An Efficient Method for Contrast Enhancement of Real World Hyper Spectral Images

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Abstract: *This paper proposed an efficient method for contrast enhancement of real world hyper spectral images. The contrast of image is an important characteristic by which the quality of image can be judged as good or poor quality. The proposed method is consists of two stages: In first stage the poor quality of image is process by automatic contrast adjustment in spatial domain and in second stage the output of first stage is further process by adaptive filtering for image enhancement in frequency domain. Simulation and experimental results on benchmark real world hyper spectral image database demonstrates that proposed method provides better results as compared to other state-of-art contrast enhancement techniques. Proposed method performs better in different dark and bright real world hyper spectral images by adjusting their contrast very frequently. Proposed method is very simple and efficient approach for contrast enhancement of real world hyper spectral images. This method can be used in different applications where images are suffering from different contrast problems.*

Keywords: *Adaptive contrast enhancement, real world hyper spectral image, image processing, histogram equalization.*

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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 collection 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. During last decade a number of contrast enhancement algorithms have been developed for contrast enhancement of images for various applications. These are Histogram Equalization (HE) [12], global HE [30], local HE [4], adaptive HE and Contrast Limited Adaptive HE (CLAHE) [27, 41], other HE based algorithms [2, 3, 6, 7, 8, 9, 10, 11, 14, 15, 17,18, 19, 20, 21, 22, 23, 24, 25, 26, 28, 29, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40] and other contrast enhancement methods [5, 13, 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 hyper spectral 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 HE based methods [12]. 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 is 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, contrast shaping based methods is 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, 12]. Another very popular technique for image contrast enhancement is HE technique [4, 12, 31]. A HE 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 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) [12]. Therefore, it is a special case of contrast shaping technique. As a standalone technique, HE is used extensively in medical imaging, satellite imagery and other applications where the emphasis is on pattern recognition and bringing out of hidden details. Therefore, HE provides too much enhancement and artifacts like contouring which is unacceptable in consumer electronics [28, 42]. During last decade a number of techniques have been proposed by various researchers to deal with these problems.

Kim [18], 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 [6], each peak of the histogram is equalized separately. An adaptation of HE, termed as CLAHE [42] divides the input image into a number of equal sized blocks and then performs contrast limited HE on each block. The contrast limiting is done by clipping the histogram before HE. This tends to tone down the over enhancement effect of HE and gives a more localized enhancement. However, it is much more computationally intensive than HE. 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 HE 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 homomorphism filter is proposed in spatial domain [12]. In this filter images normally consist of light reflected from objects. The basic nature of the image may be characterized by two components: The amount of source light incident on the scene being viewed; and the amount of light reflected by the objects in the scene but this method does not provide good image quality [28]. Another method is Histogram Specification (HS) which takes a desired histogram by which the expected output image histogram can be controlled [12]. However, specifying the output histogram is not a smooth task as it varies from image to image.

During past years various researchers have also focused on improvement of HE based contrast enhancement techniques such as mean preserving Bi-HE (BBHE) [18], Dualistic Sub-Image HE (DSIHE) [35] and Minimum Mean Brightness Error BHE (MMBEBHE) [7]. 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. 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 HE (RMSHE) is proposed which provides better contrast results over BBHE [6]. This algorithm is the improvement in BBHE. However, it has also some side effects. Hassan and Akamatsu [13] 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 have some side effects. In order to overcome the side effects of many methods another algorithm that is Exact Histogram Specification (EHS) is proposed for contrast enhancement of images [9]. In order to provide better result another technique that is Brightness Preserving Dynamic Fuzzy HE (BPDFHE) is proposed [30]. This technique is the modification of the brightness preserving dynamic HE 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 provide improved performance. Celik and Tjahjadi [5] 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 2D histogram of the input image constructed using a mutual relationship between each pixel and its neighboring pixels. A smooth 2D 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 images 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) [2], Multi Contrast Enhancement (MCE) [32], MCE with Dynamic Range Compression (MCEDRC) [23] and wavelet based domain that is ACEWD [21].

3. Proposed Method

The proposed method is consists of two stages: In first stage the poor quality of image is process by contrast enhancement algorithm in spatial domain and in second stage the output of first stage is further process in frequency domain. The proposed method is abbreviated as ACE. The model of proposed method is shown in Figure 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: The amount of source illumination incident on the scene being viewed; and the amount of illumination reflected by objects in scene.

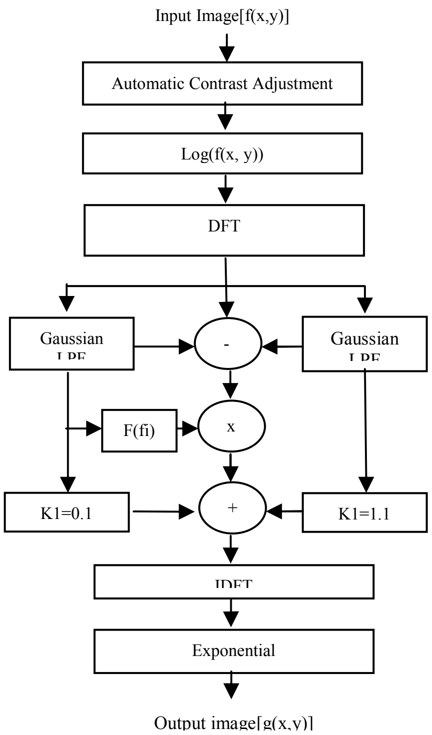


Figure 1. Block diagram of proposed adaptive contrast enhancement.

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

The nature of $i(x, y)$ is determined by illumination source and $r(x, y)$ is determined by the characteristics of the image 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 functions is not separable. However, if we define:

$$z(x,y) = ln\left[f(x,y)\right] = ln\left[i(x,y)\right] + ln\left[r(x,y)\right] \tag{1}$$

Then, the Fourier transform of $z(x, y)$ is given by:

$$Z(u,v) = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} z(x,y)e^{-j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)} \tag{2}$$

$$Z(u,v) = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\left\{\ln\left[i(x,y)\right]+\ln\left[r(x,y)\right]\right\}e^{-j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)} \tag{3}$$

$$Z(u,v) = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\ln\left[i(x,y)\right]e^{-j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)} + \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\ln\left[r(x,y)\right]e^{-j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)} \tag{4}$$

$$Z(u,v) = F_i(u,v) + F_r(u,v) \tag{5}$$

Where $F_i(u, v)$ and $F_r(u, v)$ are the Fourier transform of $ln[i(x, y)]$ and $ln[r(x, y)]$, respectively, The output of subtractor in frequency domain is given as:

$$S(u,v) = Z(u,v) - \left[Y_{ol}(u,v) - Y_{oh}(u,v)\right] \tag{6}$$

Where $Y_{ol}(u, v)$ is the output frequency response of Gaussian Low pass filter, $Y_{oh}(u, v)$ is the output frequency response of Gaussian High pass filter.

$$S(u,v) = Z(u,v) - \left[Z(u,v)\left\{H_l(u,v) - H_h(u,v)\right\}\right]$$

Where $H_l(u, v)$ is the transfer function of Gaussian low pass filter, $H_h(u, v)$ is the transfer function of Gaussian High pass filter.

$$S(u,v) = Z(u,v)\left[1-\left\{H_l(u,v) - H_h(u,v)\right\}\right]$$

$$S(u,v) = \left[1-\left\{H_l(u,v)-H_h(u,v)\right\}\right] X \left[\frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\ln\left[i(x,y)\right]e^{-j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)} + \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\ln\left[r(x,y)\right]e^{-j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)}\right] \tag{7}$$

The output of multiplier in frequency domain is given as:

$$M(u,v) = Y_{ol}\ X\ F(f_1)\ X\ S(u,v) \tag{8}$$

$$S(u,v) = Y_{ol}\ X F(f_1)\ X\left[1-\left\{H_l(u,v)-H_h(u,v)\right\}\right] X \left[\frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\ln\left[i(x,y)\right]e^{-j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)} + \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\ln\left[r(x,y)\right]e^{-j2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)}\right] \tag{9}$$

Where $F(f_l)$ is defined as: $F(f_l)=1+kf_1$, and the value of k is different for each 17×17 block The output of summer in frequency domain is given as:

$$R(u,v) = M(u,v) + K_1\ XY_{ol} + K_2\ XY_{oh} \tag{10}$$

$$R(u,v) = M(u,v) + Z(u,v)\left[K_1 H_1(u,v) - K_2 H_h(u,v)\right] \tag{11}$$

Therefore, in spatial domain:

$$r(x,y) = \frac{1}{MN}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1} R(u,v)e^{j2\pi\left(\frac{ux}{M}+\frac{vy}{n}\right)} \tag{12}$$

$$r(x,y) = i'(x,y) + r'(x,y) \tag{13}$$

Finally as $z(x, y)$ was formed by taking logarithm of the original image $f(x, y)$, therefore in spatial domain inverse (exponential) operation yields the desired output enhanced image which is denoted by $g(x, y)$ and it is given as:

$$g(x,y) = e^{r(x,y)} = e^{i'(x,y)+r'(x,y)} \tag{14}$$

$$g(x,y) = i_o(x,y) \text{ X } r_o(x,y) \tag{15}$$

The illumination component of two dimensional images generally 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).

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 $F(f_l)$.

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 automatic contrast enhancement adjustment i.e. misadjusts function of MATLAB.
- *Step* 4: Apply logarithmic transform.
- *Step* 5: Find DFT of output from Step4.
- *Step* 6: Perform adaptive filtering for image enhancement.
- *Step* 7: Find IDFT after adaptive filtering operation.
- *Step* 8: Find exponential of IDFT from Step 7.

4. Simulation Results and Discussions

In order to demonstrate the performance of proposed ACE method, it is tested on different gray scale real world hyper spectral images with dimension $M_1 \times M_2$ (512×512). In order to obtain simulation and experimental results of proposed ACE method and other existing algorithms are implemented in MATLAB software (MATLAB 7.6, release 2008a). Therefore, two experiments have been conducted on different gray scale real world hyper spectral 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 ACE 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 EMF are defined in Equations 16 and 17 respectively for gray scale real world hyper spectral images. These image quality metrics are used to compare the performance of proposed ACE method and other existing contrast enhancement techniques such as MCE [32], MCE with MCEDRC [23], EHS [9], and BPDFHE [30].

The test real world hyper spectral images used for the experiments are available on the website http://vision.seas.harvard.edu/hyperspec/explorei.html. The EME [1, 27] of image $I(i, j)$ with dimensions $M_1 \times M_2$ pixels is defined as:

$$EME_{k_1k_2} = \frac{1}{k_1k_2}\sum_{l=1}^{k_1}\sum_{k=1}^{k_2}\left[20\ln\left(\frac{I_{\max,k,l}}{I_{\min,k,l}}\right)\right] \tag{16}$$

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 EMF between output image and input image is defined as:

$$EMF = \frac{EME\ of\ output\ image}{EME\ of\ input\ imgae} \tag{17}$$

4.1. Experiment 1

In this experiment the performance of proposed ACE method is tested on different gray scale real world hyper spectral images. The performance of proposed ACE method and many existing contrast enhancement techniques has been evaluated and compared with many existing contrast enhancement techniques for image 1512, image 2512, image 3512, image 4512 and image 5512 in terms of quality parameters such as EME and EMF. The EME, EMF and CPU processing time of proposed ACE method and many existing contrast enhancement techniques for image 1512, image 2512, image 3512, image 4512 and image 5512 is given in Table 1. Therefore, it can be noticed from Table 1 that the proposed ACE method provides better results as compared to other state-of-art contrast enhancement techniques such as MCE [32], MCE with MCEDRC [23], EHS [9], BPDFHE [30].

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

Method / Parameters	EHS	BPDFHE	MCEDRC	MCE	ACE (Proposed)
image1512.tif					
EME(Original)	10.22	10.22	10.22	10.22	10.22
EME(Output)	22.44	17.77	10.64	12.84	26.87
EMF	2.19	1.74	1.04	1.26	2.62
CPU Time (second)	1.46	0.23	1.75	0.38	0.83
image2512.tif					
EME(Original)	2.47	2.47	2.47	2.47	2.48
EME(Output)	5.65	3.36	2.52	3.02	6.29
EMF	3.90	1.36	1.02	1.22	2.55
CPU Time (second)	1.56	0.19	1.77	0.38	0.76
image3512.tif					
EME(Original)	3.03	3.03	3.03	3.03	3.03
EME(Output)	7.34	3.63	3.07	3.67	9.94
EMF	2.43	1.20	1.01	1.21	3.28
CPU Time (second)	1.44	0.19	1.76	0.37	0.82
image4512.tif					
EME(Original)	3.35	3.35	3.35	3.35	3.35
EME(Output)	10.44	3.89	3.38	3.98	13.15
EMF	3.11	1.16	1.01	1.19	3.92
CPU Time (second)	1.55	0.18	1.75	0.38	0.80
image5512.tif					
EME(Original)	2.58	2.58	2.58	2.58	2.58
EME(Output)	16.86	6.05	2.60	3.09	18.60
EMF	6.53	2.34	1.01	1.20	7.20
CPU Time (second)	1.77	0.19	1.76	0.37	0.83

4.2. Experiment 2

In order to demonstrate the superiority of proposed ACE method another experiment has been conducted on different gray scale real world hyper spectral images. In this experiment visual contrast enhancement performance is presented. The enhanced contrast of image 1512 and image 2512 have been obtained and compared with result of proposed ACE method with many existing contrast enhancement techniques. The visual contrast enhancement results of proposed ACE method and many existing techniques are given from Figures 2 and 3. Therefore, it can be noticed from Figures 2-b to f and Figures 3-b to f that proposed ACE method gives better visual contrast enhancement results as compared to other existing techniques.

a) Original image.

b) Output of EHS.

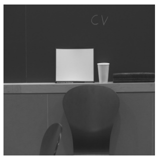
c) Output of BPDFHE.

d) Outputof MCEDRC.

e) Output of MCE.

f) Output of ACE Method (Proposed).

Figure 2. Visual Enhancement results of different algorithms for image1512.tif



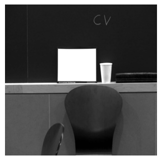
a) Original image.

b) Output of EHS.

c) BPDFHE.

d) Output of MCEDRC.

e) Output of MCE.



f) Output of ACE method(proposed).

Figure 3. Visual Enhancement results of different algorithms for image2512.tif.

5. Conclusions

This paper highlighted contrast enhancement of scale real world hyper spectral images. In this paper an efficient method has been proposed for contrast enhancement of gray scale real world hyper spectral images. The qualitative and subjective enhancement performance of proposed ACE method has been evaluated and compared to other state-of-art contrast enhancement techniques for different gray scale real world hyper spectral images. The performance of proposed ACE method was evaluated and compared in terms of EME, EMF and Execution time. The simulation results demonstrated that the proposed ACE method provided better results as compared to other state-of-art contrast enhancement techniques. The visual enhancement results of proposed ACE method were also better as compared to other state-of-art contrast enhancement techniques for different gray scale real world hyper spectral images. Therefore, proposed ACE method performed very effectively and efficiently for contrast enhancement of gray scale real world hyper spectral images. The proposed ACE 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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