Efficient Algorithm for Contrast Enhancement of Natural Images

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Abstract: *This paper proposed an efficient algorithm for contrast enhancement of natural images. The contrast of images is very important characteristics by which the quality of images can be judged as good or poor. The proposed algorithm consists of two stages: In the first stage the poor quality of an image is processed by modified sigmoid function. In the second stage the output of the first stage is further processed by contrast limited adaptive histogram equalization to enhance contrast of images. In order to achieve better contrast enhancement of images, a novel mask based on input value together with the modified sigmoid formula that will be used as contrast enhancer in addition to contrast limited adaptive histogram equalization. This new contrast enhancement algorithm passes over the input image which operates on its pixels one by one in spatial domain. Simulation and experimental results on benchmark test images demonstrates that proposed algorithm provides better results as compared to other state-of-art contrast enhancement techniques. Proposed algorithm performs efficiently in different dark and bright images by adjusting their contrast very frequently. Proposed algorithm is very simple and efficient approach for contrast enhancement of image. This algorithm can be used in various applications where images are suffering from different contrast problems.*

Keywords: *Contrast enhancement, modified sigmoid function, 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 [12], global histogram equalization [30], local histogram equalization [4], adaptive histogram equalization and Contrast Limited Adaptive histogram equalization [27, 41], other histogram equalization based algorithms [2-3, 6-11, 14-15, 17-19, 21-26, 28-29, 31-40] and other contrast enhancement methods [5, 13] 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 sigmoid function. Section 4 describes proposed algorithm for contrast enhancement of images. Section 5 gives simulation results and discussions to demonstrate the performance of proposed algorithm. Finally, the conclusions are drawn in section 6.

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 [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].

A very popular technique for contrast enhancement of image is histogram equalization technique [4, 12, 30]. 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) [12]. 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 [27, 41].

During the last decade a number of techniques have been proposed by various researchers to deal with these problems. In [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 [8], each peak of the histogram is equalized separately. An adaptation of HE, termed as Contrast Limited Adaptive Histogram Equalization (CLAHE) [41], 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 [12]. 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 [27]. 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 the past years various researchers have also focused on improvement of histogram equalization based contrast enhancement techniques such as mean preserving Bi-Histogram Equalization (BBHE) [18], dualistic Sub-Image Histogram Equalization (DSIHE) [35], and Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) [27]. 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) is proposed which provides better contrast results over BBHE [27]. This algorithm is the improvement in BBHE. However, it has also some side effects.

In [13] 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 have some side effects. The Exact Histogram Specification (EHS) [9], is the method for contrast enhancement of images. In order provides better result another technique that is Brightness Preserving Dynamic Fuzzy Histogram Equalization (BPDFHE) is proposed [29]. 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 provide improved performance. In [5], 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 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), Multi Contrast Enhancement with Dynamic Range Compression (MCEDRC) [21] and wavelet based domain that is ACEWD [20].

3. Sigmoid Function

The sigmoid function is the continuous non-linear mathematical function. The name sigmoid is derives from the fact that the function is alphabet letter "S" shaped [13]. This function is also called as logistic function:

$$f(x) = \frac{1}{1 + e^{-\left(\frac{x-\alpha}{\beta}\right)}} \quad (1)$$

This function maps the entire range of x to the domain [0, 1] of y. The parameters α and β determines the center and width of the sigmoid function respectively. The graphical illustration of sigmoid function is shown in Figure 1, it goes up smoothly and kindly.

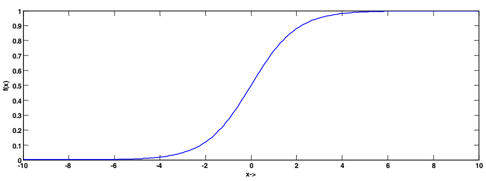

Figure1. Sigmoid function.

4. Proposed Algorithm

The proposed algorithm is consists of two stages: In first stage the poor quality of image is process by modified sigmoid function and in second stage the output of first stage is further process by contrast limited adaptive histogram equalization to enhance contrast of image. The proposed algorithm is abbreviated as Adaptive Contrast Enhancement Based on modified Sigmoid Function (ACEBSF). The model of proposed algorithm is shown in Figure 2.

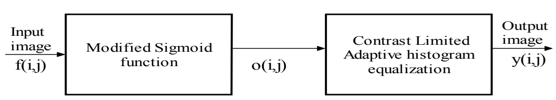

Figure 2. Block diagram of proposed algorithm.

4.1. Modified Sigmoid Function

The modified sigmoid function defined in equation 2. This mathematical formula operates upon the original image on pixel by pixel in the spatial domain. The following formula demonstrates the pixel value of the first step output image:

$$o(i,j) = f(i,j) + K_1 * \frac{f(i,j)}{1 - exp(K_1 * (K_2 + f(i,j)))} \quad (2)$$

Where K_1 is control parameter which controls the actual contrast of input image. If the value of K_1 is selected 5 then its effect on the input image is little change in the contrast, if the value of K_1 is selected 1 then its reduces contrast to about 20% of original and if the value of K_1 is selected 10 then its increase contrast about to 2.5 times the input image. Therefore a reasonable range of values of K_1 is to be selected in the experiments. For effective contrast enhancement of input images the value of K_1 should be lies between 10 to 25.

K_2 is another control parameter which represents the normalized gray value about which contrast is increased or decreased. The initial value of K_2 is selected 0.5 (i.e., the midpoint of the gray scale) but different images may require different points of the gray scale to be enhanced. Therefore a reasonable range of values of K_2 is to be selected in the experiments. For effective contrast enhancement of input images the value of K_2 should be lies between 0 to 1. The typical value of K_2 is used in the experiment is 0.5.

4.2. Contrast Limited Adaptive Histogram Equalization

The Contrast Limited Adaptive Histogram Equalization (CLAHE) is an improved version of adaptive histogram equalization. Originally it was developed for medical imaging and has proven to be successful for enhancement of low contrast images such as portal films. The contrast limited adaptive histogram equalization algorithm partitions the images into contextual regions and applies the histogram equalization to each one. This evens out the distribution of used gray values and thus makes hidden features of the image more visible. The full gray spectrum is used to express the image [11, 41]. The amount of contrast enhancement for some intensity is directly proportional to the slope of the Cumulative Distribution Function (CDF) at that intensity level. Hence contrast enhancement can be limited by limiting the slope of the CDF. The slope of CDF at a bin location is determined by the height of the histogram for that bin. Therefore the height limitation of the histogram results in limiting the slope of the CDF and hence the amount of contrast enhancement [11, 41].

4.3. Implementation Steps Involved in the Proposed Algorithm

- *Step 1:* Read the input image.
- *Step 2:* Convert input image into gray scale image if it is color image.
- *Step 3:* Select the control parameter K_1 and K_2.
- *Step 4:* Calculate f_{min} and f_{max}. These are calculated as follows: $f_{min}= min(min(f))$ and $f_{max}= max(max(f))$.
- *Step 5:* Determine $f=f-f_{min}$ and also Calculate $f=f/f_{max}$.
- *Step 6:* Calculate output of modified sigmoid function.
- *Step 7:* Output image of modified sigmoid function (i.e., o) is further passes through contrast limited adaptive histogram equalization.
- *Step 8:* Repeat steps 6 to 7 for entire image.

5. Simulation Results and Discussions

In order to demonstrates the performance of proposed ACEBSF algorithm, it is tested on different gray scale natural images with dimension Ml×M2(=512×512). In order to obtain simulation and experimental results of proposed ACEBSF algorithm, and other existing algorithm MATLAB software (MATLAB 7.6, release 2008a) is used for simulation. Therefore, two experiments have been conducted on different gray scale natural 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 ACEBSF algorithm 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 EME and EMF are defined in equations 3 and 4 respectively for gray scale natural images. These image quality metrics are used to compare the performance of proposed ACEBSF algorithm and other existing contrast enhancement techniques such as Adaptive Histogram Equalization (AHE) [27, 41], Alpha Rooting (AR) [2], Multi Contrast Enhancement (MCE) [31], Multi contrast Enhancement with Dynamic Range Compression (MCEDRC) [21], Exact Histogram Specification (EHS) [9], Brightness Preserving Dynamic Fuzzy Histogram Equalization (BPDFHE) [29], alogrithm1 [13]. The test images used for the experiments are available on the website http://dragon.larc.nasa. govt/retinex/pao/news.

The EME [1, 26] of image $I(i, j)$ with dimensions Ml×M2 pixels is defined as:

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

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 EMF between output image and input image is defined as:

$$EMF = \frac{EME\ of\ output\ image}{EME\ of\ input\ image} \quad (4)$$

- *Experiment 1*

In this experiment the performance of proposed ACEBSF algorithm is tested on different gray scale natural images. The performance of proposed ACEBSF algorithm and many existing contrast enhancement techniques has been evaluated for image1, image2 and image3 in terms of quality parameters such as EME and EMF. For image1, image 2 and image 3, the performance of proposed ACEBSF algorithm has been compared with many existing contrast enhancement techniques such as AHE [27, 41], Alpha Rooting (AR) [2], Multi Contrast Enhancement (MCE) [31], Multi Contrast Enhancement with Dynamic Range Compression (MCEDRC) [21], EHS [9], BPDFHE [29], Alogrithm1 [13]. The EME, EMF and CPU processing time of proposed ACEBSF algorithm and many existing contrast enhancement techniques for image1, image2 and image3 have been given in Table 1. Therefore, it can be noticed from Table 1 that the proposed ACEBSF algorithm provides better results as compared to other state-of-art contrast enhancement techniques.

- *Experiment 2*

In order to perform the superiority of proposed ACEBSF algorithm another experiment has been conducted on different gray scale natural images. This experiment visualizes subjective image enhancement performance, the enhanced contrast of image 1, image 2 and image 3 have been compared with result of proposed ACEBSF algorithm and many existing contrast enhancement techniques such as AHE [27, 41], AR [2], MCE [31], MCEDRC [21], EHS [9], BPDFHE [29], Alogrithm 1 [13]. The visual contrast enhancement results of proposed ACEBSF algorithm and many existing contrast enhancement techniques have been given from Figures 3 to 5. Therefore, it can be noticed from Figure 3-b to Figure 3-i, Figure 4-b to Figure 4-i, and Figure 5-b to Figure 5-i that proposed ACEBSF algorithm 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	AHE	EHS	BPDFHE	Algorithm1	AR	MCEDRC	MCE	ACEBSF
Image 1.tif								
EME (original)	12.62	12.62	12.62	12.62	12.62	12.44	12.44	**12.62**
EME (output)	18.12	16.53	15.79	12.63	13.33	12.93	15.61	**19.95**
EMF	1.47	1.31	1.25	1.00	1.06	1.02	1.24	**1.58**
CPU Time (second)	19.31	1.25	0.13	0.48	0.22	0.91	0.22	**0.17**
Image 2.tif								
EME (original)	6.51	6.51	6.51	6.51	6.51	12.44	12.44	**6.51**
EME (output)	10.36	12.11	11.07	6.51	6.91	6.55	8.05	**12.02**
EMF	1.59	1.86	1.70	1.00	1.06	1.01	1.24	**1.85**
CPU Time (second)	19.45	1.15	0.11	0.45	0.20	0.87	0.22	**0.14**
Image 3.tif								
EME (original)	18.14	18.14	18.14	18.14	18.14	12.44	12.44	**18.14**
EME (output)	24.65	17.76	19.38	18.16	19.15	19.24	23.62	**27.81**
EMF	1.36	0.98	1.07	1.00	1.06	1.06	1.30	**1.53**
CPU Time (second)	19.91	1.14	0.11	0.48	0.20	0.87	0.23	**0.14**

a) Original image.

b) Output of AR.

c) Output of AHE.

d) Output of MCE.

e) Output of EHS.

f) Output of algorithm 1.

g) Output of BPDFHE.

h) Output of MCEDRC.

i) Output of ACEBSF algorithm (Proposed).

Figure 3. Visual enhancement results of different algorithms for image 1.tif.

a) Original image.

b) Output of AR.

c) Output of AHE.

d) Output of MCE.

e) Output of EHS.

f) Output of algorithm 1.

g) Output of BPDFHE.

h) Output of MCEDRC.

i) Output of ACEBSF algorithm (Proposed).

Figure 4. Visual enhancement results of different algorithms for image 2.tif.


a) Original image (image 3.tif).


b) Output of AR.


c) Output of AHE.


d) Output of MCE.


e) Output of EHS.


f) Output of algorithm 1.


g) Output of BPDFHE.


h) Output of MCEDRC.


i) Output of ACEBSF algorithm (proposed).

Figure 5. Visual enhancement results of different algorithms for image 3.tif.

6. Conclusions

This paper highlighted contrast enhancement of natural gray scale images. In this paper a new contrast enhancement algorithm was proposed for image enhancement purpose for various applications. This algorithm was tested on different gray scale natural images. The qualitative and subjective enhancement performance of proposed ACEBSF algorithm was evaluated and compared to other state-of-art contrast enhancement techniques for different gray scale natural images. The performance of proposed ACEBSF algorithm was evaluated and compared in terms of EME, EMF and Execution time. The simulation results demonstrated that the proposed ACEBSF algorithm provided better results as compared to other state-of-art contrast enhancement techniques such as AHE, AR, MCE, MCEDRC, EHS, BPDFHE for different gray scale natural images. The visual enhancement results of proposed ACEBSF algorithm were also better as compared to other state-of-art contrast enhancement techniques for different gray scale natural images. The proposed ACEBSF algorithm proved its superiority due to its better performance, fast speed, and low CPU processing time for different natural gray scale images. Therefore, proposed ACEBSF algorithm performed very effectively and efficiently for contrast enhancement of gray scale natural images. The proposed ACEBSF algorithm can also be used for many images such as medical images, remote sensing images, electron microscopy images and even real life photographic pictures suffer from poor contrast problems during its acquisition.

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