Comparative Study of Linear and Non-linear Contrast Enhancement Techniques

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***Abstract*— Image enhancement is the process of improving the quality of image by using various techniques. There are so many techniques for image enhancement and every technique produces different result for different images. Contrast enhancement is one of the techniques of Image Enhancement that produces an image that subjectively looks better than the original image by changing the pixel intensities. In this paper, the various contrast enhancement techniques are compared with respect to image enhancement. We compared three cases: In the first case comparison between the linear contrast methods, in second case comparison between the non-linear contrast methods and third case comparison between linear and non-linear contrast methods. Analysis studies are explained and experiments show that Piecewise contrast method gives better result comparing with other techniques of linear contrast enhancement. For nonlinear contrast enhancement techniques, Histogram Equalization gives better result comparing with other non-linear contrast methods and non-linear contrast methods give better result than linear contrast methods.**

Keywords— *Linear Contrast Enhancement, Non-Linear, Contrast Enhancement, Contrast Stretching, Histogram Equalization.*

I. INTRODUCTION

The main objective of image enhancement is to process a given image so that the result is more suitable than the original image for a specific application. It accentuates or sharpens image features such as edges, boundaries, or contrast to make a graphic display more helpful for display and analysis. The enhancement doesn't increase the inherent information content of the data, but it increases the dynamic range of the chosen features so that they can be detected easily.

Contrast stretching is a simple image enhancement technique that attempts to improve the contrast in an image by `stretching' the range of intensity values it contains to span a desired range of values.

Histogram Equalization is performed by remapping the gray levels of the image based on the probability distribution of the input gray image levels. It flattens and stretches the dynamic range of the image's histogram and resulting in overall contrast enhancement.

II. IMAGE ENHANCEMENT

The aim of image enhancement is to improve the interpretability or perception of information in images for human viewers, or to provide better input for other automated image processing techniques. Image enhancement transforms images to provide better representation of image. Image enhancements techniques are used to make images lighter or darker, or to increase or decrease contrast, or to remove undesired characteristics of an image such as colour cast. The aim of image enhancement is to improve the interpretability or perception of information in images for human viewers, or to provide `better' input for other automated image processing techniques.

Image enhancement is generally used in the following three cases: noise reduction from image, contrast enhancement of the very dark, low contrast and bright image, and high light the edges of the objects in a blurring image. Noise reduction is the process of removing noise form a signal or an image. In general, images taken with both digital camera and conventional film cameras will pick up noise from a variety of sources. Therefore, it is required that the noise is removed for many further uses of these images. Contrast enhancement is acquiring clear image through brightness intensity value redistribution. That is, this is enhancing features as stretching interval between dark and brightness area.

A. Image Enhancement Techniques

The greatest difficulty in image enhancement is quantifying the criterion for enhancement and, therefore, a large number of image enhancement techniques are empirical and require interactive procedures to obtain satisfactory results. Image enhancement methods can be based on either spatial or frequency domain techniques [1].

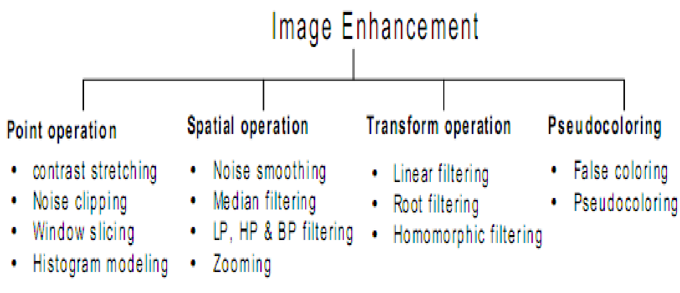

Fig. 1: Image Enhancement techniques [9].

The main aim of enhancement is to process an image so that the result is more suitable than the original image for analysis purpose. Here we concerned two main Image Enhancement techniques Linear and Non-linear Contrast Enhancement and their result analysis. Fig.1 shows some important image enhancement techniques.

III. CONTRAST ENHANCEMENT

Low-contrast images can result from poor illumination, lack of dynamic range in the image sensor, or even wrong setting of a lens aperture during image acquisition. The idea behind contrast enhancement is to increase the dynamic range of the gray levels in the image being processed.

Contrast enhancement is a simple image enhancement technique that improves the contrast in an image by stretching the range of pixel intensity values, to extend a desired range of values. This method can only apply a linear scaling function to the image pixel values [5].

By contrast enhancement a low-contrast image can be transformed into a high-contrast image by remapping or stretching the gray-level values in such a way that the histogram spans the full range [3]. In field of digital signal processing, it is referred to as dynamic range expansion. It can be expressed as shown in equation:

$$y = \begin{cases} \alpha x, & 0 \le x < a \\ \beta(x-a)+y_a, & a \le x < b \\ \gamma(x-b)+y_b, & b \le x < L \end{cases} \quad (1)$$

Where, x is an input image and y is the Stretched output and α, β and γ are the stretching constants, act as multiplier. Here, a and b are the lower and the higher range, y_a and y_b are given below by equation:

$$y_a = \alpha a;$$

$$y_b = \beta(b-a)+y_a \quad (2)$$

The purpose of contrast enhancement in the various applications is to bring the image into a range which is more familiar or normal to senses, hence it is also called normalization. The general idea in contrast enhancement is to apply a linear or non-linear scaling transform to obtain a new modified image. Here we consider two low contrast images named as Image 1 and Image 2 for both the cases linear and non- linear enhancement [12].

A. Linear Contrast Enhancement

This type referred a contrast stretching, linearly expands the original digital values of the remotely sensed data into a new distribution. By expanding the original input values of the image, the total range of sensitivity of the display device can be utilized. There are three methods of linear contrast enhancement [2]:

- Min-Max Linear Contrast Stretch
- Percentage Linear Contrast Stretch
- Piecewise Linear Contrast Stretch

1) Min-Max Linear Contrast Stretch

When using the minimum-maximum linear contrast stretch, the original minimum and maximum values of the data are assigned to a newly specified set of values that utilize the full range of available brightness values.

g(x, y)=(f(x,y)-min)/(max-min))* No. of intensity level (3)

where, g(x,y) represents the images, on the left side it represents the output image, while f(x,y) it represents input image. In this equation the "min" and "max" are the minimum intensity value and the minimum intensity value in the current image. Here "no. of intensity levels" shows the total number of intensity values that can be assigned to a pixel. For example, normally in the gray-level images, the lowest possible intensity is 0, and the highest intensity value is 255. Thus "no. of intensity levels" is equal to 255.

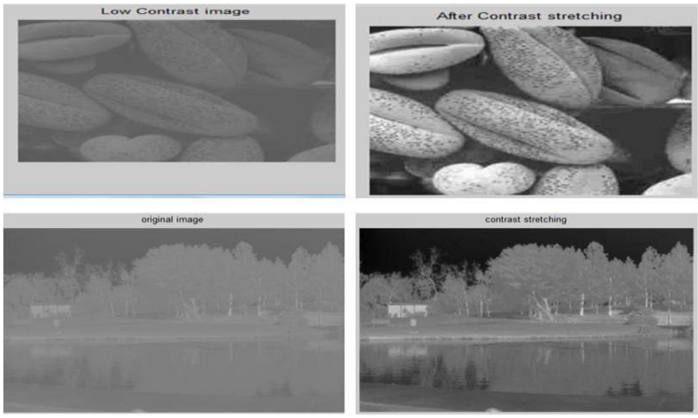

Fig 2 Min- Max Linear Contrast Stretch

2) Percentage Linear Contrast Stretch

The percentage linear contrast stretch is similar to the minimum-maximum linear contrast stretch except this method uses specified minimum and maximum values that lie in a certain percentage of pixels from the mean of the histogram. A standard deviation from the mean is often used to push the tails of the histogram beyond the original minimum and maximum values.

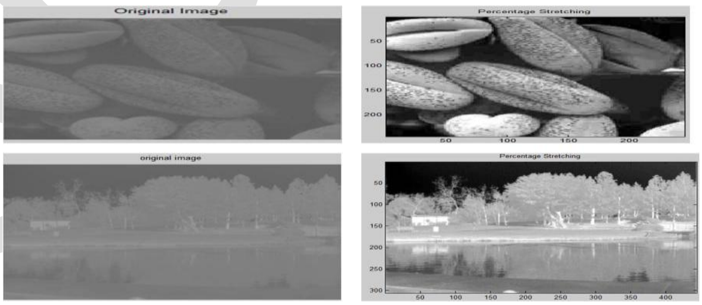

Fig 3 Percentage Linear Contrast Stretch

3) Piecewise Linear Contrast Stretch

When the distribution of a histogram in an image is bi or remodel, an analyst may stretch certain values of the histogram for increased enhancement in selected areas. This method of contrast enhancement is called a piecewise linear contrast stretch. A piecewise linear contrast enhancement involves the identification of a number of linear enhancement steps that expands the brightness ranges in the modes of the histogram. This type can be expressed by:

$$f(x,y) = \begin{cases} ax, & 0 \le x \le x_1 \\ b(x-x_1)+y_{x_1}, & x_1 \le x \le x_2 \\ c(x-x_2)+y_{x_1}, & x_2 \le x \le B \end{cases} \quad (4)$$

Where: f(x, y) is the Piecewise Linear Contrast Stretch in the image, a, b, and c are appropriate constants, which are the slopes in the respective regions and B is the maximum intensity value.

Piecewise-Linear Transformation (also called Contrast-Stretching Transformation) stretches gray-level ranges where we desire more information. This transformation increases the contrast between the darks and the lights. In simple words, the dark becomes darker and the light becomes brighter. To use this transformation, we use the function as below:

g = (1/ (1 + (m / (double (f) + eps))^ E) (5)

Where: E = slope function, m = mid-line of switching from dark value to light value, eps = MATLAB constant; distance between 1.0 and the next largest number in double-precision floating point [2^(-52)].

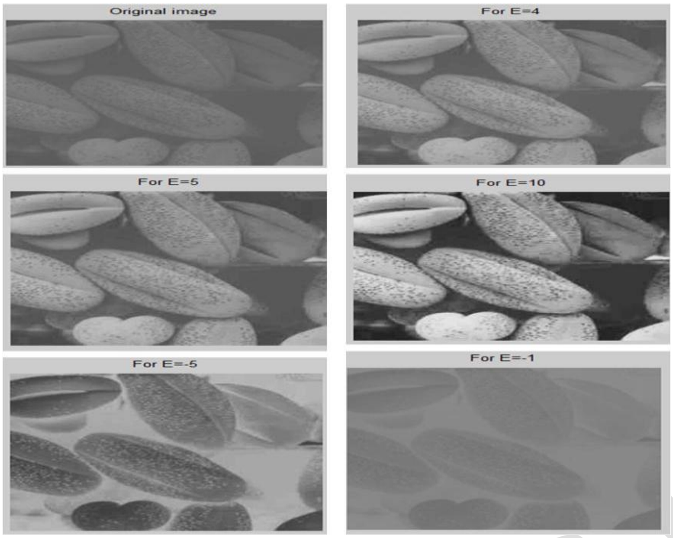

Fig.4 Piecewise Linear Contrast Stretch (Image 1)

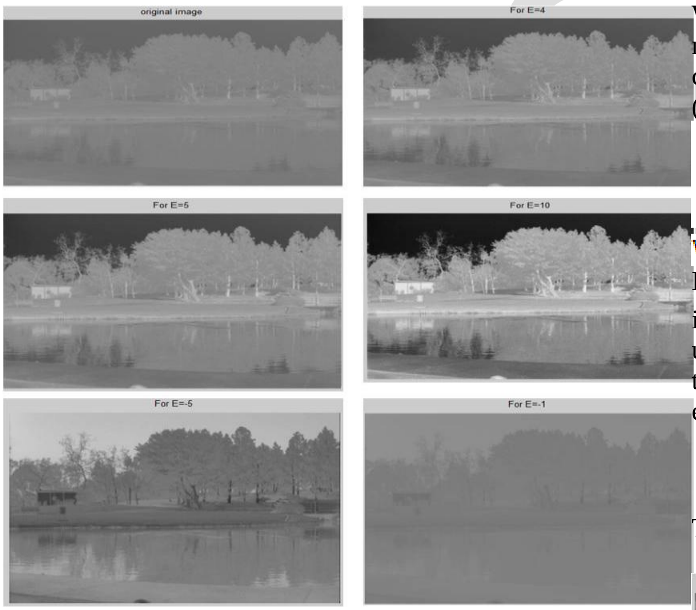

Fig.5 Piecewise Linear Contrast Stretch (Image 2)

B. *Non linear Contrast Enhancement*

Nonlinear contrast enhancement often involves histogram equalizations through the use of an algorithm. The nonlinear contrast stretch method has one major disadvantage each value in the input image can have several values in the output image, so that objects in the original scene lose their correct relative brightness value. There are three methods of nonlinear Contrast enhancement [2]**:**

- Histogram Equalizations
- Adaptive Histogram Equalization
- Homomorphic Filter

1) *Histogram Equalizations*

The objective is to map an input image to an output image such that its histogram is uniform after the mapping.

A histogram is basically a visual representation of the uniform distribution of pixels. Histogram equalization (HE) is a popular technique for enhancing image contrast due to its simplicity and effectiveness [5], [6]. This method increases the global contrast of the image, and adjusts image intensities to enhance contrast by spreading out the most frequent intensity values. By this, the intensities are better distributed on the histogram. Thus the areas of lower local contrast gain a higher contrast.

Histogram Equalization maps gray levels r of an image into gray levels S of an image in such a way that gray levels S are uniform. This expands the range of gray levels (contrast) that are near the histogram maxima, and compresses the range of gray levels that are near the histogram minima. For most images, the contrast is usually expanded for most pixels, improving many image features [7].

Consider a discrete gray scale image X={ X(i, j)} composed of L discrete gray levels denoted as $\{ X_0, X_1, X_2 \ldots\ldots\ldots X_{L-1}\}$. For a given input X, the probability density function P (X_k) is defined as:

$$P(X_k) = \frac{n_k}{n} \quad (6)$$

Where n_k is number of occurrence of gray level X. N is total number of pixels in the image. Let us also define the cumulative distribution function (cdf) corresponding to) P (X_k) as shown in equation:

$$C(x) = \sum_{j=0}^{k} P(X_j) \quad (7)$$

Where x is X_k for $k = 0,1,\ldots,L-1$ and $0 \le C(X_k) \le 1$.

Histogram equalization is a mapping scheme that maps the input image into the entire dynamic range (X_0, X_{L-1}) by using the cdf as a level transformation function. A transformation function f(x) based on the cdf is defined as in equation:

$$f(x) = X_0 + (X_{L-1} - X_0)C(x) \quad (8)$$

This is the desired output image of Histogram Equalization.

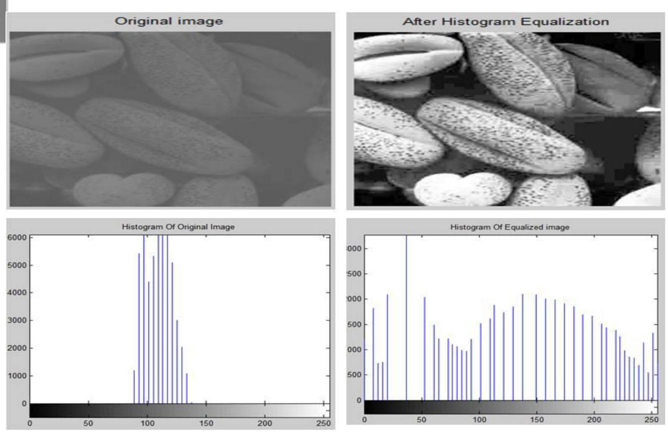

Fig. 6 Histogram Equalization (Image 1)

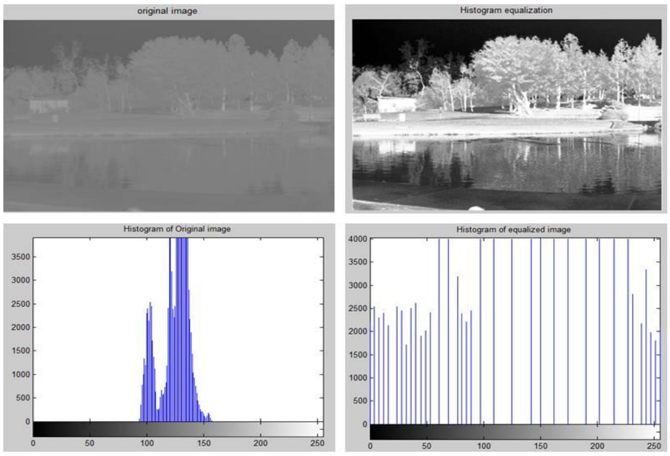

Fig 7 Histogram Equalization (Image 2)

(2) Adaptive Histogram Equalization

Adaptive histogram equalization where you can divide the image into several rectangular domains, compute an equalizing histogram and modify levels so that they match across boundaries depending on the nature of the non-uniformity of the image. Adaptive histogram equalization uses the histogram equalization mapping function supported over a certain size of a local window to determine each enhanced density value. It acts as a local operation. Therefore regions occupying different gray scale ranges can be enhanced simultaneously. According to this method, we partition the given image into blocks of suitable size and equalize the histogram of each sub block. In order to eliminate artificial boundaries created by the process, the intensities are interpolated across the block regions using bucolic interpolating functions [8].

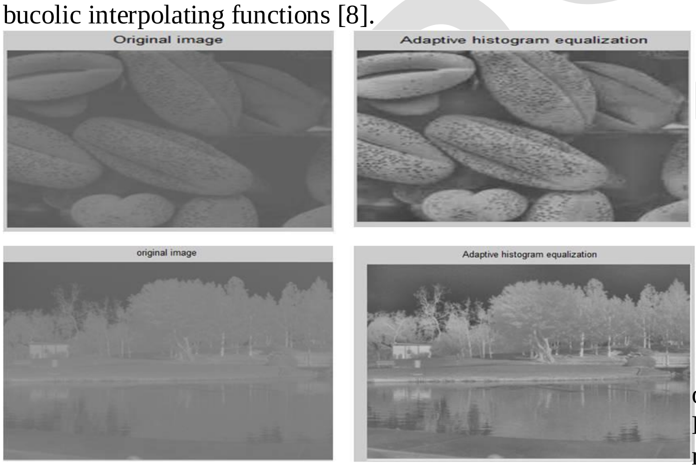

Fig 8 Adaptive Histogram Equalization

2) Homomorphic Filter

Homomorphic filter is the filter which controls both high-frequency and low-frequency components. Homomorphic filtering aims at handling large of image intensity, it has a multiplicative model [11].When images are acquired by optical means, the image of the object is a product of the illuminating light source and the reflectance of the object, as described by:

$$f(x, y) = I(x,y)\, \rho\, (x,y) \qquad (9)$$

Where I is the intensity of the illuminating light source, f is the image, and $0 \leq \rho \leq 1$ is the reflectance of the object. In order to enhance an image with poor contrast, we can use the model and selectively filter out the light source while boosting the reflectance component. The result will be an enhancement of the image. In order to separate the two components, they must be additive. We therefore transform the image into the log domain, whereby the multiplicative components become additive, as

$$l_n(f) = l_n(I) + l_n(\rho) \qquad (10)$$

Since the natural logarithm is monotonic, l_n (I) is low pass and l_n (ρ) is high pass. Now we have an image f= l_n (f), which has additive components and can therefore be selectively filtered by a linear filter. In order to enhance an image, the Homomorphic filter must have a higher response in the high-frequency region than in the low-frequency region so that the details, which fall in the high frequency region, can be accentuated while lowering the illumination component [9].

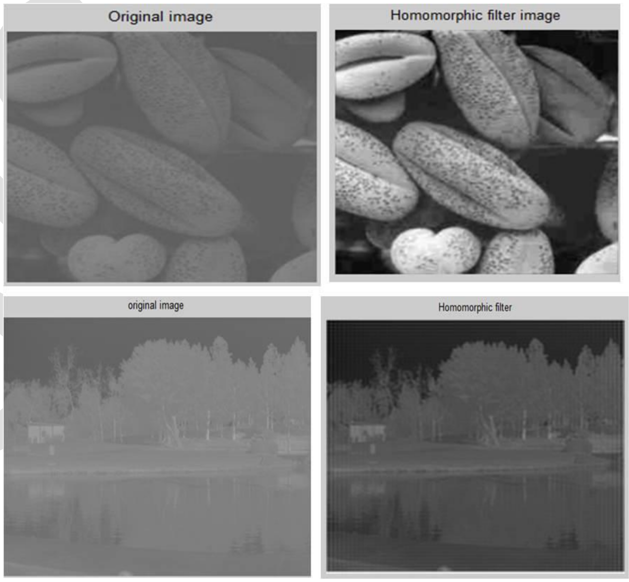

Fig 9 Adaptive Homomorphic Filter

IV. PERFORMANCE MATRICES

The two parameters used for the performance evaluation of various Contrast enhancement methods are given below.

MSE - The Mean Square error abbreviated as MSE represents the cumulative squared error between the original image and its noisy approximation. Lower the value of MSE, lower the error. MSE is given below by equation [10]:

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[x(i,j)-y(i,j)]^2$$

(11)

where x (i ,j) is noise-free m x n gray scale image and y(i ,j) is noisy approximation of x(i , j).

PSNR - The peak signal-to-noise ratio, abbreviated as PSNR, is the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. PSNR can be represented by equation [10].

$$PSNR = 10.\log_{10}\left(\frac{Max_I^2}{MSE}\right) \quad (12)$$

Here, Max_1 is the maximum possible pixel value of the image. When samples are represented using linear PCM with B bits per sample, Max_1 is 2^B -1.

TABLE I
THE PERFORMANCE OF VARIOUS LINEAR CONTRAST ENHANCEMENT TECHNIQUES FOR IMAGE 1:

Types of Image	**Linear Contrast Enhancement Techniques**	**Parameters MSE**	**PSNR**
Image 1	Min-Max	195.53	25.25
	Percentage	61.95	30.27
	Piecewise	78.18	78.11

TABLE II
THE PERFORMANCE OF VARIOUS LINEAR CONTRAST ENHANCEMENT TECHNIQUES FOR IMAGE 2

Types of Image	**Linear Contrast Enhancement Techniques**	**Parameters MSE**	**PSNR**
Image 2	Min-Max	188.48	25.41
	Percentage	61.16	30.27
	Piecewise	78.26	78.26

TABLE III
THE PERFORMANCE OF VARIOUS NON LINEAR CONTRAST ENHANCEMENT TECHNIQUES FOR IMAGE 1:

Types of Image	**Non-Linear Contrast Enhancement Techniques**	**Parameters MSE**	**PSNR**
Image 1	Histogram equalization	182.51	25.55
	Adaptive Histogram equalization	193.76	25.29
	Homomorphic Filter	11804.64	7.44

TABLE IV
THE PERFORMANCE OF VARIOUS NON- LINEAR CONTRAST ENHANCEMENT TECHNIQUES FOR IMAGE 2:

Types of Image	**Non-Linear Contrast Enhancement Techniques**	**Parameters MSE**	**PSNR**
Image 2	Histogram equalization	181.56	25.57
	Adaptive Histogram equalization	195.17	25.26
	Homomorphic Filter	16035.63	6.11

V. CONCLUSION

The Contrast enhancement methods effectively improve the visibility of low contrast images. From the experimental results it is clear that in linear contrast enhancement, Piecewise linear contrast stretch gives the minimum MSE and highest PSNR value, therefore it has given better result than others and in non-linear contrast enhancement, Histogram Equalization gives the minimum MSE and highest PSNR value, therefore it is better method than other nonlinear contrast enhancement methods and when comparing linear and nonlinear contrast enhancement methods with each other, experiments show that non-linear contrast methods have given better performance.

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