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# Review of Different Histogram Equalization Based Contrast Enhancement Techniques

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**Abstract**: Images having low contrast are usually captured in dark or bright environments. So preprocessing of such images becomes necessary to make the images suitable for other image processing applications. Image enhancement is a common problem. The histogram equalization (HE) technique is widely used for this purpose because it is simple and effective. However, it produces undesirable visual artifacts in the output image because the mean brightness of the image is changed. This paper presents a review of different techniques that can be used for contrast enhancement. The ultimate aim of these techniques is to preserve the input mean brightness so that the image looks natural in appearance.

**Keywords**: Histogram Equalization, Contrast enhancement, Histogram, DHE, BBHE.

## I. INTRODUCTION

Image enhancement is one of the most important areas of digital image processing. Image enhancement aims to improve the quality of the input image that may be acquired by a camera or other imaging system to make the output image looks better [1]. Image enhancement has received much interest in many digital image analysis applications, such as, space imagery, medical research, microscopic imaging, remote sensing, military, printing industry, textiles, forensic studies, graphic arts etc. Image enhancement processes are useful in feature extraction, image analysis and display, image restoration etc. The enhancement processes does not increase the information content in an image, instead they highlight certain specific features of interest in the image. Examples of image enhancement include edge enhancement, contrast enhancement, pseudo-coloring, noise filtering and sharpening etc [23]. Out of these contrast enhancement is a popular one.

Contrast enhancement is one of the most important techniques for image enhancement [1]. In this technique, contrast of an image is improved to make the image better for human vision. There are various techniques that can be used for contrast enhancement process. But the most common one is the histogram equalization (HE). The HE technique remaps gray levels of image based on probability distribution function (PDF) of the input image gray levels. HE flattens the histogram and stretches dynamic range of gray levels to perform overall contrast enhancement [10]. However, histogram equalization has some drawbacks that are often observed when HE is applied. First, histogram equalization transforms the histogram of original input image into a flat histogram where mean value lies somewhere in middle of gray level range. That means it does not take into account mean brightness of the input image. Second, the HE method performs enhancement based on global content, i.e. it only enhances borders and edges among objects in the image. Third, HE may result in over enhancement due to stretching of the gray levels of input image over the full gray level range [10]. Other disadvantages include change in the brightness of image after HE is applied. This technique is not commonly used in consumer electronics as it significantly changes brightness of input image and unnecessary visual deterioration is introduced [9] [13]. Therefore researchers have proposed some other brightness preserving techniques as an improvement in the traditional histogram equalization process.

Brightness Preserving Bi-HE (BBHE), Dualistic Subimage Histogram Equalization (DSIHE), Recursive Mean Separate Histogram Equalization (RMSHE), Minimum Mean Brightness Error Bi-HE (MMBEBHE), Recursive Separated and Weighted Histogram Equalization (RSWHE), Dynamic HE (DHE), Brightness preserving Dynamic HE (BPDHE) etc. are some of the techniques that aim to preserve the brightness of the image [1] [10].

The present paper is organized as follows: Histogram equalization (HE) for a digital input image with its mathematical formulation in section II; other brightness preserving enhancement techniques like BBHE, DSIHE, RMSHE (generalization of BBHE), MMBEBHE, RSWHE, DHE, and BPDHE etc. are discussed in section III. Paper concludes with Section IV containing discussion of various histogram equalization techniques.

## II. HISTOGRAM EQUALIZATION

Histogram equalization (HE) is a widely used technique for contrast enhancement because it is simple to use and better in performance on all types of images. It is most commonly used in the areas like medical image processing, radar signal processing etc. The algorithm for histogram equalization process is as follows:

For a given image $X = \{X(i, j)\}$, composed of $L$ discrete gray levels denoted as $\{X_0, X_1, ... X_{L-1}\}$, where $X(i, j)$ represents an intensity of image at the spatial location $(i, j)$ and $X(i, j) \in \{X_0, X_1, ... X_{L-1}\}$. For image $X$, probability density function $p(X_K)$ is defined as:

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$$p(X_K) = \frac{n^k}{n} \quad (1)$$

for $k = 0,1,\ldots,L-1$, where $n^k$ represents number of times $X_k$ appears in input image $X$ and $n$ is total number of samples in input image.

Here $p(X_K)$ is associated with histogram of input image which represents number of pixels having specific intensity $X_k$. A plot of $n^k$ vs. $X_k$ is known as histogram of $X$. The cumulative density function (CDF) $c(x)$ is defined on the bases of PDF,

$$c(x) = \sum_{j=0}^{k} p(X_j) \quad (2)$$

where $X_k = x$, for $k = 0,1,\ldots,L-1$. Here $c(X_{L-1}) = 1$ by definition. HE is a scheme which maps input image into the entire dynamic range, $(X_0, X_{L-1})$ by using CDF as a transform function [3].

HE works by flattening the histogram of input image and stretches dynamic range of gray levels by using cumulative density function (CDF) of the image. A Histogram represents relative frequency of occurrence of gray levels to preserve mean brightness of the input image [3]. The HE method re-maps the gray levels of input image by re-assigning intensity values of pixels to make a uniform intensity distribution. The following figures show how HE enhances the gray scale image.

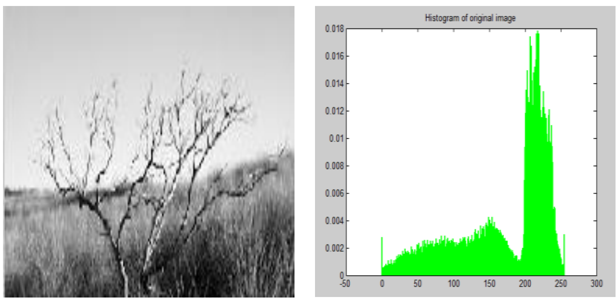


Fig1 (a) Original gray scale image and its histogram

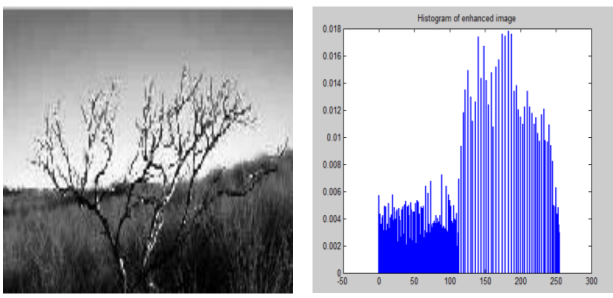


Fig1 (b) Result of HE and its histogram

The above Fig1 (a) illustrates the original image with its histogram. Fig1 (b) illustrates histogram equalization technique applied on the original image and the histogram of output image is obtained.

## III. EXISTING CONTRAST ENHANCEMENT TECHNIQUES

**A) Brightness Preserving Bi-Histogram Equalization (BBHE):**
In this technique, the input image is decomposed and two sub images are formed on the bases of mean value. One subimage contains the set of samples that are less than or equal to mean whereas the other subimage is the set of samples greater than mean. Then the method equalizes both sub images independently according to their respective histograms with a constraint that samples in the first subimage are mapped in the range from minimum gray level to input mean and samples in second subimage are mapped in the range from mean to maximum gray level [10]. That means one subimage is equalized over the range up to mean and other subimage is equalized over the range from mean based on the respective histograms. The resultant equalized sub images are bounded by each other around input mean, which has an effect of preserving the mean brightness [1][3].

BBHE has an advantage that it preserves mean brightness of the image while enhancing the contrast and, thus, provides much natural enhancement that can be utilized in consumer electronic products [3]. Following figure2 illustrates the Bi-HE process [10].

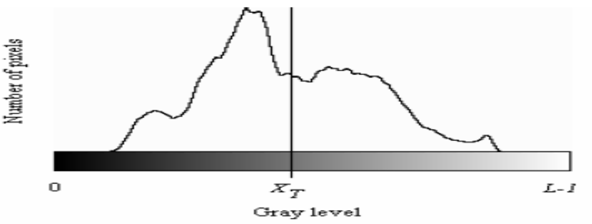


Fig2 Bi- Histogram Equalization

**B) Dualistic Subimage Histogram Equalization (DSIHE):** Some enhancement techniques change the luminance of image significantly with equalization. Such techniques can never be utilized in video systems directly. The DSIHE technique for contrast enhancement decomposes an image into two equal area sub-images, one dark and one bright, following the equal area property (*i.e.*, both sub-images have same amount of pixels) [10][14]. This decomposition is done on the bases of the gray level cumulative probability density which is equal to 0.5. Then the two sub images are taken in equalization process respectively. After enhancement, these two sub images are composed into one image. Finally, result of enhancement provides an enhanced image with its original luminance that makes it possible to be used in the video system directly [11]. There is no doubt that these two sub images represent the dark and bright areas of original image respectively. So, the gray level can be remained in its original scale respectively after subimage histogram equalization. Furthermore, contrast of the original image is also enhanced effectively post processing. The DSIHE method decomposes the images aiming at the maximization of the Shannon's entropy of the output image [1][6].

Let us say X is an image that is segmented with gray level of $X = X_e$ and the two newly obtained sub-images are

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named $X_L$ and $X_U$. So, $X = X_L \cup X_U$. Here,

$$X_L = \{X(i,j) \mid X(i,j) \lhd X_e, \forall X(i,j) \in X\} \quad (3)$$

$$X_U = \{X(i,j) \mid X(i,j) \rhd X_e, \forall X(i,j) \in X\} \quad (4)$$

It is obvious that the new sub-image $X_L$ is composed by the gray level of $\{X_0, X_1, ..., X_{e-1}\}$ while the other sub-image $X_U$ is composed by the gray level of $\{X_e, X_{e+1}, ..., X_{L-1}\}$. The aggregation of the original image's gray level distribution probability is decomposed into $\{p_0, p_1, ..., p_{e-1}\}$ and $\{p_e, p_{e+1}, ..., p_{L-1}\}$ correspondingly.

Suppose

$$p = \sum_{i=0}^{e-1} p_i \quad (5)$$

Then the normalized gray level distribution probability for sub-image $X_L$ and $X_U$ will be the following

$$\left\{ \frac{p_i}{p}, i = 0,1,..e-1 \right\} \quad (6)$$

And

$$\left\{ \frac{p_i}{1-p}, i = e, e+1,..L-1 \right\} \quad (7)$$

So the corresponding cumulative distribution function will be as follows

$$c_L(X_K) = \frac{1}{p} \sum_{i=0}^{k} p_i, \quad k=0, \quad 1,.., \quad e-1 \quad (8)$$

And

$$c_U(X_K) = \frac{1}{1-p} \sum_{i=e}^{L-1} p_i, \quad k=e, \quad e+1,.., \quad L-1 \quad (9)$$

Based on the cumulative distribution function, the transform functions for the two sub-images' histogram equalization are listed below

$$f_L(X_K) = X_0 + (X_{e-1} - X_0)c(X_K), \quad k=0, 1,.., e-1 \quad (10)$$

And

$$f_U(X_K) = X_e + (X_{L-1} - X_e)c(X_K), \quad k=e, e+1,.., L-1 \quad (11)$$

Finally, resulting image of dualistic sub-image histogram equalization (DSIHE) is obtained after these two equalized sub-images will be composed into one image [6]. Suppose Y denotes the processed image, then

$$Y = \{Y(i,j)\} = f_L(X_L) \cup f_U(X_U) \quad (12)$$

Where

$$f_L(X_L) = \{f_L(X(i,j)) \mid \forall X(i,j) \in X_L\} \quad (13)$$

$$f_U(X_U) = \{f_U(X(i,j)) \mid \forall X(i,j) \in X_U\} \quad (14)$$

Namely

$$Y(i,j) = \{X_0 + (X_{e-1} - X_0)c_L(X), \quad \text{if } X < X_e \quad (15)$$

$$\{X_e + (X_{L-1} - X_e)c_U(X), \quad \text{else.} \quad (16)$$

**C) Recursive Mean-Separate Histogram Equalization (RMSHE):**

Mean-separation means to separate an image based on the mean of input image [7]. However, RMSHE technique is an extension of BBHE (where mean-separation was done only once). In RMSHE, instead of decomposing the input image only once, it is decomposed recursively up to a recursion level r, therefore 2r sub images will be generated. Each subimage is then equalized independently with histogram equalization method. If r=0, that means no subimage decomposition is done, i.e. it is equivalent to HE method only [1] [10]. When one mean separation is done before equalization, i.e. r=1, this is equivalent to BBHE [14]. This increases a level of brightness preservation. Similarly, two mean-separations before equalization will result in much higher level of brightness preservation as compared to r=0 and r=1 levels [7]. The above discussion concludes that the level of brightness preservation will increase with the increase of number of recursive mean-separations. This technique aims to bring more extends of brightness preservation than HE and BBHE techniques.

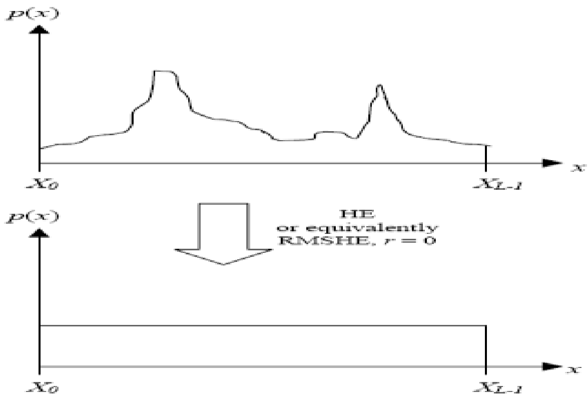


Fig3 (a) Histogram before and after HE or equivalently RMSHE, r = 0

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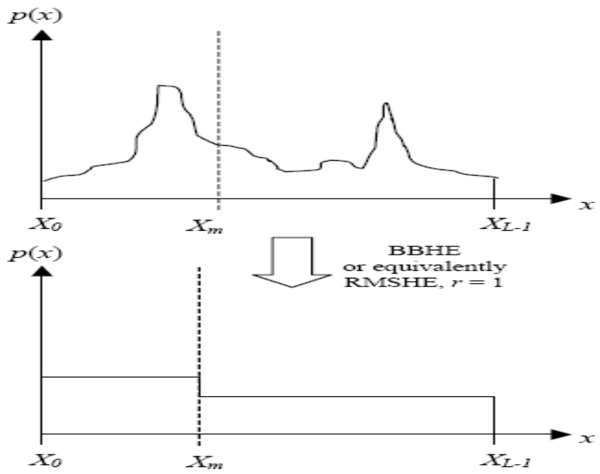

Fig3 (b) Histogram before and after HE or equivalently RMSHE, r = 1

**D) Recursive Separated and Weighted Histogram Equalization (RSWHE):**

The RSWHE technique is slightly different from the techniques discussed so far in this section. The main difference between RSWHE and other histogram equalization techniques is that RSWHE first modifies the input histogram and then runs the equalization procedure. This technique works in three modules. These are: histogram segmentation, histogram weighting and histogram equalization [1][17].

The idea behind each module in RSWHE technique is explained as follows:

**i) Histogram segmentation module** It takes the input image, computes the input histogram. The input histogram is decomposed recursively into two or more sub-histograms based on the mean and median value [16].

**ii) Histogram weighting module** In this module, sub-histograms computed in step 1 are modified through histogram weighting process using a normalized power law function.

**iii) Histogram equalization module** In this, histogram equalization process is individually applied over each of the weighted sub-histograms that were modified in step 2. A better contrast enhancement is achieved by equalizing each sub-histogram independently and annoying side effects are also reduced through RSWHE [1].

Recursive sub-image histogram equalization (RSIHE) and recursive mean separate histogram equalization (RMSHE) are some methods that are similar to RSWHE, but weighting process is not carried out in RSIHE and RMSHE.

**E) Minimum Mean Brightness Error Bi-HE (MMBEBHE):**

This is based on the principle of BBHE and DSIHE, i.e. decomposition of image into two sub images and applying equalization process independently to the resulting sub images [1] [10]. But MMBEBHE is slightly different. This technique searches for a threshold level $l_t$, which decomposes input image into two sub-images in such a way that the minimum brightness difference between the input and the output image is achieved. This is called absolute mean brightness error (AMBE) [15]. After decomposing input image by the threshold level, each of the two sub-images undergo histogram equalization process to generate the output image. The technique is summarized as follows:

a. Calculate the absolute mean brightness error (AMBE) for each possible threshold level.

b. Find a threshold level $X_T$ that yield minimum absolute mean brightness error (AMBE).

c. Separate the input histogram into two histograms based on $X_T$ found in Step 2 and equalizes both the histograms independently [14].

This technique aims to produce a method that is suitable for real-time applications.

**F) Dynamic Histogram Equalization (DHE):**

The Dynamic Histogram Equalization (DHE) technique performs well than the traditional HE so that it can enhance an image without making any loss of details in the image. DHE divides the histogram of input image into a number of sub-histograms until it ensures that no dominating portion is present in any of the newly created sub-histograms [10]. Then a dynamic gray level (GL) range is allocated for each sub-histogram to which its gray levels can be mapped by HE. To perform this, total available dynamic range of gray levels is distributed among the new sub-histograms based on their dynamic range in input image and the cumulative distribution function (CDF) of histogram values. From this allotment of stretching range of contrast, small features of the input image are prevented from being dominated and washed out, and ensure a moderate contrast enhancement of each portion in the image. Now at last, a separate transformation function is calculated for each sub-histogram based on the traditional HE method and gray levels of input image are mapped to the output image accordingly. In nutshell, the whole technique of DHE can be divided into following three parts – partitioning the histogram, allocating GL ranges for each sub histogram and applying histogram equalization on each of them [28].

**G) Brightness Preserving Dynamic Histogram Equalization (BPDHE):**

The brightness preserving dynamic histogram equalization is an extension to the traditional HE method that can produce output image with the mean intensity that is almost equal to the mean intensity of input image. Thus BPDHE maintains the mean brightness of the image and hence overcomes the limitation of histogram equalization [4]. This method is actually an extension to the DHE. The BPDHE method partitions the input histogram based on the local maximums of the smoothed histogram. However, before the histogram equalization has taken place, the BPDHE will map each partition to a new dynamic range, similar to DHE. The change in the dynamic range will cause the change in mean brightness. And the final step involves normalization of the output intensity. So, the average intensity of resultant output image will be same as the input image. Hence, BPDHE proves itself better in performing enhancement task as compared to traditional HE method, and better in preserving mean brightness when compared with DHE [4].

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## IV. CONCLUSION

Histogram equalization is a simple and effective technique that can be used for image contrast enhancement. However, it is not suitable for the consumer electronic products as it changes the mean brightness in the output image and introduces unwanted visual deterioration. Various other brightness preserving contrast enhancement techniques are used. BBHE and DSIHE separate the input image into two different sub-images based on the mean value and median value respectively. RMSHE handles higher brightness preservation than traditional HE, BBHE and DSIHE techniques. The RSWHE technique divides the input histogram into two or more subsections recursively, to modify sub histogram by means of weighting process based on normalized power law function. MMBEBHE is an extended version of BBHE technique and provides maximal brightness preservation comparatively. These methods perform good contrast enhancement, but also cause annoying side effects [15]. DHE method preserves the image details well and do not has any severe side effects. BPDHE preserves mean brightness better than BBHE, DSIHE, MMBEBHE, RMSHE, MBPHE, and DHE. The major goal of all these contrast enhancement techniques is to produce the output images in which mean brightness is preserved and the image looks better in appearance.

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