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A NOVEL ALGORITHM FOR IMAGE CONTRAST ENHANCEMENT USING HISTOGRAM EQUALIZATION

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ABSTRACT

Image enhancement improves an image appearance by increasing dominance of some features or by decreasing ambiguity between different regions of the image. A number of image contrast enhancement techniques exist to improve the visual appearance of an image. Many images such as medical images, remote sensing images, electron microscopy images and even real life photographic pictures, suffer from poor contrast. Therefore, it is necessary to enhance the contrast of images. Histogram equalization is widely used for contrast enhancement in a variety of applications due to its simple function and effectiveness. However, it tends to change the brightness of an image and hence, not suitable for consumer electronic products, where preserving the original brightness is essential to avoid annoying artifacts. In addition, HE method tends to introduce unnecessary visual deterioration including saturation effect. Preserving the input brightness of the image and keeping PSNR in the desired range are required to avoid the generation of non-existing artifacts in the output image. A number of techniques have been used to overcome its annoying effects. But each technique has its advantages and application areas. In this paper we will present a new weighted thresholded histogram equalization based method which aims to better preserve the image quality, preserves better contrast and enriches the image details.

KEYWORDS

BBHE, DSIHE, MMBEBHE, Histogram Equalization.

INTRODUCTION

Histogram is defined as the statistic probabilistic distribution of each gray level in a digital image. It can give us a general overview of an image such as gray scale, gray level distribution and its density, the average luminance of an image, image contrast, and so on. Histogram processing is the act of altering an image by modifying its histogram. Common uses of histogram processing include normalization by which one makes the histogram of an image as flat as possible.

Histogram equalization is a simple and effective method for image enhancement. Based on the image's original gray level distribution, the image's histogram is reshaped into a different one with uniform distribution property in order to increase the contrast. Histogram equalization is one of the well-known methods for enhancing the contrast of given images in accordance with the sample distribution of an image. Useful applications of the histogram equalization scheme include medical image processing and radar image processing**.** Despite its success for image contrast enhancement, this technique has a well-known drawback: it does not preserve the brightness of the input image on the output one. This drawback makes the use of HE not suitable for image contrast enhancement on consumer electronic products, such as video surveillance, where preserving the input brightness is essential to avoid the generation of non-existing artifacts in the output image. To overcome such drawback, variations of the classic HE technique have proposed to first decompose the input image into two sub-images, and then perform HE independently in each sub-image. These methods, described in details in Section III, use some statistical measures - which consider the value of the gray-levels in the image, during the decomposition step.

HISTOGRAM EQUALIZATION

The Histogram of digital image with the intensity levels in the range [0, L-1] is a discrete function.

$$h(r_k) = n_k \qquad (1)$$

Where

- r_k is the intensity value.
- n_k is the number of pixels in the image with intensity r_k.
- $h(r_k)$ is the histogram of the digital image with Gray Level r_k

Histograms are normalized by the total number of pixels in the image. Assuming a M × N image, a normalized histogram.

$$p(r_k)=\frac{n_k}{MN} \qquad (2)$$

for k=0,1,2,3……….L-1

is related to probability of occurrence of r_k in the image.

where

- $p(r_k)$ gives probability of occurrence of gray level r_k.
- Sum of all components of a normalized histogram is equal to1.

Histogram Equalization is a method of contrast adjustment using the image histogram. This method increases the global contrast of many images, especially when the usable data of the image is represented by close contrast values. With this adjustment, the intensities can be better distributed on the histogram. Histogram equalization is a technique that generates a gray map which changes the histogram of an image and redistributing all its pixels values to be as close as possible to a user specified desired histogram.

Consider the basic notations:

- X = {X(i,j)}is an image with L discrete gray levels. $\{X_0, X_1, X_2 \ldots\ldots X_{L-1}\}$.
- H(X) = $\{n_0, n_1, \ldots\ldots\ldots, n_{L-1}\}$is the image X's histogram where n_k is the no. of pixels whose gray level is X_k.
- N = total number of the image pixels.

Based on the histogram H(X), Probability Density Function (PDF) is

$$p(X_k) = \frac{n_k}{N} \qquad (3)$$

for k= 0,1,2,… L-1.
The relationship between $p(X_k)$ and X_k is defined as the probability density function (PDF), and the graphical appearance of PDF is known as the histogram. Based on the image's PDF, its cumulative distribution function (CDF) is defined as

$$c(X_k) = \sum_{i=0}^{k} p(X_k) \qquad (4)$$

for k= 0,1,2,… L-1.
It is obvious that $c(X_{L-1}) = 1$.
Thus, the transform function of histogram equalization can be defined as

$$f(X_k) = X_0 + (X_{L-1} - X_0)\, c(X_k) \qquad (5)$$

for k= 0,1,2,………. L-1.
Suppose Y={Y(i, j)} is defined as the equalized image, then

$$Y = f(X) = \{f(X(i,j)) \mid \forall X(i,j) \in X\} \qquad (6)$$

Generally, we can classify these methods in two principle categories – global and local histogram equalization. But researches have also focused on improvement of HE based on contrast enhancement.

PROBLEMS IN HISTOGRAM EQUALIZATION

1. HE does not take the mean brightness of an image into account.
2. HE is not commonly used in consumer electronics such as TV because it may significantly change the brightness of an input image and cause undesirable artifacts.
3. HE can introduce a significant change in brightness of an image, which hesitates the direct application of the histogram equalization scheme in consumer electronics
4. HE may result in over enhancement and saturation artifacts due to the stretching of the gray levels over the full gray level range.
5. It has been observed that the mean brightness of the histogram-equalized image is always the middle gray level regardless of the input mean.

More fundamental reason behind such limitations of the histogram equalization is that the histogram equalization does not take the mean brightness of an image into account.

LITERATURE REVIEW OF VARIENTS OF HE TECHNIQUES

A number of HE techniques have been developed so far. In this paper we will present a review for Brightness Preserving *Bi-histogram equalization (BBHE) in III.A, Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) in III.B, Proposed Method III.C*

A. BRIGHTNESS PRESERVING BI-HISTOGRAM EQUALIZATION

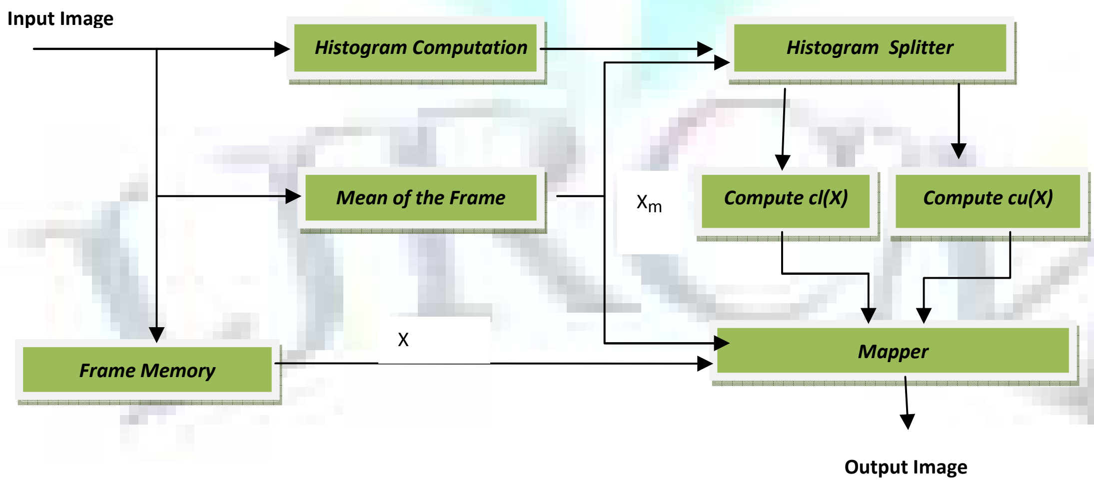
Brightness preserving Bi Histogram Equalization (BBHE) first decomposes an input image into two sub images based on the mean of the input image. One of the sub image is set of samples less than or equal to the mean whereas the second one is the set of samples greater than the mean. Then the BBHE equalizes the sub images independently based on their respective histograms with the constraint that the samples in the former set are mapped into the range from the minimum gray level to the input mean and the samples in the latter set are mapped into the range from the mean to the maximum gray level. It means first sub image is equalized over the range up to the mean and the other sub image is equalized over the range. Thus, the resulting equalized sub images are bounded by each other around the input mean, which has an effect of preserving mean brightness.

The functional block diagram for BBHE algorithm is shown in Figure 1, where the histogram computation unit counts and stores the respective numbers of occurrences n_k for k =0,1, . . . , L - 1, then the histogram splitter splits the number of occurrences as $(n_0,\ldots,n_m)$ *and* $(n_{m+1},\ldots,n_{L-1}$. The respective and independent cumulative density functions $cl(X)$ and $cu(X)$ are then computed based on $(n_0,\ldots,n_m)$ *and* $(n_{m+1},\ldots,n_{L-1})$ respectively, and after that the mapper outputs $Y(i, j)$ as

$$Y(i,j) = \begin{cases} X_0 + (X_m - X_0)\, cl(X) & \text{if } X \le X_m \\ X_{m+1} + (X_{L-1} - X_{m+1})\, cu(X), & \text{else} \end{cases} \qquad (7)$$

The computation of histogram and the mean typically need to be done during one frame period; thus a frame memory is necessary to store the image being processed.

FIGURE 1: FUNCTIONAL BLOCK DIAGRAM OF BBHE



It has been analyzed both mathematically and experimentally that this technique is capable to preserve the original brightness to a certain extends brightness preserving bi-HE. However, using input mean as the threshold level to separate the histogram does not guarantee maximum brightness preservation. The brightness preservation described here is based on an objective measurement referred as Absolute Mean Brightness Error (AMBE) which is defined as the absolute difference between the input and the output mean as follow:

$$AMBE = |\, E(\mathbf{X}) - E(\mathbf{Y})\, | \qquad (8)$$

Lower AMBE implies better brightness preservation. BBHE that set the threshold level, *XT* as input mean does not guarantee minimum AMBE. Nevertheless, there are still cases that are not handled well by both the BBHE and DSIHE. These images require higher degree of brightness preservation to avoid annoying artifacts.

B. MINIMUM MEAN BRIGHTNESS ERROR BI-HE METHOD (MMBEBHE)

Still following the basic principle of the BBHE and DSIHE methods of decomposing an image and then applying the HE method to equalize the resulting sub-images independently, MMBEBHE proposed the minimum mean brightness error Bi-HE (MMBEBHE) method.

MMBEBHE is formally defined by the following procedure:

1. Calculate the AMBE for each of the threshold level.
2. Find the threshold level, *XT* that yield minimum MBE,
3. Separate the input histogram into two based on the *XT* found in step 2 and equalized them independently as in BBHE

Step 2 and 3 are straightforward process. Step 1 requires considerable amount of computation if one full BBHE process is required to calculate the AMBE for each of the possible threshold level, especially when the number of gray level is large. This could become a major drawback of MMBEBHE in real time implementation.

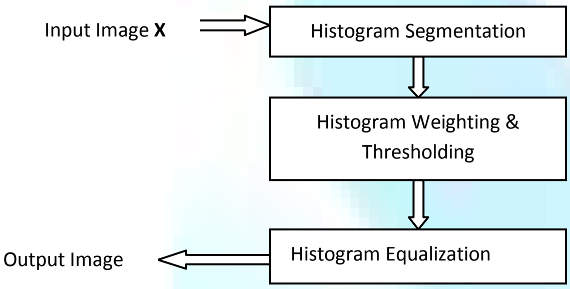
The main difference between the BBHE and DSIHE methods and the MMBEBHE one is that the latter searches for a threshold level XT that decomposes the image *I* into two sub-images *I*[0,*XT*] and *I*[*XT* +1,*L*−1], such that the minimum brightness difference between the input image and the output image is achieved, whereas the former methods consider only the input image to perform the decomposition.

Once the input image is decomposed by the threshold level XT, each of the two sub-images *I*[0,XT] and *I*[*XT* +1,*L*−1] has its histogram equalized by the HE process, generating the output image. Assumptions and manipulations for finding the threshold level XT in *O*(*L*) time complexity were made in MMBEBHE.

C. THE PROPOSED ALGORITHM

The proposed algorithm consists of three modules (see Figure 2): Histogram Segmentation, Histogram Weighting & Thresholding and Histogram Equalization. The histogram segmentation module takes the input image X, computes the input histogram H(X) and divides the input histogram in two sub-histograms. The histogram weighting module modifies the sub histograms by using normalized power law function. Then combine the two sub images. Compute the histogram equalization on this image. This is the final output image.

FIGURE 2 FUNCTIONAL BLOCK DIAGRAM OF PROPOSED METHOD



1. HISTOGRAM SEGMENTATION

In principle, this module decomposes histograms in two parts. That is, it divides the input histogram H(**X**) in two sub histograms. In fact, the module divides the input image based upon its mean value X_m . The mean value is computed as

$$X_m = \left(\sum_{k=0}^{L-1} k\,(p(k)) \right) / \left(\sum_{k=0}^{L-1} p(k) \right) \quad (9)$$

2. HISTOGRAM WEIGHTING AND THRESHOLDING MODULE

This module then modifies the input histogram as follows:

Let P(k) is the probability density function of the original histogram.

(a) Compute both the highest probability *pmax* and the lowest probability *pmin* by using (10) and (11),

$$Pmax = max_{0 \le k \le L-1} P(k) \quad (10)$$

$$Pmin = min_{0 \le k \le L-1} P(k) \quad (11)$$

(b) Compute the upper threshold value P_u as

$$P_u = v * P_{max} \quad (12)$$

when : P_{max} is highest probability value of the original PDF

v is the number defines the upper threshold normalized to Pmax (0<v<1). The value of *v* is taken as 0.5

(c) Compute the value of middle gray level X_G as:

$$X_G = (X_0+X_{L-1})/2 \quad (13)$$

(d) Compute the value of Beta as

$$Beta =(Pmax*(|mid-I_G|)/I_G) \quad (14)$$

(e) Calculating weighted thresholded probability density function for each sub image

$$P_{wt}(k) = \begin{cases} P_u & \text{If } P(k)>Pl \\ \left(\frac{P(k)-P_l}{P_u-P_l}\right)^r * P_u + beta & \text{If } Pl<=P(k)<Pu \\ 0 & \text{If } P(k)<Pl \end{cases} \quad (15)$$

Where $P_{wt}(k)$ is weighted thresholded probability density function

P_u is upper threshold

P_l is lower threshold

r is index of a normalized power law function (r>0). The value of r is taken as 0.75

k = 0,1,2,…,255

(f) Due to the above PDF modification, the sum of all the values P*wt*(*k*) from *k* = 0 to *L*-1 is no longer one, so the modified PDF needs to be normalized. The normalization is done by using (16). The resultant weighted and normalized PDF, called P*wn*(*k*), is then forwarded to the next histogram equalization module.

$$P_{wn}(X_k) = P_{wt}(X_k) \Big/ \sum_{j=0}^{L-1} P_{wt}(j) \quad (16)$$

3. HISTOGRAM EQUALIZATION

The task of histogram equalization is to compute cumulative density function and produce the output image using equations **(4), (5) and (6).**

AN INSIGHT ON THE RESULTS PRODUCED BY HE METHODS

The previous sections described methods which use HE for preserving the brightness of gray-level images. Figure 3 shows, for the lena image, the output images and respective histograms produced by these HE methods. This method is experimented the techniques on 4 images. Three quality measures have been used to access the image quality. Quality measures used are:

i) MEAN SQUARE ERROR:

Assuming that *N* is the total number of pixels in the input or output image, MSE (Mean Squared Error) is calculated through equation (17).

$$MSE = \frac{\sum_i \sum_j |X(i,j) - Y(i,j)|^2}{N} \quad (17)$$

ii) PEAK SIGNAL TO NOISE RATIO:

Based on MSE, PSNR is then defined as (18). Note that the greater the PSNR, the better the output image quality.

$$\mathrm{PSNR} = 10 \log_{10} \frac{(L-1)^2}{MSE} \quad (18)$$

iii) **ENTROPY**:

For a given PDF *p*, entropy *Ent*[*p*] is computed by (19). In general, the entropy is a useful tool to measure the richness of the details in the output image.

$$Ent[p] = -\sum_{k=0}^{L-1} p(k) \log_2 p(k) \quad (19)$$

iv) **AVERAGE MEAN BRIGHTNESS ERROR(AMBE)**

AMBE is used to measure the image brightness. For an input image X and output image Y, AMBE is given by:

$$AMBE = |XM - YM|, \quad (20)$$

where *XM* is the mean of the input image **X** = {*X*(*i*, *j*)} and
YM is the mean of the output image **Y** = {*Y*(*i*, *j*)}.

In this paper, AMBE is used to determine the image brightness. MSE is used to access the image quality. Lower the value of MSE better is the image. While both PSNR and entropy are employed to quantitatively assess the degree of contrast enhancement. In addition, for the qualitative assessment of contrast enhancement, we visually inspect the output image and see if it retains an appearance which is quite natural.

In turn, Table 1 shows the values of AMBE, Table 2 shows the values of the MSE, Table 3 shows values for PSNR, Table 4 shows values for Entropy for the four naturally existing images *living room, woman blonde, lena (512),pirate*.

TABLE 1: ABSOLUTE MEAN BRIGHTNESS ERROR (AMBE) IS USED TO ASSESS THE IMAGE BRIGHTNESS

IMAGE	CHE	BBHE	MMBEBHE	PROPOSED
living room	7.64	12.05	20.93	9.53
woman blonde	6.31	8.08	27.18	4.58
pirate	16.83	13.25	13.42	5.66
lena	4.22	7.95	16.92	3.84
Average	8.75	10.3325	19.6125	5.9025

TABLE 2: MEAN SQUARED ERROR (MSE)

IMAGE	CHE	BBHE	MMBEBHE	PROPOSED
living room	100.63	89.47	170.44	46.07
woman blonde	132.73	85.52	190.48	80.89
pirate	37.23	49.32	173.69	48.93
lena	103.88	89.24	169.60	81.29
Average	93.6175	78.3875	176.053	64.295

TABLE 3: PEAK SIGNAL TO NOISE RATIO (PSNR) IS USED TO QUANTITAIVELY ASSESS THE CONTRAST ENHANCEMENT

IMAGE	CHE	BBHE	MMBEBHE	PROPOSED
living room	28.10	28.61	25.81	31.49
woman blonde	26.90	28.81	25.33	29.05
pirate	32.42	31.20	25.73	31.23
lena	27.96	28.62	25.83	29.03
Average	28.845	29.31	25.675	30.2

TABLE 4: ENTROPY IS ALSO USED TO QUANTITAIVELY ASSESS THE CONTRAST ENHANCEMENT

IMAGE	CHE	BBHE	MMBEBHE	PROPOSED
living room	7.00	7.00	6.95	7.19
woman blonde	6.75	6.70	6.69	6.90
pirate	7.15	7.14	7.13	7.20
lena	7.32	7.31	7.32	7.41
Average	7.055	7.0375	7.0225	7.175

Here, we have two goals: brightness preserving and contrast enhancement. So AMBE is used to assess the degree of brightness preservation, while MSE, PSNR and Entropy are employed to quantitatively assess the degree of contrast enhancement. In addition, for the qualitative assessment of contrast enhancement, we visually inspect the output image and see if it retains an appearance which is quite natural.

A. Assessment of Brightness Preservation

Table 1 shows a matrix of AMBE values, where rows correspond to 4 test images and columns correspond to 4 HE-based methods. Here, Proposed method produces the minimum values for AMBE for all images. Based on these observations, we learn that Proposed method is the best brightness preserving method.

B. Assessment of Contrast Enhancement

Table 2 shows a matrix of MSE and Table 3 shows a matrix of PSNR values. Its size and structure are the same as in Table 2. Remember that the greater the PSNR, the better the image quality. Proposed method makes the highest scores in all test images

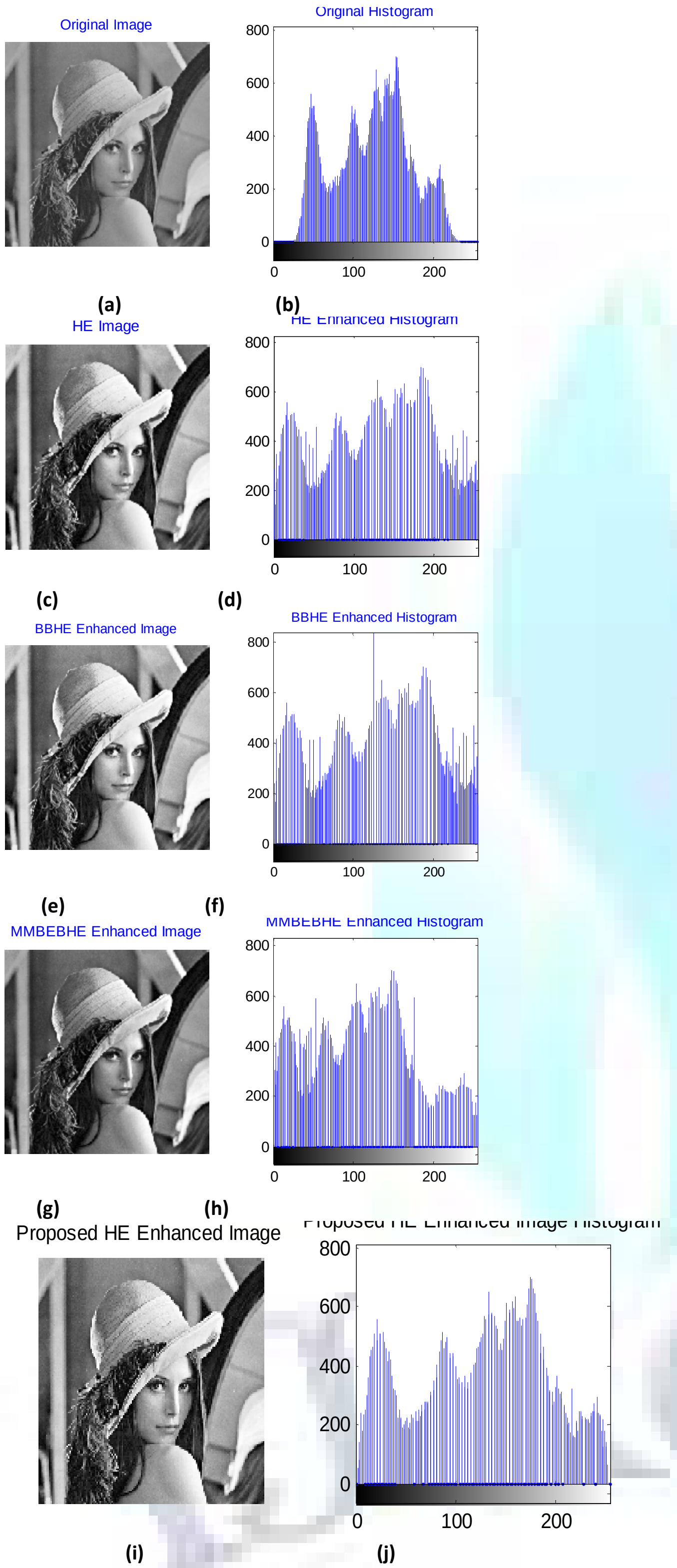
A matrix of entropy values are given in Table 4. In general, the higher the entropy is, the richer details and information the image holds. A careful examination of the entropy values reveals that Proposed method produces good comparative results in all images.

C. Inspection of Visual Quality

In addition to the quantitative evaluation of contrast enhancement using the PSNR and entropy values, it is also important to qualitatively assess the contrast enhancement. The major goal of the qualitative assessment is to judge if the output image is visually acceptable to human eyes and has a natural appearance.

Test result for image lena are as shown below in figure 3:

FIGURE 3: RESULT OF HE METHODS. (A) ORIGINAL IMAGE (B) HISTOGRAM OF ORIGINAL IMAGE (C)-(H) CHE, BBHE, MMBEBHE ENHANCED IMAGES AND THEIR RESPECTIVE HISTOGRAM (I) PROPOSED METHOD IMAGE (J) HISTOGRAM OF PROPOSED METHOD IMAGE



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