Performance analysis of contrast enhancement using various statistical operations and neighborhood processing

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ARTICLE INFO	ABSTRACT
	Histogram Equalization is a simple and effective contrast enhancement technique. In spite of its popularity Histogram Equalization still have some limitations –produces artifacts, unnatural images and the local details are not considered, therefore due to these limitations many other Equalization techniques have been derived from it with some up gradation. In this proposed method statistics play an important role in image processing, where statistical operations is applied to the image to get the desired result such as manipulation of brightness and contrast. Thus, a novel algorithm using statistical operations and neighborhood processing has been proposed in this paper where the algorithm has proven to be effective in contrast enhancement based on the theory and experiment.

Introduction

Vision being the most vital part of our senses, it is no doubt that images play an important role in human perception. Thus, digital image processing covers a wide field of applications. Image enhancement techniques are used as a pre processing tool in image processing to make the output image subjectively look better. The Histogram Equalization is a well known image enhancement method. While contrast may appear to be the simplest of image controls, they affect in such a way that changing it can cause quite complex effects in our image. Histogram Equalization (H.E) is a contrast enhancement process which consists of generating an output image with a uniform histogram. Utilizing the information contained in a histogram, it allows us to improve the contrast of an image. There are many Histogram Equalization methods for digital image contrast enhancement. Despite its simplicity and popularity, the histogram of the output image may contain many empty bins because it is shifted from the original histogram. It may cause clipping in some visually important areas. The paper is divided into six sections, section 2 gives a brief introduction about Histogram Equalization., section 3 covers some methods related to Histogram Equalization, Section 4 discusses about our proposed method, which is a unique combination of CHE and statistical operators using neighborhood process, section 5 gives us the result and discussion, and followed by the conclusion in section 6 [1][2][3].

HISTOGRAM EQUALIZATION

Histogram equalization is one of the most useful forms of nonlinear contrast enhancement. When an image histogram is equalized, all pixel values of the image are redistributed so that it increases the separation between the minimum and maximum pixels and thus increasing the contrast. [1][2] The histogram gives the relative frequency distribution of a gray scale image, so to get a uniform histogram for the output image take the gray levels as the histogram gives the relative frequency distribution of a gray random variables, obtain the probability density function and cumulative distribution.

For a given image X, the probability density function $P(X_r)$ is defined as

$$P(X_r)=n^r/n \tag{1}$$

for $r = 0, 1\ldots L - 1$, where n^r represents the number of times that the level (X_r) appears in the input image X and n is the total number of samples in the input image .The cumulative density function is defined as

$$C(X) = \sum_{j=0}^{r} P(Xj) \tag{2}$$

Note that C $(X_{L-1}) = 1$

Transform function $f(x)$ based on the cumulative density function is given as

$$f(x) = X_0 + (X_{L-1} - X_0)C(x) \tag{3}$$

Then the output image of the HE, Y = {Y *(i, j)}*, can be expressed as

$$Y = f(X)$$

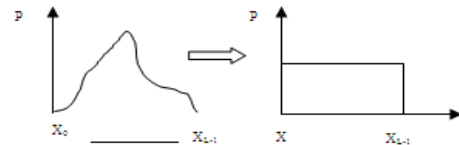$$= \{f(X\ (i, j) \mid \forall\ X\ (i, j)\ \in X\} \tag{4}$$

Fig 1: Histogram and its Equalized Histogram for H.E.

Related Work

There are many Histogram Equalization (HE) methods for digital image contrast enhancement. Some of the well known HE methods are discussed below:
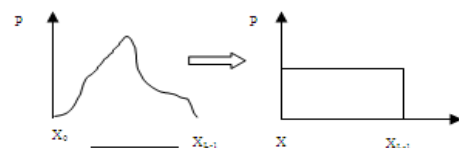

Fig 1: Histogram and its Equalized Histogram for H.E.

Classical Histogram Equalization (CHE):

The Classical Histogram Equalization is a global operation. Hence, it does not preserve the image brightness.

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Since, CHE uses the information of the whole intensity values inside the image for its transformation function, it also enhances the noise in the image and this degrades the quality of the image. To overcome these drawbacks and increase contrast enhancement and brightness preserving many HE-based techniques have been proposed [4][5].

Brightness Preserving Bi-Histogram Equalization Methods (BPBHE):

BPBHE overcomes the drawback of CHE. The BPBHE firstly decomposes an input image into two sub images based on the mean brightness value of the input image [4][5]. One of the sub images is the set of samples less than or equal to the mean whereas the other one is the set of samples greater than the mean. Then the BBPHE equalizes the sub images independently based on their respective histograms.

$$X = X_L \cup X_U \qquad (5)$$

Where X_m be the mean of the image X, the sub-image X_L is composed of $\{X_0, X_1 \ldots X_m\}$ and the other image X_U is composed of $\{X_{m+1}, X_{m+2} \ldots X_{L-1}\}$.

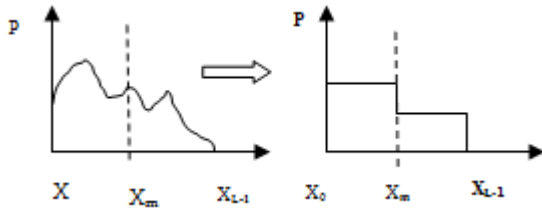$$X_{m} = (X_0 + X_{L-1}) / 2 \qquad (6)$$

Fig: 2: BI-histogram Equalization Method

Flow chart of various algorithm steps for BBPHE is shown in Figure 3

Fig: 3: Flowchart of BBHE

Recursive Mean Separate Histogram Equalization (RMSHE):

In some images, the level of brightness preservation in BPBHE is not sufficient to avoid unpleasant artifacts. They clearly show that higher degree of brightness preservation is required for these images to avoid unpleasant artefacts. While the separation is done only once in BPBHE, RMSHE perform the separation recursively; separate each new histogram further based on their respective means In this case RMSHE produce better result as discussed above[6][7][8].

Note that, computationally speaking, this method presents a problem: the number of decomposed Sub-histogram is a power of two.
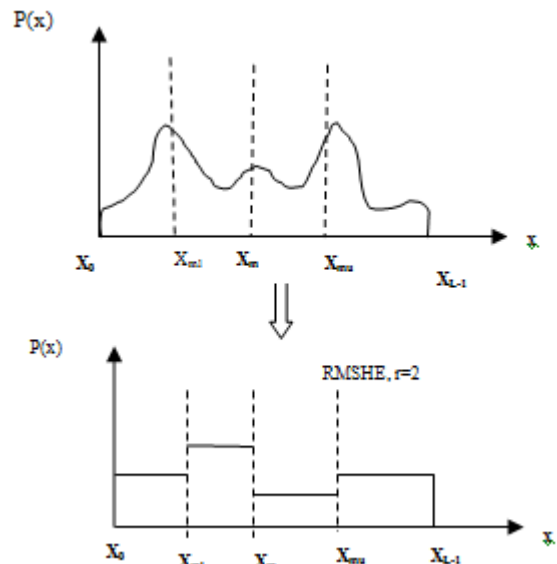

Fig: 4: **Histogram and histogram equalization for RMSHE, r=2**

ackground Brightness Preserving Histogram Equalization:

For plain images the density of the background levels is much higher than the other levels [9]. In this method the histogram is divided according to the foreground and the background levels. This method is able to enhance the image contrast while preserving the background brightness for images with well-defined background brightness.
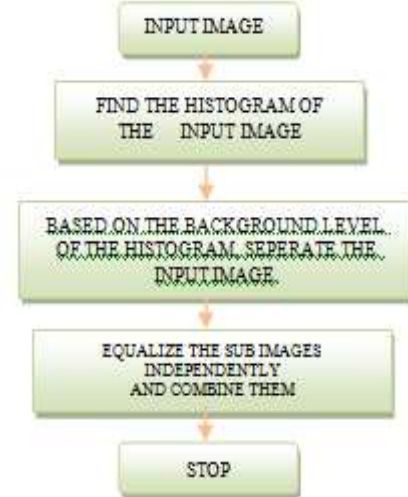

Fig 5: A general Algorithm of Background Brightness Preserving Histogram Equalization.

The steps for performing this method are as follows:

- Decomposes the input image into sub-images based on background levels and non-background levels range.
- Each sub-image is equalized independently, and
- Then combined into the final output image.

If for an image I having K gray levels. If region R_b is the background level having M gray levels in the range N to N+M-1, where $M < K$ and region R_1 and R_2 has non- background levels in the range 0 to N-1 and N+M to K-1 levels respectively as shown in figure below.

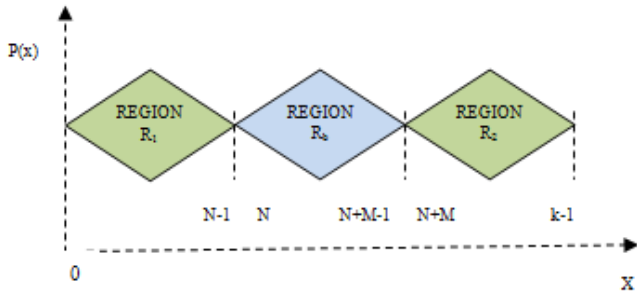The output image G can be expressed as

$$G = f_1 \cup f_b \cup f_2$$

Fig 6: Decomposition of image into sub-images based on background levels

Proposed method for contrast enhancement usng various statistical operations and neighborhood processing:

To this end, the original image is subdivided randomly into sectors, which are equalized independently and as mentioned before it has come to our notice that these methods cannot adapt with the local brightness features of the input image. As a result of which images may lose its true feature. To overcome this limitation, an extension to HE using statistical operators and neighboring process is introduced. It is based on the fact that mapping of each pixel is derived from nearby pixels. We illustrate the basic approach to local thresholding using the standard deviation and mean of the pixels in a neighborhood of every point in an image. These two quantities are quite useful for determining local thresholds because they characterise the perceived brightness and contrast of the image.

MEAN: Mean is the most basic of all statistical measure. Means are often used in geometry and analysis. The overall brightness of the grey scale is measured using the mean.

Standard Deviation:

It is a most widely used measure of variability or diversity used in statistics. In terms of image processing it shows how much variation or "dispersion" exists from the average (mean, or expected value). A low standard deviation indicates that the data points tend to be very close to the mean, whereas high standard deviation indicates that the data points are spread out over a large range of values.

We have followed the following flowchart to carry out our technique effectively:
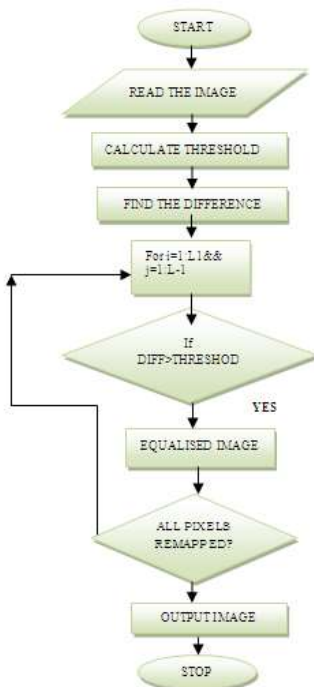

Fig 7: The flowchart for the proposed method

Take the input image I of dimensions M×N and then apply Histogram Equalization on I, we now get the equalized image $I_{equalised}$

  i.   Pad the input image I by two rows and columns
  ii.   Calculate the maximum and the minimum intensity of the image using the formula

$$X = \frac{maximum\ intensity - minimum\ intensity}{2} \qquad (7)$$

  iii. Calculate the mean value of the image

$$Mean = \sum_{i=1}^{M} \sum_{j=1}^{N} \frac{I(i,j)}{M \times N} \qquad (8)$$

  iv.   Calculate the threshold by using the following formula

$$Threshold = abs(X - mean) \qquad (9)$$

  v.   Now select a pixel by using a window of size 3×3, and then using its neighborhood calculate the standard eviation

Calculate the Local standard Deviation for each pixel I(i,j) using its eight neighbor $M_L=3$ and $N_L=3$ using the formula

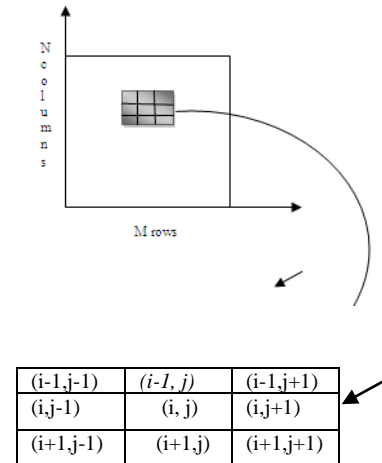$$\sigma_L = \sqrt{\frac{1}{M_L \times N_L} \sum_{i=1}^{M_L} \sum_{j=1}^{N_L} (x(i,j) - mean)^2} \qquad (10)$$

(i-1,j-1)	(i-1, j)	(i-1,j+1)
(i,j-1)	(i, j)	(i,j+1)
(i+1,j-1)	(i+1,j)	(i+1,j+1)

Fig 8: An image with its 8 neighbors ($M_L=3$ and $N_L=3$)

  vi.   Calculate the difference that is,

$$diff = (I(i,j) - \sigma_L) \qquad (11)$$

  vii. Using the following criteria check whether the difference which is given in equation (11) is less or greater than the threshold given in equation (9)

  a) If diff is greater than threshold then we replace the original image I by the equalized image in step 2 by $I_{equalized}$
  b) Else it is left as it is.

  viii. The window then slides over to the next pixel and the steps 7 to 9 are repeated until the last pixel is mapped.
  ix.   check whether if all the pixels are remapped with the equalized value
  x.   The equalize output image is obtained

Image Quality Assessment:

It is necessary to quantify the quality of an image. The metrics used to quantify an image is discussed below:

A. The Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE):

he Peak Signal to Noise Ratio (PSNR) and Mean Square Error are used to characterize the image quality. So here PSNR are computed and compared. Higher the PSNR better is the image quality.

SNR is the evaluation standard of the reconstructed image quality, and is important measurement feature. PSNR is measured in decibels (dB) and is given by:

$$PSNR = 20 * \log_{10} \frac{255}{RMSE} \tag{12}$$

here the value 255 is maximum possible value that can be attained by the image signal. Mean square error (MSE) is defined as

$$MSE = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [I(i,j) - K(i,j)]^2 \tag{13}$$

$$RMSE = \sqrt{MSE} \tag{14}$$

Where m*n is the size of the original image.

MSE is the root mean square Error and I is the equalized image and K is the noisy image. Higher the PSNR value is, better the reconstructed image is.

B. Structural Similarity (SSIM):

The main limitation of MSE and PSNR is that it relies strictly on numerical comparison and does not consider any biological factors. The SSIM is an index measuring the structural similarity between two images in a manner that is more consistent with human perception than traditional techniques like MSE and PSNR. The SSIM metric is calculated on various windows of an image. The measure between two windows x and y of common size $N \times N$ is:

$$SSIM(x, y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)} \tag{15}$$

Where,

μ_x is the average of x

μ_y is the average of y

σ_x^2 is the variance of x

σ_y^2 is the variance of y

σ_{xy} is the covariance of x and y

L is the dynamic range of the pixel-values

$k_1 = 0.01$ and $k_2 = 0.03$ by default

$c_1 = (k_1 L)^2$, $c_2 = (k_2 L)^2$ two variables to stabilize the division with weak denominator

C. Contrast to noise ratio (CNR):

This measure is used in imaging to quantify the quality of acquired images. It is a difficult quantity to define, because it depends on the human observer as much as the quality of the actual image.

It can be defined as

$$C = \frac{|S_A - S_B|}{\sigma_0} \tag{16}$$

Where S_A and S_B are signal intensities for signal producing structures A and B in the region of interest and σ_0 is the standard deviation of the pure image noise.

Usually the PSNR ant the MSE is not appropriate for measuring the contrast in an image, so CNR gives a better result. It is also known as Visibility metrics. More the value better is the result.

Result and Discussion

The performance of the proposed algorithm was tested on a low contrast 8 bit gray scale image of size 512×512 test image using MATLAB tool. Figure 9 show the result obtained using the classical Histogram Equalization technique and the proposed algorithm. The Histograms for the enhanced images are shown in Figure 10.The improvement in the brightness and quality is clearly seen from the images. Table 1 gives the comparison of the classical Histogram Equalization technique and the proposed algorithm in terms of PSNR, SSIM and CNR. The CNR which is an important parameter for measuring the contrast in an image gives a very distinct value. So higher value of CNR means the image has a better quality.
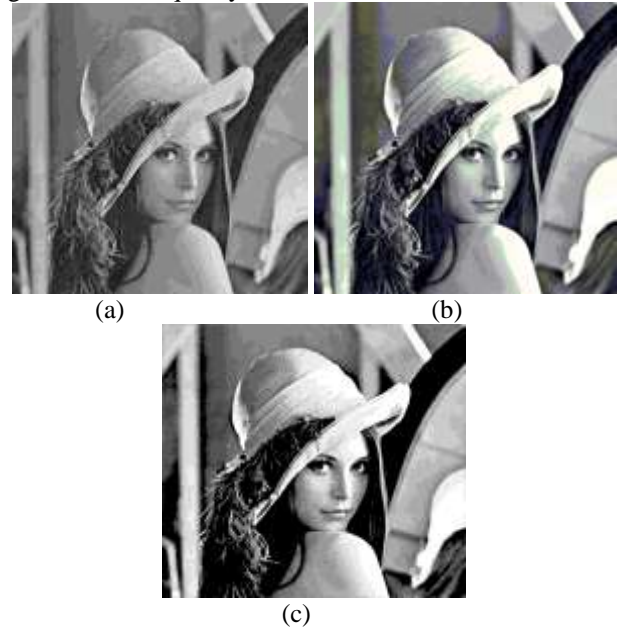

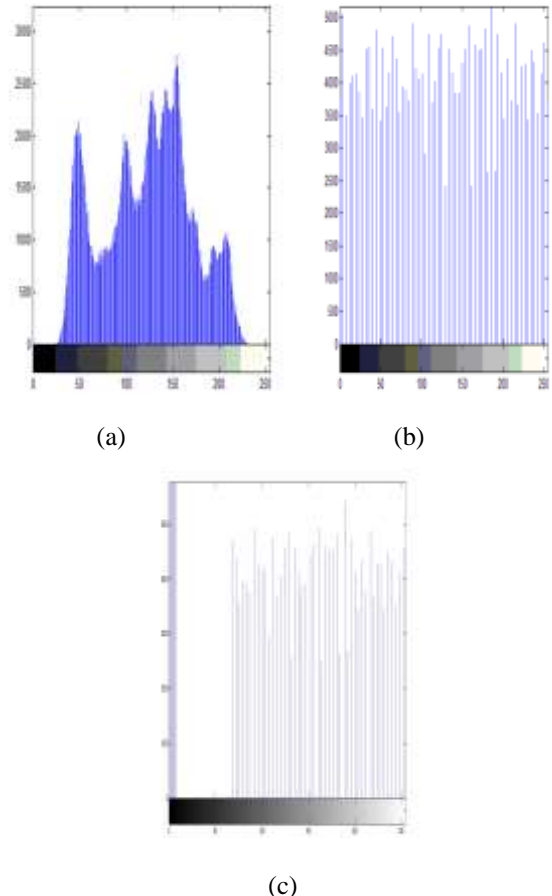**Fig 9: (a) Original image (b) Enhanced image by CHE (c) Enhanced image by the proposed method**

Fig 10:(a) Histogram of test image (b) Histogram by CHE (c) Histogram by the proposed method

Table 1: Comparison between MSE, PSNR, SSIM and CNR

Techniques	MSE	PSNR	SSIM	CNR
Classical H.E	106.6576	27.81	0.8536	55.5988
Proposed Algorithm	105.7610	27.90	0.6944	62.4071

Conclusions

In this paper, an efficient algorithm based on statistical operations and neighborhood processing has been implemented where the proposed method ensures consistency in preserving the image details and is free from any side effects and the brightness of the image can also preserved. It achieves a better quality of image through visual inspection and quantitative accuracy of PSNR, SSIM and CNR as compared to the Classical Histogram Equalization technique.

Acknowledgment

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