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Performance Analysis of Histogram Equalization Based Techniques for Image Contrast Enhancement

[1]V. Magudeeswaran and [2]C.G. Ravichandran
[1]PSNA College of Engineering and Technology, Tamilnadu, India
[2]Excel Engineering College, Kommarapalayam, Tamilnadu, India

Abstract: Image enhancement improves an image appearance by increasing dominance of some features or by decreasing ambiguity between different regions of the image. Histogram based image enhancement technique is mainly based on equalizing the histogram of the image and increasing the dynamic range corresponding to the image. Histogram Equalization is one of the common methods used for improving contrast in digital images. As a result, such image creates side-effects such as washed out appearance and false contouring due to the significant change in brightness. In order to overcome these problems, mean brightness preserving HE based techniques have been proposed. Generally, these methods partition the histogram of the original image into sub-histograms and then independently equalize each subhistogram with histogram equalization. This study presents a review of recent histogram based techniques for still image contrast enhancement. Comparisons with the best available results are given in order to illustrate the best possible technique that can be used as powerful image enhancement.

Key words: Contrast enhancement, histogram equalization, histogram modification, image enhancement, brightness

INTRODUCTION

Image enhancement is one of the main areas in digital image processing. The main purpose of image enhancement is to bring out details that are hidden in an image or to increase the contrast in a low contrast image. It produces an output image that subjectively looks better than the original image by changing the pixel's intensity of the input image (Ravichandran and Magudeeswaran, 2012; Pei *et al*., 2004). Image enhancement can also be used to provide a better input for other automated image processing systems. It is used as a preprocessing step in medical image processing, speech recognition, texture synthesis and many other image/video processing applications.

Contrast enhancement plays a significant role in image processing for both human and computer vision (De La Torre *et al*., 2005). It is mainly used to improve the appearance of an image and makes it easier for visual interpretation, understanding and analysis of image (Gonzalez and Woods, 1992). There are several reasons for an image or video to have poor contrast: the poor quality of the used imaging device, lack of expertise of the operator and the adverse external conditions at the time of acquisition. These effects result in under-utilization of the offered dynamic range. As a result, such images and videos may not reveal all the details in the captured scene and may have a washed-out and unnatural look. Contrast enhancement targets to eliminate these problems, thereby to obtain a more visually-pleasing or informative image or both. There are many image enhancement techniques have been proposed and developed. One of the most popular image enhancement methods is Histogram Equalization (HE) (Wang and Ye, 2005). HE is a technique commonly used for image contrast enhancement, since HE is computationally fast and simple to implement. HE performs its operation by remapping the gray levels of the image based on the probability distribution of the input gray levels (Jain, 1989).

However, HE is rarely employed in consumer electronic applications such as video surveillance, digital camera and television since HE tends to introduce some annoying artifacts and unnatural enhancement including intensity saturation effect. One of the reasons to this problem is because HE normally changes the brightness of the image significantly and thus makes the output image becomes saturated with very bright or dark intensity values. Hence, brightness preserving is an important characteristic needed to be considered in order to enhance the image for consumer electronic products. In order to overcome the above mentioned problems, mean brightness preserving histogram equalization based techniques have been proposed in the literature. Generally, these methods separate the histogram of the

Corresponding Author: V. Magudeeswaran, PSNA College of Engineering and Technology, Tamilnadu, India

input image into several sub histograms and the equalization is carried out independently in each of the sub-histograms. This study describes different image enhancement techniques for mean brightness preservation.

MATERIALS AND METHODS

HE based Enhancement Methods: In this study, researchers review some of the existing HE approaches.

Histogram Equalization (HE): Histogram is defined as the statistical probability distribution of each gray level in a digital image. Histogram Equalization (HE) is a very popular technique for contrast enhancement of images contrast of images is determined by its dynamic range which is defined as the ratio between the brightest and the darkest pixel intensities. The histogram provides information for the contrast and overall intensity distribution of an image. Suppose input image f(x, y) composed of discrete gray levels in the dynamic range [0, L-1] then the transformation function $C(r_k)$ is defined as:

$$S_k = C(r_k) = \sum_{i=0}^{k} p(r_i) = \sum_{i=0}^{k} \frac{n_i}{n} \quad (1)$$

$$0 \le sk \le 1 \text{ and } k = 0, 1, 2,..., L-1$$

Where:

n_i = The number of pixels having gray level r_i
n = The total number of pixels in the input image
$P(r_i)$ = The Probability Density Function (PDF) of the input gray level r_i

Based on the PDF, the Cumulative Density Function (CDF) is defined as $C(r_k)$. This mapping in Eq. 1 is called Histogram Equalization (HE) or Histogram Linearization. Here, s_k can easily be mapped to the dynamic range of [0, L-1] multiplying it by (L-1). However, HE produces an undesirable checkerboard effects on enhanced images (Gonzalez and Woods, 1992). Another problem of this method is that it also enhances the noises in the input image along with the image features.

Brightness preserving Bi-Histogram Equalization (BBHE): In order to overcome the limitations of HE, several brightness preserving methods have been proposed (Rajavel, 2010). One of the popular brightness preserving methods is the mean Brightness preserving Bi-Histogram Equalization (BBHE) introduced by Kim (1997). At the beginning, the BBHE divides the original histogram into two sub-histograms based on the mean brightness of the input image as shown in Fig. 1. One of the sub image is set of samples less than or equal to the mean whereas the other one is the set of samples greater than the mean. In this method, the separation intensity X_T is presented by the input mean brightness value which is the average intensity of all pixels that construct the input image. After this separation process, these two histograms are independently equalized by HE. Consequently, the mean brightness can be preserved because the original mean brightness is retained.

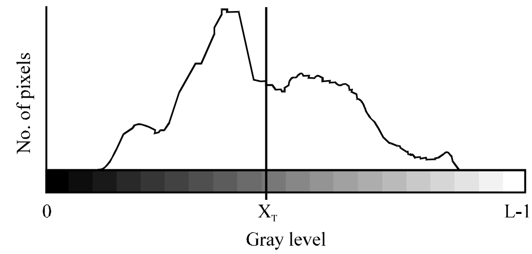

Fig. 1: Bi-histogram equalization: the histogram with range from 0 to L-1 is divided into two parts with separating intensity X_T. This separation produces two histograms. The first histogram has the range of 0 to X_T while the second histogram has the range of X_{T+1} to L-1

Recursive Mean-Separate Histogram Equalization (RMSHE): Another description of the BBHE, called Recursive Mean-Separate Histogram Equalization (RMSHE) proposed by Chen and Ramli (2003a, b). This method recursively separates the histogram into multi sub-histograms instead of two sub-histograms as in the BBHE. Initially, two sub-histograms are formed based on the mean brightness of the original histogram. Subsequently, the mean brightness from the two sub-histograms obtained earlier are used as the second and third separating points in creating more sub-histograms. In a similar fashion, the algorithm is executed recursively until the desired numbers of sub-histograms are met. Then, the HE approach is applied independently on each of the sub-histogram. However, no significant enhancement is performed by the RMSHE when the number of divided sub histograms is large.

The methods discussed above are based on dividing the original histogram into several sub-histograms by using either the median or mean brightness. Even though the mean brightness is well conserved by the above mentioned methods but fails to expand the region of sub-histogram located near to the minimum or maximum value of the dynamic range.

Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE): In order to optimize the mean brightness preservation of the input image, an improved version of the BBHE, called Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) has been introduced by Chen and Ramli (2003a, b). Similar to the

BBHE, this method has two sub-histograms but the separating point is set by finding the minimum mean brightness error between the input and the enhanced images. MMBEBHE is formally defined by the following procedure:

1 Calculate the Absolute Mean Brightness Error (AMBE) for each of the threshold level
2 Find the threshold level, X_T that yield minimum Mean Brightness Error (MBE)
3 Separate the input histogram into two based on the X_T found in step 2 and equalized them independently as in BBHE

The main difference between the BBHE and DSIHE methods and the MMBEBHE one is that the latter searches for a threshold level X_T that decomposes the image I into two sub-images $I[0, X_T]$ and $I[X_T+1, L-1]$ 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 $I[0, X_T]$ and $I[X_T+1, L-1]$ has its histogram equalized by the HE process, generating the output image.

Absolute Mean Brightness Error (AMBE): It is the difference between original and enhanced image and is given as:

$$\text{AMBE} = \left|E(x)-E(y)\right|$$

Where:
E(x) = Average intensity of input image
E(y) = Average intensity of enhanced image

Dualistic Sub-Image Histogram Equalization (SIHE): Following the same basic ideas used by the BBHE Method of decomposing the original image into two sub-images and then equalize the histograms of the sub-images separately. The DSIHE algorithm separates the histogram into two sub-histograms with equal number of pixels where the median of the input image is used as the separating point instead of mean brightness of the input image.

Recursive Sub-Image Histogram Equalization (RSIHE): Recursive Sub-Image HE (RSIHE) iteratively divides the histogram based on median rather than mean values. Since, the median value is used each partition shares the same number of pixels. Therefore, both RMSHE and RSIHE divide the histogram into 2^r number of partitions and they preserve the brightness to better extend than previous partitioning method to enhance the visual outlook. However, finding the optimal value of r is difficult and with a large value of r there will be no enhancement despite the fact that the brightness preservation property is fulfilled adequately.

RESULTS AND DISCUSSION

In this study, researchers compare the performance of various existing HE-Based Methods such as the conventional Histogram Equalization (HE), Brightness preserving Bi-Histogram Equalization (BBHE), Recursive Mean-Separate Histogram Equalization (RMSHE), Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE), Dualistic Sub-Image Histogram Equalization (DSIHE) and Recursive Sub-Image Histogram Equalization (DSIHE). The experiment results are collected using low light environment images.

Figure 2a and b shows that HE provides a significant improvement in image contrast. However, it also amplifies the noise level of the images along with some artifacts and undesirable side effects such as washed out appearance

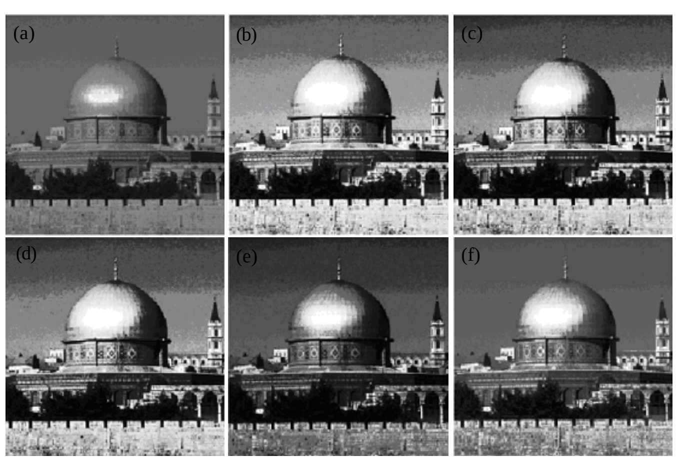

Fig. 2: Simulation results of the sample image; a) original image; b) HE-ed image; c) BBHE-ed image; d) DSIHE-ed image; e) MMBEBHE-ed image and f) RSIHE-ed image

Table 1: Absolute Mean Brightness Error (AMBE)

Methods	HE	BBHE	RMSHE	DSIHE	RSIHE	MMBEBHE
Chen and Ramli (2003a, b)	96.70	13.30	-	41.50	-	6.24
Sengee and Choi (2008)	42.76	42.75	27.33	10.73	14.66	22.17
Kim and Chung (2008)	98.82	16.75	4.56	47.08	20.23	-
Rajavel (2010)	55.80	55.90	-	13.40	17.20	30.40

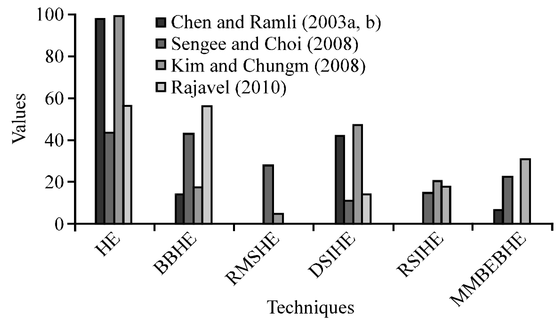

Fig. 3: Comparison of absolute mean brightness error of various HE based techniques

Figure 2c and d show that the BBHE and DSIHE Methods which produce unnatural look and insignificant enhancement to the resultant image. However, it also has unnatural look because of over enhancement in brightness. The results of MMBEBHE and RSIHE, Fig. 2e and f show good contrast enhancement, they also cause more annoying side effects depending on the variation of gray level distribution in the histogram. In this study, Table 1 shows the values of AMBE which can be used to determine the image brightness. Figure 3 presents comparison of Absolute Mean Brightness Error (AMBE) of various HE based techniques.

CONCLUSION

This study presents the comparisons of various recent histogram based techniques in still images for better perception. Many histogram based techniques like conventional Histogram Equalization (HE), Brightness preserving Bi-Histogram Equalization (BBHE), Recursive Mean-Separate Histogram Equalization (RMSHE), Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE), Dualistic Sub-Image Histogram Equalization (DSIHE) and Recursive Sub-Image histogram Equalization (RSIHE) algorithms has been implemented and compared. Comparisons with the best available results are given in order to illustrate the best possible technique that can be used as powerful image enhancement.

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