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A Comparative Analysis of Histogram Equalization based Techniques for Contrast Enhancement and Brightness Preserving

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Abstract

Histogram Equalization (HE) is a simple and effective image enhancement technique.But, it tends to change the mean brightness of the image to the middle level of the permitted range, and hence is not a very suitable for consumer product. While preserving the original brightness is essential to avoid annoying artefacts. To preserve brightness and to enhance contrast of images, numerous methods are introduced, but many of them present unwanted artefacts such as intensity saturation, over-enhancement and noise amplification. In the present paper, available histogram equalization based methods are reviewed and compared with image quality measurement (IQM)tools such as Absolute Mean Brightness Error (AMBE) to assess brightness preserving and Peak Signal-to-Noise Ratio (PSNR) to evaluate contrast enhancement.

Keywords: *Histogram equalization, contrast enhancement, brightness preserving, quality measures*

1. Introduction

Image enhancement is aprocess of changing the pixels intensity of the input image;to make the output image subjectively look better [1] Contrast enhancement is an important area in image processing for both human and computer vision. It is widely used for medical image processing and as a pre-processing step in speech recognition, texture synthesis, and many other image/video processing applications [2-5].Contrast is created by the difference in luminance reflectance from two adjacent surfaces. In our visual perception, contrast is determined by the difference in the color and brightness of an object with other objects. If the contrast of an image is highly concentrated on a specific range, the information may be lost in those areas which are excessively and uniformly concentrated. The problem is to enhance the contrast of an image in order to represent all the information in the input image.Brightness preserving methods are in very high demand to the consumer electronic products. Numerous histogram equalization (HE) based brightness preserving methods tend to produce unwanted artefacts [6].

In spite of fundamental advantage in histogram equalization, it has a significant drawback of changing the brightness globally, which results in either under-saturation or over-saturation of important regions. Due to this reason, for the implementation of contrast enhancement in consumer electronic products it is advised that the loss of intensity values by the histogram processing should be minimized in the output image. The first challenge of modified histogram has been proposed by Kim, in 1997 [7] using bi-histogram equalization (BHE) technique. In this paper, histogram equalization based bi-histogram equalization, multi-histogram equalization and clipping histogram equalization techniques are discussed and reviewed. Few techniques from each category

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are tested using different test images and compared, based on image quality assessment values.

The present paper is organized in five sections. Section 1deliversbrief introduction, Section 2 covers various methods related to histogram equalization, which preserve the brightness as well as contrast of the image. Section 3 describes various image quality assessment methods, comparison of various methods isgiven in Section 4 and Section 5 provides concluding remarks.

1.1. Histogram Equalization Methods

The most popular technique for contrast enhancement of images is histogram equalization (HE) [7-11]. It is one of the well-known methods for enhancing the contrast of a given image in accordance with the samples distribution [12, 13]. HEis a simple and effective contrast enhancement technique which distributes pixel values uniformly such that enhanced image have linear cumulative histogram. It stretches the contrast of the high histogram regions and compresses the contrast of the low histogram regions [14].The HE technique is a global operation hence; it does not preserve the image brightness. HE has been widely applied when the image needs enhancement, such as medical image processing, radar image processing, texture synthesis, and speech recognition [10, 15], [16]. HE usually introduces two types of artefacts into the equalized image namelyover-enhancement of the image regions with more frequent gray levels, and the loss of contrast for the image regions with less frequent gray levels [17].To overcome these drawbacks several HE-based techniques are proposed and aremore focused on the preservation of image brightness than the improvement of image contrast. Few methods often generate images with annoying visual artefacts and unnatural appearances, though the image brightness is preserved to some extent [18].

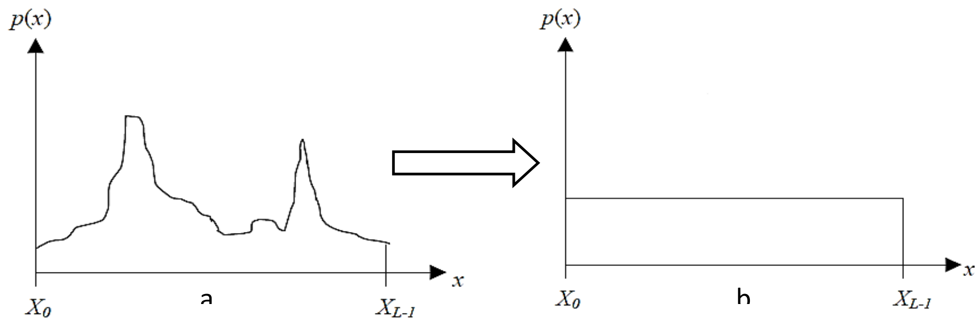

Figure 1. Histogram Equalization
(a) Histogram (b) Equalized Histogram

2. Histogram Equalization based Techniques

Histogram equalization is a simple and an effective contrast enhancement technique which distributes pixel values uniformly such that enhanced image have linear cumulative histogram and is a global operation.Hence, it does not preserve the image brightness. To overcome these drawbacks and increase contrast enhancement and brightness preserving many HE-based techniques have been proposed.

2.1. Bi-Histogram Equalization Methods

Bi-histogram equalization methods divide the histogram into two sub-histograms based on different dividing points. Later, each sub-histogram is equalized individually based on histogram equalization. These methods can preserve image brightness more, when compared to Histogram Equalization method.

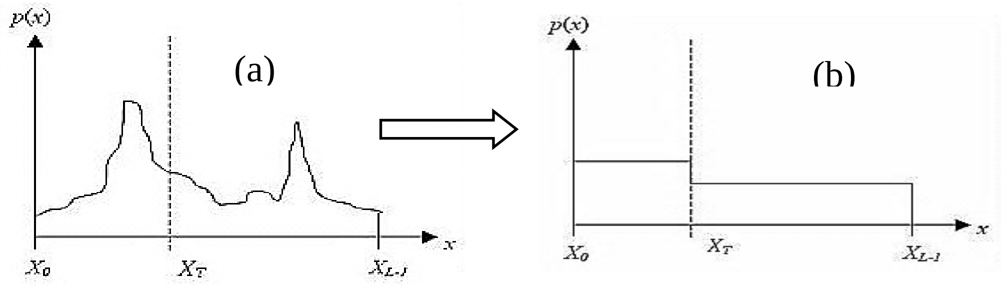

Figure 2. Bi-histogram Equalization Method (a) Input Histogram Divides into Two sub-histograms (b) Equalized Sub-histograms

First Mean based separation technique, Brightness Preserving Bi-Histogram Equalization (BBHE) has been proposed by Kim in 1997 [7] to preserve the mean brightness of a given image while contrast is enhanced and it preserves the brightness of image at some extent and shown better result than HE. Similar to BBHE, Wang et al. in 1999[19] proposed Dualistic Sub-Image Histogram Equalization (DSIHE), but this method used median value instead of mean to separate the input histogram and shown better brightness preserving than BBHE and HE. DSIHE is the best processing technique to preserve the original image brightness and also enhance the image information effectively. BBHE and DSIHE are not much suitable for images requiring higher degree of brightness preservation to avoid annoying artefacts.

For higher degree of preservation Chen and Ramli in 2003 [20, 21] proposed Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) an extended method of BBHE and the separation based on threshold level, which would yield minimum Absolute Mean Brightness Error (AMBE). The ultimate goal behind this method is to allow maximum level of brightness preservation in Bi-Histogram Equalization to avoid unpleasant artefacts and unnatural enhancement due to excessive equalization, and also to formulate an efficient, recursive and integer-based solution to approximate the output mean as a function of threshold level. Simulated results from [22], MMBEBHE clearly indicates that it has preserved better brightness and yielded a more natural enhancement. BBHE and MMBEBHE have a better preservation and enhancement levelscompared to HE and DSIHE. But, MMBEBHE shows poor brightness preservation and enhancement, where the images that require far more brightness preservation it fails to control the over enhancement of the image.

Bi-Histogram Equalization with Neighbourhood Metric (BHENM) has been introduced by Sengee *et al.*, [23] in 2010, which divide the large histogram bins that cause washout artefacts into sub-bins using neighbourhood metrics, and the histogram of the original image is separated into two sub-histograms based on the mean of the histogram. Then, sub-histograms are equalized independently using refined histogram equalization, which produce flatter histograms. The distinction neighbourhood metric is to sort pixels of equal intensity into different sub-bins, to improve image local contrast, and to separate the histogram into two sub-histograms and then equalize them independently to preserve the image brightness.

Range Limited Bi-Histogram Equalization (RLBHE) has been proposed by Zuo *et al.*, in 2012[24], which divides the input histogram into two independent sub-histograms by a threshold that minimizes the intra-class variance. This was carried out to effectively separate the objects from the background. This method achieves visually a more pleasing contrast enhancement while maintaining the input brightness and it is easy to implement in real-time processing.

2.2. Multi Histogram Equalization Methods

In order to enhance contrast, preserving brightness and improve natural looking of the images, multi-histogram equalization technique decomposes the input image into several sub-images, and then applies the classical histogram equalization process to each of sub-histogram. Image processed by Multi-HE methods preserves the image brightness and prevent introduction of undesirable artefacts but not significantly enhance the contrast [32].

Wongsritong *et al.*, [25] in 1998, has proposed Multi Peak Histogram Equalization with Brightness Preserving (MPHEBP) to improve the brightness preserving of the image. In this method, the input histogram will be smoothed and divided based on the local maxima. Wongsritong et al. claimed that the performance of MPHEBP in maintaining the mean brightness is better than BBHE.

Recursive Mean-Separate Histogram Equalization (RMSHE) has been proposed by Chen and Ramli in 2003 [26], is to divide the input histogram into two, based on its mean before equalizing them independently. This separation is done one time in BBHE, but in this method new histograms (separated) were further divided based on their mean value. It has been analysed mathematically that the output image's mean brightness would converge to the input image's mean brightness as the number of recursive mean separations increases. In order to achieve higher brightness preservation, this model is proposed to perform the mean separation recursively and separate the resulting histograms again based on their respective means. Similar to RMSHE, Recursive Sub-Image Histogram Equalization (RSIHE) is proposed by Sim *et al.*, [27] in 2007 and it separates the input histogram based on a gray level with median, but RMSHE uses mean-separation and both the methods share the same characteristics in equalizing the sub-histograms. Both methods shown good brightness preserving because of multi separation of histogram, but for bright images these methods lead to over enhancement.

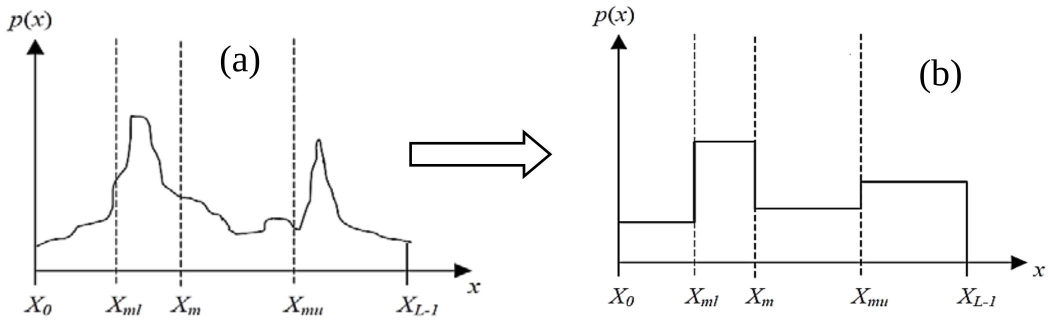

Figure 3. Recursive Mean-Separate Histogram Equalization (RMSHE) (a) Separated Histogram (b) Equalized Histogram (r=2)

Dynamic Histogram Equalization (DHE) has been introduced by Wadud *et al.*, [28] in 2007 to eliminate the domination of higher histogram components on lower histogram components in the image histogram and to control the amount of stretching of gray levels for reasonable enhancement of the image features by using local minima separation of histogram. DHE has shown better and a smooth enhancement of the image. However, the DHE neglects the mean brightness preserving and tends to intensity saturation artefacts. To overcome the drawback of the DHE, Brightness Preserving Dynamic Histogram Equalization (BPDHE) has been proposed by Ibrahim and Kong [29] in 2007, an extension method of the DHE and Multi Peak Histogram Equalization with Brightness Preserving (MPHEBP) and divides the input histogram based on local maximum value. BPDHE shown better contrast enhancement compared to MPHEBP and mean brightness preserving compared to DHE.

Menotti *et al.,* [30] in 2007 proposed Minimum Within-Class Variance Multi-Histogram Equalization (MWCVMHE) and Minimum Middle Level Squared Error Multi Histogram Equalization (MMLSEMHE) techniques to yields images with natural appearances, at the cost of contrast enhancement. MWCVMHE partitions the input histogram into multiple sub-histograms by minimizing within-class variance and then applies histogram equalization in each sub-histogram separately. MMLSEMHE uses the Otsu threshold selection technique to select separating points, before equalizing each sub-histogram independently with HE. MMLSEMHE is more computationally complex because it estimates the optimal number of sub-histograms from all possible sub-histograms to minimize certain discrepancy functions [31]. Both the methods preserves the brightness to a maximum extent but the contrast enhancement is less intensive.

In 2008, Kim and Chung [18] proposed Recursively Separated and Weighted Histogram Equalization (RSWHE) to enhance the image contrast as well as to preserve the image brightness. This method splitsthe input histogram into two or more sub-histograms recursively based on the mean or median of the image. Also the resulted sub-image histograms will change through a weighting process based on the power law function. RMSHE and RSIHE are similar to RSWHE in terms of recursive histogram segmentation, but they do not execute the histogram weighting function as in RSWHE. RSWHE-M and RSWHE-D are two different implementations of RSWHE: that is, RSWHE-M performs the mean-based segmentation and RSWHE-D performs the median-based segmentation. From the experimental results, the RSWHE-M method is found to be better than the RSWHE-D for brightness preserving and contrast enhancement.

Wadud *et al.*, [32] in 2008, has been introduced Spatially Controlled Histogram Equalization (SCHE) dividing it to a number of sub-histograms until it ensures that no dominating portion is present in any of the newly created sub-histograms. Then a dynamic gray level (GL) range is allocated for each sub-histogram to which its gray levels can be mapped by HE. This total dynamic range of gray levels of the output image is distributed among the sub-histograms based on their dynamic range in the input image and cumulative distribution function (CDF) of histogram values.

Sheet *et al.*, [33] in 2010 introduced a modification to BPDHE technique through fuzzy statistics of digital images referred to as Brightness Preserving Dynamic Fuzzy Histogram Equalization (BPDFHE) and it computes the fuzzy histogram and then partitioning the histogram into multiple sub-histograms based on local maxima. Every valley portion between two consecutive local maxima forms a partition. When the dynamic equalization of these partitions is performed, the peaks of the histogram do not get remapped and resulting in a better preservation of the mean image –brightness while increasing the contrast.

In 2012, Khan *et al.,* [34] has proposed Weighted Average Multi Segment Histogram Equalization (WAMSHE), which decomposes smoothed histogram into multiple segments based on optimal thresholds and equalized each segment by histogram equalization. WAMSHE shown better brightness preserving and contrast enhancement among Multi-histogram equalization methods and also helps to reduce the noise present in the image.

2.3. Clipped Histogram Equalization Methods

Generally, histogram equalization stretches the contrast of the high histogram regions, and compresses the contrast of the low histogram regions [14]. As a result, when the object of interest in an image only occupies a small portion of the image, this object will not be successfully enhanced by histogram equalization and this method also extremely pushes the intensities towards the right or the left side of the histogram, causing level saturation effects. To overcome these problems, Clipped Histogram Equalization (CHE) methodsare used to restrict the enhancement rate. CHE modifies the shape of the input histogram by reducing or increasing the value in the histogram's bins based on a threshold limit before the equalization is taking place. This threshold limit is also known as the clipping limit, or the plateau level of the histogram. The histogram will be clipped based on this threshold value. In some cases clipped portion will be redistributed back to the histogram and then histogram equalization is carried out. Clipped Histogram Equalization (CHE) is far more effective for contrast enhancement than the existing HE-based methods.

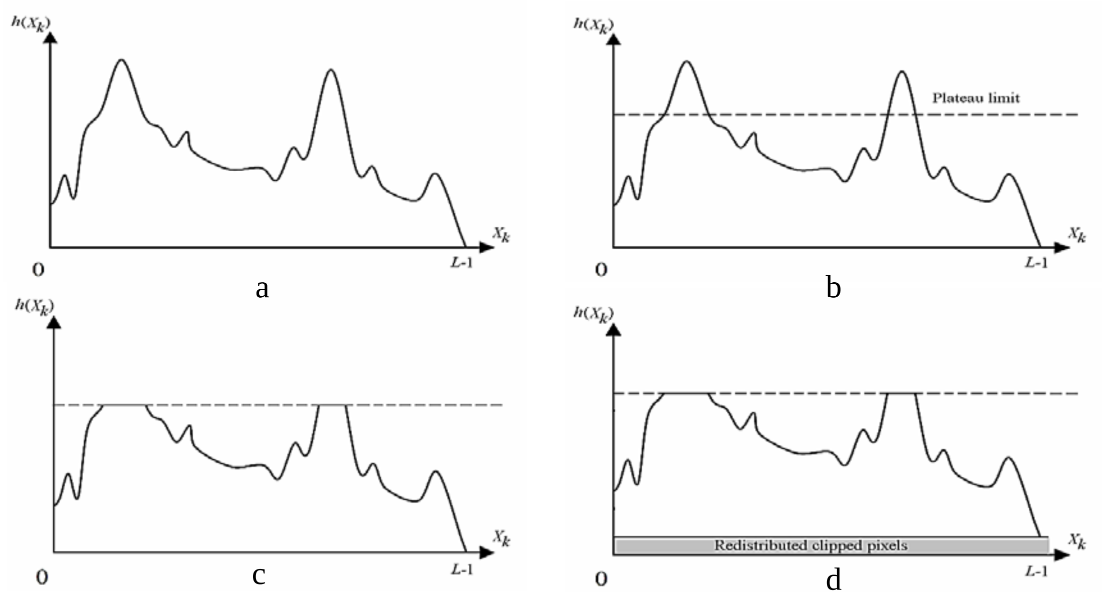

Figure 4. Clipped Histogram Equalization(CHE) Method (a). The Original Input Histogram (b). The Settings of the Plateau Limit (c). Clipping the Histogram based on the Plateau Limit (d). Redistribution of Clipped Portion Back into the Modified Histogram

The major drawbacks of CHE method arethosemethods require manual setting of the plateau level of the histogram which are not suitable for automatic systems and some of the methods put weight to the modified histogram. The weight factor is also dependent to the user.

Yang *et al.*, [35] in 2003 proposed a simple enhancement rate control mechanism, Bin Underflow and Bin Overflow (BUBO), which controls the rate of enhancement by putting constraints on the maximum and minimum gradient of the mapping function. With this enhancement rate control mechanism, the HE can enhance the contrast to variable rates, and also perform various image processing tasks such as black/white level stretch or automatic brightness control.

In 2006, Wang *et al.*, [36] proposed Self-Adaptive Plateau Histogram Equalization (SAPHE) to enhance the main objects and suppress the background for infrared images. In SAPHE, histogram of the image is filtered with median filter to reduce the fluctuation and also to remove some empty bins inside the histogram and find the local maximum value and global maximum value of histogram for plateau threshold value. By eliminating median filter from SAPHE, Nicholas *et al.*, [37] in 2009 introduced modified SAPHE (MSAPHE) to enhance microscopic images. SAPHE failed to detect local peaks in the image and MASAPHE has overcome this problem.

Kim and Paik, in 2008 [15] introduced a new contrast enhancement method for controlling noise amplification as well as preserving the original brightness of the image named as Gain-Controllable Clipped Histogram Equalization (GC-CHE). It is an interpretation of BBHE and RMSHEmethods. Based on clipping level, histogram of the image is clipped and the clipped portion is then re-distributed to the entire dynamic range by locally regulating the clipping gain. While enhancing the contrast of a low light-level image, the contrast elevation ration is adjusted to solve the noise amplification problem according to the input image and compensate contrast using the gain control method.

In 2009, Ooi *et al.*, [38], proposed Bi-Histogram Equalization Plateau Limit (BHEPL) as the fusion of the BBHE and clipped histogram equalization. Similar to BBHE, the BHEPL decomposes the input image into two sub-images by using mean brightness of the image. Then, these sub-histograms are clipped by using the plateau limit as the mean of the number of intensity occurrence and the decomposed sub-histograms are equalized independently. BHEPL method avoids excessive enhancement and over amplification of noise in the image.

Ooi *et al.*, [39] in 2010 introduced clipping based Quadrants Dynamic Histogram equalization (QDHE), which separates the histogram into four sub-histograms based on the median of the input image. Then, the resultant sub-histograms are clipped according to the mean of intensity occurrence of the input image before new dynamic range is assigned to each sub-histogram and are equalized individually. QDHE is most robust method to extract the details of the low contrast images.

Liang *et al.*, [40] in 2012, proposed Double Plateaus Histogram Equalization (DPHE) for infrared image enhancement. In this method, upper and lower threshold values could be calculated by searching local maximum and predicting minimum gray interval and be updated in real time. The value of upper threshold is set to be 20-30% of the total pixels, while the lower threshold value is set to be 5-10% of it. The upper threshold is utilized in the algorithm for preventing over-enhancement of background noise with typical gray levels, and the lower threshold is set for protecting detailed information with fewer pixels from being combined.

Bi-HE methods enhance the image contrast significantly and may preserve the brightness to some extent, but it introduces undesirable artefacts. Decomposition of image histogram into several sub-histograms, Multi-HE methods shown better brightness preservation and prevent introduction of undesirable artefacts but may not significantly enhance the contrast. CHE methods provide well brightness preservation without any artefacts by clipping the histograms using threshold values and are not shown significant contrast enhancement. Methods like GC-CHE sacrificed the amount of contrast for controlling noise and for preserving the original intensity level.

3. Image Quality Measurement Tools

The present section describes the image quality measurement tools used to evaluate the ability of the enhancement techniques to maintain the mean brightness preserving and contrast enhancement.

3.1. Absolute Mean Brightness Error (AMBE)

An objective measurement is proposed to rate the performance in preserving the original brightness. It is stated as Absolute Mean Brightness Error (AMBE). It is defined as the absolute difference between the mean of the input and the output images and is proposed to rate the performance in preserving the original brightness [20, 21].

$$AMBE = |E(\boldsymbol{X}) - E(\boldsymbol{Y})| \tag{1}$$

X and Y denotes the input and output image, respectively, and E (.) denotes the expected value, *i.e.*, the statistical mean. Lower AMBE indicates the better brightness preservation of the image. Equation (1) clearly shows that AMBE is designed to detect one of the distortions–excessive brightness changes [22].

3.2. Peak Signal-to-Noise Ratio (PSNR)

Let, X(i,j) is a source image that contains M by N pixels and a reconstructed image Y(i,j), where Y is reconstructed by decoding the encoded version of X(i,j). In this method, errors are computed only on the luminance signal; so, the pixel values X(i,j) range between black (0) and white (255)[27]. First, the mean squared error (MSE) of the reconstructed image is calculated as;

$$MSE = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[X(i,j)-Y(i,j)]^2}{M\times N} \quad (2)$$

The root mean square error is computed from root of MSE. Then the PSNR in decibels (dB) is computed as;

$$PSNR = 20log_{10}(\frac{Max(Y(i,j))}{RMSE}) \quad (3)$$

Greater the value of PSNRbetter the contrast enhancement of the image.

4. Results and Discussion

This section gives the result of comparison of histogram equalization based on contrast enhancement methods including Histogram Equalization (HE) described in previous sections. For comparative analysis, different methods from each category are selected and compared with various test images (.tiff format). Bi-histogram equalization methods (BBHE, DSIHE and MMBEBHE),Multi-histogram equalization methods (RMSHE, RSIHE, DHE, BPDHE and RSWHE) and Clipped Histogram equalization methods (GC-CHE and BHEPL) algorithm codes are prepared individually using MATLAB R2013a. Then, the techniques are compared with various test images using image quality measurement tools such as Absolute Mean Brightness Error (AMBE) and Peak Signal-to-Noise Ratio (PSNR). The results of test images *tire* and *random_matches* are shown in Figure 5 and Figure 6 and the image quality assessment measures such as AMBE and PSNR values are tabulated in Table 1 and Table 2.

By comparing test images, it is found that, theAMBE values for Brightness Preserving Dynamic Histogram Equalization (BPDHE) and Gain-Controllable Clipped Histogram Equalization (GC-CHE) methods are very close to zero as shown in Table 1. So, these methods have shown excellent brightness preserving than other methods. Higher PSNR values of these methods are representing good contrast enhancement. The output images (*tire* and *random_matches*) of these methods are very clear from other images as shown in figure 5 and figure 6.

Bi-Histogram Equalization Plateau Limit (BHEPL) method has also shown good brightness preserving (low AMBE value) like 0.4424 for *random_matches*image and 0.5167 for *bottom left* image. The bright images like *face*, *pirate*, *lenna* and *cygnusloophas* shown AMBE values as 10.1918, 18.4798, 18.0420 and 10.5876 respectively and the enhancement of contrast (high PSNR value)also good in all most all test images as shown in Table 1 and Table 2.

Dynamic Histogram Equalization (DHE) technique ismore effective than AMBE (Table 1) signifying less brightness preserving and less values of PSNR (Table 2) withpoor contrast enhancement. From Figures 5(i) and 6(i), the output images (*tire* and *random_matches)* of DHE method are not clear and introduced unpleasant noise. BPDHE, the extension of DHE has shown better brightness preserving and contrast enhancement. The AMBE values of BBDHE are very close to GC-CHE and equal to zero as shown in Table 1. From the Figures 5(j) and 6(j), it is clear that output images of BPDHE are better than DHE output images. Recursively Separated and Weighted Histogram Equalization (RSWHE) have shown poor brightness preserving and better contrast enhancement as shown in Figures 5(h) and 6(h).

Recursive Sub-Image Histogram Equalization (RSIHE) technique had shown well brightness preserving for images *bottom left*, *Cameraman*, *Face*, *Hurricane Andrew* and *Lenna*. The output image of RSIHE, *tire* has over enhanced and the information is lost at the bottom portion of the image as shown in Figure 5(g). For image *random_matches*, RSIHE introduced annoying noise and resulted in a loss of information and blurredas shown in Figure 6(g).

RecursiveMean-Separate HistogramEqualization (RMSHE) method has shown an effective brightness preserving for the dark images like *bottom left* and *random matches*. RMSHE has shown over-enhancement along with unpleasant noise as shown in Figures 5(f) and 6(f).

Table 1. AMBE (Absolute Mean Brightness Error) is used to assess the Brightness Preservation

Methods / Test Images	Bi-HE based methods				Multi-HE based methods					CHE based methods	
	HE	**BBHE**	**DSIHE**	**MMBEBHE**	**RMSHE**	**RSIHE**	**RSWHE**	**DHE**	**BPDHE**	**BHEPL**	**GC-CHE**
Tire	73.9839	10.5931	10.5902	7.9303	10.5931	14.3908	87.3272	13.2311	0.0177	11.4161	0.0207
bottom_left	89.1241	1.3690	1.3090	0.8748	1.3507	0.1226	33.5589	92.3282	0.0080	0.5167	0.0143
Cameraman	16.3252	6.2892	6.2892	6.454	51.4698	0.5492	81.5401	4.2791	0.0196	32.7843	0.1524
Face	34.6246	5.3253	5.3253	5.6512	15.3253	3.8747	81.1056	60.2757	0.0067	10.1918	0.1494
Hurricane Andrew	46.8385	12.5674	12.5674	2.0976	34.7984	4.5396	86.9096	25.3724	0.0166	23.1766	0.1591
Pirate	21.0831	10.7211	10.7211	7.4088	29.6300	12.6007	90.0211	5.5032	0.0141	18.4798	0.1827
Lenna	25.7646	13.4390	13.4390	11.9834	34.8473	3.8747	93.8800	57.0144	0.0501	18.0420	0.1064
Cygnusloop	73.6604	17.0133	17.0133	14.8379	17.0133	17.1394	72.1871	15.8675	0.0769	10.5876	0.0000
random_matches	23.7511	9.8049	9.80249	7.4088	9.8049	14.6534	91.1458	57.4373	0.0173	0.4424	0.3143
crabpulsar-radio	95.1651	22.9177	22.9177	19.1010	22.9177	19.1946	79.4310	15.8675	0.0911	28.6446	0.0000

Table. 2. PSNR (Peak Signal-to-Noise Ratio) is used to Assess the Contrast Enhancement

Methods / Test Images	Bi-HE based methods				Multi-HE based methods					CHE based methods	
	HE	**BBHE**	**DSIHE**	**MMBEBHE**	**RMSHE**	**RSIHE**	**RSWHE**	**DHE**	**BPDHE**	**BHEPL**	**GC-CHE**
Tire	24.3860	26.9449	26.9449	27.9813	26.9449	26.5144	24.1860	12.4549	28.6816	27.8688	61.6174
bottom_left	24.6083	41.4113	41.4113	43.9353	31.2500	44.2483	24.0654	7.8294	20.6533	50.7017	46.6330
Cameraman	27.4644	12.3898	12.3898	12.5304	12.3898	12.4052	24.1948	7.1210	30.0270	25.8974	45.1465
Face	25.1803	16.9539	30.0499	29.9194	29.0778	29.3232	24.0839	11.1102	31.6110	27.1169	44.6332
Hurricane Andrew	25.0338	14.4200	14.4200	14.1253	14.4188	14.7385	24.0733	15.8035	31.2857	27.9395	37.2249
Pirate	27.0173	16.9539	16.9539	15.7232	15.9436	15.7897	24.0654	13.8814	33.3448	26.8443	39.4450
Lenna	26.5047	15.5009	15.5009	14.8170	14.5668	14.5756	24.0654	11.4277	33.3705	26.8806	40.0804
Cygnusloop	24.0655	26.8559	26.8559	27.1388	26.4729	26.5381	25.6065	9.3087	25.0548	28.6036	----------
random_matches	26.5391	28.3707	28.3707	30.3890	28.3707	25.9067	24.1862	10.6251	27.7894	42.6757	34.1527
crabpulsar-radio	24.0689	26.9385	26.9385	27.0782	26.9043	27.0236	26.0179	9.3087	26.8169	27.2378	----------

Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) technique had shown better brightness preserving and there is no much variation in contrast enhancement, compared to BBHE and DSIHE. MMBEBHE is an extended method of BBHE and showed a better brightness preserving and contrast enhancement than BBHE. However, it is not controlled over-enhancements as shown in Figure 5(e) and revealed less brightness preserving for bright images like *Cygnusloop* (AMBE is 14.8379) from Table 1.

Dualistic Sub-Image Histogram Equalization (DSIHE) and Brightness Preserving Bi-Histogram Equalization (BBHE) techniques has shown all most same brightness preserving and contrast enhancement for all test images. DSIHE and BBHE are shown more value of AMBE and over-enhancement as shown in Figures 5(c), 5(d), 6(c) and 6(d).

All the above methods have overcome the drawbacks of the histogram equalization and enhanced the contrast and also preserved the brightness of the image, as given in Tables 1 and 2 and as shown in Figures 5 and 6, Brightness Preserving Dynamic Histogram Equalization (BPDHE) and Gain-Controllable Clipped Histogram Equalization (GC-CHE) methods are more suitable for both brightness preserving and contrast enhancement of the images as well.

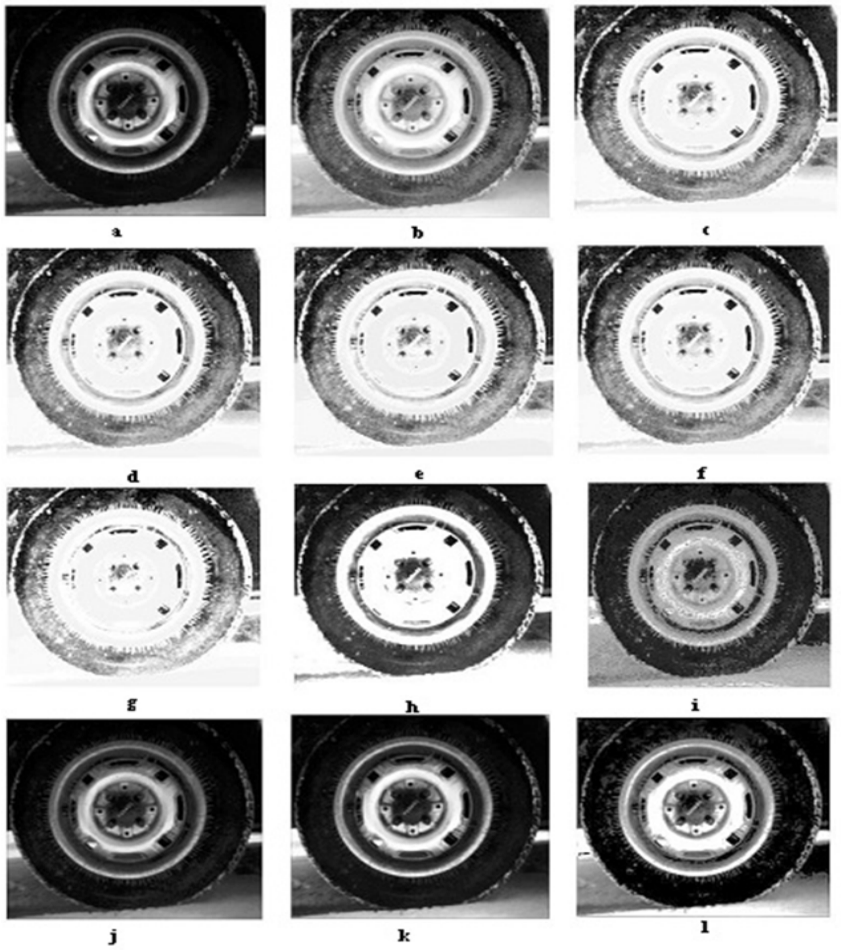

Figure 5. Performance Comparison using *Tire* Image

(a). Original Image (b). Histogram Equalization, (c).Brightness Preserving Bi-Histogram Equalization (BBHE), (d).Dualistic Sub-Image Histogram Equalization (DSIHE), (e).Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE), (f). Recursive Mean-Separate Histogram Equalization (RMSHE) (r=2), (g). Recursive Sub-Image Histogram Equalization (RSIHE), (h). Recursively Separated and Weighted Histogram Equalization (RSWHE), (i). Dynamic Histogram Equalization (DHE), (j).Brightness Preserving Dynamic Histogram Equalization (BPDHE), (k).Bi-Histogram Equalization with Plateau Limit (BHEPL) and (l). Gain-Controllable Clipped Histogram Equalization (GC-CHE)

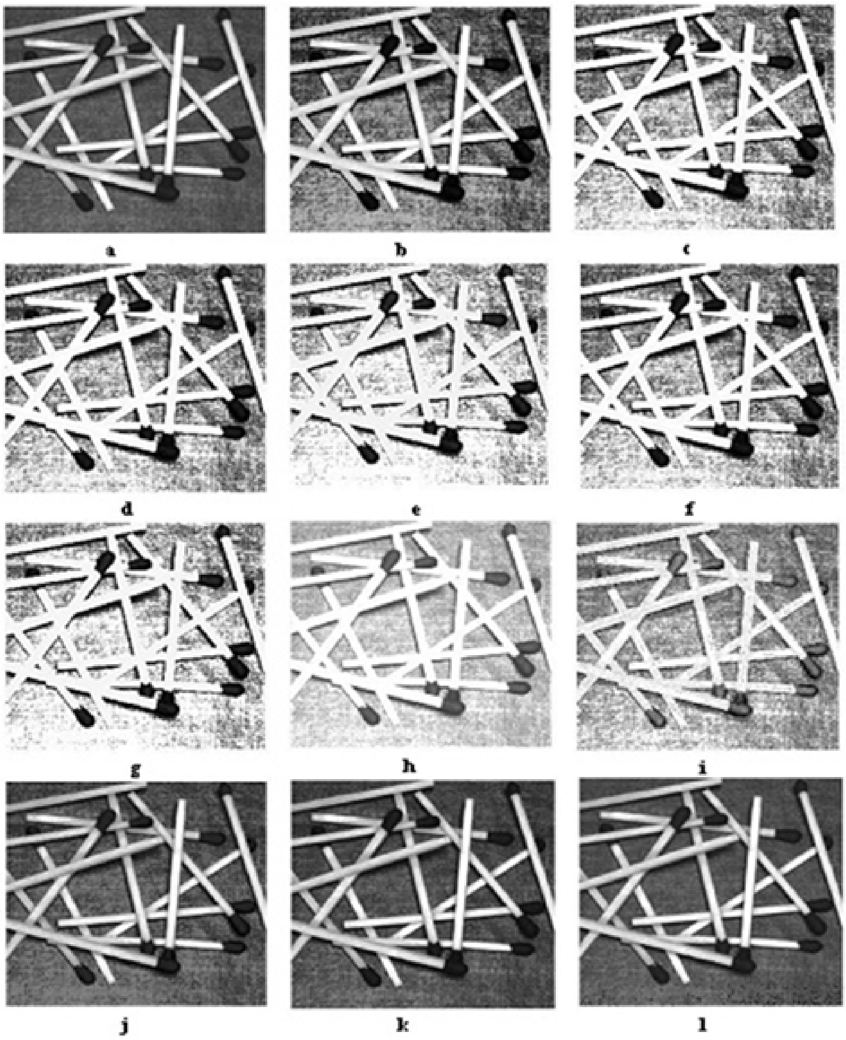

Figure 6. Performance Comparison using *random_matches* Image

(a). Original Image (b). Histogram Equalization, (c).Brightness Preserving Bi-Histogram Equalization (BBHE), (d).Dualistic Sub-Image Histogram Equalization (DSIHE), (e).Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE), (f). Recursive Mean-Separate Histogram Equalization (RMSHE) (r=2), (g). Recursive Sub-Image Histogram Equalization (RSIHE), (h). Recursively Separated and Weighted Histogram Equalization (RSWHE), (i). Dynamic Histogram Equalization (DHE), (j).Brightness Preserving Dynamic Histogram Equalization (BPDHE), (k).Bi-Histogram Equalization with Plateau Limit (BHEPL) and (l). Gain-Controllable Clipped Histogram Equalization (GC-CHE)

5. Conclusions

The present paper gives the review of existing histogram-based contrast enhancement techniques for brightness preserving and contrast enhancement. Bi-histogram equalization methods such as BBHE, DSIHE and MMBEBHE, Multi-histogram equalization methods such as RMSHE, RSIHE, DHE, BPDHE and RSWHE and Clipped Histogram equalization methods such as GC-CHE and BHEPL techniques are compared with Image Quality Measurement (IQM) tools such as absolute mean brightness error (AMBE) and peak signal-to-noise ratio (PSNR).All the techniques have overcome the drawbacks of histogram equalization and have shown abetter brightness preserving and contrast enhancement than HE. For BBHE, DSIHE, MMBEBHE, RMSHE, RSIHE and RSWHE methods, the contrast of the images is improved, but the problem of the intensity saturation occurs in some regions of the image as well and also presented stimulatedamplification of noise in the output image. All these techniques show brightness preserving, but show a less brightness preservation for bright images like *Pirate*, *Lenna* and *Cygnusloop*. MMBEBHE, the extension method of BBHE has shown a better brightness preserving. But it could not control over-enhancement of the image. Due to over-enhancement in MMBEBHE, RMSHE and RSIHE, there is a loss of information in the output image. RSIHEtechniquehas also shown more over-enhancement than MMBEBHE and RMSHE. RSWHE and DHE methods have shown good brightness preserving as well as acontrolled over-enhancement, but introduced annoying noise in the output image. BHEPL technique hasalso shown good brightness preserving except bright images like *Cameraman*, *Face*, *Hurricane Andrew*, *Pirate* and *Lenna*. BPDHE technique has given very less value of AMBE, and is almost zero (0.0067 to 0.0911) indicating good brightness preserving and high values of PSNR showsbettercontrast enhancement.GC-CHE method hasalso shownless values of AMBE (0 to 0.1827) and high values of PSNR (34.1527 to 61.6174). The output images of BPDHE and GC-CHE are very clear without any noise and there is no loss of information. BPDHE and GC-CHE techniques are more suitable for consumer electronic products where preserving the original brightness is essential.

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