Bi-Level Weighted Histogram Equalization for Scalable Brightness Preservation and Contrast Enhancement for Images

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Abstract: *A new technique, Bi-Level Weighted Histogram Equalization (BWHE) is proposed in this paper for the purpose of better brightness preservation and contrast enhancement of any input image. This technique applies bi-level weighting procedure on Brightness preserving Bi-Histogram Equalization (BBHE) to enhance the input images. The core idea of this method is to first segment the histogram of the input image into two, based on its mean and then weighting constraints are applied to each of the sub-histogram separately. Finally, those two histograms are equalized independently and their union produces a brightness preserved and contrast enhanced output image. This technique is found to preserve the brightness and enhance the contrast of input images better than its contemporary methods.*

Keywords: *Contrast enhancement, brightness preservation, histogram equalization, peak signal to noise ratio, absolute mean brightness error, structural similarity index matrix.*

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1. Introduction

Contrast enhancement techniques are used in image and video processing to achieve better visual perception [5, 8, 15]. In general, histogram equalization based contrast enhancement is achieved through the redistribution of intensity values of an input image. Histogram modification based techniques are the most recognition and texture synthesis. Popular techniques to achieve better contrast enhancement. Histogram Equalization (HE) is one of the most commonly used algorithms to perform contrast enhancement due to its simplicity and effectiveness [9]. The HE techniques use linear cumulative histogram of an input image and distribute its pixel values over its dynamic intensity range. Useful applications of HE enhancement include medical image processing, speech

HE methods can be categorized into two as global and local. Global HE methods improve the image quality by extending dynamic range of intensity using the histogram of the whole image. HE is an ideal example of this approach that is widely used for contrast enhancement [9]. HE is achieved by normalizing the intensity distribution using its cumulative distribution function so, that the resultant image may have a uniform distribution of intensities. Since HE is based on the intensity distribution of the entire image, it causes washed-out effect by changing the average intensity to middle level.

Local Histogram Equalization (LHE) methods use the histogram and the statistics obtained from the neighbourhood pixels of an image for equalization. They usually divide the original image into several non-overlapped sub-blocks and perform HE operation on the individual sub-blocks. The resultant image is produced by merging the sub-blocks using the bi-linear interpolation method. The major drawback of these methods is the introduction of discontinuity, called blocking effect which occurs near the boundaries of the sub-blocks. Histogram Specification (HS) [9] is another method in which the expected output of the image histogram can be controlled by specifying the desired output histogram. However, specification of the output histogram pattern is purely image dependent.

In this paper, a novel HE based method called, Bi-Level Weighted Histogram Equalization (BWHE) is proposed that implements a new bi-level weighting technique, applied to Brightness preserving Bi-Histogram Equalization method (BBHE). This method is proved to be computationally simple and exhibits better brightness preservation and contrast enhancement.

In section 2, the traditional HE and a few recently proposed HE based methods are described. Section 3 presents the principle of the proposed technique, BWHE. Section 4 discusses the metrics to measure the image quality of the enhanced image. In sections 5, the results are discussed and the conclusion is given in section 6.

2. Histogram Equalization Methods

The traditional HE technique [9], is described below: Let $X=\{X(i, j)\}$ denotes a digital image, where $X(i, j)$ denotes the gray level of a pixel at (i, j). The total number of pixels in the image is N and the image intensity is digitized into L levels as $\{X_0, X_1, ..., X_{L-1}\}$. So, it is obvious that $X(i, j)\in\{X_0, X_1, ..., X_{L-1}\}\ \forall(i, j)$. If n_k denotes the total number of pixels with gray level X_k in the image, then the Probability Density Function (PDF) of X_k is given as:

$$p(X_k) = \frac{n_k}{N}, k = 0,1,...,L-1 \tag{1}$$

The plot between $p(X_k)$ and X_k is defined as the histogram of an image. The Cumulative Density Function (CDF) based on the images PDF is defined as:

$$C(X_k) = \sum_{i=0}^{k} p(X_i) \tag{2}$$

where $k=0, 1,..., L-1$ and it is known that $C(X_{L-1})=1$. The transformation function of HE is defined as:

$$f(X_k) = X_0 + (X_{L-1} - X_0) \times C(X_k), k = 0,1,....,L-1 \tag{3}$$

Thus, HE flattens the histogram of an image resulting a significant change in the brightness.

A new HE based brightness preservation method known as BBHE was proposed [7], in the year 1997. BBHE first segments the histogram of input image into two, based on its mean; the one ranging from minimum gray level to mean and the other from mean to the maximum. Then, it equalizes the two histograms independently. It has been clearly proved that BBHE can preserve the original brightness to a certain extent [2]. In the year 1999, Wan *et al.* [16], proposed a method called equal area Dualistic Sub-Image Histogram Equalization (DSIHE) which is an extension of BBHE. DSIHE differs from BBHE only in the segmentation process. The input image is segmented into two, based on median rather than mean. This method is well suited only for images which are not having uniform intensity distribution. Moreover, the brightness cannot be preserved significantly in DSIHE. Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) [1] is another method proposed in 2003. MMBEBHE is an extension of BBHE which performs the separation based on the threshold level, which would yield minimum difference between input and output mean, called Absolute Mean Brightness Error (AMBE). This technique is also, not free from side effects.

In the year 2003, another technique called Recursive Mean Separate Histogram Equalization (RMSHE) was proposed in which the histogram of the given image is partitioned recursively [3]. Each segment is equalized independently and the union of all the segments gives the contrast enhanced output. This technique has been clearly proved to be a better method among the recursive partitioning approaches [2]. In the year 2007, Sim *et al.* [14], Proposed a similar method, called Recursive Sub-Image Histogram Equalization (RSIHE). RSIHE has the same characteristics as RMSHE in equalizing an input image, except that RSIHE chooses to separate the histogram based on gray level with cumulative probability density equal to 0.5, whereas RMSHE uses mean-separation approach. This method is proved to have an edge over RMSHE. But, the recursion procedure increases the computational complexity and the resultant image is very similar to that of original input image. Moreover, finding a generic optimal recursion level applicable to all types of images is still a challenge for all of these methods.

A fast and effective method for video and image contrast enhancement, known as Weighted Thresholded HE (WTHE) was proposed [17]. This technique provides a convenient and effective mechanism to control the enhancement process, while being adaptive to various types of images. WTHE method provides a good trade-off between the two features, adaptivity to different images and ease of control, which are difficult to achieve in the GHE-based enhancement methods. In this method, the probability density function of an image is modified by weighting and thresholding prior to HE. A mean adjustment factor is then added with the expectation to normalize the luminance changes. Two more weighting techniques, Weight Clustering HE (WCHE) [10], and Recursively Separated and Weighted HE (RSWHE) [6] were developed in the year 2008. Both these techniques used different weighting principles and attained their own success. Ibrahim and Kong [4], recently proposed Sub-Regions Histogram Equalization (SRHE) which outputs sharpened images. In 2011, Shanmugavadivu *et al.* [11, 12, 13], proposed histogram equalization based methods for enhancing edges and contrast of input images by suitably modifying their histograms.

3. Bi-Level Weighted Histogram Equalization

BWHE is a method which combines the power of WTHE and BBHE. Here, a new bi-level weighting procedure is developed and applied to BBHE. WTHE is a technique which is well known for enhancing the contrast of an image in a scalable way whereas BBHE is meant for brightness preservation. Hence, our method gives scalable contrast enhanced as well as brightness preserved output. The BWHE algorithm is given below:

1. Input the image, $F(i, j)$ with a total number of 'n' pixels in the gray level range $[X_0, X_n]$.
2. Segment $F(i, j)$ into lower sub- images $F_L(i, j)$ and upper sub-image $F_U(i, j)$ based on its mean 'm'.

3. Compute the Probability Density Functions (PDF), $P_L(r_k)$ and $P_U(r_k)$ for the lower and upper sub-images respectively.
4. Find the mean PDF of lower and upper sub-images as m_L and m_U respectively.
5. Apply the following constraints to the lower sub-image as:

$$P_{LC}(r_k) = T(P_L(r_k)) = \begin{cases} \alpha & \text{if } P_L(r_k) > \alpha \\ \left(\dfrac{P_L(r_k) - \beta}{\alpha - \beta}\right)^r \times \alpha & \text{if } \beta \le P_L(r_k) \le \alpha \\ 0 & \text{if } P_L(r_k) < \beta \end{cases} \quad (4)$$

where $\alpha = v \times max(P_l(r_k))$, $0.1 < v < 1.0$, $\beta = 0.0001$ and 'r' is the power factor such that $0.1 < r < 1.0$.

6. Find the mean PDF of constrained lower sub-image as m_{LC}.
7. Find mean error m_{eL} as: $m_{eL} = m_{LC} - m_L$
8. Add m_{eL} to $P_{LC}(r_k)$.
9. Find the cumulative density function $C_L(F_L(i,j))$ using $P_{LC}(r_k)$ and apply the HE procedure as:

$$F_L'(i,j) = X_0 + (m - X_0) \times C_L(F_L(i,j)) \quad (5)$$

10. Apply the following constraints to the upper sub-image as:

$$P_{UC}(r_k) = T(P_U(r_k)) = \begin{cases} \alpha & \text{if } P_U(r_k) > \alpha \\ \left(\dfrac{P_U(r_k) - \beta}{\alpha - \beta}\right)^r \times \alpha & \text{if } \beta \le P_U(r_k) \le \alpha \\ \beta & \text{if } P_U(r_k) < \beta \end{cases} \quad (6)$$

where, $\alpha = v \times max(P_l(r_k))$, $0.1 < v < 1.0$, $\beta = mean(P_U(r_k))$ and 'r' is the power factor such that $0.1 < r < 1.0$.

11. Find the mean PDF of constrained upper sub-image as m_{UC}.
12. Find mean error m_{eU} as: $m_{eU} = m_{UC} - m_U$.
13. Add m_{eU} to $P_{UC}(r_k)$.
14. Find the cumulative density function $C_U(F_U(i,j))$ using $P_{UC}(r_k)$ and apply the HE procedure as:

$$F_U'(i,j) = (m+1) + (X_n - (m+1)) \times C_U(F_U(i,j)) \quad (7)$$

15. Final enhanced output image is given as:

$$F_O = F_L'(i,j) \cup F_U'(i,j) \quad (8)$$

The constraints applied to the lower and upper sub-images helps in equalizing the images in a controlled and scalable way. The original PDFs of the lower and upper sub-images are clamped to the upper threshold α and lower threshold β. The calculations of α are different for the sub-images and are clearly given in steps 5 and 10. While calculating, α the parameter v is fixed in the range 0.1 to 1.0 so, as to clip the PDFs with high probabilities. When the v value goes beyond this limit, over-enhancement occurs. The β value of lower sub-image is fixed as low as possible (0.0001) since it is less important in controlling the enhancement and the same of upper sub-image is fixed as mean($P_U(r_k)$) so, as to equalize the PDFs nearer to the mean value of the upper sub-image. The transformation functions T(.) specified in the steps 5 and 10 transform all PDFs between the upper and lower thresholds using a normalized power law function with index $r>0$. The 'r' value is always less than one so, as to protect the lesser probabilities and hence the over-enhancement is very rare. The optimal 'v' and 'r' values for lower and upper sub-images are found iteratively. The mean errors which are calculated in steps 7 and 12 are added to the modified PDFs of the upper and lower sub-images to compensate the change of mean luminance level.

4. Image Quality Measurement

There are three well known parameters to measure the quality of the output image. They are: Peak Signal to Noise Ratio (PSNR) for measuring the contrast enhancement [6], Absolute Mean Brightness Error (AMBE) [6] for measuring the mean brightness and Structural Similarity Index Matrix (SSIM) for measuring after-enhancement image quality [14].

4.1. Peak Signal to Noise Ratio

For the PSNR, the source image $X(i,j)$ and the output image $Y(i, j)$ are assumed to have M by N pixels. Errors are computed only on the luminance signal so, that the pixel values of $X(i, j)$ ranges between black (0) and white (255). First the Mean Squared Error (MSE) of the reconstructed image is computed as follows:

$$MSE = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[X(i,j) - Y(i,j)]^2}{M \times N} \quad (9)$$

The Root Mean Squared Error (RMSE) is the square root of MSE. The PSNR in decibels (dB) is computed as:

$$PSNR = 20 \log_{10}\left(\frac{max(Y(i,j))}{RMSE}\right) \quad (10)$$

After the application of an enhancement procedure, the enhanced output image having higher $PSNR$ value is expected to have improved contrast.

4.2. Absolute Mean Brightness Error

The AMBE of an input image $X=\{X(i, j)\}$ and the output image $Y=\{Y(i,j)\}$ is computed as:

$$AMBE(X, Y) = |X_M - Y_M| \quad (11)$$

where X_M is the mean of the input image X and Y_M is the mean of the output image Y. If the mean difference is lower, then the brightness of the Input image is preserved in the output too.

4.3. Structural Similarity Index Matrix

The Structural Similarity Index Matrix to assess the image quality is defined as:

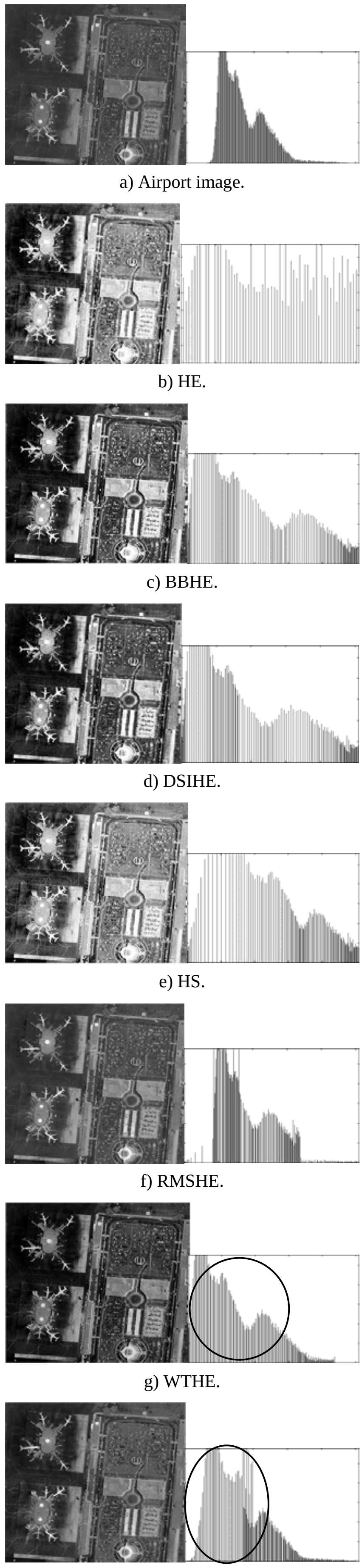
$$SSIM(X,Y)=\frac{(2\mu_X\mu_Y+C_1)(2\sigma_{XY}+C_2)}{(\mu_X^2+\mu_Y^2+C_1)(\sigma_X^2+\sigma_Y^2+C_2)} \quad (12)$$

where X and Y are the reference and the output images respectively; μ_X is the mean of image X, μ_Y is the mean of image Y; σ_X is the standard deviation of image X, σ_Y is the standard deviation of image Y, σ_{XY} is the square root of covariance of images X and Y, C_1 and C_2 are constants. The *SSIM* value between two images X and Y is generally in the range zero to one. If the image $X=Y$, then the $SSIM=1$ which implies that when the *SSIM* value of two images is nearing 1, the degree of structural similarity between the two is higher.

5. Results and Discussion

The performance of the proposed method, BWHE was tested on standard test images such as Einstein, Peppers, Putrajaya, Truck, Village, Aircraft, Bottle, Eight, Airport, Cameraman, F16 and Girl. To compare the performance of BWHE, the same images are enhanced with the contemporary enhancement techniques HE, BBHE, DSIHE, HS, RMSHE and WTHE. The performance of all these methods is measured qualitatively in terms of human visual perception and quantitatively using PSNR, AMBE and SSIM.

The qualitative performance of BWHE and the contemporary methods are illustrated using Airport image and its histogram which is given in Figure 1. The enhanced images of the same by HE, BBHE, DSIHE, HS, RMSHE and WTHE are shown in Figures 1-b to 1-g. It is evident from the visual comparison that BBHE exhibits better performance than HE due to its partition-based enhancement. Moreover, it is apparent from Figures 1-d, 1-e and 1-f that DSIHE, HS and RMSHE introduce unwanted artifacts in the enhanced images. Figure 1-g is the result of WTHE which is closely matching with the results of BWHE but still it is also, not free from unwanted side effects and degradation in the original brightness. For example, the original intensity of the encircled area of the Airport image in Figure 1-a has been changed by WTHE as shown in Figure 1-g. This intensity variation has been clearly shown in the histogram pattern also, and there exists a remarkable deviation from the original image's histogram pattern. Figure 1-h clearly shows that the visual result of BWHE is better than those of other HE techniques and is free from over-enhancement. Comparatively, BWHE is proved to retain the original brightness of Airport image. Similarly, BWHE is found to produce better results for other images too.



a) Airport image.

b) HE.

c) BBHE.

d) DSIHE.

e) HS.

f) RMSHE.

g) WTHE.

h) BWHE.

Figure 1. Comparison Results by various HE techniques b-g.

Table 1. Comparison of PSNR values.

Image \ Method	HE	BBHE	DSIHE	HS	RMSHE (r=2)	WTHE	BWHE
Einstein	14.9772	16.1678	16.5590	16.1721	24.3070	22.2114	26.9695
Peppers	22.6708	26.6785	26.6894	24.8050	27.1802	32.5050	39.0989
Putrajaya	15.1254	18.1904	17.9499	16.7731	25.7865	28.4031	34.9096
Truck	13.4020	17.4732	16.3376	14.3226	19.3053	29.8150	36.1199
Village	17.4181	22.2929	21.4134	19.0391	26.8144	34.5230	35.9524
Aircraft	10.2104	14.2317	12.0170	11.2325	17.6622	23.7310	23.2456
Bottle	12.6761	18.4965	17.6775	12.9664	28.4096	30.6490	35.9032
Eight	9.6472	23.9524	20.6771	10.9912	21.8560	25.7608	32.3086
Airport	12.0211	15.9741	15.2702	12.5401	27.1712	21.8517	27.7481
Camaeraman	19.0970	18.2183	18.8204	19.7467	27.3098	28.4114	30.9003
F16	11.6879	25.1643	18.1811	12.5023	27.5471	31.0755	38.7506
Girl	13.0246	14.6792	12.6028	13.8071	20.3592	21.7714	30.6430

Table 2. Comparison of AMBE values.

Image \ Method	HE	BBHE	DSIHE	HS	RMSHE (r=2)	WTHE	BWHE
Einstein	19.8477	11.9201	1.3760	22.0291	2.4768	0.9367	0.0037
Peppers	7.9139	0.9129	1.5084	9.6817	3.1180	0.7858	0.0034
Putrajaya	14.0813	16.7132	7.3522	11.5181	3.3907	0.5669	0.0021
Truck	20.2301	0.8760	5.7135	22.8239	10.8077	0.3528	0.0082
Village	15.2045	2.5019	5.8159	16.9096	1.6550	0.4160	0.0034
Aircraft	47.6156	13.6671	28.1940	43.3634	4.5403	1.3915	0.0457
Bottle	50.3206	15.8077	18.1076	52.0631	3.8726	3.9171	0.0012
Eight	70.4973	6.6443	2.0291	59.5879	4.3631	0.0735	0.0008
Airport	44.5755	7.4727	12.3669	46.9097	6.0828	0.5834	0.0123
Camaeraman	8.6955	24.1245	17.4851	11.2027	0.1774	1.6099	0.0192
F16	51.8537	6.1298	16.2240	48.9414	1.9894	0.3003	0.0001
Girl	5.3007	10.9764	16.0626	1.5309	10.1170	0.1763	0.0002

Table 3. Comparison of SSIM values.

Image \ Method	HE	BBHE	DSIHE	HS	RMSHE (r=2)	WTHE	BWHE
Einstein	0.6672	0.7099	0.6950	0.7430	0.8033	0.8770	0.9327
Peppers	0.9286	0.9542	0.9553	0.9577	0.9365	0.9918	0.9978
Putrajaya	0.6471	0.8637	0.8217	0.7298	0.8951	0.9810	0.9921
Truck	0.5538	0.8027	0.7504	0.6233	0.8359	0.9894	0.9944
Village	0.7814	0.8924	0.8843	0.8596	0.8868	0.9950	0.9915
Aircraft	0.3544	0.6493	0.5670	0.4055	0.6219	0.8871	0.8870
Bottle	0.7517	0.8847	0.8700	0.7685	0.9433	0.9796	0.9913
Eight	0.3549	0.8152	0.7579	0.4192	0.7901	0.8701	0.9926
Airport	0.6053	0.6912	0.6738	0.6563	0.9367	0.8593	0.9292
Camaeraman	0.8069	0.8128	0.8110	0.7939	0.8878	0.9902	0.9840
F16	0.5407	0.9614	0.8327	0.6088	0.9203	0.9902	0.9962
Girl	0.3535	0.5693	0.3994	0.4204	0.6844	0.9187	0.9711

Further, the qualities of the test images which are enhanced using the above mentioned techniques are measured in terms of PSNR, AMBE and SSIM and are given in Tables 1, 2 and 3 respectively. From Table 1, it is observed that BWHE produces higher PSNR values. Hence, it is a better method for enhancing the contrast. It is also, noted from Table 2 that the absolute mean difference is very low for BWHE which endorses the brightness preservation in the output images. It is evident from the SSIM values furnished in Table 3 that BWHE has produced values that are closer to 1, which signifies the structural similarity between the original and the enhanced images.

6. Conclusions

The mean brightness of the enhanced images is found to drastically deviate from that of the original ones, due to the mean shift introduced by the mechanism of the histogram equalization based enhancement techniques. However, the proposed BWHE is proved to address this problem effectively. This technique is devised to accomplish two major desired objectives of brightness preservation and contrast enhancement of any given input image. Moreover, this non-recursive algorithm is computationally simple and provides significant scalability. As image enhancement is deemed as an inevitable component in processing medical images, satellite images etc., it is essential to preserve the vital details of the original images in the enhanced ones. In this context, the controlled contrast enhancement guaranteed by BWHE provides viable solutions to objectively improve the contrast and brightness of the input image, with a greater degree of detail preservation as portrayed by the SSIM measure.

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