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Histogram Modification Framework for Image Contrast Enhancement and Brightness Preserving

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Abstract: Histogram Equalization (HE) is one of the most popular methods 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. 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 sub-histogram. This study presents a simple histogram modification framework for still image contrast enhancement to improve image contrast without making any loss in image details. The proposed method consists of two stages. First, histogram of the original image is modified with respect to uniform histogram. In the second stage, the modified histogram of the original image is separated into two sub-histograms based on the mean of the original image and then equalizes them independently to preserve image brightness. By introducing the enhancement parameter, the level of the contrast enhancement can be adjusted based on the input image contrast. The experimental results show that it preserves more brightness and produces natural looking images than the other conventional methods. The proposed method has been tested using several images and gives better visual quality as compared to several other methods.

Key words: Histogram equalization, image contrast enhancement, histogram modification, histogram partition, brightness

INTRODUCTION

Image enhancement is one of the most interesting and important issues in digital image processing field. 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 (Kabir *et al*., 2010). Image enhancement produces an output image that subjectively looks better than the original image by changing the pixel's intensity of the input image (De La Torre, 2005).

There are many image enhancement techniques have been proposed and developed. One of the most popular image enhancement methods is Histogram Equalization (HE). HE becomes a popular technique for contrast enhancement because this method is simple and effective. HE flattens and stretches the dynamic range of the resultant image histogram and as a consequence, it enhances the contrast of the image and gives an overall contrast improvement (Wang and Ye, 2005; Starck *et al*., 2003; Mukherjee and Mitra, 2008; Kim *et al*., 2001). 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 limitations of HE and to preserve image brightness, several brightness preserving histogram equalization techniques have been proposed. At first, Kim (1997) proposed Brightness preserving Bi-Histogram Equalization (BBHE), BBHE divides the input image histogram into two parts based on the mean of the input image and then each part is equalized independently. Consequently, the mean brightness can be preserved because the original mean brightness is retained. Wang *et al*. (1999) proposed Dualistic Sub-Image Histogram Equalization (DSIHE), which is similar

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brightness is retained. Wang *et al.* (1999) proposed Dualistic Sub-Image Histogram Equalization (DSIHE), which is similar to BBHE except that the median of the input image is used for histogram partition instead of mean brightness. Chen and Ramli (2003a) proposed Minimum Mean Brightness Error Bi-histogram Equalization (MMBEBHE) which is the extension of BBHE method that provides maximal brightness preservation. This algorithm finds the minimum mean brightness error between the original and the enhanced image. Then, it employs the optimal point as the separating point instead of the mean or median of the input image. Though, these methods can perform good contrast enhancement, they also cause more annoying side effects depending on the variation of gray level distribution in the histogram. Recursive Mean Separate HE (RMSHE) is another improved version of BBHE (Chen and Ramli, 2003b). This method recursively separates the histogram into multi sub-histograms instead of two sub-histograms as in the BBHE. Initially, two sub-histograms are created based on the mean brightness of the original histogram. Subsequently, the means 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. The methods discussed are based on dividing the original histogram into several sub-histograms by using either the median or mean brightness. Although, the mean brightness is well preserved by the aforementioned methods, these methods cannot further expand the region of sub-histogram located near to the minimum or maximum value of the dynamic range. However, it is also not free from side effects (Chen *et al*., 2006).

In order to deal with above problem, Abdullah-Al-Wadud *et al.* (2007) proposed a Dynamic Histogram Equalization (DHE) technique. DHE partitions the original histogram based on local minima. However, DHE does not consider the preserving of brightness. For this purpose, Ibrahim and Kong proposed Brightness Preserving Dynamic Histogram Equalization (BPDHE) (Kong and Ibrahim, 2008). This method partitions the image histogram based on the local maxima of the smoothed histogram. It then assigns a new dynamic range to each partition. Finally, the output intensity is normalized to make the mean intensity of the resulting image equal to the input one. Although, the BPDHE performs well in mean brightness preserving, the ratio for brightness normalization plays an important role. A small ratio value leads to insignificant contrast enhancement. For large ratio (i.e., ratio value >1), the final intensity value may exceed the maximum intensity value of the output dynamic range. The exceed pixels will be quantized to the maximum intensity value of gray levels and produce intensity saturation problem (in MATLAB environment). Brightness Preserving Dynamic Fuzzy Histogram Equalization (BPDFHE) has been proposed by Sheet *et al.* (2010) which is an enhanced version of BPDHE that uses fuzzy statistics of digital images for their representation and processing. Representation and processing of images in the fuzzy domain enables the technique to handle the inexactness of gray level values in a better way, resulting in improved performance. The BPDFHE technique manipulates the image histogram in such a way that no remapping of the histogram peaks takes place while only redistribution of the gray-level takes place.

To overcome the abovementioned drawbacks, a simple histogram modification framework is proposed for still image contrast enhancement to improve image contrast while preserving image brightness and it enhances the images without making any loss in image details.

Histogram equalization: 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.

Let f be the input image composed of L discrete gray levels denoted as $\{f_0, f_1, \ldots f_{L-1}\}$. For a given image f, the probability density function $P(f_k)$ is defined as:

$$P(f_k) = \frac{n^k}{n} \quad (1)$$

for k = 0, 1, 2, ..., L-1, where n_k represents the number of times that the gray level f_k appears in the input image f and n is the total number samples in the input image. Note that $P(f_k)$ is associated with the histogram of input image which represents the number of pixels that have a specific intensity f_k. In fact, a plot of f_k Vs n_k is called as histogram of input image f. The respective cumulative density function is then defined as:

$$C(f_k) = \sum_{j=0}^{L-1} p(f_j) \quad (2)$$

for k = 0, 1, 2, ..., L-1. Note that $C(f_{L-1}) = 1$ by definition. Histogram equalization is a method that maps the input image into entire dynamic range, $(f_0\ f_{L-1})$, by using the cumulative distribution function as a transform function. That is, let us define a transform function T(f) based on cumulative density function as:

$$T(f) = \{f_0 + (f_{L-1} - f_0)C(f_k)\} \quad (3)$$

Then, the enhanced image of HE g = g (i, j) can be expressed as:

$$g(i, j) = T(f) = \{T(f(i, j)) \mid \forall f(i, j) \in f\} \quad (4)$$

Where:

f and g = The original and enhanced images
(i, j) = The 2D coordinates of the images
T = The intensity transformation function which maps the original image into the entire dynamic range (f_0 f_{L-1})

However, HE produces an undesirable checkerboard effects on enhanced images. Another problem of this method is that it also enhances the noises in the input image along with the image features (Agaian *et al*., 2007; Abdullah-Al-Wadud *et al*., 2007; Wang and Ward, 2007; Polesel *et al*., 2000; Ibrahim and Kong, 2009; Kim and Paik, 2008).

MATERIALS AND METHODS

Proposed research: In this study, a simple histogram modification framework is proposed to preserve the mean brightness of the image which leads to contrast enhancement. A simple block diagram of proposed method is shown in Fig. 1 and the corresponding steps are given blow.

Step 1: Histogram computation and modification: The histogram of the original image is modified with respect to the uniform histogram. The image histogram is modified so that to retain the brightness levels which correspond with the main information in the image and to suppress the remaining data.

Step 2: Histogram partition and equalization: The modified histogram is divided into two sub-histograms based on the input mean of the original image. One of the modified sub-histogram is set of samples less than or equal to the mean whereas the other one is the set of samples greater than the mean. Then, histogram equalization is carried out in each partition of the modified histogram independently. However, the results are then combined together to form a complete enhanced image.

Histogram computation and modification: The main objective of this method is to obtain a modified histogram

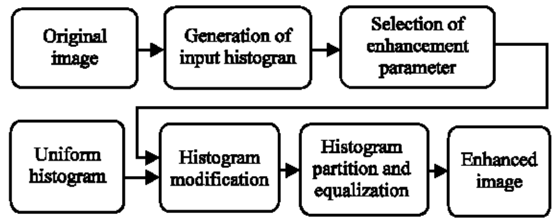

Fig.1: Simple block diagram of the proposed method

that is closer to a uniformly distributed histogram. The modified histogram $\bar{H}$ is the weighted average of original hi and uniform histogram u:

$$\bar{H} = \frac{h_i + \gamma u}{1+\gamma} = \left(\frac{1}{1+\gamma}\right)h_i + \left(\frac{\gamma}{1+\gamma}\right)u \quad (5)$$

Where:

$\bar{H}$ = The modified histogram, hi is the input histogram
u = The uniform histogram
γ = The enhancement parameter

Various levels of contrast enhancement can be achieved by varying the parameter γ. HE obtained by γ = 0 corresponds to the standard HE and as γ goes to infinity it converges to preserving the original image.

Histogram partition and equalization: Consider the input image X. Based on input mean Xm, the modified histogram $\bar{H}$ is decomposed into two sub histograms $\bar{H}_L$ and H_U as:

$$\bar{H} = \bar{H}_L \cup \bar{H}_U \quad (6)$$

Where:

$$\bar{H}_L = \left\{X(i, j) \mid X(i, j) \le X_m, \forall X(i, j) \in \bar{H}\right\} \quad (7)$$

And:

$$\bar{H}_U = \left\{X(i, j) \mid X(i, j) \le X_m, \forall X(i, j) \in \bar{H}\right\} \quad (8)$$

Next, define the respective probability density functions of the modified sub histograms $\bar{H}_L$ and $\bar{H}_U$ as:

$$P_L(X_k) = \frac{n^k{}_L}{n_L} \quad (9)$$

where, k = 0, 1, ………, m and:

$$P_U(X_k) = \frac{n^k{}_U}{n_U} \quad (10)$$

Where:

K $= m+1, m+2, ..., L-1$
n_U^k, n_L^k = The respective umbers of X_k in $\bar{H}_L$ and $\bar{H}_U$
n_L^k, n_U^k = The total number of samples in $\bar{H}_L$ and $\bar{H}_U$

Note that P_L (X_k) and P (X_k) are associated with the modified histogram of the input image which represents the number of pixels that have a specific intensity X_k. The respective cumulative density functions for modified sub-histograms $\bar{H}_L$ and $\bar{H}_U$ are then defined as:

$$C_L(X_k) = \sum_{j=0}^{k} p_L(X_j) \tag{11}$$

And:

$$C_U(X_k) = \sum_{j=m+1}^{k} p_U(X_j) \tag{12}$$

Let us define the following transform functions based on cumulative density functions as:

$$f_L(X_k) = X_0 + (X_m - X_0) C_L(X_k) \tag{13}$$

And:

$$f_U(X_k) = X_{m+1} + (X_{L+1} - X_{m+1}) C_U(X_k) \tag{14}$$

Based on these transform functions, the decomposed sub-images are equalized independently and the composition of the resulting equalized sub-images constitute the enhanced image. That is the enhanced image Y = {Y(i, j)} is expressed as:

$$Y = f_L(\bar{H}_L) \cup f_U(\bar{H}_U) \tag{15}$$

Where:

$$f_L(\bar{H}_L) = \left\{ f_L(X(i,j)) \mid \forall X(i,j) \in \bar{H}_L \right\} \tag{16}$$

And:

$$f_U(\bar{H}_U) = \left\{ f_U(X(i,j)) \mid \forall X(i,j) \in \bar{H}_U \right\} \tag{17}$$

If we note that, $0 \leq C_L(X_K), C_U(X_K) \leq 1$, it is easy to see that $f_L(\bar{H}_L)$ equalizes the sub-image $\bar{H}_L$ over the range (X_0, X_m) whereas $f_U(\bar{H}_U)$ equalizes the sub-image $\bar{H}_U$ over the range (Xm+1, XL-1). As a consequence, the input image X is equalized over the entire dynamic range (X_0, X_{L-1}) with the constraint that the samples less than the input mean are mapped to (X_0, X_m) and the samples greater than the mean are mapped to (Xm+1, XL-1). The experimental results will be compared and shown in the next study.

RESULTS AND DISCUSSION

In this study, comparison among the proposed method and several other conventional methods such as HE, BBHE, MMBEBHE, DHE and BPDFHE is presented. A subjective assessment to compare the visual quality of the images is carried out. Figure 2a shows the resulting images obtained by the various existing methods and our proposed ones for the seed image. Figure 2b 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. Figure 2c shows that the BBHE method produces 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 BPDFHE (Fig. 2d and e) shows good contrast enhancement, they also cause more annoying side effects depending on the variation of gray level distribution in the histogram. The second test image is cameraman (Fig. 3). The cameraman

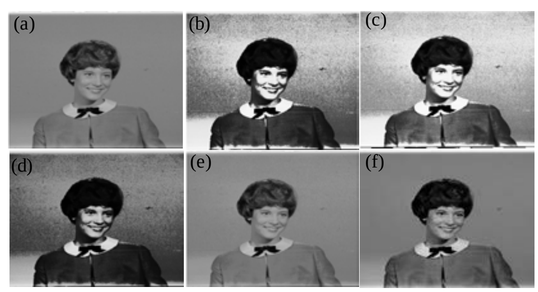

Fig. 2: Simulation results of the Girl1 image; a) Original image; b) HE-ed image; c) BBHE-ed image; d) MMBEBHE-ed image; e) BPDFHE-ed image; f) Proposed image

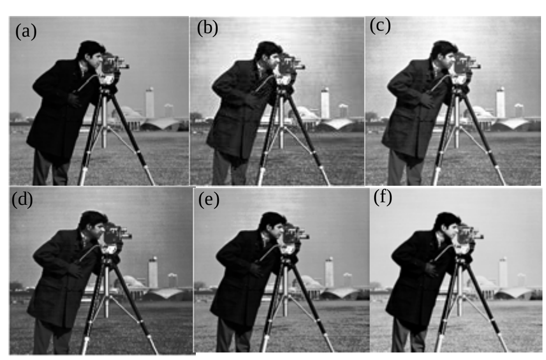

Fig. 3: Simulation results of the cameraman image; a) Original image; b) HE-ed image; c) BBHE-ed image; d) MMBEBHE-ed image; e) BPDFHE-ed image; f) Proposed image

Table 1: Comparison of CII values

Image ID	HE	BBHE	MMBEBHE	BPDFHE	Proposed method
Girl	1.3204	1.3337	1.2973	1.2292	1.3435
Couple	0.8842	0.7973	0.9509	0.9407	0.9411
Lena	1.4209	1.4416	1.4264	1.3532	1.4474
House	1.3638	1.3443	1.3524	1.2447	1.3443
Baboon	1.1884	1.1773	1.2222	1.0238	1.1984
Aircraft	1.3776	1.0859	1.2958	1.1750	1.5727
Truck	1.1175	1.0865	1.1015	0.9927	1.1194
Village	1.1072	1.0270	1.2200	1.2351	1.3279
Einstein	0.9203	0.8446	0.9380	0.9678	0.9889
Cameraman	1.1773	1.1795	1.2000	1.0435	1.1206

Table 2: Comparison of AIC values

Image ID	HE	BBHE	MMBEBHE	BPDFHE	Proposed method
Girl	5.2793	5.2891	5.3054	5.4233	5.3826
Couple	6.2496	6.1872	6.1897	6.0126	6.2782
Lena	7.3356	7.3442	7.3361	7.2853	7.3678
House	6.2521	6.2411	6.2335	6.2754	6.3364
Baboon	7.2378	7.2365	7.2061	7.2576	7.2514
Aircraft	5.4111	5.5249	5.4601	5.4798	5.5106
Truck	5.9072	5.9325	5.8659	5.9460	5.9243
Village	7.1867	7.1814	7.2313	7.1344	7.2528
Einstein	6.9554	6.9710	6.9554	6.9748	6.9957
Cameraman	6.7699	6.8081	6.7536	6.7754	6.8791

has almost the same intensity with its background. Observe that resulting images of HE, BBHE, MMBEBHE and BPDFHE have mean brightness much brighter compared to the original image and hence, results in unpleasant artifacts in the over-equalized background. Also, the cameraman region's contrast is reduced. These artifacts are not seen with proposed one. Proposed method has preserved the brightness very well and yielded a more natural enhancement. By visually inspecting the images on these figures, we can clearly see that only the proposed method is able to generate natural looking image and still offer contrast enhancement. Further, the qualities of the test images which are enhanced using the above mentioned techniques are measured in terms of CII, AIC are given in Table 1 and 2, respectively. From the analysis of CII values furnished in Table 1, it is found that proposed method produces greater CII values as compared to the other conventional methods. Hence, the proposed method improves local contrast of an image as compared to the conventional methods. According to Table 2, the proposed method produces the highest AIC, thus becomes the best method to bring out the details of the images. In addition, the AIC results show that the proposed method improves the contrast of the input images in better way which is numerically indicated by the greater AIC values as compare to the other conventional methods. Based upon qualitative and quantitative analyses, the proposed method has been found effective in enhancing contrasts of images in comparison to a few existing methods.

CONCLUSION

In this research, a simple histogram modification framework is presented for image contrast enhancement. Histogram of original image is modified with respect to uniform histogram and separates the modified histogram into two sub-histograms based on the mean of the original image and then equalizes them independently to preserve image brightness. The level of contrast enhancement can be adjusted depending on the input image contrast by varying a single enhancement parameter. The experimental results show that the proposed method can effectively and significantly eliminate washed-out appearance. Moreover, it enhances the image without making any loss to image details. In addition to that, it does not produce any unwanted artifacts that occurred in conventional methods.

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