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Modified Dynamic Histogram Equalization For Image Enhancement in Gray-scale Images

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Abstract: To improve the quality of digital images captured in low light environment from consumer electronics devices like cell phone cameras, Modified Dynamic Histogram Equalization (MDHE) is proposed. Initially, the proposed method divides the histogram into two sub-histograms based on median. Then 2nd sub-histogram is further divided into two sub-histograms based on median of it. The resultant sub-histograms are clipped according to the mean of the intensity occurrence of the input image independently. The new dynamic range is allocated to each sub-histogram. The first sub-histogram is equalized independently using Global Histogram Equalization (GHE) method. GHE is found the better enhancement for lower gray-levels and suffers over-enhancement problem in higher gray-level. The proposed method utilizes the advantages of both GHE and QDHE. This method utilizes GHE for enhancing lower gray-levels and QDHE for enhancing higher gray-levels. Simulation results show that the proposed method yields better quality images in terms of Discrete Entropy value compared with other conventional methods.

Keywords: Clipping, dynamic range expansion, gray-level allocation, histogram equalization, partitioning the histogram

INTRODUCTION

Due to portability and easy implementation, a digital camera has become an additional multi-purpose function embedded in cell phone by many manufacturers. However the quality of the image which is captured in cell phone cameras is usually poor as a result of low contrast. In either case, the image captured produces annoying artifacts as a result of low contrast.

For contrast enhancement, Histogram Equalization (HE) is a simple and widely utilized method in literature. The fundamental idea of HE is to remap the intensity values of the input image into new intensity levels through a transform function created from Cumulative Density Function (CDF). Although this method is capable to increase the contrast of an image, the enhanced image tends to have unnatural enhancement and intensity saturation artifacts, due to the error in brightness mean-shifting:

$$P[r_k] = n_k/n, \qquad \text{for } k = 0 \text{ to } L-1 \qquad (1)$$

$$C(X) = \sum \{P(X_j)\} \qquad (2)$$

where, x_j = X, for j = 0, l ..., L – 1

In order to overcome the limitations of HE, several brightness preserving methods have been proposed. Generally, these enhancement methods can be classified into two categories-Partitioned Histogram Equalization (PHE) or Dynamic Partitioned Histogram Equalization (DPHE). The PHE and DPHE utilize histogram statistical information to separate the original histogram into several sub-histograms.

One of the popular PHE-based methods is the '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. Then, HE is implemented independently in each sub-histogram. Consequently, the mean brightness can be preserved because the original mean brightness is retained.

A bi-histogram equalization method has also been proposed by Wan *et al*. (1999), called the 'Dualistic Sub-Image Histogram Equalization' (DSIHE). 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. Wan *et al*. (1999) claimed that, the enhanced image preserves the mean brightness and entropy of the input image.

The methods discussed above 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 in Fig. 1, where X_m is the mean of input image and L is the number of gray levels (L = 256 for an 8-bit image). In low

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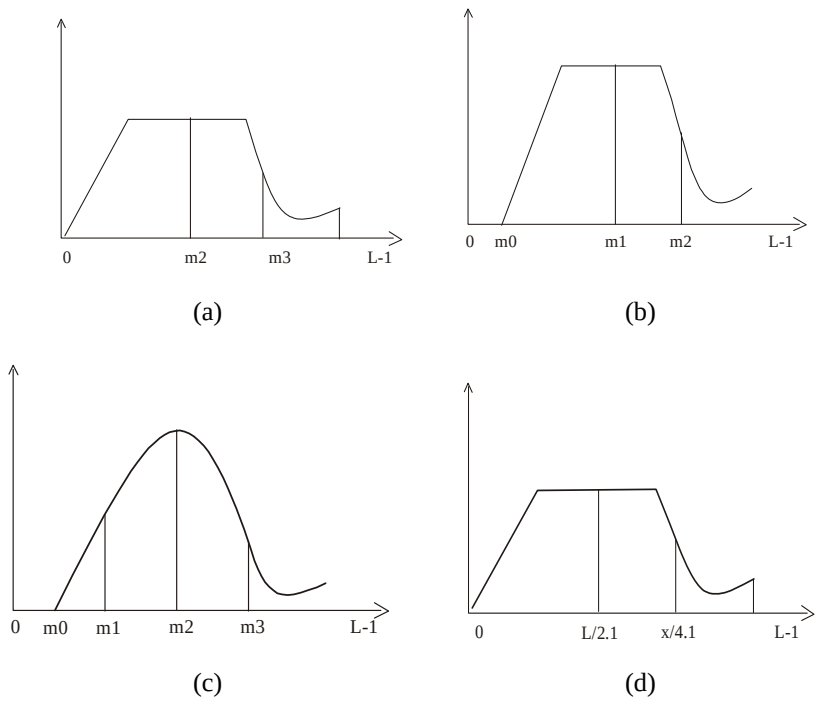


Fig. 1: Process of MDHE, (a) histogram plot, (b) plot after clipping, (c) plot for expanding dynamic range, (d) histogram plot for MDHE

contrast image, most of the PHE-based methods can preserve the mean brightness of the image but fail to emphasize on the image details due to the non-expandable side sub-histogram. For DPHE, there are only two methods existing in literature.

EXISTING METHODOLOGY

Quadrants dynamic histogram equalization: The Quadrants Dynamic Histogram Equalization (QDHE), proposed by Chen and Ramli (2003 a, b). In QDHE, the following processes are carried out for enhancing the image, they are:

- Histogram partitioning
- Clipping process
- New dynamic range allocation
- New gray-level allocation
- Histogram equalization

By means of median partitioning is done here, the QDHE partitions the original histogram into 4 sub-histograms. All quadrants have equal size. Clipping process is done using Self-Adaptive Plateau Histogram Equalization (SAPHE) method. Then, a new dynamic range is assigned to each sub-histogram based on the number of pixels in that sub-histogram. Finally new gray level is allocated using starting and ending point computed by the dynamic range. Then Histogram Equalization (HE) is carried out by means of Cumulative Density Function (CDF) for the number of pixels in that image.

Generally, the QDHE does not consider the mean brightness preservation. Thus, the DHE based method may cause saturation and it is insufficient to smooth a noisy histogram. The advantage of this method is that it controls the enhancement rate by clipping process and at the same time it clips out the pixels in lowest gray-levels. As a result, the image quality is poorer in this region.

Due to partition in lower levels, the enhancement is restricted to the corresponding dynamic range. Because of this, the lower gray level enhancement is very less compared with GHE. The finest details of the image are not well-preserved, while the picture is taken in a low light environment. But this problem never occurs in higher gray level. Because the number of pixels in higher gray level is very less and also the enhancement made by QDHE is sufficient compared with conventional methods. But the pixels nearer to the black look brighter. In the QDHE method, the pixels nearer to white is enhanced very smoothly because it uses clipping process to control the enhancement rate

Proposed method: It should be mentioned that the scope of this study focuses on enhancement of images obtained low illumination environment. The proposed method

overcomes the narrow non-expandable side sub-histogram of an ill-illuminated image histogram as presented. In GHE, the pixels nearer to the white are over-enhanced. Therefore, the proposed method is a DPHE based method, named Modified Dynamic Histogram Equalization (MDHE), which uses the advantages of both GHE & QDHE, to give a better quality image with good resolution.

The process of MDHE is as follows-the original histogram is divided into several sub-histograms based on the median brightness of the input image as the separating points. Clipping process is carried out to control the enhancement rate. Then, a new dynamic range is assigned to each sub-histogram. Finally, the HE approach is applied independently on each sub-histogram.

Modified Dynamic Histogram Equalization for image enhancement (MDHE): In this section, we discuss the algorithmic construction of the proposed MDHE method in great details. The MDHE consists of four processes, namely the histogram partitioning, clipping, gray level range allocation and histogram equalization.

Histogram partitioning: Therefore, the MDHE utilizes the median intensity value of the input image histogram in partitioning the histogram. Initially, the histogram of the original image is divided into two sub-histograms. Similarly, the median of the 2nd sub-histogram is used as separating point to further divide the sub-histogram into two smaller sub-histograms each. Thus, there are total of three sub-histograms obtained. Then, the minimum and maximum intensity values of the input histogram are set as the separating points. The median-based partition approach tends to segment the number of pixels equally in each sub-histogram. Hence, each separating point can be calculated using the following equations:

$$m_1 = 0.5 * \{I_{width} * I_{height}\} \quad (3)$$

$$m_2 = 0.75 * \{I_{width} * I_{height}\} \quad (4)$$

Clipping process: The reason behind the clipping process is to control the enhancement rate of histogram equalization in order to overcome unnatural and over-enhancement of the processed image to occur. The median value of the non-empty bins is set as the clipping threshold, *Tc*. However, in order to reduce the computational complexity, T_c is replaced by the average of the number of intensity in the proposed MDHE. The bins with higher value than the threshold value are replaced by the threshold value itself as shown in Fig. 1b.

New gray-level allocation: In order to balance the enhancement space for each sub-histogram, the proposed MDHE allocates a new gray level dynamic range based

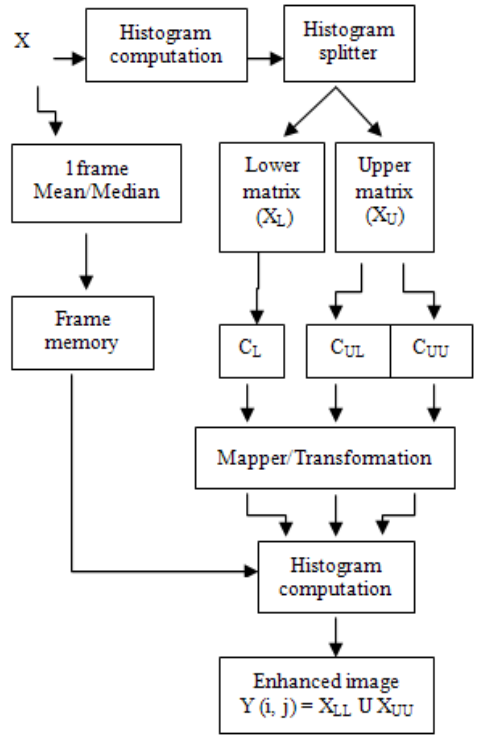


Fig. 2: Block diagram

on the ratio of gray level spans and total number of pixels for each sub-histogram. This concept is also adopted by the DHE. Mathematically, this process is described as follows:

$$\text{Span}_i = m_{i+1} - m_i \qquad \text{for } i = 1:3 \quad (5)$$

$$\text{Range}_i = (L-1)*\text{span}_i / \sum_k span_k \quad \text{for } K = 1:3 \quad (6)$$

where, $span_i$ is the dynamic gray level used by i^{th} sub-histogram in the input image. *Mi* is the ith separating point; M_i is the total number of pixels in ith sub-histogram. $Range_i$ is given as the dynamic level range for i^{th} sub-histogram in the output image. In the ith sub-histogram the new dynamic range is allocated from $[i_{start}\ i_{end}]$ defined by (7) and (8), respectively.

Block diagram (Fig. 2):

New dynamic range allocation: The new dynamic range is allocated by assigning new starting and ending point values by using these equations. Here 'i' denotes the corresponding i^{th} sub-histogram, for this case the value of i varies from 1 to 3.

The first i_{start} value is initialized to the minimum intensity value of the new dynamic range:

$$i_{start} = (i-1)_{end}+1 \quad (7)$$

$$i_{end} = i_{start} + range_i \quad (8)$$

Histogram equalization: After the new dynamic ranges have been determined for all the quadrant sub-histograms, the final step in the MDHE is to equalize each sub-histogram independently. If the *i*-th histogram is allocated at gray level from [i_{start} i_{end}], then the output of histogram equalization, *y (x)* of this partition can be determined by using the transfer mapping function in Eq. (9):

$$Y(x) = [(i_{start} - i_{end}) * CDF\ (X_K)] + i_{start} \quad (9)$$

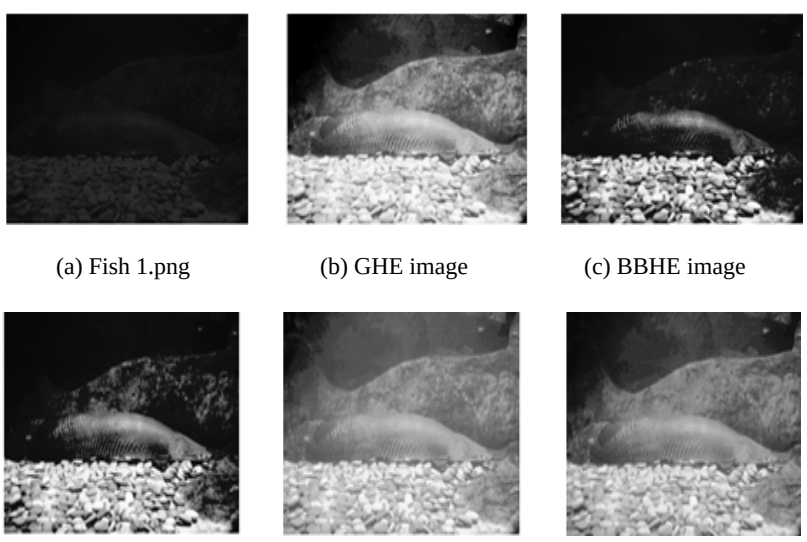
for k = 1, 2 and 3

where, $CDF\ (X_k)$ is the cumulative density function of a sub-histogram. In a general GHE equation is used. But i_{start} and i_{end} are used instead of the minimum and maximum intensities in the output dynamic range.

(a) Original image (b) GHE image (c) BBHE image

(a) DSIHE image (b) QDHE image (c) MDHE image

Fig. 3: Enhanced images for various histogram equalization techniques for 'Genting.png' of size 247 X 300 (a) original image, (b) GHE image, (c) BBHE image, (d) DSIHE image, (e) QDHE image, (f) MDHE image



(a) Fish 1.png (b) GHE image (c) BBHE image

(d) DSIHE image (e) QDHE image (f) MDHE image

Fig. 4: Enhanced images for various histogram equalization techniques for 'Fish 1.png' of size 300X220, (a) original image, (b) GHE image, (c) BBHE image, (d) DSIHE image, (e) QDHE image, (f) MDHE image

(a) Fish 1.png

(b) GHE image

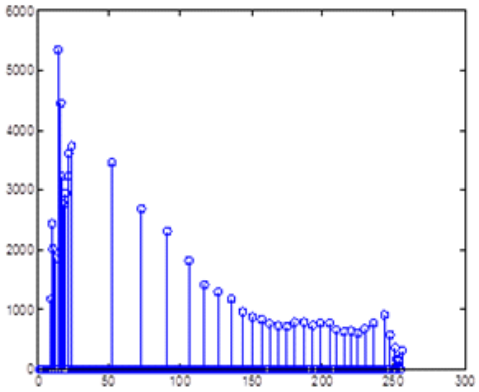
(c) BBHE image

(d) DSIHE image

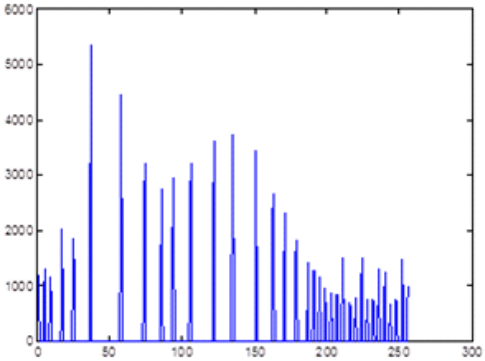
(e) QDHE image

(f) MDHE image

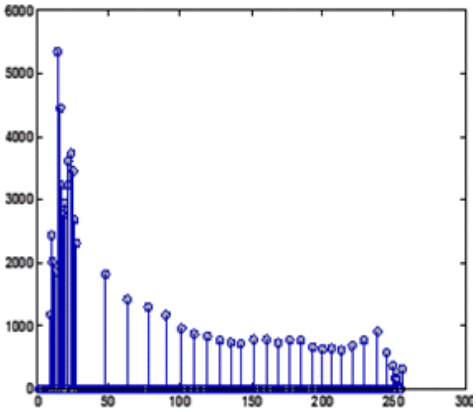
Fig. 5: Enhanced images for various histogram equalization techniques for 'Fish 2.png' of size 331X258, (a) original image, (b) GHE image, (c) BBHE image, (d) DSIHE image, (e) QDHE image, (f) MDHE image



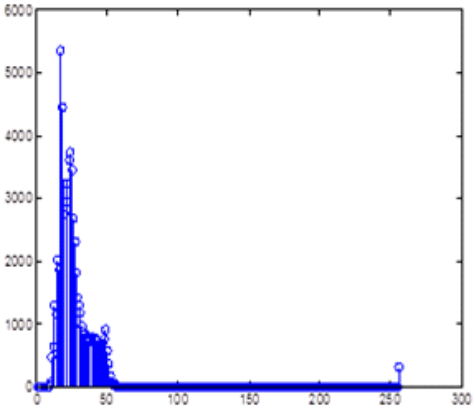
(a) Fish 1.png plot



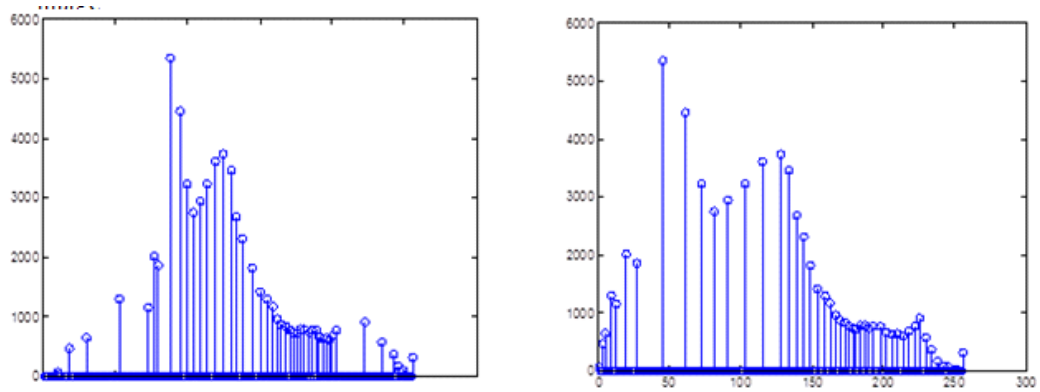
(b) GHE plot



(c) BBHE plot



(d) DSIHE plot



(e) QDHE plot (f) MDHE plot

Fig. 6: Histogram Plots for various techniques of "Fish1.png" of size 300X220, (a) original image, (b) GHE image, (c) BBHE image, (d) DSIHE image, (e) QDHE image

RESULTS AND DISCUSSION

This method is proposed to enhance the contrast of the image which is taken in dim-light environment. The proposed method eliminates over-enhancement, noise amplification and intensity saturation problems occurring in GHE method and also produces better enhancement for smaller gray levels unlike in QDHE.

The enhanced images for GHE, BBHE, DSIHE, DHE, QDHE and MDHE are shown in Fig. 3, 4 and 5. In Fig. 6, histogram plots for various techniques are shown. The enhanced images of different methods are compared in terms of the discrete Entropy as in Table 1 and 2 shows the average execution time of the different methods. In order to visualize the detail preserving capability, we show the histogram of simulated results for the 'Fish 2' image in Fig. 6. The histograms of resultant 'Fish 2' images after applying with those methods are illustrated in Fig. 5.

Based on Fig. 3b, 4b and 5b, the conventional HE is able to successfully enhance the contrast of those images. However, it also amplifies the noise level of the images. Moreover, the tendency for the conventional HE to produce intensity saturation is very high. It can be seen at the small stones with bright intensity in Fig. 3b, 4b and 5b. This is proven in Fig. 6b as the HE-ed histogram is concentrated on the right side of the histogram. For the BBHE and DSIHE methods, the contrast of the images are improved, but the problem of intensity saturation occurs in some regions of the image as well. This problem can be clearly demonstrated on the 'Genting.jpg' in Fig. 3c and d; the background of the 'Fish 1' image in Fig. 4c and d; and the fish body of the 'Fish 2' image in Fig. 5c and d.

From the experimental results, the drawback of these four methods is obviously seen by only preserving the mean brightness of the images without emphasizing on the image details significantly. The image histograms of the BBHE, DSIHE, QDHE and MDHE methods in Fig. 6c, d, e and f are shown, respectively.

Table 1: Comparison of discrete entropy values for various he techniques in terms of bits

Technique	Genting.png in bits	Fish.png in bits	Fish2. png in bits
Original	5.6151	5.0365	4.4824
GHE	5.1369	4.7330	4.3989
BBHE	5.1236	4.6025	4.3888
DSIHE	5.1000	4.7030	4.4766
QDHE	5.5812	4.8551	4.4699
MDHE	5.6006	4.9002	4.4823

Table 2: Comparison of Avg. execution time for various he techniques

Technique	Avg. execution time in sec
HE	7.1148
BBHE	7.5907
DSIHE	6.9918
DHE	9.0832
QDHE	5.1212
MDHE	7.3114

Obviously, it shows that the sub-histogram at the left side in each histogram is not successfully expanded. But in MDHE, the non-expandable region is expanded as much as possible.

Among the implemented state-of the-art methods, in term of enhancing the contrast as well as preserving the image details, the DHE outperforms other conventional methods. However, the QDHE tends to produce noise artifacts on the images (i.e., as shown on the sky region of the "Genting.jpg" image and the background of 'Fish 2' in Fig. 4e and intensity saturation (i.e., as shown on small bright stone regions of the Fig. 5e. Moreover, the

evidence of the intensity saturation problem is clearly shown in Fig. 3e, where the QDHE method only stretches the intensity range of the 'Fish 2' image with high pixels distribution, while intensity range with low pixels distribution is suppressed from Fig. 4e and 5e.

Furthermore, the MDHE method yields best performance and it has be seen, for examples, at the faces of the people in Fig. 3f, the background and the fish body of the Fig. 5f and white stone regions of the Fig. 4f. The problems of intensity saturation, noise amplification and over-enhancement are avoided. The contrast for all tested images is successfully enhanced; thus, producing better and clearer images.

Discrete entropy value: In order to demonstrate the capability of proposed method in extracting the details from the images, discrete entropy is taken as the quantitative evaluation. The discrete entropy E (x) is defined as:

$$E(X) = P(X_k) * \sum_k \left(\log_2\left[P\left\{X_k\right\}\right]\right) (\log_2[P\{X_k\}] \quad (10)$$

where, $P(X_k)$ is the normalized probability of the kth gray level. Higher value of the entropy indicates that more information is brought out from the images. The discrete entropy values computed for the methods implemented are tabulated in terms of bits in Table 1.

Average execution time: This study further analyses the capability of the tested techniques based on execution time. Table 2 shows the average execution time of sample images. Overall, the MDHE is ranked third after the HE and the BBHE methods in terms of execution time speed. In addition, the proposed MDHE method needs shorter execution time computation compared to the DHE and the BPDHE. This shows that the proposed MDHE has less complexity than the DHE and the BPDHE method.

Furthermore, previous subjective analysis has also favored the MDHE by producing better processed images than QDHE and GHE.

CONCLUSION

This proposed method utilizes the advantages of both Global Histogram Equalization (GHE) and Quadrants Dynamic Histogram Equalization (QDHE). It enhances the lower sub-histogram based on GHE approach to give high enhancement rate because the fine details of the image lie in this sub-histogram. Also it utilizes QDHE approach to avoid intensity saturation at higher gray levels. So it is the best suitable method for enhancing the digital images which is captured in low-light environment. The discrete entropy value obtained by MDHE is very close to the original image entropy value. It utilizes less execution time for enhancing the image than conventional methods.

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