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Review of Histogram Separation Based Contrast Enhancement Methods

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Abstract: **Histogram equalization is a well known contrast enhancement technique. A number of techniques have been introduced based on histogram equalization to overcome its drawbacks. Many of these are able to produce a satisfactory result for a wide variety of images. The goal of this paper is to provide a systematic review of contrast enhancement methods based on histogram separation and compares their results using using image quality measures such as AMBE, entropy, PSNR and Tenengrad values.**

1. INTRODUCTION

The goal of the image enhancement algorithms rises from the fact that many captured images can be of low quality because of poor contrast. In many forms of imaging devices, the quality of images and videos is often affected by a variety of factors including distortion and noise produced by the imaging device, lack of experience in taking images/videos by the operator, and adverse environmental conditions, such as unfavourable illumination. As a result, the captured images or videos may not reveal sufficient details of the true scene and, even worse, may contain artifacts such as washed-outs and unnatural appearances. In these cases, contrast enhancement techniques are useful to produce more visually pleasing and informative images.

A number of contrast enhancement methods has been introduced till date. These techniques are commonly referred to as Direct and Indirect methods of contrast enhancement. Most methods in the literature belong to second category. These techniques modify the image through some pixel mapping such that the histogram of the processed image is more spread than that of the original image. Further, the techniques in this subgroup can categorized as global and local contrast enhancement techniques. Global contrast enhancement techniques are simple and powerful but cannot adapt to the local brightness features of the input image because these techniques use only global information collected over the entire image. Local contrast enhancement techniques adjust picture element i.e. pixel values are over smaller regions of an image to improve the visualization of structures in both the darkest and the lightest portions of the image at the same time. Histogram Equalization is a well known and widely used contrast enhancement technique. The focus of this research work is to implement HE, CLAHE, BBHE, DSIHE, RMSHE and QDHE and compare their results using quality measures discussed in the section IV of this paper.

2. HISTOGRAM EQUALIZATION TECHNIQUES

Histogram Equalization (HE) [1]: It is a very popular method for contrast enhancement. This approach is generally useful for images with poor intensity distribution. It stretches the dynamic range of the image's histogram and results in overall contrast improvement. This technique is a fully automatic technique and don't require any parameters to be adjusted for enhancement and is suitable for monotonic and non linear illumination.

Steps of the algorithm:

a) Obtain the histogram of the input image such that X=X{(i, j)} contains L discrete gray levels denoted as $\{X_0, X_1, X_2, \ldots, X_{L-1}\}$ where each X(i, j) represents an intensity of the image at spatial location (i, j) and each X(i, j) $\in \{X_0, X_1, X_2, \ldots, X_{L-1}\}$. Suppose $H(X)=\{n_0, n_1, n_2, \ldots, n_k, \ldots, n_{L-1}\}$ be the histogram of the image X where n_k is the number of pixels whose gray level is X_k.

b) For the given input image, the probability density function(PDF) $p(X_k)$ is for each gray level intensity is defined for each each gray level k

$$p(X_k) = n_k / N \quad \text{for } k=0, 1, 2, \ldots, L-1$$

c) Here n_k is the number of times gray level X_k appears in the input image and N is total number of pixels in the input image and is calculated as $N= n_0+n_1+n_2+\ldots+n_{L-1}$.

d) Based on this PDF, the cumulative density function(CDF) is defined as:

$$c(k) = \sum_{j=0}^{k} p(j)$$

for k=0, 1, 2, …, L-1

e) Based on the CDF, histogram equalization now maps input gray level X_k into output gray level using level transformation function denoted as f(k) and is defined as

$f(k)=X_0+(X_{L-1}-X_0).c(k)$

The output image Y={Y(i, j)} of the histogram equalization is expressed as Y=f(X)={f(X(i, j) | for each X(i, j) Є X}

Though HE is simplest and effective technique but it does not preserve the brightness of the input image and has drawback over enhancement which gives unnatural look and makes it unsuitable for many applications.

Contrast Limited Adaptive Histogram Equalization: The difference between ordinary adaptive methods and contrast limited adaptive histogram equalization (CLAHE) [3], [4] is its contrast limiting. The aim of CLAHE is to get an image with uniformly distributed intensity levels over the whole intensity scale. This adaptive method was introduced to overcome the drawback of noise amplification. CLAHE limits the amplification by clipping the histogram at a predefined value before computing the CDF. This limits the slope of the CDF and therefore of the transformation function. The value at which the histogram is clipped, known as clip limit, depends on the normalization of the histogram and thereby on the size of the neighbourhood region. Steps of the algorithm:

a) Obtain all the inputs: Image, Number of regions in row and column directions, Number of bins for the histograms used in building image transform function (dynamic range), Clip limit for contrast limiting (normalized from 0 to 1).

b) Pre process the limits: Determine real clip limit from the normalized value if necessary, pad the image before splitting it into regions.

c) Process each contextual region (tile) thus producing gray level mappings: Extract a single image region, make a histogram for this region using the specified number of bins, clip the histogram using clip limit, create a mapping (transformation function) for this region.

d) Interpolate gray level mappings in order to assemble final CLAHE image: Extract cluster of four neighbouring mapping functions, process image region partly overlapping each of the mapping tiles, extract a single pixel, apply four mappings to that pixel, and interpolate between the results to obtain the output pixel; repeat over the entire image.

Brightness Preserving Bi Histogram Equalization [2]

Histogram equalization changes the brightness of the image to a considerable level which is very undesirable for consumer electronics. BBHE technique was introduced based on the assumption that Histogram Equalization do not consider the mean brightness of the image which leads to aforesaid drawbacks. Therefore, BBHE makes use of the mean brightness of the image.

Based on the mean called threshold value it decomposes the input image into two sub images and perform equalization on the both images independently. Since, two sub images are bounded to each other around the input mean, therefore mean brightness is preserved. Steps of the algorithm:

a) Obtain the histogram of the input image such that X=X{(i, j)} contains L discrete gray levels denoted as $\{X_0, X_1, X_2, \ldots, X_{L-1}\}$ where each X(i, j) represents an intensity of the image at spatial location (i, j) and each X(i, j) Є $\{X_0, X_1, X_2, \ldots, X_{L-1}\}$. Suppose H(X) =$\{n_0, n_1, n_2, \ldots, n_k, \ldots, n_{L-1}\}$ where n_k is the number of pixels whose gray level is X_k.

b) Divide the input image into two sub images X_L and X_U based on the mean intensity value X_m called threshold value using its histogram such that $X_L= \{X_0, X_1 \ldots X_m\}$ and $X_U= \{X_{m+1}, X_{m+2} \ldots X_{L-1}\}$ for each X(i, j) Є X.

$X= X_L$ Ǔ X_U

c) For the two sub images define two probability density functions $p_L(X_k)$ and $p_U(X_k)$,)

d) Based on these PDFs, respective cumulative density functions(CDF), $c_L(X_k)$ and $c_U(X_k)$ is defined as

e) Based on these CDFs, like HE transformation functions are defined denoted as $f_L(X_k)$ and $f_U(X_k)$.

The output image of the histogram equalization is expressed as

$$Y = \{Y(i,j)\} = f_L(X_L) \cup f_U(X_U)$$
$$f_L(X_L) = \{f_L(X(i,j)) \text{ for each } X(i,j) \in X_L\} \text{ and}$$
$$f_U(X_U) = \{f_U(X(i,j)) \text{ for each } X(i,j) \in X_U\}$$
$$X = X_L \cup X_U$$

This technique uses cumulative density function is as a transform function as a transfer function and XL and XU are equalized independently.

Though HE is simplest and effective technique but it does not preserve the brightness of the input image and has drawback over enhancement which gives unnatural look and makes it unsuitable for many applications.

Dualistic Sub Image Histogram Equalization[5]
This method focused on the maximization of Shanon's Entropy to find the threshold value in order to divide the image into two sub images. It has been proved mathematically that segmentation entropy achieved maximum value only when two sub images had equal area and contain same amount of pixels giving one dark image and a bright image respecting the equal area property. Then the two images are equalized respectively.

The main advantage of this algorithm was that besides enhancing an image effectively it preserved the original image luminance from shifting. This can be proven by the fact that the luminance of the processed image using equal area DSIHE is the average of the segmentation gray level and the middle gray level of the image's gray scale range. Respecting to the equal area property two sub images obtained after segmentation remain in two segmented gray level scales respectively after equalization Therefore, it is sure that original image could be kept from significant shift.

Recursive Mean Separation Histogram Equalization[6]
This method is an extension to BHE. This method uses a recursive way to decompose the input image into sub images in such a way that a scale r is achieved and number of sub images generated from the procedure is 2r.After that each sub image is enhanced independently using classical histogram equalization.

a) When r=0, no decomposition occurs and the equalization is completely like GHE.

b) When r=1, X is divided into two sub images X_L and X_U based on the mean value of input image X_m.

c) When r=2, X is divided into four sub X_{LL}, X_{LU}, X_{UL}, X_{UU} images by using X_{ML} and X_{MU} as the mean values of X_L and X_U respectively.

d) When r=n, X is divided into 2^n sub images by considering the mean values of the sub images.

The recursive level of RMSHE is defined by $S=2^r$, where S is the number of sub images and r is the recursive level.

Probability density functions and cumulative density functions are defined like BBHE for each sub image.

Classical histogram equalization is performed on all the sub images independently using the transformation functions.

As the recursion level grows the output mean eventually converge to input mean. Therefore, the degree of brightness preservation ranges from minimum to the maximum as the recursion level grows. So, this algorithm is very suitable for consumer electronics where the types of images are difficult to tackle by one specific level of brightness preservation.

Quadrants Dynamic Histogram Equalization[7]
This algorithm involves four major steps such as histogram partitioning, clipping, allocation of new gray level range, histogram equalization.

Histogram Partitioning: QDHE separates the input image histogram based on median intensity value into two sub histograms. These two sub histograms are further subdivided into two based on their respective median intensity values generating four sub histograms. Each separating intensity can be calculated using the following equations:

$$m1 = 0.25 \times \{I_{width} \times I_{height}\}$$

$$m2 = 0.50 \times \{I_{width} \times I_{height}\}$$

$$m3 = 0.75 \times \{I_{width} \times I_{height}\}$$

Clipping: QDHE uses average of the number of pixels as a threshold values for clipping, in order to control the level of enhancement controls the over enhancement. The method decides the threshold value based on modified- SAPHE. The bins with higher value than the threshold were replaced by the threshold value itself.

New Gray Level Allocation Range: This step is performed to balance the enhancement space for each sub histogram. QDHE allocates a new gray level dynamic range based on the ratio of gray level spans and total number of pixels for each sub histogram as given below

$$: range_i = (L-1) \times span_i \div \sum_{k=1}^{4} span_k$$

In the i-th sub histogram the dynamic range is allocated from $[i_{start}, i_{end}]$ defined by following equations:

$i_{start} = (i-1)_{end}+1$
$i_{end} = i_{start}+range_i$

Histogram Equalization: After allocation of new dynamic range for each sub histogram, equalization of each sub histogram is performed independently using cumulative distribution function using istart and iend instead of minimum and maximum intensities in the output dynamic range.

3. RESULTS AND ANALYSIS

For comparative analysis, a number of test images (.jpg format) are selected, and results are obtained with individual codes of these techniques using MATLAB R 2010a. Among a number of test images selected, results of two test image's X-ray Luggage and car are presented in Figure 1 which show original images with their enhanced versions along with their histograms.

Table 1: Absolute Mean Brightness Error

Images	airphoto	Car	X-Ray Luggage 1	alcos_photo	office
HE	7	15	24	24	70
CLAHE	3	1	1	17	40
BBHE	7	20	27	15	33
DSIHE	0	13	33	14	33
RMSHE (r=2)	2	2	8	2	2
QDHE	13	42	6	65	57

The histogram of the original image is narrow and occupies less dynamic intensity range. On the other, histograms of the enhanced images are disturbed uniformly over the dynamic range of intensity scale which in turn improves the contrast revealing a lot more details as compared to original image. Images in Figure1(b) show that conventional HE can successfully enhance the contrast of an image but it amplifies the noise level of the image which is clearly visible in the HE-ed car iamge .Moreover, the conventional HE tends to produce intensity saturation, and it is clearly visible from HE-ed images. Background of HE- ed car image shows that beside amplification of noise image, there is lose of details of the tree and house in the background. It is evident from the histograms of these images as the histograms of the original images are concentrated towards the centre while their equalized histograms occupy full scale range and don't preserve the mean brightness level. Among the implemented methods CLAHE outperforms other conventional methods. For all the test images CLAHE uniformly distributes the image histograms while preserving the mean brightness. Due to the contrast limiting property of CLAHE, there is no amplification of noise signal. it is evident from the results of all the test images that CLAHE has overcame almost all the drawbacks of histogram equalization and their corresponding histograms show that image pixels has occupied a full scale range with a limit on the highest intensity of contrast.

BBHE and DSIHE show almost similar results for all the test images. These methods significantly improve the contrast of the image and preserve the mean brightness. But the problem of intensity saturation occurs. The degree of over enhancement is less because of the brightness preservation property of the BBHE and DSIHE. RMSHE is unable to perform satisfactorily on all the types of low contrast test images. The histograms also equalized slightly but are concentrated on the narrow range of the intensity scale. From the results it is evident that RMSHE is unable to enhance the contrast effectively and interpret details of the test images as compared to other methods. There is a problem of intensity saturation also. Histograms equalized using RMSHE are also not expanded successfully though they are equalized slightly. QDHE has performed quite well for almost all the types of images. It has effectively enhanced the contrast of the image and preserved the details of the images. From images in 1(g) it is clear that QDHE-ed histograms are disturbed evenly than other methods. All the intensity ranges are successfully stretched besides preserving the details in all the intensity levels. Image details are clearly visible in almost all the images but for certain type of images there was a problem of intensity saturation and the histogram of the image was also densely concentrated towards the bright side.

Table 2: Entropy

Images	Airphoto	Car	X-Ray Luggage 1	alcos_photo	Office
Original	7.102	4.794	6.498	6.495	6.837
HE	5.974	4.584	5.229	5.945	5.906
CLAHE	7.906	6.518	7.257	7.524	7.696
BBHE	6.965	4.782	6.234	6.387	6.708
DSIHE	6.957	4.782	6.253	6.389	6.707
RMSHE	6.941	4.498	6.226	6.301	6.672
QDHE	7.047	4.791	6.257	6.473	6.829

Table 3: Peak Signal to Noise Ratio

Images	Airphoto	Car	X-Ray Luggage1	Alcos photo	office
HE	15.834	11.444	18.067	13.232	10.060
CLAHE	17.117	23.707	20.690	18.174	13.925
BBHE	16.551	11.721	16.834	13.778	13.409
DSIHE	16.335	11.789	16.076	13.825	13.337
RMSHE (r=2)	24.705	35.472	22.134	28.462	36.332
QDHE	20.120	13.021	24.136	11.014	11.617

For classical HE the overall comparison of AMBE, PSNR and TEN, points towards a poor performance of thie stechnique. As it is evident from the results that AMBE for DSIHE and CLAHE show least values of 0 and 1. So these methods show better brightness preservation as compared to HE, BBHE, RMSHE and QDHE methods. For CLAHE the average is minimum, so this technique has done the best brightness preservation. The PSNR value of car image, processed using CLAHE is largest, which shows that along with brightness preservation less significant noise level has been amplified. The values of AMBE are minimum for RMSHE, it is because histograms of the images using this technique are equalized very slightly, so a major shift has not occurred in the intensity values. Since AMBE is a measure of the difference between the original and enhanced image, so there has not occurred a major change. As signified by value of entropy there is a certain loss of information also. QDHE has given good qualitative results, but on the basis of quantitative metrics to certain extent it is able to preserve brightness. The entropy is a measure of information content present in an image. An image with higher entropy is regarded to have better quality. However images with lower entropy may show better contrast as compared to images with higher entropy values.

Table 4: Tenengrad Values

Images	airphoto	Car	X-Ray Luggage1	alcos_photo	office
Original ($\times 10^4$)	2.169	0.071	3.403	0.045	0.484
HE	9.074	5.628	4.433	0.496	2.303
CLAHE	9.020	7.683	6.390	0.425	2.490
BBHE	8.564	5.092	4.391	0.417	2.626
DSIHE	8.798	5.377	4.185	0.415	2.641
RMSHE	4.165	0.156	5.292	0.165	5.238
QDHE	5.469	1.974	5.026	0.362	2.000

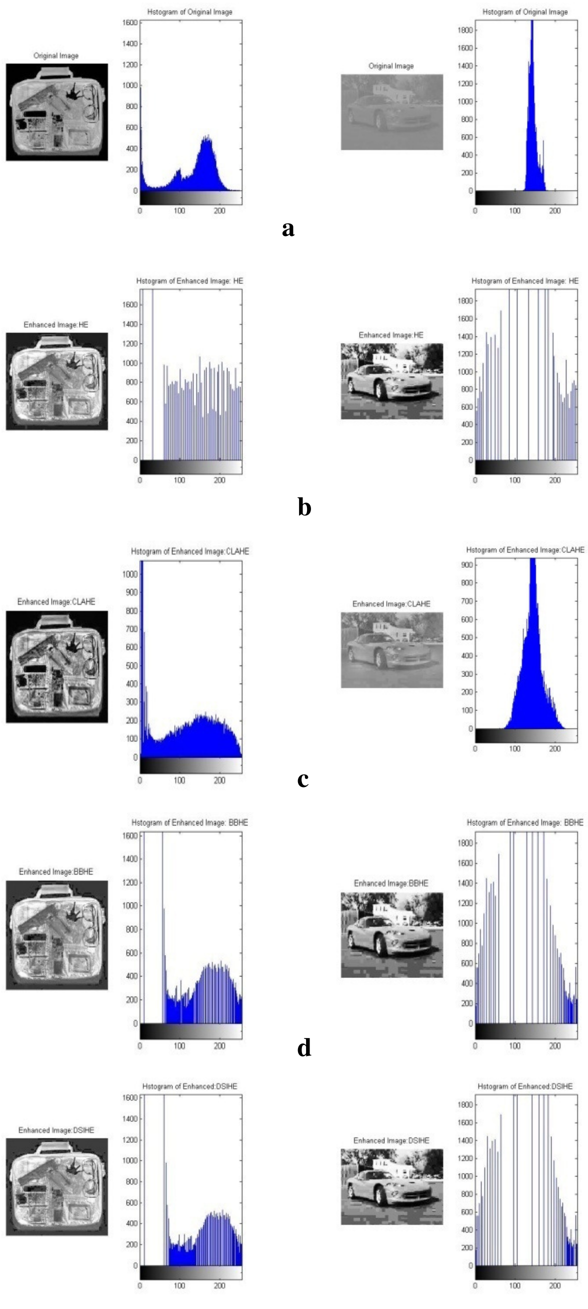
In the Table 2 the computed values of entropy of the original and enhanced images have been compared. For the results compiled here show that the CLAHE have highest value of entropy while the value has degraded than the original value for HE, BBHE, DSIHE, RMSHE and QDHE. For CLAHE the value has increased for all the test images than its original value. Therefore, CLAHE is better to preserve the information content. This degradation is highest for histogram equalization clarifying that classical histogram equalization looses a lot more details than other equalization techniques during the process of equalization. QDHE can be regarded as the second most effective technique for information preservation among all the techniques under consideration as the difference between the entropies of original and enhanced images is very less. BBHE and DSIHE show less loss of details while enhancing the contrast of the images than CLAHE and QDHE. Though RMSHE has performed poorly to enhance the contrast of test images but the loss of information is less as compared to HE, BBHE and DSIHE. However, it is possible that images with lower value of entropy may show better contrast. As illustrated by Soong-Der Chen [8], that entropy can never be increased by monotonic probability density function in its discrete form and HE tends to combine the gray levels of relatively low probability density which in turn results in lower entropy although this action considerably increases the image contrast.

The higher value of TEN indicates better quality of image. It is evident from results that there is a significant difference in the Tenengrad values of the original images and enhanced images. These values are highest for most of images enhanced using CLAHE. So these images possess better quality. Tenengrad values for BBHE and DSIHE are almost similar and images can be regarded as of good quality but for some images they amplified the noise levels. Though the HE-ed images can be regarded as of good quality images based on tenengrad value but we cannot ignore the problem of intensity saturation. As it is evident from the qualitative measures RMSHE has not performed good for almost all the images, similar analysis can be made from the TEN values. There is a quite less difference between the values of original and enhanced images as compared to other techniques. QDHE TEN values are more than RMSHE but less than all other techniques. This technique has given quite good performance based on both qualitative and qualitative analysis. The TEN values have significantly risen for HE, CLAHE, BBHE and DSIHE and QDHE. Though HE, CLAHE, BBHE and DSIHE are less immune to noise but for certain images these methods can generate images with high quality. Compareing average values of all the four measures it is evident that HE is contains highest average value of AMBE and lowest values for entropy and PSNR. This shows that it is poor to preserve mean brightness and information content and suppress the noise signal at the time of equalization. it is poor to preserve mean brightness and information content and suppress the noise signal at the time of equalization.

CLAHE can better preserve the brightness and information content and moreover it is immune to noise amplification also This is the only technique among all other techniques being compared for which the value of entropy has increased than the average value of original image. BBHE and DSIHE, both the techniques have performed better than HE but their noise amplification is almost similar to HE. The average value of AMBE is lowest for RMSHE which shows it has done better brightness preservation than other techniques but it has failed to enhance the contrast of the images. Average value of entropy for RMSHE is slightly more than HE but less than all other techniques and the average value of entropy of the original image, so it is clear that there is a loss of information also during equalization. The higher value of PSNR and TEN shows its capability of noise suppression and good image quality. QDHE has obtained higher average value of AMBE, which shows that it is poor to preserve the mean brightness but better than RMSHE to preserve information content, less immune to noise than RMSHE and CLAHE but more capable than HE, BBHE and RMSHE though can generate images of better quality.

4. CONCLUSION

From the results it has been analysed that local contrast enhancement techniques perform better than global techniques. Histogram equalization unable to preserve image details and amplifies noise level. CLAHE is a good technique produced good quality images that are able to preserve brightness of image and its details and suppress noise level. BBHE and DSIHE are able to preserve the brightness of the enhanced images but unable to eliminate the problem the intensity saturation though the degree of over enhancement is less than HE. RMSHE is unable to enhance the contrast of the image and there is a loss of information content also but performed well to suppress noise signal. QDHE is unable to preserve the mean brightness but based on qualitative analysis it has satisfactorily enhanced the contrast and preserved image details. The above analysis has been drawn from the visual quality of the images, their histograms and the values of quantitative evaluation.



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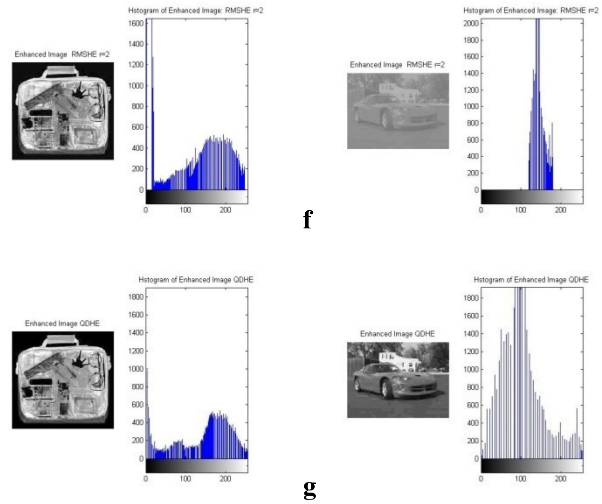

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Figure 1. XRayLagguage.jpg and car.jpg Image (a). Original Image (b) Histogram Equalization (c) Contrast Limited Adaptive Histogram Equalization (d) Brightness Preserving Bi- Histogram Equalization (e) Dualistic Sub Image Histogram Equalization (f) Recursive Mean Separated Histogram Equalization (g) Quadrants Dynamic Histogram Equalization

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