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A Comparative Analysis of Adaptive Contrast Enhancement Equalization Techniques

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Abstract - **Histogram equalization is a most widely used method for contrast enhancement. It is both effective and simple. But the standard histogram equalization many times results in change of brightness of the complete image. Many applications including consumer electronics can't afford this change in the original brightness of the image. To preserve the original brightness, new contrast enhancement schemes like bi-histogram equalization (BHE), recursive mean-separate histogram equalization (RM.SHE), clipped histogram equalization (CHE) and gain-controllable clipped histogram equalization (GC-CHE) are introduced [1]. These methods are analysed in this paper, along with existing standard histogram equalization method. The above mentioned schemes not only perform equalization but also preserve the original brightness of the image. The GC-CHE scheme uses controllable gain clipped histogram equalization which takes into account the mean brightness of the image to calculate clipping rate and the clipping threshold. The rate of clipping is controlled adaptively for contrast enhancement which preserves the mean brightness. It is found that under various conditions, the GC-CHE method performs better than the other equalization methods.**

Index Terms - bi-histogram equalization (BHE), recursive mean-separate histogram equalization (RMSHE), gain-controllable clipped histogram equalization (GC-CHE)

I. INTRODUCTION

Histogram equalization is very widely used which enhances the contrst of the image. It uniformly distributes the probability of intensity values. Hence, the dynamic range of original image is stretched, which in turn improves the contrast. Many areas like medical imaging, texture synthesis, defects analysis etc have been benefited by histogram equalization. Nowadays, video enhancement in digital broadcasting is also been done using histogram equalization.

Keeping aside the advantages, the histogram equalization changes the brightness of the image globally. Due to this, some important regions in the image get either under or over-saturated and important information gets lost. Hence, adaptive histogram equalization techniques have been proposed with the objectives as-

(a) The brightness of the original image should get preserved in the output image.

(b) The noise (artifacts) in the output image should be as low as possible.

(c) The contrast should get increased to an acceptable level i.e. the output image should have sufficiently high contrast compared to original image.

The first method known as bi-histogram equalization tries to overcome the drawback of standard HE method by dividing the histogram of origial image into two parts (based on the mean) and then equalizing them separately. Up to some extent this method preserves the brightness. Another method, based on this approach know as dualistic sub-image histogram equalization (DSHE) is been proposed by Wanet al. It uses median value instead of the image mean for separating the histogram. In other words, the threshold of separation is the median which produces equal number of pixels in each sub-histogram which are then equalized independently. DSHE is better than BHE in preserving the brightness of original image. Cumulative probability density of 0.5 in each of sub-histograms ensures maximum entropy in output image [2]. The degree of brightness preserved by BHE and DSHE is not high.

To achieve even higher degree of brightness preservation, Chen and Ramli introduced recursive mean-separate histogram equalization (RMSHE) [3]. This method performs BHE iteratively for *n* number of times. That is each sub-histogram is again subdivided into two sub-histograms for *n* times which produces 2^n sub-histograms. For large number of iterations, RMSHE achieves good brightness preservation. But, if the number of iterations is too large, the output image produced is exactly similar to input image. This condition is known as null processing. As a solution to avoid this as well as to preserve brightness without introducing additional noise, clipped histogram equalization (CHE) method is been proposed. In CHE, the maximum value of histogram is controlled by clipping it above the predefined threshold value. Degree of brightness preservation is very good in CHE but the degree of contrast enhancement is below average. Hence a modified CHE method, known as gain-controllable clipped histogram equalization (GC-CHE) is proposed by Taekyung Kim and Joonki Paik [4]. GC-CHE dynamically controls the clipping level and appropriately re-distributes dynamic range by locally regulating the clipping gain. It gives best result in terms of brightness preservation and noise minimization, compared to previously mentioned schemes.

II. LITERATURE REVIEW

This section summarizes all the equalization techniques which have been analyzed.

A. Standard Histogram Equalization:

Let r_k be in the range [0,L-1]. Then the probability density function (PDF) is defined as-

$$r_k = \frac{n_k}{k} \text{, for } k=0,1,..,L-1 \quad (1)$$

Where, r_k represents the k^{th} intensity level, n_k represents the number of times r_k has occurred and n represents total number of pixels in the image. Probability of intensity levels $P(r_k)$ is nothing but histogram of original image. The cumulative density function (CDF) can be defined as-

$$c(r_k) = \sum_{j=0}^{k} p(r_j) \text{, for } k=0,1,..,L-1 \quad (2)$$

HE maps the input image into another image having uniform histogram. For having uniform histogram, it uses CDF as the intensity transformation function given as-

$$T(r) = r_0 + r_{L-1} - r_0.C(r) \quad (3)$$

So, the output image resulting from SHE can be given as-

$$g(x,y) = T(f(x,y)) \quad (4)$$

Here, ‘f’ is the input image and ‘g’ is the equalized output image.

B. Bi-histogram Equalization:

This method divides the original histogram into two parts based on the mean of the image. Let ‘m’ be the mean of input image ‘f(x,y)’. Based on this mean, the original image is divided into two sub-images f1 & f2 as-

$$f = f_1 \cup f_2 \text{ and } f_1 \cap f_2 = \varnothing \text{ ;}$$

$$f(x,y) = f_1(x,y) + f_2(x,y)$$

$$f_1(x,y).f_2(x,y) = 0 \quad \text{for all (x,y)} \quad (5)$$

Where,

$$f_1(x,y) \in \{0,1,...,m-1\} \quad (6)$$

$$f_2(x,y) \in \{m, m+1,..., L-1\} \quad (7)$$

Now, as per the standard procedure, the histograms corresponding to each sub-image is calculated as-

$$f_1(r_k) = \frac{n_k^L}{n^L} \text{ for } k=0,1,..,m-1 \quad (8)$$

and

$$f_2(r_k) = \frac{n_k^U}{n^U} \text{ for } k=m,m+1,\dots,L-1 \quad (9)$$

Corresponding CDFs are given by-

$$c_1(r_k) = \sum_{j=0}^{k} P_1(r_j) \text{ and } c_2(r_k) = \sum_{j=m}^{k} P_2(r_j) \quad (10)$$

We will have two intensity transformation functions for BHE, defined as-

$$T_1(r) = r_0 + (r_{m-1} - r_0).c_1(r) \quad (11)$$

and

$$T_2(r) = r_m + (r_{L-1} - r_m).c_2(r) \quad (12)$$

According to these intensity transformation functions, sub-images are equalized independently to produce output image as-

$$g(x,y) = T_1(f_1(x,y)) + T_2(f_2(x,y)) \quad (13)$$

So, finally the input image gets equalized over the entire range [0,L-1].

C. Recursive Mean-Separate Histogram Equalization:

The BHE method preserves a certain level of brightness by decomposing the image into two sub-images. RMSHE performs this decomposition multiple times to achieve even higher degree of brightness preservation. In other words, RMSHE is nothing but BHE if number of recursion is one.

Consider that input image is decomposed into four parts based on the means of the two sub-histograms as-

$$m_1 = \frac{\int_0^m rp(r)dr}{\int_{X_0}^{X_m} p(r)dr} = 2\int_0^m rp(r)dr \quad (14)$$

and

$$m_2 = \frac{\int_m^{L-1} rp(r)dr}{\int_m^{L-1} p(r)dr} = 2\int_m^{L-1} rp(r)dr \quad (15)$$

Where, $$\int_0^m p(r)dr = \int_m^{L-1} p(r)dr = \frac{1}{2} \quad (16)$$

Since $f(x,y)$ has two identical distributions around m. The result of RMSHE with recursion level 2, can be given as-

$$g(x,y) = T_{LL}(f_{LL}(x,y)) + T_{LU}(f_{LU}(x,y)) + T_{UL}(f_{UL}(x,y)) + T_{UU}(f_{UU}(x,y)) \quad (17)$$

D. Clipped Histogram Equalization:

The CHE method is more effective than the previously discussed methods. It clips the histogram above the pre-specified threshold and redistributes the histogram as shown below-

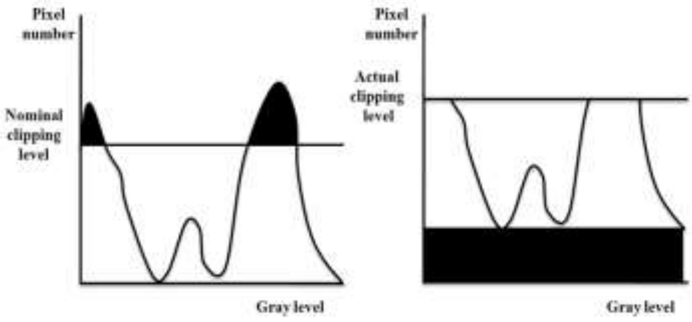

Fig.1. Histograms (a) before and (b) after CHE.

The CHE does a good job in preserving the brightness but the contrast of the output image is not up to the mark.

E. Gain-controllable Clipped Histogram Equalization:

Most of the contrast enhancement techniques suffer from noise amplification in the output image. Noise causes serious degradation in the quality of output image. GC-CHE is the most effective contrast enhancement technique which not only preserves the brightness but also keeps the noise content to the minimum extent. It controls both the clipping level and local gain to produce the best results.

E.1) Clipping Level Control

The GC-CHE method dynamically controls the clipping level and redistributes the dynamic range of the image with the help of local regulation of clipping gain. By computing the PDF and the CDF using Equations (18) and (19), contrast enhancement is achieved using Equation (20) with a proper clipping level C.

$$pdf[k] = \frac{1}{MN} \left\| \{i, j\} \mid f(i, j) = k \right\| \quad (18)$$

$$cdf[k] = \sum_{t=1}^{k} pdf(t) \quad (19)$$

and

$$g(i, j) = C.cdf[f(i, j)] \quad (20)$$

For solving the noise amplification problem in enhancing the contrast of a low light-level image, we adjust the contrast elevation ratio according to the input image and compensate contrast using the gain control method given in equations (21) and (22).

$$B_{cr} = \{k, if\_cdf[k] = 0.5\} \quad (21)$$

and

$$CR = 100 - B_{cr} * 0.4 \quad (22)$$

Where, B_{cr} represents mean brightness, *CR* represents the clipped-rate in the range of [0-100]. Fig.2 illustrates the proposed histogram re-distribution method, where T_{cr} represents 50% intensity of the histogram. In the dark region, the clipping ratio increases, and the slope of the CDF becomes linear so that the output is the same to the input intensity. The low and high local gains represent clipping levels of dark and bright regions, respectively.

After fixing the global gain, the global gain rate is adaptively controlled in the range [0-100]. If the rate is 100%, histogram equalization is applied on the global image without adjusting the local gain. With the given global gain, contrast enhancement is performed by controlling the local gain.

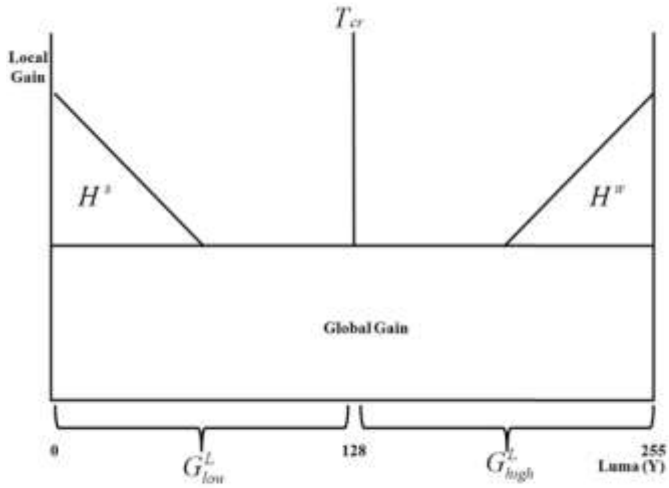

Fig.2. Histogram distribution using high and low clipping levels

E.2) Local Gain Control:

The black level region and the white level region are determined in the clipped histogram. The contrast correction in the black level region is different from that of the white level region over the entire image. Similarly, the local gain is divided into low and high parts as below.

The high and low local gains can be calculated as-

$$G^L_{low} = \frac{G^T - G^G}{2} \; \& \; G^L_{high} = \frac{G^T - G^G}{2} \quad (23)$$

where G^T, G^G, $G^L{}_{low}$, and $G^L{}_{high}$ respectively represent the total gain, the global gain, the first local gain, and the second local gain, respectively. G^T is the ratio of a clipped portion to the original brightness histogram. The distribution of global gain is uniform throughout the clipped histogram while the distribution of local gain is limited to a particular region of the clipped histogram. When the global gain is 100%, the local gain is 0%. That is a uniform gain is applied over the entire region without controlling the local gain, which is nothing but the CHE. When the clipping rate is 20%, total gain becomes 20. For 50% of the global gain, corresponding value will be 10. So the first and the second local gains will have a value of 5 (Equation (23)). After determining the global gain and the local gain, the clipped histogram is corrected by-

$$H^G = \tilde{P} + \frac{G^G}{k} \quad (24)$$

where k represents the total number of gray levels, H_G is the corrected histogram using the global gain, and P is the clipped histogram.
Black level correcton using the first local gain is done using-

$$H^B = P; if, k \geq k_B$$

$$H^B = \tilde{P} + \frac{2 \bullet G_{low}^L}{k_B^2}.k, otherwise \qquad (25)$$

where H_B represents the black-level corrected histogram and k_B represents the gray level of the black region. The histogram remains the same in the region which is brighter than k_B else it is corrected.
White level correction using the second local gain is done using-

$$H^W = P; if, k \geq k_W$$

$$H^W = \tilde{P} + \frac{2 \bullet G_{high}^L}{k_W^2}.k, otherwise \qquad (26)$$

where H_W represents the white-level corrected histogram and k_W the gray level of the white region. The histogram remains the same in the region which is brighter than k_W else it is corrected.

III. Result And Discussion

The low contrast image (Fig.3) is taken as a reference input image. The output images are obtained by using SHE, BHE, RMSHE, CHE and GC-CHE are as shown in Fig.4, 5, 6, 7 & 8 respectively. The simulation is done using MATLAB.

It is seen that the SHE enhances the contrast but the brightness reproduction in the output image is very poor. The BHE produces good brightness but RMSHE performs better than BHE in terms of brightness preservation. But both the methods introduce some noise in the output image. CHE does very well in minimizing the noise and preserving the brightness but at the cost of poor contrast enhancement. Amongst all the above, GC-CHE produces very good result. It not only preserves the brightness but also enhances contrast keeping the noise level as low as possible.

Fig.3. Input Image

Fig.4. Output of SHE

Fig.5. Output of BHE

Fig.6. Output of RMSHE

Fig.7. Output of CHE

Fig.8. Output of GC-CHE

IV. Conclusion

The experimental results show that adaptive equalization methods like BHE, RMSHE, CHE performs better than SHE by preserving the brightness of input images. The GC-CHE method was found to perform better by enhancing the image without introducing undesirable artefacts or noise. Also, it is a simple and effective method which can be easily implemented in a real-time environment using system-on-chip which can open many areas of application.

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