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An Adaptive Contrast Enhancement Algorithm with Details Preserving

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***Abstract*—This paper presents an adaptive contrast enhancement algorithm with details preserving (ACEDP) to enhance gray-scale image. Initially, the input image is classified into low-, middle- or high-level image based on the gray-level distribution of maximum number of pixels. The proposed ACEDP algorithm assigns different plateau functions for different type of image and histogram clipping is then performed followed by histogram equalization. Simulation results show that the proposed technique outperforms several techniques in literature. It demonstrates good ability in contrast enhancement as well as details preservation.**

***Keywords*—Image contrast enhancement; histogram clipping; details preserving**

I. INTRODUCTION

Image contrast enhancement with details preservation plays an important role in many fields including medical field, remote sensing, military and agriculture. The purpose of contrast enhancement is to create image with better visual quality by manipulating the pixel intensity of the image. Various techniques have been proposed to enhance the contrast in an image and conventional histogram equalization (CHE) is the most popular amongst all the techniques due to its effectiveness and ease of implementation. CHE remaps the gray levels of the image based on the probability density function (PDF) and hence flattens and stretches the dynamic range of the histogram [1]. Nevertheless, CHE suffers from a well-known limitation: mean brightness shifting which results in the generation of unwanted artifacts and gives non-natural looking on the image [2]. Furthermore, saturation effect by CHE contributes to loss of information [3].

Many techniques have been proposed to overcome the drawbacks of CHE. The initial idea was proposed by Kim [4]. By segmenting the input histogram into two sub-histograms using the mean brightness of the image, the proposed technique, Brightness Preserving Bi-Histogram Equalization (BBHE) has been experimentally proved that it is able to preserve the mean brightness of the image and at the same time, it can reduce the saturation effect and avoid unnatural enhancement and annoying artifacts [5]. Then, a similar technique, Dualistic Sub-image Histogram Equalization (DSIHE) is proposed [1]. Median value is used as the threshold for histogram segmentation.

In year 2003, a generalization scheme of BBHE, Recursive Mean-Separate Histogram Equalization (RMSHE) is proposed by Chen and Ramli [6] and Recursive Sub-image Histogram Equalization (RSIHE), a generalization scheme of DSIHE is then proposed by Sim et al. [7]. These techniques segment the input histogram more than once according to a user-defined scale, *r* and generate 2^r sub-histograms. The threshold used for RMSHE is the mean value whereas RSIHE uses median value. Both RHSHE and RSIHE techniques suffer from the same limitation, where the optimal value for *r* is usually unknown [8].

On the other hand, image enhancement has also been performed with the objective of the proposed techniques is to retain the information in the image. In year 2012, Abdullah proposed Modified Histogram Equalization (MHE) which alters the accumulations in the input histogram before histogram equalization [9]. By eliminating the domination of larger histogram component, the author claims that MHE is able to enhance the contrast of the image while preserving the small parts in the image. On the same year, Adaptive Histogram Equalization Algorithm (AHEA) which uses the information entropy as the target function has been proposed [2]. AHEA introduces a new parameter β in the histogram equalization formula and thus adaptively adjusts the spacing of two adjacent gray levels in the output histogram based on the type of input image. Experiment results reveal that AHEA is excellent in retaining the information entropy of the image.

Another type of histogram equalization based technique is the clipped histogram equalization. Histogram clipping is performed to control the enhancement rate while preventing intensity saturation in the image. Bi-histogram Equalization Plateau Limit (BHEPL), the combination of techniques BBHE and clipped histogram equalization has been proposed in [5]. Initially, BHEPL decomposes input histogram into two sub-histograms as in BBHE. Then, the average number of intensity occurrence for each sub-histogram is calculated and set as the plateau limit for histogram clipping. Finally, CHE is performed on the clipped-histograms to enhance the image.

A modified version of BHEPL, Bi-histogram Equalization Median Plateau Limit (BHEPL-D), is proposed [10]. In BHEPL-D, the threshold is the same as in BHEPL. But median of the occupied intensity is used as the plateau limit instead of average number of intensity to clip the sub-histograms. Experimental results show that BHEPL-D

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outperforms BHEPL in terms of details preservation, noise level amplification and execution time. In [11], the author compares the combination of mean and median for histogram segmentation and histogram clipping. It is found that the use of median intensity value to segment the input histogram followed by median of the occupied intensity as the plateau limit gives the best result. The name of the technique is given as BPPLHE-1DD where the '1' stands for dividing the histogram once and 'DD' means the use of median value for both histogram segmentation and histogram clipping. For simplification, we only use BPPLHE to represent this technique.

Motivated by the idea of histogram clipping, we propose a new method to clip the input histogram to achieve better contrast enhancement with good ability in details preservation. The rest of this paper is organized as follows. In the next section we present the proposed technique, namely Adaptive Contrast Enhancement Algorithm with Details Preserving (ACEDP) in detail. Section 3 shows the experimental results and discussions. Finally, Section 4 concludes our work.

II. ADAPTIVE CONTRAST ENHANCEMENT ALGORITHM WITH DETAILS PRESERVING (ACEDP)

In year 1948, Shannon introduced the idea of entropy measurement in his landmark publication "A Mathematical Theory of Communication" [12]. In image processing, entropy is a measurement image information [1]. The ultimate goal of histogram equalization is to obtain a uniform distribution for it probability density function. This can be explained by one of the properties of Shannon's entropy, where the image information is maximized when the probability distribution of the message is uniform.

However, as mentioned in previous section, the saturation effect by CHE tends to cause information loss in the resultant image. Thus, we propose a modified technique to enhance the contrast of the image while retaining the details of the image.

The proposed ACEDP algorithm consists of the following stages:

i. Classification of image type based on the distribution of maximum number of pixels according to their intensities;

ii. Defining 3 functions as the plateau levels for the three image types;

iii. Histogram clipping and equalization.

A. Classification of Image Type

Firstly, the histogram of the input gray-level image is created. Two thresholds values, namely upper threshold and lower threshold are set as 85 and 170 respectively. These threshold values are selected based on the idea to divide the dynamic range of a histogram into three equal parts. Reference [2] demonstrates the usage of the same threshold values. The image is classified as low-, middle- or high-gray level based on the maximum number of pixel intensities that falls in one of the 3 categories as shown in Fig. 1.

1: **IF** ***maximum_no_of_pixels_intensities < 85***
2: **THEN** ***image_type=low gray level***
3: **ELSE IF** ***maximum_no_of_pixels_intensities >170***
4: **THEN** ***image_type=high gray level***
5: **ELSE** ***image_type=middle gray level***

Fig. 1. Image type classification.

1: **IF** ***image_type=low_gray_ level***
2: **THEN** $level(k) = c_1 k + \max(pdf)$ (1)
3: **IF** ***image_type= middle_gray_ level***
4: **THEN** $level(k) = mean(pdf)$ (2)
5: **IF** ***image_type=high_ gray_ level***
6: **THEN** $level(k) = c_2 k + mean(pdf)$ (3)

Fig. 2. Determination of plateau level based on image type.

B. Defining Plateau Levels

The proposed ACEDP technique assigns different functions for histogram clipping according to the image type. If the image is relatively dark with the maximum number of pixels having intensities less than 85 (low-gray-level-typed image), (1) is used as the plateau level. Similarly, for middle-gray-level-typed image and high-gray-level-typed image, the plateau levels are defined as (2) and (3) respectively as shown in Fig. 2. Constants c_1 and c_2 are the slopes of the plateau level. From the experiments, the suitable range of c_1 is [-0.015,-0.005] and for c_2 is [0.005,0.007]. In this experiment, the values used are -0.01 and 0.007 respectively.

C. Histogram Clipping and Equalization

With the plateau level obtained from the previous step, histogram clipping is then performed.

Consider an input image X , the histogram for intensity k , $P(k)$ is defined as:

$$P(k) = n_k \text{, for } k = 0,1,\ldots,L-1 \tag{4}$$

Where n_k is the occurrence of intensity k in the image and L is the total number of gray levels in the image. The probability density function (PDF) of the image, $r(k)$ is defined as:

$$r(k) = \frac{P(k)}{N} \text{, for } k = 0,1,\ldots,L-1 \tag{5}$$

where N is the total number of pixels in the image. The summation of all $r(k)$ is equals to one as shown in (6).

$$\sum_{i=0}^{L-1} r(i) = 1 \quad (6)$$

The cumulative density function (CDF), *c(k)* is then defined as:

$$c(k) = \sum_{i=0}^{k} r(i), \text{ for } k = 0,1,\ldots,L-1 \quad (7)$$

The histogram clipping process is performed using (8).

$$P_{clip} = \begin{cases} P(k), & \text{for } P(k) \le level(k) \\ level(k), & \text{for } P(k) > level(k) \end{cases} \quad (8)$$

After the clipping process, CHE is applied using (9) to enhance the image.

$$f(k) = X_0 + (X_{L-1} - X_0) \cdot \sum_{k=0}^{L-1} P_{clip}(k) \quad (9)$$

where X_0 and X_{L-1} represent the minimum and maximum gray levels respectively.

III. RESULTS AND DISCUSSIONS

In order to compare the performance of the proposed ACEDP technique, six other techniques have been implemented, namely Conventional Histogram Equalization (CHE), Modified Histogram Equalization (MHE) [9], Adaptive Histogram Equalization Algorithm (AHEA) [2], Bi-histogram Equalization Plateau Limit (BHEPL) [5], Bi-histogram Equalization Median Plateau Limit (BHEPL-D) [10] and Brightness Preserving Plateau Limit Histogram Equalization (BPPLHE) [11]. These techniques will be evaluated in terms of contrast enhancement, details preservation and naturalness of image. All the techniques will be tested using 85 benchmark images downloaded from the public image database [13]. Two test images, namely *Hill* and *Woman* as shown in Figs. 3 and 4 respectively are used to visually evaluate the performance of all techniques implemented.

Three objective functions are then employed to investigate the performance of ACEDP technique. In order to evaluate the ability of the proposed ACEDP technique in retaining the information of the image, entropy is calculated. On the other hand, the output-input standard deviation and contrast improvement evaluation serve as the measurement for contrast enhancement.

According to information theory, Shannon entropy can be used to measure the richness of the information in the image [1, 10, 12, 14]. The entropy of the image can be calculated using (10).

$$Entropy = -\sum_{i=1}^{N} r(i) \log_2 r(i) \quad (10)$$

The percentage of information entropy (Entropy %) is calculated for the ease of comparison:

$$Entropy\,\% = \frac{Entropy_{\text{Output}}}{Entropy_{\text{Input}}} \times 100 \quad (11)$$

The calculation of output-input standard deviation is performed using (12). It is the difference between the standard deviation of enhanced image and the standard deviation of input image.

$$\text{Stand. Dev.} = \text{Stand. Dev.}_{\text{Output}} - \text{Stand. Dev.}_{\text{Input}} \quad (12)$$

Apart from standard deviation, the deviation of gray levels in the image, used for contrast improvement evaluation, is calculated with the image contrast function as shown in (13) has been used in [15, 16].

$$C_{contrast} = \frac{1}{WH}\sum_{u=1}^{W}\sum_{v=1}^{H} g^2(u,v) - \left|\frac{1}{WH}\sum_{u=1}^{W}\sum_{v=1}^{H} g(u,v)\right|^2 \quad (13)$$

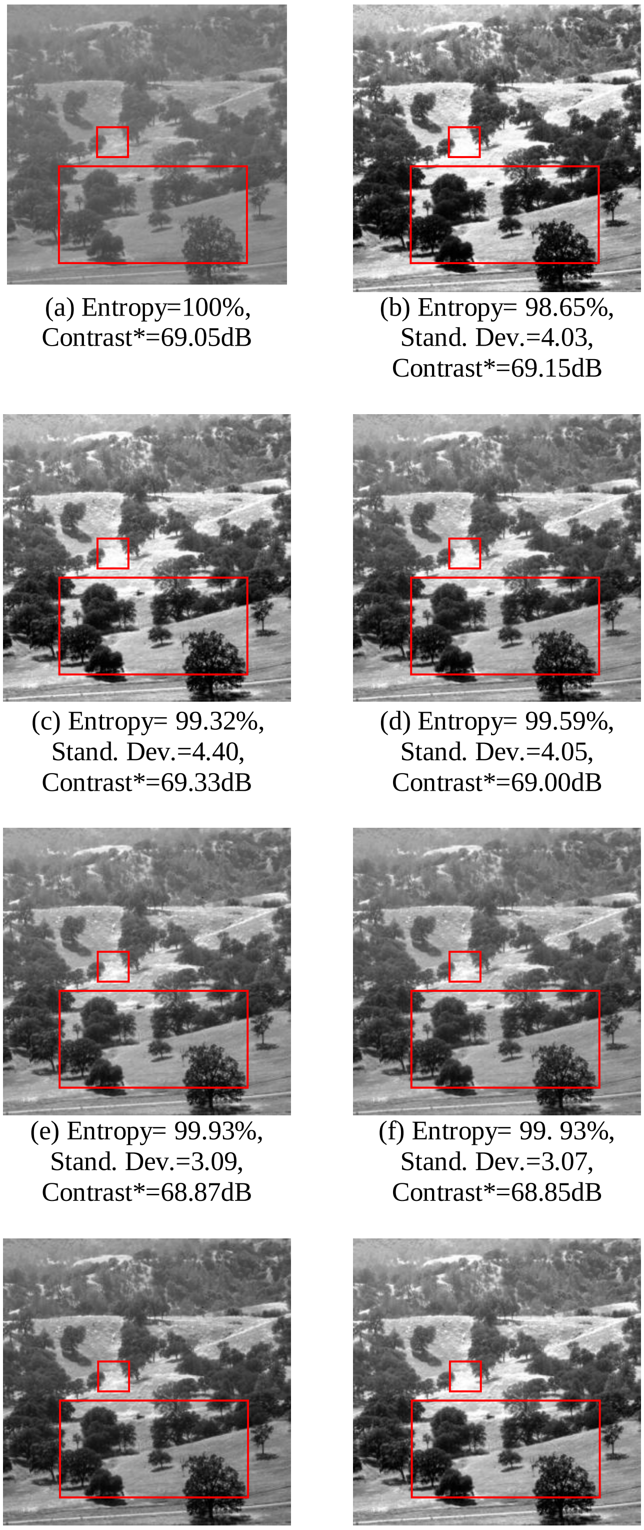
where W and H are the width and height of the image respectively, $g(u,v)$ is the intensity of the pixel at 2-dimentional position (u,v). We convert $C_{contrast}$ into decibel (dB) unit using:

$$C^{*}_{contrast} = 10\log_{10} C_{contrast} \quad (14)$$

For all the three evaluation functions (i.e. entropy, output-input standard deviation and contrast improvement evaluation), larger value is desired as it indicates better details preservation ability as well as better contrast enhancement.

From Fig. 3, for test image *Hill*, it is obvious over-enhancement problem occurs in most of the resultant images. This could be clearly observed at the center of the hill. On the other hand, the texture of the trees as highlighted with the big box in Fig. 3(h) appears to be more smooth and natural. All techniques demonstrate similar ability in terms of details preservation with their similar entropy values. In terms of contrast enhancement, the proposed ACEDP technique demonstrates comparable performance with all the other techniques. This can be observed on trees highlighted with larger box. In addition to good contrast with its clear edges of trees, the image appears to have natural-looking. This is further supported by the second largest output-input standard deviation value. Even though CHE-ed and MHE-ed images have contrast improvement measurement greater than the proposed ACEDP-ed image, the ACEDP-ed image is able to retain more information in the image.

For the second test image *Woman* as shown in Fig. 4, the ability of the proposed ACEDP technique in terms of details preservation is not far-off as compared to all the other techniques. This observation is supported with the percentage of entropy with the difference of only 0.93%, with the range within 99.05% and 99.98%. Lots of the image information are



(a) Entropy=100%, Contrast*=69.05dB

(b) Entropy= 98.65%, Stand. Dev.=4.03, Contrast*=69.15dB

(c) Entropy= 99.32%, Stand. Dev.=4.40, Contrast*=69.33dB

(d) Entropy= 99.59%, Stand. Dev.=4.05, Contrast*=69.00dB

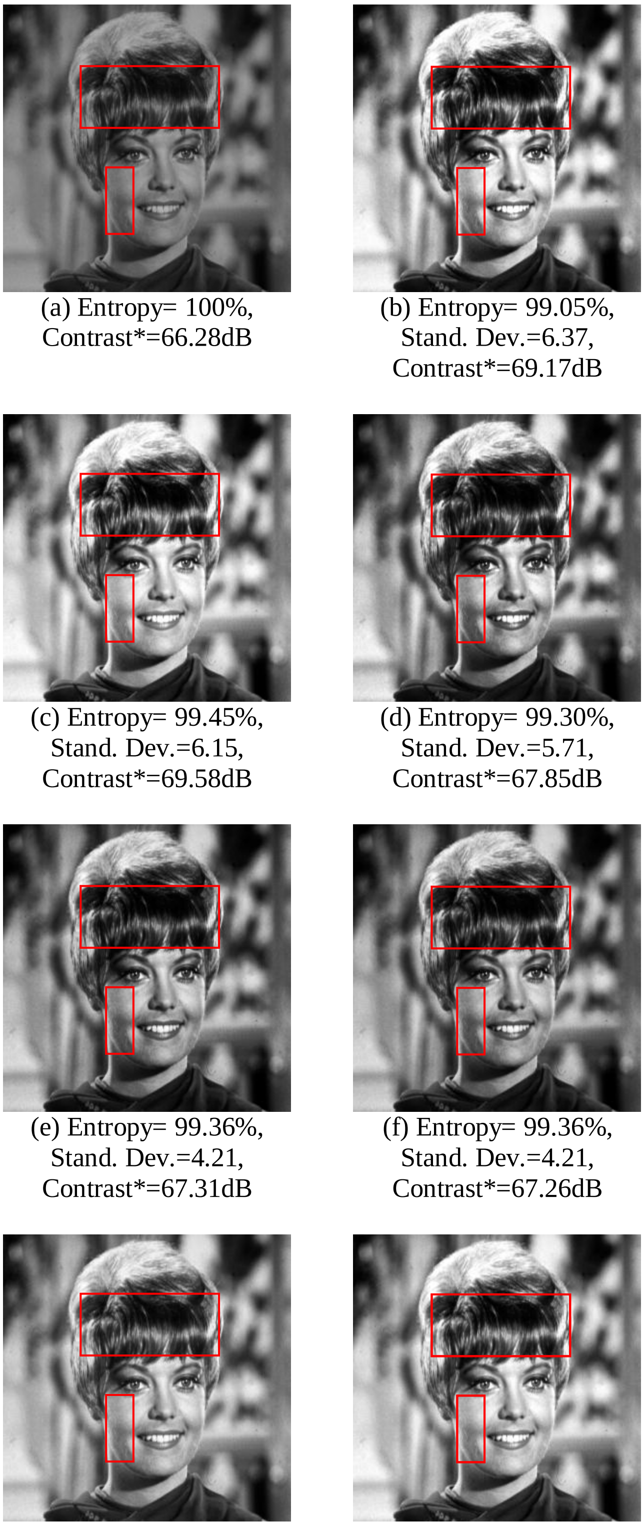
(e) Entropy= 99.93%, Stand. Dev.=3.09, Contrast*=68.87dB

(f) Entropy= 99. 93%, Stand. Dev.=3.07, Contrast*=68.85dB

(g) Entropy= 99.98%, Stand. Dev=2.82, Contrast*=67.76dB

(h) Entropy= 99.60%, Stand. Dev.=4.10, Contrast*=69.06dB

Fig. 3. (a) Test image *Hill*, (b) CHE-ed image; (c) MHE-ed image; (d) BHEPL-ed image; (e) BHEPL-D-ed image; (f) BPPLHE-ed image; (g) AHEA-ed image and (h) ACEDP-ed image (the proposed method).



(a) Entropy= 100%, Contrast*=66.28dB

(b) Entropy= 99.05%, Stand. Dev.=6.37, Contrast*=69.17dB

(c) Entropy= 99.45%, Stand. Dev.=6.15, Contrast*=69.58dB

(d) Entropy= 99.30%, Stand. Dev.=5.71, Contrast*=67.85dB

(e) Entropy= 99.36%, Stand. Dev.=4.21, Contrast*=67.31dB

(f) Entropy= 99.36%, Stand. Dev.=4.21, Contrast*=67.26dB

(g) Entropy= 99.98%, Stand. Dev.=4.34, Contrast*=69.00dB

(h) Entropy= 99.62%, Stand. Dev.= 5.81, Contrast*=69.63dB

Fig. 4. (a) Test image *Woman*, (b) CHE-ed image; (c) MHE-ed image; (d) BHEPL-ed image; (e) BHEPL-D-ed image; (f) BPPLHE-ed image; (g) AHEA-ed image and (h) ACEDP-ed image (the proposed method).

TABLE I. AVERAGE VALUES OF QUANTITATIVE ANALYSES.

Techniques	**Quantitative Analyses**		
	Entropy (%)	***Standard Deviation***	***Contrast* (dB)***
CHE	97.69	2.60	68.12
MHE	97.98	2.53	67.78
AHEA	**99.74**	1.96	67.32
BHEPL	98.38	2.37	67.07
BHEPL-D	92.45	2.47	65.31
BPPLHE	93.58	2.20	65.83
ACEDP	98.57	**2.62**	**68.27**

successfully preserved and this can be seen from the woman's hair highlighted with larger box. Less saturation occurs here. Furthermore, the enhanced image by ACEDP technique has more homogenous regions. One of the examples is shown on her face, where less small regions appear. In terms of contrast enhancement, the input image has relatively low contrast but the enhanced image by ACEDP technique successfully improves the contrast while preserving the natural looking in the image with its highest contrast improvement measurement. Moreover, the proposed ACEDP-ed image is ranked third in the output-input standard deviation measurement. All these analyses results support our observation of test image *Women*.

With the encouraging results from two test images, we perform the analyses on 85 test images to further investigate the performance of the ACEDP technique. Table I presents the average values of quantitative analyses for these test images. The best value for each analysis is made bold. Table 1 suggests that the proposed ACEDP technique outperforms all the other techniques in contrast enhancement with its largest standard deviation and contrast improvement measurements with slight tolerance in entropy value. ACEDP technique demonstrates great ability in retaining information in the image as it possesses the second highest entropy value after AHEA technique.

IV. CONCLUSION

This paper presented a modified version of histogram equalization technique. The novelty of the proposed ACEDP technique is the selection of clipping function based on image type. Experiment results show that ACEDP technique can effectively enhance the contrast of the image while preserving the most of the details in the image.

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