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Research Note

An Automatic Contrast Enhancement Technique Using Combination of Histogram-Based Methods

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Abstract— **This paper proposes the combination of histogram based methods in order to achieve an improved contrast enhancement technique. In the proposed method, at first the histogram is modified in a way that deals with the histogram spikes with less computational complexity. A method is then utilized to preserve the mean brightness of image. In addition, black and white stretching is applied to increase the quality of resulting image. A new method is also introduced so that the stretching parameters can be selected proportional to the intensity distribution of each image. The proposed method is fully automatic, robust against noise, and user-friendly. Experimental results indicate the efficiency of the new technique from both of the objective and subjective viewpoints.**

Keywords- contrast enhancement, histogram equalization, automatic control, brightness, streching.

I. INTRODUCTION

Contrast enhancement has an important role in image processing. Conventional contrast enhancement methods often fail to achieve satisfactory results due to several reasons such as: they are not able to enhance all kinds of images; they cannot be automatically applied to images because their parameters should be set manually, and so on. In order to overcome these problems, many techniques have been introduced. The methods proposed in the literature for contrast enhancement fall into two categories: direct methods and indirect methods. In direct methods, a contrast measure is defined and is tried to be improved. For example, the method of [1] maps an image from the space domain to fuzzy domain using the S-function as the membership function. Then, fuzzy entropy principles and fuzzy set theory are utilized to obtain an adaptive fuzzy contrast enhancement method.

Indirect methods do not define any specific contrast measures and mainly modify histogram by assigning new values to the original intensity levels. Most of the methods in the literature belong to this category.

From another point of view, contrast enhancement methods can be applied either globally or locally. In global methods, a single mapping function is derived from image and used to enhance the contrast. In local methods, the neighborhood of each pixel is used to obtain a local mapping function. For example, in block overlapped histogram equalization [2], the overlapped sub-blocks of image are histogram equalized according to the histogram of each sub-block.

One of the most popular global contrast enhancement techniques is histogram equalization (HE). Most of the indirect methods are derivatives of the conventional histogram equalization technique.

Histogram equalization method is the most popular algorithm for contrast enhancement due to its effectiveness and simplicity which is performed by spreading out the most frequent intensity values. In fact, in histogram equalization the goal is to change the original image to an image with uniform distribution of intensity values. Suppose that $X=\{X(i,j)\}$ denotes a digital image, where $X(i,j)$ specifies the grey level of a pixel at the location of (i,j) as $X(i,j)=\{r_k \mid k=0,1,2,\ldots,L-1\}$, where r_k is the kth grey level and L is the number of different intensity levels. The probability of occurrence of the intensity level r_k , $p(r_k)$, is defined as:

$$p(r_k)=\frac{n_k}{N}, \quad k=0,1,2,...,L-1 \qquad (1)$$

where n_k is the number of pixels with the intensity r_k and N is the total number of pixels in the image. The plot of $p(r_k)$ versus r_k is commonly referred to histogram [3]. Histogram equalization is the mapping of the pixels with the intensity r_k to the pixels with the intensity s_k by the following relation:

$$\begin{aligned} s_k &= T(r_k)=(L-1)\sum_{i=0}^{k} p(r_i) \\ &= r_0+(r_m-r_0)\sum_{i=0}^{k} p(r_i) \end{aligned} \qquad (2)$$

where r_0 and r_m are the minimum and maximum grey levels of the image, respectively. Histogram equalization can be applied to either the histogram of image or the modified histogram.

The conventional histogram equalization results in unnatural look and over-enhanced image. One of the major reasons of this problem is the existence of spikes in the histogram which happens because of large smooth areas in the image. The mapping function maps a narrow range of grey levels to a large range which results in contouring and grainy noise [4, 5]. Some common ways to deal with histogram spikes are low-pass filtering and modifying the cumulative function [6, 7]. In [8], the authors modified the histogram of image to deal with histogram spikes. To obtain the modified histogram, they take into account the pixels that have some contrast with their neighborhood. In fact, the probability of occurrence of intensity level becomes a conditional probability. The weighted average of the resulting histogram and a uniform histogram along with black and white stretching results in the modified histogram. The uniform histogram is obtained from the number of pixels that satisfy the condition of having contrast with neighbors. Then, by equalizing the modified histogram, the contrast will increase without amplifying the noise. However, a disadvantage of this method [8] is that the selection of stretching parameters is done by the user. There are other approaches to the histogram based contrast enhancement [4, 5]. Gray-level grouping (GLG) is an algorithm that groups histogram bins and then redistributes these groups iteratively [4]. GLG can adjust the level of enhancement and is robust to histogram spikes. The method proposed in [9] proposes to modify histogram of the image by weighting and then thresholding before histogram equalization. The weighting and thresholding are performed by clamping the original histogram at upper and lower thresholds, and transforming all values between the upper and lower thresholds using a normalized power law function.

Another reason of deficiency of the conventional histogram equalization is the mean brightness changing, because the mean brightness of the resulting image will be in the middle of grey-scale despite of the mean brightness of original image. This causes washed-out and noisy results [10]. To deal with this problem, dualistic sub-image histogram equalization (DHSE) [10] and bi-histogram equalization (BHE) [11] methods have been proposed which divide the image into two sub-images based on the median and mean intensity, respectively. Then, each sub-image is separately equalized and finally, the results are combined. However, the two mentioned methods do not solve the spikes issue in the contrast enhanced images.

In this paper, our goal is to deal with the spikes while preserving the mean brightness of image to improve contrast, so that the image looks more naturally. For this purpose, we first modify the histogram using the method of [8], then, apply the method of [11] to preserve the brightness, and finally perform black and white stretching. Further, a method is proposed to select the parameters of stretching automatically. Experimental results show that the proposed method has better performance than the previous methods from the subjective and objective viewpoints.

The rest of this paper is organized as follows. In Section II, the proposed method is explained. In Section III, experimental results are provided. Finally, in Section IV conclusion and future works are presented.

II. PROPOSED METHOD

In the proposed method, at first the method of [8] is improved by separating the black and white stretching parts from histogram modification and making its parameters change automatically depending on the intensity distribution of image. Then, this method is combined with BHE method of [11] to obtain images with higher quality. In the following, each part is described in detail.

At the first stage, the histogram of input image is modified as follows:

$$g[n]=(1-k^*)u[n]+k^*h[n] \qquad (3)$$

where $g[n]$ is the modified histogram, k^* determines the level of enhancement that depends on the level of contrast and a factor which is controlled by the user. $u[n]$ is the uniform histogram obtained from the number of pixels that satisfy the condition of having contrast with neighbors (number of pixels with contrast divided by L), and $h[n]$ is the histogram obtained by taking into account the pixels that have contrast with their neighborhood. Histogram spikes are created due to large numbers of pixels having the same gray-levels; these pixels usually come from smooth areas in the image. Hence, taking into account the pixels that have some level of contrast with their neighbors will solve the histogram spike problem at the very beginning. That is, histogram spikes problem is solved in the first stage of histogram computation, so there is no need for additional operations such as smoothing or low pass filtering. To decide which pixels have contrast with their neighborhoods, local variations can be used. For this purpose, the difference of the intensity of each pixel with the second pixel next to it, is calculated, i.e. $(|X(i,j)-X(i,j-2)|)$. Then, the difference is compared with a threshold value T. If the difference is more than the threshold, the pixel is taken into account in the histogram identification. Therefore, for $n = r_0,...,r_m$ where r_0 and r_m are the minimum and maximum grey levels of image, respectively, we have

$$h_{new}[n]=\begin{cases} h_{old}[n]+1 & if \ |X(i,j)-X(i,j-2)|>T \\ h_{old}[n] & else \end{cases} \quad (4)$$

where the initial values of $h[n]$ are set to zero.

Next, an image X_{new} with the histogram $g[n]$ is defined and is divided into two sub-images as X_{newL} and X_{newU}, based on the mean intensity of image as follows:

$$X_{newL}=\{X_{new}(i,j)\,|\,X_{new}(i,j)\le r_e\} \quad (5)$$

$$X_{newU}=\{X_{new}(i,j)\,|\,X_{new}(i,j)> r_e\} \quad (6)$$

where r_e denotes the mean brightness of the image X_{new}. The corresponding probability density functions of the sub-images are defined as:

$$P_L(r_k)=\frac{n_k}{n_L}, \quad k=0,1,2,\dots,e-1 \quad (7)$$

$$P_U(r_k)=\frac{n_k}{n_U}, \quad k=e,e+1,,\dots,L-1 \quad (8)$$

where n_k is the number of pixels with the intensity of r_k, e denotes the index of r_e, and

$$n_L=\sum_{k=0}^{e-1} n_k \quad (9)$$

$$n_U=\sum_{k=e}^{L-1} n_k \quad (10)$$

Analogous to the histogram equalization method, in which a cumulative density function is used as a transform function, we equalize the histogram of two sub-images separately using the following transform functions

$$T_L[r_k]=r_0+(r_e-r_0)\sum_{i=0}^{k} P(r_i), \quad k=0,1,2,\dots,e-1 \quad (11)$$

$$T_U[r_k]=r_e+(r_m-r_0)\sum_{i=e}^{k} P(r_i), \quad k=e,e+1,\dots,L-1 \quad (12)$$

Then, the above two transform functions are combined in the following manner:

$$T[r_k]=\begin{cases} T_L[r_k] & if \quad r_k\le r_e \\ T_U[r_k] & else \end{cases} \quad (13)$$

Next, the black and white stretching is applied to improve the results:

$$T_{out}[r_k]=\begin{cases} r_k\times\left(\frac{1}{1+\alpha}\right) & r_k\le b \\ r_k\times T[r_k] & b<r_k<w \\ w+(r_k-w)\times\left(\frac{1}{1+\alpha}\right) & r_k\ge w \end{cases} \quad (14)$$

Eq. (14) implies that the intensity of pixels with the value of less than b decreases and the intensity of the pixels with the value of more than w increases. The intensities between b and w are mapped by the transform function $T[r_k]$. $1/(1+\alpha)$ is a value that determines the level of stretching.

In this work, b and w are obtained by measuring the brightness of image. We know that dark images need white stretching and bright images need black stretching. If the mean brightness of image is less than the median intensity level, it is considered as dark; otherwise it is a bright one. After many trials, we found that it is better to set w proportional to the mean intensity and b equal to r_0 for dark images, i.e.

$$\text{if} \quad r_e<r_{med}\Rightarrow\begin{cases} b=r_0 \\ w=co_w(r_m+r_e) \end{cases} \quad (15)$$

where r_{med} is the median gray level and co_w is in the interval $[0.5,\frac{r_m}{r_m+r_e}]$ selected by an automatic numerical sweep, based on the best results obtained for the objective criterion. Further, for bright images, b is chosen proportional to the mean intensity and w is set equal to r_m, i.e.

$$\text{if } r_e > r_{med} \Rightarrow \begin{cases} b = co_b(r_0 + r_e) \\ w = r_m \end{cases} \quad (16)$$

Otherwise

$$\begin{cases} b = r_0 \\ w = r_m \end{cases} \quad (17)$$

where an automatic numerical sweep is again performed in the interval $[\frac{r_e}{r_e + r_0}, 0.5]$ to select the appropriate value for co_b.

α in (14) is determined according to the image contrast as follows

$$\alpha = \frac{total\ number\ of\ pixels}{number\ of\ pixels\ with\ contrast} \quad (18)$$

It is obvious that the mentioned parameters are selected dynamically based on the intensity distribution of each image.

Based on the transform function in (14), the resulting equalized image constitutes the output image. That is, the output image Y is expressed as

$$\begin{aligned} Y &= \{Y(i,j)\} \\ &= T_{out}(X_{new}(i,j)) \end{aligned} \quad (19)$$

I. EXPERIMENTAL RESULTS

In this section, the performance of the new method is evaluated and compared with the results of histogram equalization and the recently introduced methods [8, 9]. Subjective and objective criteria are used to assess the performance. As an objective criterion, we use the entropy $(H = -\sum_{i=r_0}^{r_m} p(r_i)\log_2(p(r_i)))$ which indicates the amount of information of image. Another objective criterion is AMBE (Absolute Mean Brightness Error). AMBE is the absolute difference between the mean values of the input and output images [8] and is one of the major criteria widely used in the literature to evaluate contrast enhancement methods. The proposed algorithm has been applied on many different test images but only a few of them are shown. Fig. 1.a demonstrates the original grey-scale Plane image and Fig. 1.b depicts the histogram equalized image which achieves the maximum contrast at the expense of amplified noise and unnatural look. We have shown the result of [8] in Fig. 1.c. and our method in Fig. 1.d. It is observed that the brightness of the image in our method is more natural and the details are more visible. H (entropy) and AMBE of the proposed method and the methods of [8] and [9] are presented in Table I. From the results, it is concluded that our method has better performance than the previous methods. That is, the proposed method results in images with more entropy and less AMBE which are the desired features in contrast enhancement techniques.

For color images, we have applied the new method only to the luminance component. Figs. 2.a, 3.a., and 4.a show three different color images. The corresponding histogram equalized images are depicted in Figs. 2.b, 3.b, and 4.b, respectively. The results of the method of [8] are demonstrated in Figs. 2.c, 3.c, and 4.c., and the results of our method are illustrated in Figs. 2.d, 3.d, and 4.d. We note that in Fig. 3.c the color of trees became darker but in Fig. 3.d the color is more natural. In Fig. 4.c., the image has a visually pleasing look but the color of the pink flower got extremely brighter while in our method, the color is more preserved. From the figures and Table I, it is again noted that the proposed method outperforms the methods of HE, [8], and [9]. However, objective criteria do not work properly for the case of contrast enhancement method proposed in [8]. That is, the objective and subjective criteria do not necessarily yield similar results.

II. CONCLUSION AND FUTURE WORKS

The need for an automatic contrast enhancement method, which is able to adjust its parameters to every kind of image, is always a challenging problem in image processing. On the other hand, objective and subjective criteria do not necessarily yield the same results, i.e. some processes may not have as good subjective results as objective results and vice versa. In this paper, a method was proposed in order to achieve a fully automatic process to deal with histogram spikes by modifying the histogram with a less computational complexity. In addition, the resulting images have more natural look by solving the mean brightness preserving problem and applying black and white stretching method. It was shown that the new method yields less AMBE and more entropy than the previously presented methods which are desired features. Further, the natural look and fewer artifacts are visible in the resulting images.

However, there still exist some drawbacks. Taking into account only the pixels that have some level of contrast with their neighbors in histogram computation may cause loss in the information of image. Further, using histogram equalization itself results in amplifying noise in the resulting image. Future works can focus on these two problems to find an optimum contrast enhancement algorithm with more robustness against noise.

TABLE I. QUANTITATIVE MEASUREMENT RESULTS. AMBE DENOTES THE ABSOLUTE MEAN BRIGHTNESS ERROR, AND H DENOTES THE DISCRETE ENTROPY.

	AMBE				H				
Images	**HE**	**[9]**	**[8]**	**proposed**	**Original**	**HE**	**[9]**	**[8]**	**proposed**
Plane	48.23	5.16	3.34	3.12	6.32	4.96	6.03	6.08	6.26
Hats	23.84	12.60	3.13	3.02	6.89	5.91	6.87	6.89	6.86
Island	22.18	9.88	14.13	13.58	7.01	5.96	6.97	6.98	7.12
Window	17.11	20.84	14.49	13.96	6.80	5.79	6.82	6.83	6.75
average	27.84	12.12	8.77	8.42	6.75	5.65	6.67	6.69	6.74

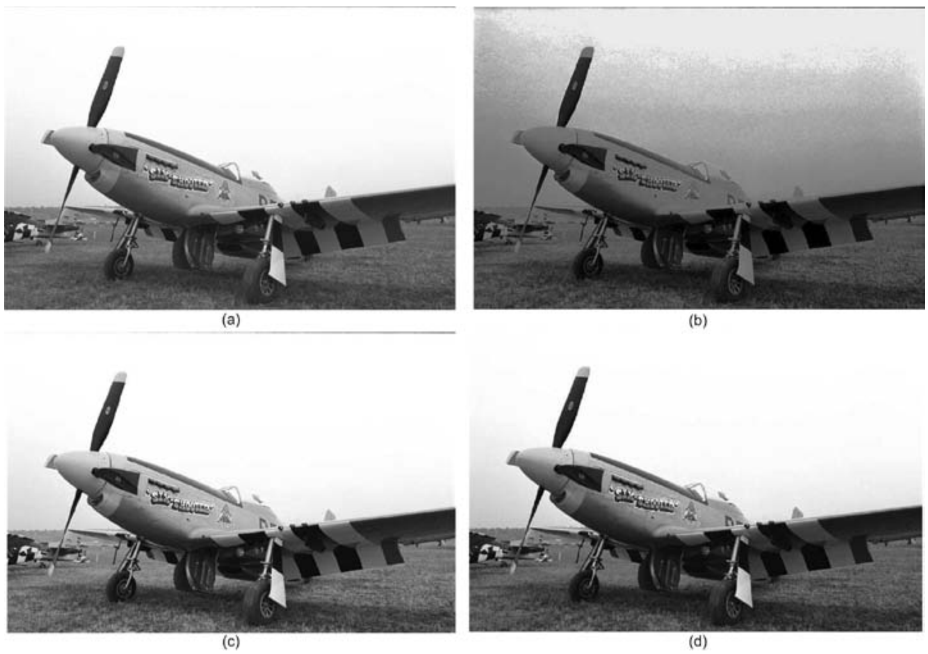

Figure1. The effect of different contrast enhancement methodes for *plane* image, (a) original image, (b) histogram equalization, (c) method of [8], (d) proposed method

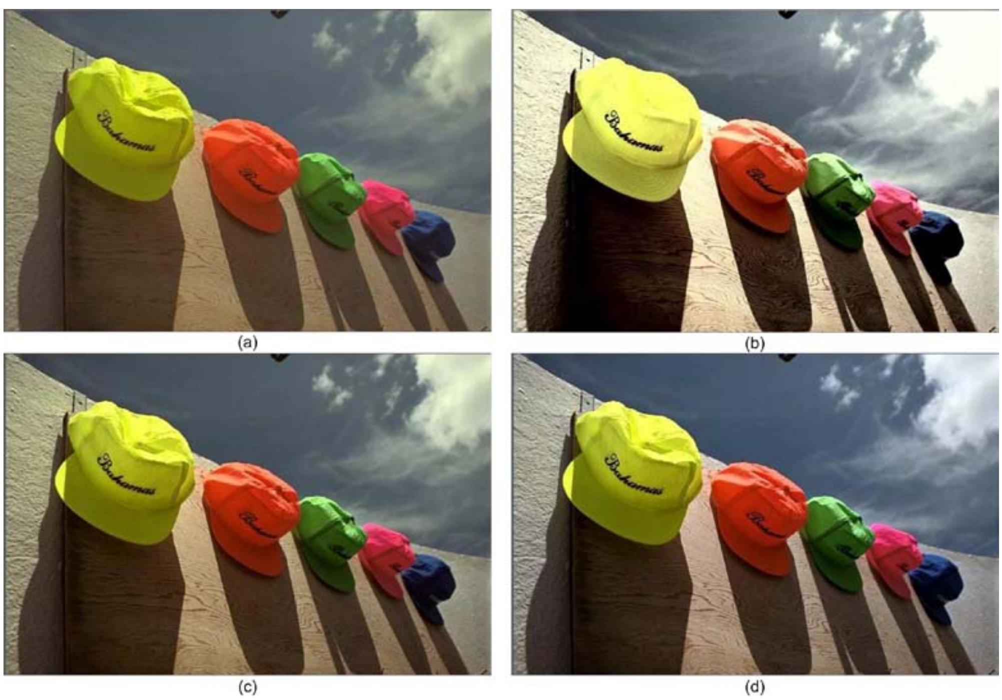

Figure 2. Results for *Hats* image, (a) original image, (b) histogram equalization,(c) method of [8], (d) proposed method

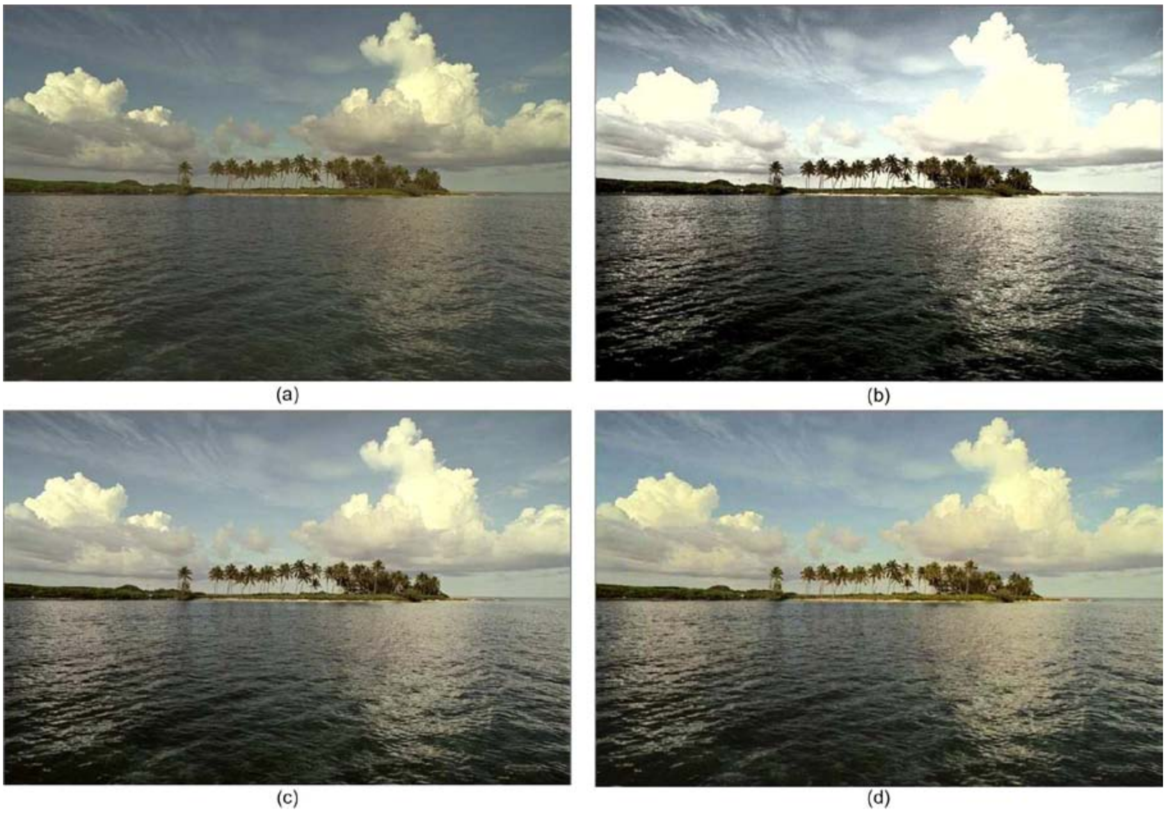

Figure 3. Results for *Island* image, (a) original image, (b) histogram equalization, (c) method of [8], (d) proposed method

Figure 4. Results for *Window* image, (a) original image, (b) histogram equalization, (c) method of [8], (d) proposed method

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