Bi-Histogram Equalization with a Plateau Limit for Digital Image Enhancement

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**Abstract — ***Many histogram equalization based methods have been introduced for the use in consumer electronics in recent years. Yet, many of these methods are relatively complicated to be implemented, and mostly require a high computational time. Furthermore, some of the methods require several predefined parameters from the user, which make the optimal results cannot be obtained automatically. Therefore, this paper presents Bi-Histogram Equalization with a Plateau Level (BHEPL) as one of the options for the system that requires a short processing time image enhancement. First, BHEPL divides the input histogram into two independent sub-histograms. This is done in order to maintain the mean brightness. Then, these sub-histograms are clipped based on the calculated plateau value. By doing this, excessive enhancement can be avoided. Experimental results show that this method only requires 34.20ms, in average, to process images of size 3648×2736 pixels (i.e. 10 Mega pixels images). The proposed method also gives better enhancement results as compared with some multi-sections mean brightness preserving histogram equalization methods*[1].

Index Terms — Image contrast enhancement, histogram equalization, brightness preserving enhancement, clipped histogram equalization.

I. INTRODUCTION

Global Histogram Equalization (GHE), although is simple to be implemented, and one of the popular methods for digital image enhancement, this method is not suitable to be implemented in consumer electronic products, such as television, digital camera, and camcorder. This is because GHE tends to cause level saturation effects in small but visually important areas [1]. This saturation effect, not only degrades the appearance of the image, but it also leads to information lost [2]. Furthermore, the excessive change in brightness level introduce by GHE leads to annoying artifacts and unnatural enhancement. The noise level in the image is also enhanced or magnified significantly [3]. Thus, although GHE can increase the brightness level in the image, this method might significantly degrade the quality of the image.

The idea of keeping the mean brightness of an image for consumer electronic products is first introduced by Kim [4]. By preserving the mean brightness, it is not only can maintain the artistic value of the image, but it is also proven that this methodology can reduce the saturation effect, and able to avoid unnatural enhancement and annoying artifacts on the output image.

The mean brightness preserving histogram equalization (MBPHE) methods basically can be divided into two main groups, which are bisections MBPHE, and multi-sections MBPHE. Bisections MBPHE group is the simplest group of MBPHE. Fundamentally, these methods separate the input histogram into two sections. These two histogram sections are then equalized independently. The major difference among the methods in this family is the criteria used to divide the input histogram. Brightness preserving Bi-Histogram Equalization (BBHE) [4] and Quantized Bi-Histogram Equalization (QBHE) [5] use the average intensity value as their separating point. Dual Sub-Image Histogram Equalization (DSIHE) [6] uses the median intensity value as the separating point. Minimum Mean Brightness Error Bi-HE (MMBEBHE) [7],[8] uses the separating point that produces the smallest Absolute Mean Brightness Error (AMBE).

However, bisections MBPHE can preserve the mean brightness only to a certain extent. However, some cases do require higher degree of preservation to avoid unpleasant artifacts [9]. Furthermore, bisections MBPHE can only preserve the original mean brightness if and only if the input histogram has a quasi-symmetrical distribution around its separating point [10]. But, most of the input histograms do not have this property. This condition leads to the failure of bisections MBPHE in preserving the mean intensity in real life applications.

Works in [9], [11]-[21] are a few of multi-sections MBPHE. Multi-sections MBPHE group has a better mean brightness preservation as compared with the group of bi-sections MBPHE. In multi-sections MBPHE, the input histogram is divided into R sub-histograms, where R is any positive integer value. Each sub-histogram is then equalized independently. The creation of the sub-histograms can be carried out recursively (e.g. by using the mean or median intensity value), or based on the shape of the input histogram itself (e.g. using the locations of local maximum or local minimum).

[1]This work is partly supported by Ministry of Science, Technology and Innovation Malaysia, under ScienceFund Grant SF-01-01-05-SF0255, and by Universiti Sains Malaysia under Postgraduate Fellowship Scheme, Incentive Grant, and Research Universiti Postgraduate Research Grant.

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Contributed Paper
Manuscript received August 25, 2009

Yet, in these methods, the detection of the separating points' process normally requires complicated algorithms, which then associated with relatively high computational time. Furthermore, these methods usually increase the hardware requirement in the implementations for consumer electronic products. In addition, most of these methods put too much constrain on keeping the mean intensity value. As a consequence, not much enhancement could be obtained from most of these methods.

One type of histogram equalization based methods that is still not being fully studied for the use in consumer electronic products is the clipped histogram equalization. By altering the input histogram before the equalization is taking place, clipped histogram equalization methods are able to control the enhancement rate. As a consequence, these methods can avoid over amplification of noise in the image. Example of clipped histogram equalization methods are Histogram Equalization with Bin Underflow and Bin Overflow (BUBOHE) [22], Weighted and Thresholded Histogram Equalization (WTHE) [1], Gain-Controllable Clipped Histogram Equalization (GC-CHE) [23], Self-Adaptive Plateau Histogram Equalization (SAPHE) [24], and Modified SAPHE (MSAPHE) [25].

Unfortunately, in order to obtain a good enhancement result, BUBOHE, WTHE and GC-CHE require the user to manually set the parameters' value. Thus, these methods are not so suitable to be used in an automated image enhancement system. SAPHE selects its parameter value automatically, based on the median value of the local peaks of the corresponding input histogram. However, in some cases, SAPHE fails to detect any local peaks in the image, and therefore fails to set its parameter [25]. MSAPHE is introduced to overcome this problem. MSAPHE sets the plateau limit as the median value of the non-empty histogram bins.

In this paper, we combine bi-sections MBPHE (i.e. BBHE) with clipped histogram equalization. This paper is organized as follow. Section II will briefly explain histogram equalization, which is the backbone of this project. Introduction to clipped histogram equalization will also be included. Section III will present our methodology. The experimental results will be shown in Section IV, and Section V is our conclusion.

II. Histogram Equalization

A. Transformation Function for Histogram Equalization

For a given image $\boldsymbol{X}$, the histogram for intensity x, $h(x)$ is defined as:

$$h(x) = n_x, \qquad \text{for } x = 0,1,\ldots,L-1 \tag{1}$$

where n_x is the number of occurrence of intensity x in the image. The probability density function, $p(x)$ is given by:

$$p(x) = \frac{h(x)}{N}, \qquad \text{for } x = 0,1,\ldots,L-1 \tag{2}$$

with N is the total number of pixels in the image. Then, the cumulative density function, $c(x)$ is defined by (3).

$$c(x) = \sum_{k=X_0}^{x} p(k) \tag{3}$$

The transformation function $f(x)$ for the standard histogram equalization maps the input image into the entire dynamic range, $[X_0, X_{L-1}]$, by using $c(x)$. This is given by the following equation.

$$f(x) = X_0 + (X_{L-1} - X_0).c(x) \tag{4}$$

From here, the output image produce by histogram equalization, $\boldsymbol{Y}=\{Y(i,j)\}$, can be expressed as:

$$\boldsymbol{Y} = \{Y(i,j)\} = \{f(X(i,j)) \mid \forall X(i,j) \in \boldsymbol{X}\} \tag{5}$$

where (i,j) are the spatial coordinates of the pixel in the image.

However, a better histogram equalization transformation function has been suggested in [26]. Therefore, in our implementation, this modified transformation function has been employed instead of (4). This improved transformation function is given as:

$$f(x) = X_0 + (X_{L-1} - X_0).\left[c(x) - 0.5p(x)\right] \tag{6}$$

B. Clipped Histogram Equalization

Histogram equalization stretches the contrast of the high histogram regions, and compresses the contrast of the low histogram regions [19]. As a consequence, when the object of interest in an image only occupies a small portion of the image, this object will not be successfully enhanced by histogram equalization. This method also extremely pushes the intensities towards the right or the left side of the histogram, causes level saturation effects.

Clipped histogram equalization methods try to overcome these problems by restricting the enhancement rate. For histogram equalization methods, the enhancement is obtained from the transformation function. As given by (4) or (6), it is known that the enhancement from histogram equalization is heavily dependent to $c(x)$. Therefore the enhancement rate is proportional to the rate of $c(x)$. The rate of $c(x)$ is given by the following equation:

$$\frac{d}{dx}c(x) = p(x) \tag{7}$$

Therefore, if we want to limit the enhancement rate, we can do so by limiting the value of $p(x)$, or $h(x)$ [27].

Therefore, clipped histogram equalization modifies the shape of the input histogram by reducing or increasing the value in the histogram's bins based on a threshold limit before the equalization is taking place. An example is shown in Fig. 1.

This threshold limit is also known as the clipping limit, or the plateau level of the histogram. The histogram will be clipped based on this threshold value. The clipped portion is then redistributed back into the histogram in some cases. Histogram equalization is then carried out using this modified histogram.

There are two major problem associated with clipped histogram equalization. First, most of the methods need the user to set manually the plateau level of the histogram, which make these methods not suitable for automatic systems. SAPHE selects the plateau level automatically, but the process is relatively complicated, and sometimes fails in its execution. Second, some of the methods put weight to the modified histogram. The weight factor is also dependent to the user.

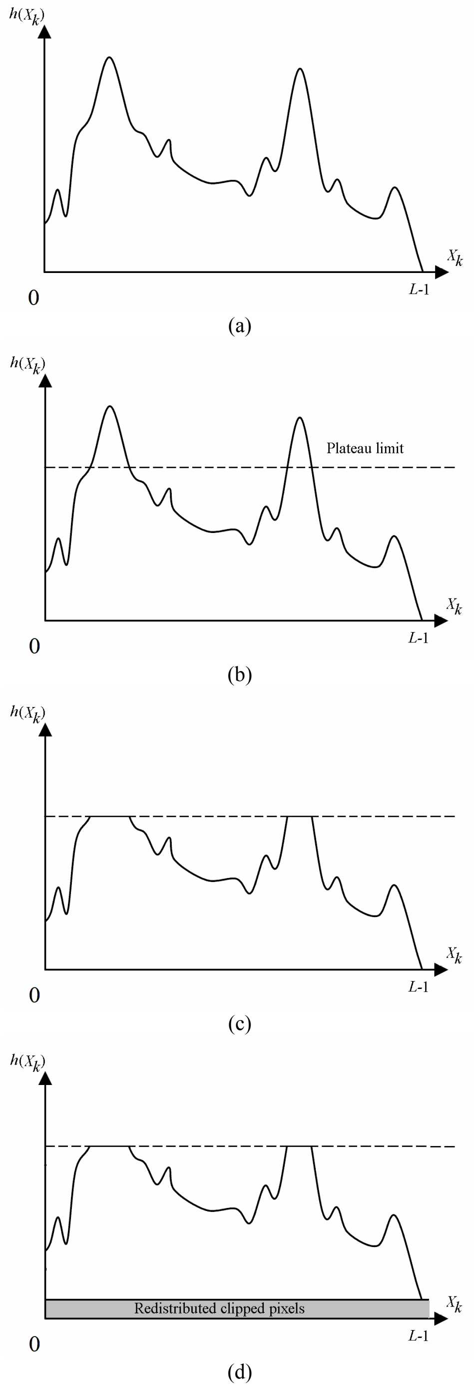

Fig. 1. An example of the process in clipped histogram equalization method. (a) The original input histogram. (b) The setting of the plateau limit. (c) The clipping of the histogram based on the plateau limit. (d) In some cases, the clipped portion is redistributed back into the modified histogram.

The process also requires further processing time. Methods that require the redistribution of the clipped portion increase the complexity of them.

Therefore, we simplified the method of clipped histogram equalization by assigned the plateau limit automatically, based on a simple calculation, in order to make it more suitable for an automated system. This will be described in the next section.

III. Methodology

This section describes the methodology of Bi-Histogram Equalization with a Plateau Value (BHEPL). First, similar to BBHE [4], the average intensity of the input image, X_m, is calculated. Then, BHEPL decomposes the input image into two sub-images $\mathbf{X}_L$ and $\mathbf{X}_U$ based on X_m as given in (8) to (10).

$$\mathbf{X} = \mathbf{X}_L \cup \mathbf{X}_U \tag{8}$$

where

$$\mathbf{X}_L = \left\{ X(i,j) \mid X(i,j) \le X_m, \forall X(i,j) \in \mathbf{X} \right\} \tag{9}$$

and

$$\mathbf{X}_U = \left\{ X(i,j) \mid X(i,j) > X_m, \forall X(i,j) \in \mathbf{X} \right\} \tag{10}$$

Note that the sub-image $\mathbf{X}_L$ is composed of $\{X_0, X_1, .., X_m\}$, and the another sub-image $\mathbf{X}_U$ is composed of $\{X_{m+1}, X_{m+2}, .., X_{L-1}\}$. Actually, this condition separates the input histogram into two sections, as shown in Fig. 2(a).

The histogram created from $\mathbf{X}_L$ is denoted as h_L, and the histogram created from $\mathbf{X}_U$ is denoted as h_U. By using these histograms, BHEPL finds two plateau limits T_L and T_U, for $\mathbf{X}_U$ and $\mathbf{X}_L$, respectively (see Fig. 2(b)). The values for T_L and T_U are set automatically, by using (11) and (12).

$$T_L = \frac{1}{X_m + 1} \sum_{k=0}^{X_m} h_L(k) \tag{11}$$

and

$$T_U = \frac{1}{(L-1) - X_m} \sum_{k=X_m+1}^{X_{L-1}} h_U(k) \tag{12}$$

As given by (11) T_L is actually the average of h_L. Similarly, from (12), T_U is the average of h_U.

Next, in order to control the enhancement rate of BHEPL, sub-histograms h_L and h_U are clipped as given in (13) and (14). This is shown in Fig. 2(c). The clipped histogram versions are denoted as h_{CL} and h_{CU}.

$$h_{CL}(x) = \begin{cases} h_L(x) & \text{if } h_L(x) \le T_L \\ T_L & \text{elsewhere} \end{cases} \tag{13}$$

and

$$h_{UL}(x) = \begin{cases} h_U(x) & \text{if } h_U(x) \le T_U \\ T_U & \text{elsewhere} \end{cases} \tag{14}$$

By clipping the histogram using the plateau limit as the average of the number of intensity occurrence, the enhancement rate of BHEPL will not be beyond the enhancement rate of an ideal histogram equalized image (i.e.

an image with a flat histogram). The input image with a good contrast and high entropy value normally will have an almost flat histogram. For this case, not much portions from the input histogram will be clipped. For poor contrast image, the input histogram is normally being dominated by a certain range of intensity values. By using plateau values, the histogram bins in these ranges will be clipped in order to avoid intensity saturation in the output image.

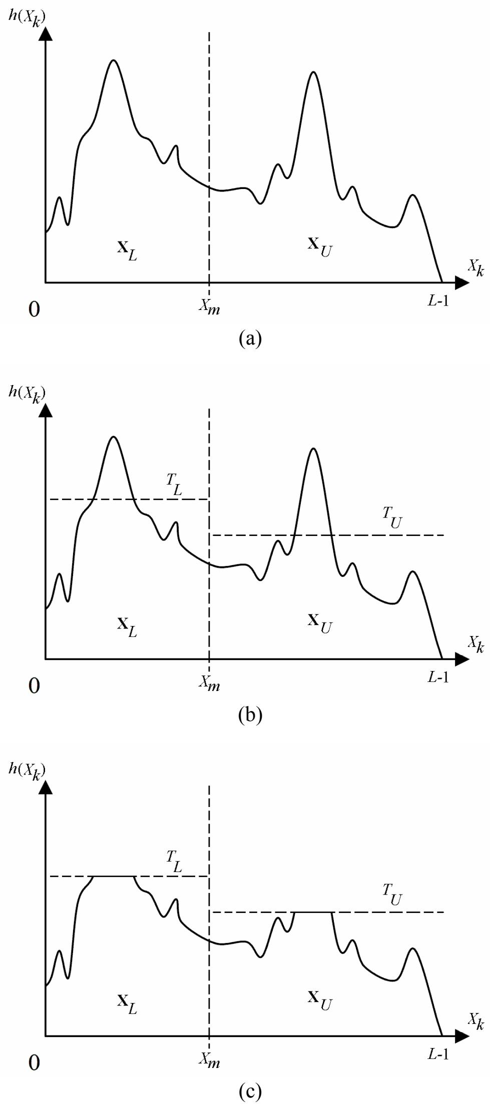

Fig. 2. An example of the process in BHEPL. (a) The original input histogram is divided into two based on X_m. (b) The setting of the plateau limits. (c) The clipping of the histogram based on the plateau limits.

After the clipping process, BHEPL defines M_1 and M_2 as:

$$M_1 = \sum_{k=X_0}^{X_m} h_{CL}(k) \tag{15}$$

$$M_2 = \sum_{k=X_{m+1}}^{X_{L-1}} h_{CU}(k) \tag{16}$$

M_1 is actually the total number of samples in $\mathbf{X}_L$ and M_2 is the total number of samples in $\mathbf{X}_U$.

Then, the respective probability density functions for $\mathbf{X}_L$ and $\mathbf{X}_U$ are given by equation (17) and (18).

$$p_L(X_k) = \frac{h_L(X_k)}{M_1}, \qquad \text{for } k = 0,1,...,m \tag{17}$$

$$p_U(X_k) = \frac{h_U(X_k)}{M_2}, \qquad \text{for } k = m+1, m+2,..., L-1 \tag{18}$$

Next, the respective cumulative density functions for $\mathbf{X}_L$ and $\mathbf{X}_U$ are defined by using (19) and (20).

$$c_L(X_k) = \sum_{j=0}^{m} p_L(X_j) \tag{19}$$

$$c_U(X_k) = \sum_{j=m+1}^{L-1} p_U(X_j) \tag{20}$$

By definition, $c_L(X_m)$=1 and $c_U(X_{L-1})$=1.

As BHEPL is a histogram equalization based method, cumulative density functions are used as the transform functions to assign the new intensity values to the input image. The transform functions for BHEPL are defined in (21) and (22).

$$f_L(x) = X_0 + (X_m - X_0).\left[c_L(x) - 0.5\, p_L(x)\right] \tag{21}$$

$$f_U(x) = X_{m+1} + (X_{L-1} - X_{m+1}).\left[c_U(x) - 0.5\, p_U(x)\right] \tag{22}$$

The decomposed sub-images are equalized independently based on their transform functions. Finally, the output image of BHEPL, Y, is expressed by (23) to (25).

$$\mathbf{Y} = \{Y(i,j)\} = f_L(\mathbf{Y}_L) \cup f_U(\mathbf{Y}_U) \tag{23}$$

where

$$f_L(\mathbf{X}_L) = \left\{ f_L(X(i,j)) \mid \forall X(i,j) \in \mathbf{X}_L \right\} \tag{24}$$

and

$$f_U(\mathbf{X}_U) = \left\{ f_U(X(i,j)) \mid \forall X(i,j) \in \mathbf{X}_U \right\} \tag{25}$$

It is worth noting that we do not redistribute the clipped portions back into the modified histogram. As a consequence, BHEPL is simple to be implemented and less hardware and circuitries are needed.

IV. Experimental Results

In addition to BHEPL, ten other methods have been implemented for comparison. They are linear stretching (LS), global histogram equalization (GHE), Brightness Preserving Bi-Histogram Equalization (BBHE) [4], Dual Sub-Image Histogram Equalization (DSIHE) [6], Minimum Mean Brightness Error Histogram Equalization (MMBEBHE) [7], Recursive Mean-Separate Histogram Equalization (RMSHE) [9], Recursive Sub-Image Histogram Equalization (RSIHE) [13], Multi-Peak Histogram Equalization (MPHE) [11], Dynamic Histogram Equalization (DHE) [12], and Modified Self-Adaptive Plateau Histogram Equalization (MSAPHE) [25]. BBHE, DSIHE and MMBEBHE present the bisections MBPHE. RMSHE, RSIHE, MPHE and DHE present the multi-sections MBPHE. MSAPHE presents the clipped histogram equalization methods.

Fig. 3. Results of all methods tested in this work using "*Image1*". (a) Input image. (b) LS-ed image. (c) GHE-ed image. (d) BBHE-ed image. (e) DSIHE-ed image. (f) MMBEBHE-ed image. (g) RMSHE-ed image. (h) RSIHE-ed image. (i) MPHE-ed image. (j) DHE-ed image. (k) MSAPHE-ed image. (l) BHEPL-ed image (i.e. the proposed method).

For the implementation of both RMSHE and RSIHE, we set the recursion level (i.e. r) to be equal to two. With this parameter setting, both RMSHE and RSIHE will divide the input histogram into four sub-histograms.

In this work, three sample images of size 3648×2736 pixels (i.e. 10 Mega pixels images), have been used for the evaluation purpose. These sample images are shown in Fig. 3(a), Fig. 4(a), and Fig. 5(a). *Image1* is a sample of an image with good contrast. *Image2* and *Image3* are used to present low contrast images, dominated by low intensity values.

From Fig. 3, we can see that all the methods tested in this experiment produce almost equivalent good enhancement results. Not much artifacts can be seen from these output images. This is because the input image is already has a good contrast; its intensity values occupy a wide dynamic range, and are not too concentrated on a certain range.

Fig. 4. Results of all methods tested in this work using "*Image2*". (a) Input image. (b) LS-ed image. (c) GHE-ed image. (d) BBHE-ed image. (e) DSIHE-ed image. (f) MMBEBHE-ed image. (g) RMSHE-ed image. (h) RSIHE-ed image. (i) MPHE-ed image. (j) DHE-ed image. (k) MSAPHE-ed image. (l) BHEPL-ed image (i.e. the proposed method).

From Fig. 4 and Fig. 5, we can see that LS does not enhance the image much. GHE changes the intensity values abruptly, and therefore, tends to produce level saturation effect. Similarly, the results from MBPHE methods also suffer from intensity saturation artifacts and unnatural enhancement. The results from MSAPHE and BHEPL are acceptable.

In order to evaluate the ability of the enhancement method to maintain the mean brightness, the Average Absolute Mean Brightness Error (*AAMBE*) will be used as the performance measure. *AAMBE* is defined as:

$$AAMBE = \frac{1}{S}\sum_{n=1}^{S}\left|\widetilde{\mathbf{X}} - \widetilde{\mathbf{Y}}\right| \qquad (26)$$

Fig. 5. Results of all methods tested in this work using "*Image3*". (a) Input image. (b) LS-ed image. (c) GHE-ed image. (d) BBHE-ed image. (e) DSIHE-ed image. (f) MMBEBHE-ed image. (g) RMSHE-ed image. (h) RSIHE-ed image. (i) MPHE-ed image. (j) DHE-ed image. (k) MSAPHE-ed image. (l) BHEPL-ed image (i.e. the proposed method).

where S is the total number of sample images, $\tilde{\mathbf{X}}$ is the average intensity of test image n, while $\tilde{\mathbf{Y}}$ is the average intensity of the corresponding output image.

If the mean brightness of the input is successfully maintained in the output image, this can be seen by a small value of *AAMBE*. Therefore, a method with mean brightness preservation ability will produce small *AAMBE* value.

Table I shows the *AAMBE* measure obtained from three sample images. Table II shows the average execution time of each method to process a ten Mega pixels image. From Table I, we can see that LS, MMBEBHE, and DHE produce output images with *AAMBE* less than ten. However, as referred to Fig. 3 to Fig. 5, not much enhancement could be obtained from these methods.

TABLE I
AAMBE MEASURE OBTAINED FROM THREE SAMPLE IMAGES

Method	AAMBE
LS	6.27
GHE	79.04
BBHE	49.95
DSIHE	44.01
MMBEBHE	4.27
RMSHE	17.28
RSIHE	20.11
MPHE	45.83
DHE	2.8
MSAPHE	50.94
BHEPL	27.89

TABLE II
AVERAGE EXECUTION TIME OBTAINED FROM THREE SAMPLE IMAGES

Method	Average execution time
LS	51.67ms
GHE	32.07ms
BBHE	33.33ms
DSIHE	34.40ms
MMBEBHE	62.67ms
RMSHE	62.00ms
RSIHE	62.33ms
MPHE	62.33ms
DHE	57.33ms
MSAPHE	34.47ms
BHEPL	34.20ms

Table I suggests that BHEPL has a good brightness preserving ability. This method produces a smaller *AAMBE* value as compared with some other MBPHE methods, including BBHE, DSIHE, and MPHE. Among the methods with minimum artifacts, we can see that BHEPL also produces a smaller *AAMBE* value compared with the one produce by MSAPHE. Table II shows that BHEPL method is only require a short processing time. The processing time required by BHEPL is as equal to the one used by GHE and other bisections MPHE.

V. CONCLUSION

In this paper, BHEPL has been proposed as a hybrid between mean brightness preserving histogram equalization method with clipped histogram equalization method. Experimental results show that this proposed method can enhance the images without producing unwanted artifacts. The method also is able to maintain the mean brightness better than some well known mean brightness preserving histogram equalization methods.

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