Histogram Equalization Based Mean Self – Adaptive Plateau Histogram Equalization for Brightness Preserving and Contrast Enhancement

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Abstract: Histogram Equations (HE) is a simple and effective method for contrast enhancement as it can automatically define the intensity transformation function based on statistical characteristics of the image. Where preservation of the original brightness is essential to avoid annoying artefacts, HE tends to alter the brightness of the entire image and it stretches the contrast of the high histogram regions, and compresses the contrast of the low histogram regions. HE also produces saturation effects by extremely pushing the intensities towards the right or the left side of the histogram. Plateau Histogram Equalization (PHE) or Clipping Histogram Equalization (CHE) is a technique to implement the HE to overcome these drawbacks. In the present paper, a adapted method of Self-Adaptive Plateau Histogram Equalization (SAPHE), developed with mean filter and mean threshold value is described and compared the experimental results with Histogram Equalization (HE), Bi-Histogram Equalization with Plateau Limit (BHEPL), Self-Adaptive Plateau Histogram Equalization (SAPHE) and Modified Self-Adaptive Plateau Histogram Equalization (Modified SAPHE) by using image quality measures such as Absolute Mean Brightness Error (AMBE) and Peak-Signal to Noise Ratio (PSNR).

Keywords: Histogram Equalization, Brightness Preserving, Contrast Enhancement, Clipped Histogram Equalization, image quality, Self-Adaptive Plateau Histogram Equalization

Introduction:

Image enhancement is one of the most interesting and important phase in the domain of digital image processing. Image enhancement is a process involving changing the pixels’ intensity of the input image, so that the output image should subjectively looks better [1]. The main purpose of image enhancement is to bring out details that are hidden in the image, or to increase the contrast in a low contrast image. Image enhancement is used to transform an image based on the psychological characteristics of the human visual system [2]. Contrast enhancement is an important step in image processing for both human and computer vision. It is widely used for medical image processing and as a pre-processing step in speech recognition, texture synthesis, and many other image/video processing applications [3-6]. Contrast enhancement is classified into indirect and indirect methods of contrast enhancement [7]. Histogram equalization [8] and histogram specification are two well-known indirect methods, where histogram of the image is modified. Because of stretching the global distribution of the intensity, indirect method is not efficient and effective. On the other hand, in the direct method of contrast enhancement, a definition of the contrast is used to measure the contrast and enhance the image by modifying the contrast measurement [9][10][11][12]. Histogram Equalization (HE) is one of the most common methods used for improving contrast in digital images. Histogram equalization results in either under-saturation or over-saturation of important regions of the image due to its drawback of changing the brightness globally. It is generally stretches the contrast of the high histogram regions, and compresses the contrast of low histogram regions [13]. As a result, 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.

To overcome the drawbacks of Histogram Equalization (HE) method several HE-based techniques have been proposed. Based on the method of modification of histogram equalization, the techniques are categorized into Bi-Histogram Equalization, Multi-Histogram Equalization and Clipping Histogram Equalization methods. Bi-histogram equalization methods are preserving the brightness and enhance contrasts of the image significantly, but introduces over-enhancement or over-brightness along with annoying artefacts in the image. Multi histogram equalization methods are perform with good brightness preserving without introducing any undesirable artefacts, but sacrifices the enhancement of the contrast in the image. Clipping histogram equalization methods are superior in control the enhancement rate, brightness preserving and avoiding over amplification of noise in the image.

In this paper, one of the existing clipped or plateau histogram equalization called Self-Adaptive Plateau Histogram Equalization is implemented and modified by introducing mean filter and mean threshold value instead of median filter and median threshold value respectively for contrast enhancement and brightness preserving of digital images. The implemented and modified methods Mean Self-Adaptive Plateau
Histogram Equalization (MSAPHE) and Modified Mean Self-Adaptive Plateau Histogram Equalization (Modified MSAPHE) are briefly discussed, analysed and compared with Histogram Equalization (HE), Self-Adaptive Plateau Histogram Equalization (SAPHE), Modified Self-Adaptive Plateau Histogram Equalization (Modified SAPHE) and other clipped histogram equalization methods. Bi-Histogram Equalization With Plateau Limit (BHEPL) [15] based on image quality measures such as AMBE and PSNR.

The present paper is organized in five sections; Section 1 provides brief introduction of image processing and contrast enhancement and section 2 describes the principles and methods of clipped histogram equalization techniques. Section 3 defines various image quality assessment methods used for assessment of performance of techniques in terms of contrast enhancement and brightness preserving. Results and comparative discussion of methods are specified in section 4 and concluding remarks are presented in section 5.

**The principles of Self-Adaptive Plateau Histogram Equalization (SAPHE)**

Clipping or Plateau Histogram Equalization

In histogram equalization methods, the enhancement rate is proportional to the rate of cumulative density function c(x). Limit the enhancement rate by limiting the value of p(x) or h(x) [14] as shown in equation (1).

\[
dc(x) = p(x)
\]

Where, p(x) and h(x) are probability density function and histogram of intensity ‘x’, respectively for a given image ‘X’. A clipped histogram equalization method restricting the enhancement rate to overcome the drawbacks of histogram equalization method and 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. The histogram will be clipped with threshold or clipping limit and clipped portion is redistributed back into the histogram in the cases of dark images or where, brightness preserving is more essential. There are two major problems associated with clipped histogram equalization are, 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 and some of the methods put weight to the modified histogram. The weight factor is also dependent on the user [15].

Appropriate plateau threshold value would greatly enhance the contrast of the image and in the plateau histogram equalization method, the threshold value ‘T’ is selected and if the value of histogram of an image P(K) is greater than T, then it is shifted to equal \[ T \]

[16], otherwise it is unchanged. The plateau histogram of an image \[ P_T(k) \] is computed as:

\[
P_T(k) = \begin{cases} 
\frac{p(k)}{T}, & \text{if } p(k) \leq T, \\
\frac{p(k)}{T}, & \text{if } p(k) > T, 
\end{cases}
\]

Where, ‘k’ represents the gray level of an image, \( 0 \leq k \leq 255 \) for 8-bit data. Then, the cumulative histogram of an image \( F_T(k) \) is calculated as follows:

\[
F_T(k) = \sum_{j=0}^{k} P_T(j) \quad 0 \leq k \leq 255
\]

**Self-Adaptive Plateau Histogram Equalization (SAPHE)**

Self-Adaptive Plateau Histogram Equalization (SAPHE) [16] has proposed to enhance the main objects and suppress the background for infrared images. In SAPHE, the original histogram \( h(x) \) is obtained from the input image, for \( 0 \leq x \leq L-1 \). Histogram \( h(x) \), is filtered by using a median filter of 3-neighbour (i.e. a median filter of size 1X7 pixels), to reduce the fluctuation and also to remove some empty bins inside the histogram. A new congregation histogram \( \{h(x)\} \) is formed based on non-empty bins in the filtered histogram. Where, J is the number of nonzero units in filtered histogram.

Local maximum values and global maximum value of \( h(x) \) are found by applying differential operation to \( h(x) \) as shown below:

\[
h'(x) = h(x) - h(x-1), \quad 1 \leq x \leq J
\]

A sub-congregation \( \{h(x_i)\} \) or histogram local maximum values \( h(x_i) \), are found by using the equations (6) and (7):

\[
h'(x) < \min [h'(x-1), h'(x+1)]
\]

\[
h(x-1) > 0, h'(x+1) < 0
\]

Where, \( 0 \leq x \leq J, 1 \leq i \leq N_{max} \) and \( N_{max} \) is the number of local maximum values. The global maximum value \( h(x_0) \) is found out from \( h(x) \). Median \( h_m \), is derived from sub-congregation \( \{h(x_i)\} \), \( k \leq i \leq N_{max} \). Then, the evaluated \( h_m \), is the plateau threshold value (i.e. T). The modified histogram \( h_{mod}(x) \) with the threshold value could be generated by equation (8):

\[
h_{mod}(x) = \begin{cases} 
h(x), & \text{for } h(x) \leq T \\
T, & \text{otherwise}
\end{cases}
\]

PDF is found from \( h_{mod}(x) \) and then cumulative density function (CDF), c(x), is determined from the PDF. The transformation function, f(x) is obtained for the final output image as per the equation (9):
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\[ f(x) = \frac{(l-1)c(x)}{c(l-1)} \]  

(9)

SAPHE has been successfully implemented for infrared images, but still it has a limitation in detecting local maximum value to determine the plateau threshold value.

**Modified Self-Adaptive Plateau Histogram Equalization (Modified SAPHE)**

Modified self-Adaptive Plateau Histogram Equalization (Modified SAPHE) [17] has proposed to microscopic images by eliminating 1D median filtering, not only to speed up the process, but also to select the threshold value globally from the entire histogram range without considering local maximum and global maximum values.

SAPHE method has either failed to detect histogram local maximum, or only detect one histogram local maximum and it couldn’t determine the plateau threshold value T. If SAPHE detects only one local maximum, that maximum value is actually the global maximum of the histogram. In this case, the output image was exactly the same as the image obtained from Histogram Equalization (HE). Because of these reasons Modified SAPHE is not compared results with SAPHE. To overcome these drawbacks and improve the contrast and brightness preserving of digital images, a new algorithm namely Mean Self-Adaptive Plateau Histogram Equalization (MSAPHE) and followed by Modified Mean Self-Adaptive Plateau Histogram Equalization (Modified MSAPHE) are proposed, analysed and compared the results with existing algorithms.

**Mean Self-Adaptive Plateau Histogram Equalization (MSAPHE)**

Mean Self-Adaptive Plateau Histogram Equalization (MSAPHE), which is proposed in this paper, consists of four steps;

1. Smoothening the input image histogram with 3-neighbour Median/Mean filter
2. Find the local maximum and global maximum values
3. Selection of optimal mean plateau value
4. Modify the histogram according to mean plateau value and equalize the histogram
5. Normalizing the image brightness

In MSAPHE, histogram of the original image is filtered by using a 3-neighbour median/mean filter to reduce the fluctuation and also to remove some empty bins inside the histogram. From the filtered histogram, local maximum value and global maximum values are found and then, mean of the local maximums is derived. The mean value is treated as mean plateau threshold value and modified the histogram using equation (8). The PDF is calculated from the modified histogram and then, cumulative density factor (CDF) is derived from this PDF. The transformation function \( f(x) \) is derived from the equation (9) and then normalizes the image for brightness preserving.

**Modified Mean Self-Adaptive Plateau Histogram Equalization (Modified MSAPHE)**

Modified Self-Adaptive Plateau Histogram Equalization (Modified SAPHE) is similar to Modified SAPHE, but the plateau threshold value is mean of the global histogram instead of median threshold value.

MSAPHE and Modified MSAPHE are tested with test images in the cases of filtered with a 3-neighbour median filter and a 3-neighbour mean filter. In the case of mean filter both SAPHE and MSAPHE are showing good contrast enhancement and brightness preserving. SAPHE had been developed exclusively for infrared images and Modified SAPHE is developed for enhancement of microscopic images. Results of both the methods are compared only with histogram equalization and in Modified SAPHE; author didn’t compare the results with SAPHE. In this paper, developed MSAPHE and Modified MSAPHE are compared with HE, SAPHE, Modified SAPHE and other clipped histogram equalization method Bi-Histogram Equalization with Plateau Limit (BHEPL).

**Measurement Tools to Asses Image Quality**

The present section describes the measurement tools used in this paper to evaluate the ability of the enhancement techniques to maintain the mean brightness.

**Absolute Mean Brightness Error (AMBE)**

An objective measurement is proposed to rate the performance in preserving the original brightness. It is stated as Absolute Mean Brightness Error (AMBE) and is defined as the absolute difference between the mean of the input and the output images and is proposed to rate the performance in preserving the original brightness [18] [19].

\[ AMBE = |E(X) - E(Y)| \]  

(10)

X and Y denotes the input and output image, respectively, and \( E(.) \) denotes the expected value, i.e. the statistical mean. Lower AMBE indicates the better brightness preservation of the image. Equation (10) clearly shows that AMBE is designed to detect one of the distortions—excessive brightness changes [20].

**Peak Signal-to-Noise Ratio (PSNR)**

Let, \( X(i,j) \) is a source image that contains M by N pixels and a reconstructed image \( Y(i,j) \), where Y is reconstructed by decoding the encoded version of \( X(i,j) \). In this method, errors are computed only on the luminance signal; so, the pixel values \( X(i,j) \) range between black (0) and white (255). First, the mean squared error (MSS) of the reconstructed image is calculated as;

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From the output images of cameraman and random_matches, MSAPHE has shown good contrast enhancement and brightness preserving (figure 1 and figure 2).

For the output images of test images bottom_left, crowd, face, WashingtonDC_Band3_564, and cameraman; MSAPHE has given better PSNR values (48.9815, 43.4112, 41.6105, 36.9924 and 36.9469 respectively) and less value of AMBE (0.4859, 0.7320, 1.0646, 0.8828 and 1.0374 respectively). SAPHE has presented quite less values of PSNR (48.8710, 42.7508, 41.1393, 36.9425 and 36.5885 respectively), indicating little poor contrast enhancement than MSAPHE, and SAPHE also introduced unwanted noise in the image (figure 1(d) and 2(d)). From figure 1, the results of test image cameraman, HE method has shown over brightness and there is no brightness preserving (AMBE value 16.3252 from table 2) in the back ground of the image and less contrast enhancement (PSNR value 27.4644 from table 2) as shown in figure 1(b). BHEPL also has shown less PSNR value 25.8974 from table 1 and good AMBE value 3.7843 from table 2, but for bright images crabpulsar-radio and pirate, it has failed in preserving the brightness (AMBE values 28.6446 and 18.4798 respectively) from table 2.

SAPHE, Modified SAPHE and Modified MSAPHE are shown good contrast enhancement but introduced undesirable artefacts in the image (figure 1(d), 1(e), 1(g); 2(d), 2(e), 2(g)), because SAPHE has a drawback of detecting the local maximum and in Modified SAPHE and Modified MSAPHE, input histogram is not filtered and threshold value has taken globally. SAPHE has given greater PSNR values than HE and BHEPL, indicating well contrast enhancement, for cameraman (36.5885) and for random_matches (35.9456) from table 1 and it has shown little poor brightness preserving for cameraman (AMBE 2.1240) and for random_matches (2.1087) from table 2. Even for bright images crabpulsar-radio (AMBE 3.8908) and pirate (AMBE 6.0846), SAPHE shown better brightness preserving than BHEPL. But, it has presented unwanted noise in the output images from figure 1(d) and 2(d).

Modified SAPHE also showed better contrast enhancement and brightness preserving for almost all test images, for cameraman (PSNR 38.9469 and AMBE 1.6269) and for random_matches (PSNR 36.2774 and AMBE 2.2309), but introduced unwanted noise in the output images 1(e) and 2(e). Modified MSAPHE, has not much preserving the brightness as Modified SAPHE, for cameraman (AMBE 3.6724) and random_matches (AMBE 3.3681) from table 2 and also introduced unnecessary artefacts due to global selection of mean threshold value for histogram modification from figure 1(g) and 2(g).
Due to median filtering of the input histogram and mean threshold value from local maximum and global maximum, MSAPHE has given well contrast enhancement (greater PSNR values) and brightness preserving (less AMBE values) than HE, BHEPL, SAPHE, Modified SAPHE and Modified MSAPHE. For bright images like crabpulsar-radio and pirate, has shown sacrificed contrast enhancement (PSNR 32.0271 and 29.5325 respectively) and less brightness preserving (AMBE 2.5980 and 3.0604). For cameraman (PSNR 36.9469 and AMBE 1.0374) and for random_matches (PSNR 35.9742 and AMBE 3.3681) values from table 1 and 2, representing healthy contrast enhancement and brightness preserving. The proper modification of histogram with mean threshold value, no noise is appeared in the output images of cameraman and random_matches from figure 1(f) and 2(f).

<table>
<thead>
<tr>
<th>Test Images</th>
<th>HE</th>
<th>BHEPL</th>
<th>SAPHE</th>
<th>Modified SAPHE</th>
<th>MSAPHE</th>
<th>Modified MSAPHE</th>
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</thead>
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<td>38.6723</td>
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<td>32.5338</td>
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<td>27.1169</td>
<td>41.1393</td>
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<td>41.6105</td>
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<td>27.9395</td>
<td>37.8353</td>
<td>36.1068</td>
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<td>26.8806</td>
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<tr>
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<td>33.3825</td>
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<table>
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<th>Test Images</th>
<th>HE</th>
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<th>SAPHE</th>
<th>Modified SAPHE</th>
<th>MSAPHE</th>
<th>Modified MSAPHE</th>
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<td>10.1918</td>
<td>1.1507</td>
<td>0.6547</td>
<td>1.0646</td>
<td>1.1867</td>
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<td>3.1766</td>
<td>1.1738</td>
<td>1.6493</td>
<td>1.2050</td>
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<td>3.3681</td>
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<tr>
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<td>1.7745</td>
<td>0.8828</td>
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</table>
Using Mean Filter:
In this process, the input histograms of both methods SAPHE and MSAPHE are filtered with mean filter and filtered histograms are modified with median threshold value in SAPHE and mean threshold value is used for MSAPHE technique. From the test images cameraman, bottom_left, face and crowd images, SAPHE with mean filter method shows high values of PSNR 38.9490, 51.9612, 45.9040 and 44.2494
respectively (table 3) and low values of AMBE 1.6304, 0.3217, 0.5702 and 0.6839 respectively (table 4), are exhibiting good contrast enhancement and brightness preserving. For images cameraman and random_matches, HE is shows very less PSNR (27.4644 and 26.5391 respectively) and BHEPL also shows very less contrast enhancement (PSNR 25.8974 and 27.7894 respectively) from table 3. HE also shows very poor brightness preserving for cameraman (AMBE 16.3252) and for random_matches (AMBE 23.7511) from table 4, but BHEPL shows good brightness preserving mean less AMBE values (bottom_left 0.5156, random_matches 0.4424 and crowd 2.6951) almost all test images compared to HE except bright images like crabpulsar-radio (AMBE 28.6446) and pirate (AMBE 18.4798). SAPHE shows slightly better contrast enhancement than the method of median filter, for cameraman (PSNR 38.9490) and for random_matches (PSNR 36.6659) and good AMBE values for cameraman (1.6034) and random_matches (2.0614) but output images are not much free from artefacts because of the drawbacks of SAPHE from figure 3(d) and 4(d). Modified SAPHE also shows well contrast enhancement and AMBE values like SAPHE, for cameraman (PSNR 38.6723, AMBE 1.6269) and random_matches (PSNR 36.2774, AMBE 2.2309) from table 3 and table 4, but shows additional annoying artefacts in the output image, because of non-filtering the input histogram during the process from figure 3(e) and 4(e). MSAPHE has shown better PSNR and AMBE values in the case of mean filter with mean threshold value without introducing any noise in the output images. MSAPHE has given good contrast enhancement for images face (PSNR 46.2367), crowd (PSNR 44.4017), cameraman (PSNR 39.4115) and Hurricane_Andrew (PSNR 37.4260) from table 3. It also given good AMBE values very close zero for images, bottom_left (AMBE 0.2894), face (AMBE 0.5127) and crowd (AMBE 0.6314) from table 4 representing well brightness preserving of images. For images cameraman (PSNR 39.4115 and AMBE 1.5323) and random_matches (PSNR 36.6882 and AMBE 2.0343), presenting efficient contrast enhancement and brightness preserving, without any disturbances in the output images as shown in figure 3(f) and 4(f).

Modified SAPHE and Modified MSAPHE are shown good contrast enhancement without filtering the input histogram but introduced annoying artefacts in the output images of cameraman and random_matches as shown figure 3(e), 3(g), 4(e) and 4(g) respectively.
Fig. 3: Performance comparison using Cameraman image

Conclusions:
The present paper provides the Histogram Equalization (HE) based Mean Self-Adaptive Plateau Histogram Equalization (MSAPHE), a modified method of Self-Adaptive Plateau Histogram Equalization (SAPHE) with mean filter to filter input histogram instead of median filter and mean threshold value as a replacement for median threshold value.
In both the cases of median and mean filtering, SAPHE and MSAPHE are shown very good contrast enhancement and brightness preserving for all images, but SAPHE has introduced noise or artefacts because its drawback in detecting local and global maximum values to identify the median threshold value. Sometimes if it identifies only one local maximum, it will be the global maximum of that histogram. MSAPHE has shown better PSNR and AMBE values compared to HE, BHEPL, SAPHE, Modified SAPHE, Modified MSAPHE methods from table 1, 2, 3 and 4. HE and BHEPL are not given considerable PSNR values, but BHEPL has given very good brightness preserving for images bottom_left (0.5167), random_matches (0.44424) and crowd (2.9951) except bright images like crabpulsar-radio (AMBE 28.6446) and pirate (AMBE 18.4798).

Comparing to median filtering, in case of mean filtering, MSAPHE has given very good brightness preserving for dark images like bottom_left (AMBE 0.2894), crowd (AMBE 0.6314) and white images like face (AMBE 0.5127) and good contrast enhancement for images face (PSNR 46.2367), crowd (PSNR 44.4017), cameraman (PSNR 39.4115) and Hurricane Andrew (PSNR 37.4260) from table 3. Better contrast enhancement and brightness preserving of MSAPHE representing that, it is overcome the drawback of SAPHE in detecting local maximum and global maximum for determining the threshold value for proper histogram modification.

Modified Mean Self-Adaptive Plateau Histogram Equalization (Modified MSAPHE), a modified method of MSAPHE has given good contrast enhancement (PSNR) and quite poor AMBE values (pirate 6.0996, lenna 4.9752 and NASA_Mariner6_Mars 4.7580), because of non-filtering of the input histogram and resulted in zero value of histogram bins which introduced artefacts in the output images. Modified method of SAPHE, Modified Self-Adaptive Plateau Histogram Equalization (Modified SAPHE) also introduced annoying noise in the output images, but shown good contrast enhancement and brightness preserving.

MSAPHE, a mean threshold-based self-adaptive plateau histogram is an efficient method to enhance the contrast and preserving the brightness of digital images.

References: