Modified Self – Adaptive Plateau Histogram Equalization with Mean Threshold for Brightness Preserving and Contrast Enhancement

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Abstract* - Histogram Equalization (HE) is a simple, effective and widely used contrast enhancement technique as it can automatically define the intensity transformation function based on statistical characteristics of the image, but it tends to change the mean brightness of the image to the middle level of the gray level range. HE also produces saturation effects by extremely pushing the intensities towards the right or the left side of the histogram. To surmount these drawbacks, Clipping or Plateau Histogram Equalization techniques for brightness preserving and contrast enhancement have been proposed, but, these are not suitable for automatic systems because of manual selection of threshold level. Self-Adaptive Plateau Histogram Equalization (SAPHE) selects the threshold level automatically, but the process is relatively complicated and sometimes fails in execution. To overcome these drawbacks, a Modified Self - Adaptive Plateau Histogram Equalization with Mean threshold (Modified SAPHE-M) is proposed in this paper and compared the experimental results with Histogram Equalization (HE), 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:* Image contrast enhancement, histogram equalization, brightness preserving enhancement, plateau histogram equalization.**

I. INTRODUCTION

Image enhancement is one of the most important phase in the domain of digital image processing and it is a process involving changing the pixels' intensity of the input image [1]. The main drive of image enhancement is to bring out the 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 direct 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 [9-12]. To overcome the drawbacks of Histogram Equalization (HE) method, several HE-based techniques have been proposed. Based on the modification of input image histogram, the techniques are categorized into Bi-Histogram Equalization, Multi-Histogram Equalization and Clipping or Plateau 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, a clipped or plateau histogram equalization method, called Modified Self-Adaptive Plateau Histogram Equalization with Mean threshold (Modified SAPHE-M) has been proposed. It is a modified method of Self-Adaptive Plateau Histogram Equalization (SAPHE) by introducing mean threshold value instead of median threshold value for enhancement of contrast and brightness preserving of digital images. The developed Modified SAPHE-M is briefly discussed, analysed and compared with Histogram Equalization (HE), Self-Adaptive Plateau Histogram Equalization (SAPHE), Modified Self-Adaptive Plateau Histogram Equalization (Modified SAPHE) based on image quality measure values 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 the 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.

II. THE PRINCIPLE OF CLIPPING OR PLATEAU HISTOGRAM EQUALIZATION

A. 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 $h(x)$ [13] as shown in equation (1).

$$\frac{d\,c(x)}{dx} = p(x) \qquad (1)$$

Here, $p(x)$ 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. 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 [14], otherwise it is unchanged. The plateau histogram of an image $P_T(k)$ is computed as;

$$P_T(k)\begin{cases} P(k) & P(k) \le T, \\ T, & P(k) > T, \end{cases} \qquad (2)$$

Where, 'k' represents the gray level of an image, $0 \le k \le 255$ for 8-bit data. Then, the cumulative histogram of an image $F_T(k)$ is calculated as follows;

$$F_T(k) = \sum_{j=0}^{k} P_T(j) \qquad 0 \le k \le 255 \qquad (3)$$

$$D_T(k) = \left\lfloor \frac{255.F_T(k)}{F_T(255)} \right\rfloor \qquad (4)$$

Where, $D_T(k)$ is the value of 'k' after enhancement, and ⌊⌋ represents truncation to the next lower integer. While T equals to 1, previous enhancement algorithm is histogram projection, and while T equals to $P_{max}(k)$, it is histogram equalization. Clipped histogram equalization methods are not much suitable for automatic systems because of manual setting of plateau level, but in SAPHE, the plateau level will be automatically selected and the process is relatively complicated and sometimes fails in its execution [15].

B. Self-Adaptive Plateau Histogram Equalization (SAPHE)

Wang et al. [14] have proposed Self-Adaptive Plateau Histogram Equalization (SAPHE) to enhance the main objects and supress the background for infrared images. In SAPHE, the original histogram $h(x)$ is obtained from the input image, for $0 \le x \le L\text{-}1$. 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 $\{h(x)\ |0 \le x \le J\}$ 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 in equation (5);

$$h'(x)=h(x)-h(x\text{-}1), \quad for\ 1 \le x \le J \qquad (5)$$

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

$$|h'(x)|<min\{|h'(x\text{-}1)|,|h'(x+1)|\} \qquad (6)$$

$$h'(x\text{-}1)>0,\ h'(x+1)<0 \qquad (7)$$

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

$$h_{mod}(x) = \begin{cases} h(x), & for\ \ h(x) \le T \\ T, & otherwise \end{cases} \qquad (8)$$

Probability Density Function (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 obtains the final output image as per the equation (9);

$$f(x)=\left\lfloor \frac{(L-1).c(x)}{c(L-1)} \right\rfloor \qquad (9)$$

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

C. Modified Self-Adaptive Plateau Histogram Equalization (Modified SAPHE)

Modified self-Adaptive Plateau Histogram Equalization (Modified SAPHE) have introduced by Kong et al. [16] 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 Modified Self-Adaptive Plateau Histogram Equalization with Mean threshold (Modified SAPHE-M) is proposed, analysed and compared the results with existing algorithms.

D. Modified Self-Adaptive Plateau Histogram Equalization with Mean Threshold (Modified SAPHE-M)

Modified Self-Adaptive Plateau Histogram Equalization with Mean threshold (Modified SAPHE-M), which is proposed in this paper, consists of five steps;

1. Smoothening the input image histogram with 3-neighbour Median 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 Modified SAPHE-M, histogram of the original image is filtered by using a 3-neighbour median filter to reduce the fluctuation and also to remove empty bins inside the input histogram. From the filtered histogram, local maximum value and global maximum values are found and then, mean of the sub-congregation (set of values of filtered histogram) is derived from the equations (5), (6) and (7). The mean value is treated as plateau threshold value (*T*) and modified the histogram using equation (8). Further PDF is calculated from the modified histogram and then, cumulative density function (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. This normalization will make sure that the mean output intensity will be almost equal to the mean input intensity.

III. 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 preserving and contrast enhancement.

A. 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 [17] [18].

$$AMBE = |E(\boldsymbol{X}) - E(\boldsymbol{Y})| \qquad (10)$$

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 [19].

B. 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 Square Error (MSS) of the reconstructed image is calculated from equation (11);

$$MSS = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[X(i,j)-Y(i,j)]^2}{M \times N} \qquad (11)$$

The root mean square error is computed from root of MSE. Then the PSNR in decibels (dB) computed from the equation (12). Greater the value of PSNR gives better the contrast enhancement of the image.

$$PSNR = 20log_{10}(\frac{Max(Y(i,j))}{RMSE}) \qquad (12)$$

IV. RESULTS AND DISCUSSION

This section provides the experimental results of Modified SAPHE-M along with SAPHE, Modified SAPHE and HE for comparison. Proposed Modified SAPHE-M is developed using MATLAB programme and for comparative analysis, algorithm codes are also prepared for existing methods SAPHE, Modified SAPHE and HE. 10 different test images are compared using image quality assessment measures such as Absolute Mean Brightness Error (AMBE) and

Peak Signal-to-Noise Ratio (PSNR). Lower AMBE indicates the higher brightness preservation and higher PSNR gives greater the contrast enhancement of the image.

In this paper, Modified SAPHE-M is developed with mean threshold value for histogram modification. Modified SAPHE-M, SAPHE, Modified SAPHE and HE methods are tested with different test images and for comparative analysis, *Hurricane Andrew* and *bottom_left* images are considered in this paper. Results of *Hurricane Andrew* and *bottom_left* images are shown in figure 1 and figure 2 and the image quality assessment measures such as PSNR and AMBE values are tabulated in table 1 and table 2 respectively.

SAPHE and Modified SAPHE-M methods have been filtered the input histograms with median filter and median and mean threshold values are used for histogram modification respectively. For Modified SAPHE-M, the output images of test images *bottom_left, crowd, face, WashingtonDC_Band3_564, and cameraman;* has given better PSNR values (*48.9815, 43.4112, 41.6105, 36.9924 and 39.9469 respectively*) and less value of AMBE (*0.4059, 0.1320, 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 Modified SAPHE-M, and SAPHE also introduced unwanted noise in the image (figure 1(c) and 2(c)). From figure 1, the results of test image *Hurricane Andrew*, HE method has shown over brightness and there is no brightness preserving (AMBE *46.8385* from table 2) in the back ground of the image and less contrast enhancement (PSNR *25.0338* from table 1) as shown in figure 1(b).

SAPHE has given good contrast enhancement but introduced undesirable artefacts in the image (figure 1(c) and 2(c)), due to a drawback of detecting the local maximum and global maximum values for identification of median threshold value, resulting improper modification of filtered histogram producing noisy output image. Modified SAPHE, input histogram is not filtered and threshold value has taken globally. SAPHE has given greater PSNR values than HE, indicating well contrast enhancement, for *Hurricane Andrew* (*PSNR 37.5772*) and for *bottom_left (PSNR 48.8710*) from table 1 and it has shown little poor brightness preserving for *cameraman* (*AMBE 2.1240*), *random_matches* (*AMBE 2.1087*), *NASA_Mariner6_Mars* (*AMBE 3.8111*) and has shown very poor brightness preserving for bright images *crabpulsor_radio* (*AMBE 3.8908*), *Cygnusloop* (*AMBE 3.4184*) and *lenna* (*AMBE 3.5773*) from table 2. Modified SAPHE also shown, for *Hurricane Andrew* (*PSNR 36.1068 and AMBE 1.6493*) and for *bottom_left (PSNR 24.2115 and AMBE 0.6837)*, but introduced unwanted noise in the output images from figures 1(d) and 2(d) due to not filtering of the input histogram.

Due to median filtering of the input histogram and mean threshold value from local maximum and global maximum values of sub-congregation histogram *$\{h(x_i)\}$*, Modified SAPHE-M has given well contrast enhancement (greater PSNR values) and brightness preserving (less AMBE values) than HE, SAPHE and Modified SAPHE. For bright images like *crabpulsar-radio* and *pirate*, has shown sacrificed contrast enhancement (*PSNR 32.0217 and 31.5325 respectively*) and less brightness preserving (*AMBE 2.5980 and 3.0604 respectively*). For *Hurricane Andrew (PSNR 37.9688 and AMBE 1.0050)* and for *bottom_left (PSNR 48.9815 and AMBE 0.4059*) values from table 1 and 2, representing healthy contrasts enhancement and brightness preserving. The proper modification of histogram with mean threshold value, has given better output images of *Hurricane Andrew* and *bottom_left* from figure 1(e) and 2(e) without presenting any noise, representing the overcoming of drawbacks of SAPHE in identifying the threshold value by detecting the local maximum and global maximum values from filtered input histogram.

TABLE 1: ASSESSMENT OF CONTRAST ENHANCEMENT USING **PSNR**

Methods / *Test Images*	*HE*	*SAPHE*	*Modified SAPHE*	*Modified SAPHE-M*
cameraman	27.4644	36.5885	38.6723	39.9469
bottom_left	24.6083	48.8710	24.2115	48.9815
crabpulsar-radio	24.0689	31.7629	32.8220	32.0217
cygnusloop	24.0655	32.5368	31.8271	33.5338
face	25.1803	41.1393	40.1173	41.6105
Hurricane Andrew	25.0338	37.8353	36.1068	37.9688
lenna	26.5047	32.5772	33.4663	35.7256
pirate	27.0173	29.5666	29.5022	31.5325
random_matches	26.5391	35.9456	36.2774	36.9742
crowd	26.4628	42.7508	41.5153	43.4112
NASA_Mariner6_Mars	25.5758	33.0513	30.5639	33.3825
WashingtonDC_Band3_564	24.5542	36.9425	31.0423	36.9924

TABLE 2: ASSESSMENT OF BRIGHTNESS PRESERVING USING **AMBE**

Methods / *Test Images*	*HE*	*SAPHE*	*Modified SAPHE*	*Modified SAPHE-M*
cameraman	16.3252	2.1240	1.6269	1.0374
bottom_left	89.1241	0.4668	0.6837	0.4059
crabpulsar-radio	95.1651	3.8908	3.1356	2.5980
cygnusloop	73.6604	3.4189	3.4463	2.1679
face	34.6246	1.1507	0.6547	1.0646
Hurricane Andrew	46.8385	1.1738	1.6493	1.0050
lenna	25.7646	3.5773	3.2736	2.5679
pirate	21.0831	6.0846	6.0958	3.0604
random_matches	23.7511	2.1087	2.2309	1.1144
crowd	16.4857	0.8119	0.9616	0.1320
NASA_Mariner6_Mars	29.4974	3.8111	5.0082	3.6408
WashingtonDC_Band3_564	65.6660	1.9613	1.7745	0.8828

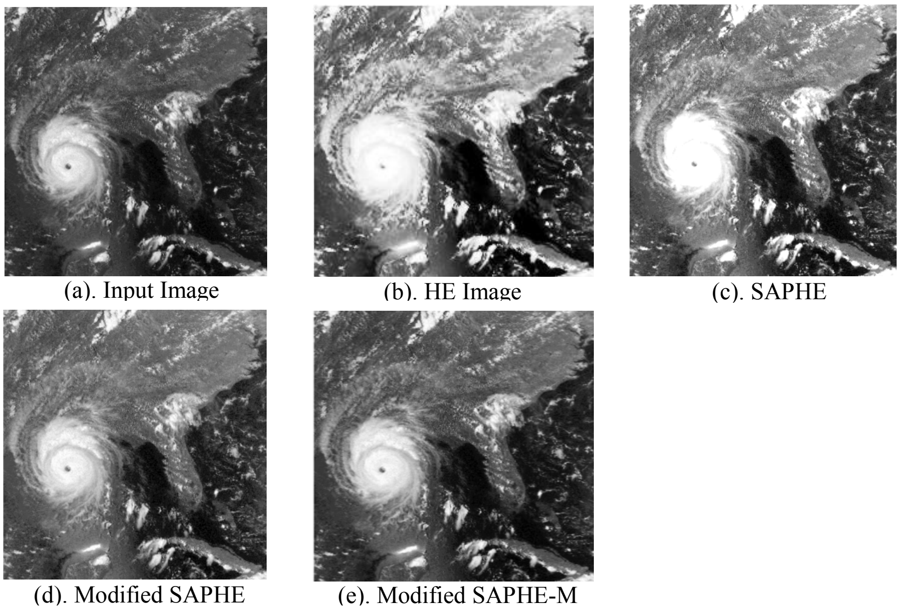

Figure.1: Performance comparison of *Hurricane Andrew* image

(a). Original Image, (b). Histogram Equalization, (c). Self-Adaptive Plateau Histogram Equalization (SAPHE), (d). Modified Self-Adaptive Plateau Histogram Equalization (Modified SAPHE), (e). Modified Self-Adaptive Plateau Histogram Equalization with Mean threshold (Modified SAPHE-M)

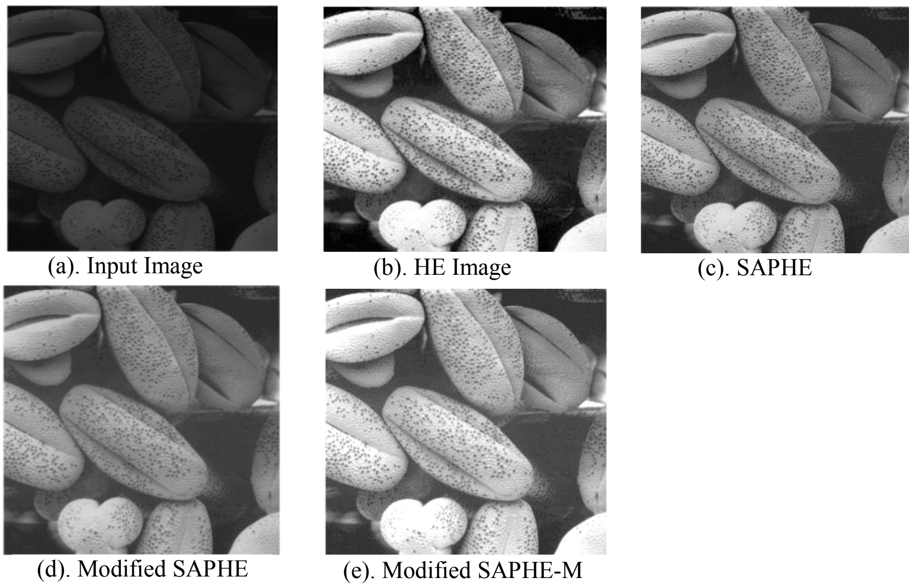

Figure.2: Performance comparison of *bottom_left* image

(a). Original Image, (b). Histogram Equalization, (c). Self-Adaptive Plateau Histogram Equalization (SAPHE), (d). Modified Self-Adaptive Plateau Histogram Equalization (Modified SAPHE), (e). Modified Self-Adaptive Plateau Histogram Equalization with Mean threshold (Modified SAPHE-M)

V. CONCLUSIONS

In this paper, Histogram Equalization (HE) based Modified Self-Adaptive Plateau Histogram Equalization with Mean threshold (Modified SAPHE-M), a modified method of Self-Adaptive Plateau Histogram Equalization (SAPHE) has been proposed to overcome the drawbacks of SAPHE and for better contrast enhancement and brightness preserving of digital images. Modified SAPHE-M is similar to SAPHE in terms of detecting the local maximum and global maximum but, instead of median threshold value, mean threshold value is used for histogram modification. SAPHE has given good contrast enhancement and brightness preserving except for few bright images, but has shown annoying noise or artefacts because of its drawback in detecting local and global maximum values for identifying the median threshold value. Sometimes if it identifies only one local maximum, it will be the global maximum of that histogram. Modified SAPHE, a modified method of SAPHE, also introduced annoying noise in the output images because of not filtering the empty bins from input histogram, but shown good contrast enhancement and brightness preserving. Experimental results shows that Modified SAPHE-M can enhance the images without introducing unwanted artefacts and gives better contrast enhancement (PSNR values) and brightness preserving (AMBE values) compared to HE, SAPHE, Modified SAPHE methods. Additionally, similar to HE-based techniques, Modified SAPHE-M is easy to develop and because of its simplicity, it can be used for in real time system applications. This method can also be used for remote sensing satellite images for contrast enhancement and brightness preserving for better feature extractions based on various applications.

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