Standard Intensity Deviation Approach based Clipped Sub Image Histogram Equalization Algorithm for Image Enhancement

Sandeepa K S , Basavaraj N Jagadale
Department of Electronics
Kuvempu University
Karnataka, India

J S Bhat
Department of Physics
Karnataka University
Karnataka, India

***Abstract*—The limitations of the hardware and dynamic range of digital camera have created the demand for post processing software tool to improve image quality. Image enhancement is a technique that helps to improve finer details of the image. This paper presents a new algorithm for contrast enhancement, where the enhancement rate is controlled by clipped histogram approach, which uses standard intensity deviation. Here standard intensity deviation is used to divide and equalize the image histogram. The equalization processes is applied to sub images independently and combine them into one complete enhanced image. The conventional histogram equalization stretches the dynamic range which leads to a large gap between adjacent pixels that produces over enhancement problem. This drawback is overcome by defining standard intensity deviation value to split and equalize the histogram. The selection of suitable threshold value for clipping and splitting image, provides better enhancement over other methods. The simulation results show that proposed method out performs other conventional histogram equalization (HE) methods and effectively preserves entropy.**

Keywords—Standard intensity deviation; histogram clipping; histogram equalization; contrast enhancement; entropy

I. Introduction

Digital imagery plays an important role in the fields of medical, industry, civil, security, astronomy, animation, forensic, web design. Image processing, helps human visual perception, visual quality and is used in many areas of image enhancement, image compression, image de-noising, image sharpening etc. Image enhancement is the process of making digital image more suitable for visualization or for further analysis and identifying key features of image. Contrast enhancement of an image is one of the well-known techniques in image enhancement. The contrast is created by the difference in luminance reflectance from two adjacent surfaces [1], [2] and enhancement is a technique of changing the pixel intensity of the input image. The quality of image contrast reduces, due to various factors, like of poor and ambient light conditions, aperture size and shutter speed of camera [3]. Histogram equalization is a technique that improves image contrast by adjusting image intensity and is used in wide range of applications as it is a simple method can be implemented easily. Its performance is limited because it tends to change the mean brightness of the image to the middle of the gray level and creates undesirable effects that lead to over enhancement [4]. This method doesn't preserve image brightness because it is global operation and introduces the noise artifacts. To overcome this problem, different methods of histogram equalization were proposed to enhance the image brightness [5].

To preserve mean brightness of the image, Brightness preserving bi-histogram equalization (BBHE) method was proposed [6]. Here, mean value is used to bisect the histogram and then equalize both sub images independently. Another method, Dualistic sub image histogram equalization (DSIHE), follows BBHE and it differs in that it uses median value instead of mean to create sub images [7]. But, these methods fail to preserve the brightness of the image effectively. To improve the preservation of brightness, minimum mean brightness error bi-histogram equalization [MMBEBHE] was tried [8]. This method uses histogram separation based on threshold value and is an extension of BBHE, however, it fails to control the over enhancement.

To improve the visual quality of image, multi-histogram equalization approaches have come into existence. They are, recursive mean separate histogram equalization [RMSHE] [9], which performs BBHE recursively and recursive sub image histogram equalization [RSIHE], that performs division of histogram based median value [10]. From both methods, selection of number of iterations is an annoying issue and may lead to over enhancement. To overcome, over enhancement problem, histogram clipping approach was used and it helped in avoiding saturation effect and preserved the details of the image by controlling high frequency bins [11]-[13].

The exposure based sub image histogram equalization [ESIHE] performs enhancement of low exposure image by using exposure threshold value for image sub division [14]. This method equalizes, sub images individually and uses clipped histogram for controlling, over enhancement. It doesn't consider the variation of the exposure value from each gray value and stretches the contrast at high intensity region. This method is well suited for low exposure images and produce better visual quality images.

This paper refers to the ESIHE and proposes a contrast enhancement algorithm by defining new standard intensity deviation value instead of exposure threshold value. This improves the effect of enhancement in terms of average information contents. The performance of proposed method was analyzed by enhancing low exposure images and low exposure underwater images. We find that the proposed method helps in enhancing contrast, visual quality and average information contents of the images, as compared to others methods.

The paper is structured as follows: Section 2 describes the proposed method. Experimental results and discussion are given in Section 3 and the conclusion is given in Section 4.

II. Proposed Algorithm

The conventional histogram equalization methods improve the image contrast by stretching the dynamic range of the image using cumulative distribution function. Fig. 1(a), (c), (e) and (g) represent original image, HE image, BBHE image and ESIHE image, respectively. Fig 1(b), (d), (f) and (h) are the histograms of respective images. Fig. 1(c), (e) and (g) illustrates over enhancement problem, where, road, top of the truck and soil portions of image texture are very bright, which is highlighted in red square boxes. The reason for this problem is large gap between two adjacent gray values of the histogram (Fig. 1(d), (f) and (h)). The gap denotes the number of gray levels between two neighboring gray values, and large gap between the adjacent pixels leads to over enhancement problem [15].

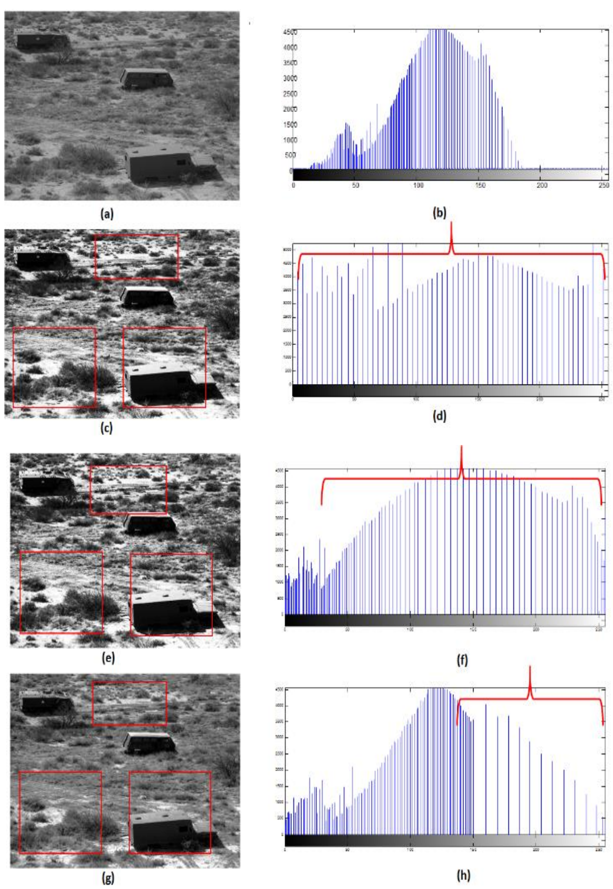


Fig. 1. Result of field image and its histogram (a) original image; (b) original image histogram; (c) HE image;(d) HE histogram; (e) BBHE image;(f) BBHE histogram; (g) ESIHE image; (h) ESIHE histogram.

From Fig. 1, it is found that, gap between adjacent pixels, affect the enhancement quality and selection of threshold value to divide the image histogram also plays an important role. To overcome these problems explained earlier, the standard intensity deviation based clipped sub image histogram equalization (SIDCSIHE) algorithm is presented by defining new threshold value. This value is being used to divide the image histogram, as it helps to enhance image contrast by preserving maximum information and minimizing the gap between adjacent pixels. The algorithm consists of three steps, namely standard intensity deviation value calculation, histogram clipping and histogram equalization.

A. Standard Intensity Deviation Value Calculation

To measure volatility of the image intensity, the standard deviation function σ , by finding the variance between corresponding intensity and mean image histogram is given by (1) [16].

$$\sigma = \left(\frac{\sum_{i=1}^{L}(i-H_{\mu})^{2} x H(i)}{\sum_{i=1}^{L} H(i)}\right)^{1/2} \quad (1)$$

The mean image histogram of the low contrast image is given by (2).

$$H_{\mu} = \frac{\sum_{i=1}^{L} H(i)\, i}{\sum_{i=1}^{L} H(i)} \quad (2)$$

where $H(i)$, is image histogram with its corresponding intensity i and L is its total number of gray levels. The normalized standard deviation value is expressed as in (3) and its range is [0 1]. Another parameter X_{SID} is defined in (4), by using normalized standard deviation value and it also used to modify each input gray level by dividing the image into two sub images.

$$\sigma_{norm} = \left(1 - \left(\sigma/_{L}\right)\right) \quad (3)$$

$$X_{SID} = L * \sigma_{norm} \quad (4)$$

B. Histogram Clipping

The process of clipping histogram controls the enhancement rate. The threshold value T_C given in (5) is calculated as an average number of grey level occurrences. The histogram bins are clipped, and is greater than the clipping threshold as given by (6). The histogram is then clipped by clipping threshold as shown in Fig. 2(b).

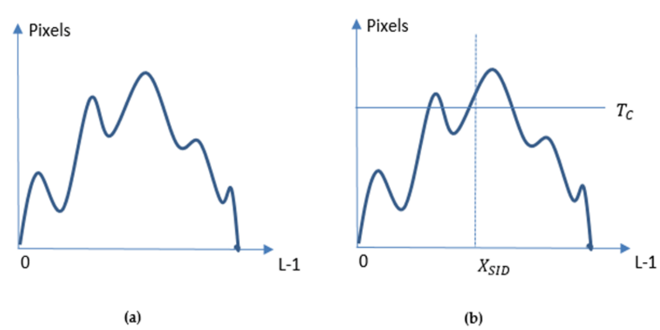


Fig. 2. Sub division process (a) Image Histogram sub division and clipping; (b) Image Histogram sub division and clipping.

$$T_c = mean\ (H(i)) \tag{5}$$

$$H_c(i) = T_c\ \ for\ H(i) \geq T_c \tag{6}$$

where $H(i)$ and $H_C(i)$ are the original and clipped histogram, respectively. The histogram clipping consumes lesser time as it needs less number of computations [14].

C. Clipped Histogram Sub Division and Equalization

Based on standard intensity deviation value X_{SID}, the clipped histogram is divided into two sub images I_{low} and I_{up} with ranges varying from 0 to X_{SID} and X_{SID}+1 to $L-1$ respectively. The probability of these two sub images are $P_{low}(i)$ and $P_{up}(i)$, respectively

$$P_{low}(i) = {H_c(i)}/{N_{low}} \quad \text{for } 0 \leq i \leq X_{SID} \tag{7}$$

$$P_{up}(i) = {H_c(i)}/{N_{up}} \quad \text{for } X_{SID} \leq i \leq L-1 \tag{8}$$

where N_{low} and N_{up} are total number of pixels in each sub images and its cumulative distribution function $C_{low}(i)$, $C_{up}(i)$ can be defined as:

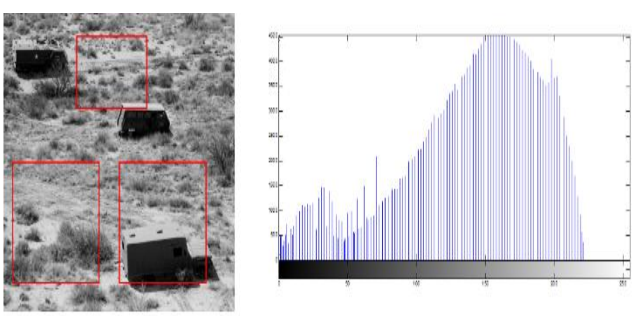
$$C_{low}(i) = \sum_{i=0}^{X_{SID}} P_{low}(i) \tag{9}$$

$$C_{up}(i) = \sum_{i=X_{SID}+1}^{L-1} P_{up}(i) \tag{10}$$

The histogram equalization is done individually for two sub images using the transfer function $F(i)$ as expressed in (11):

$$F(i) = \begin{cases} X_{SID} * \quad C_{low} & for\ 0\ \leq i \leq X_{SID} \\ (X_{SID}+1) +\ (L - X_{SID}+1) * C_{up} & for\ X_{SID+1} \leq i \leq L-1 \end{cases} \tag{11}$$

The sub images are combined into one final image by the transfer function $F(i)$ for further analysis. Fig. 3(a) is the processed image appears cleaner and overcome over enhancement in the highlighted boxes. Fig. 3(b) represents its histogram, has overcome the gap between the adjacent pixels which lead to better image quality.



(a) (b)

Fig. 3. Result of field image and its histogram (a) SIDCSIHE image; (b) SIDCSIHE image histogram.

D. Algorithm of SIDCSIHE

- Compute input image histogram H_i.
- Compute standard intensity deviation value and threshold parameter X_{SID}.
- Compute Histogram clipping $H_c(i)$ based clipping threshold T_c.
- The input clipped histogram splits into two sub images based X_{SID} .
- Histogram Equalization is applied on individual sub image histogram.
- Integrate both images into final image.

III. Results and Discussion

The pre-eminence of the proposed method is illustrated by comparing both objective and subjective assessments with well-known methods.

A. Objective Assessment

To verify the effect of enhancement, the objective assessment has been carried out and compared on the basis of entropy. Entropy means average information content that is the measure of richness of image details. A higher value indicates the availability of more information content and is perceived to have better quality of the image. Equation (12) defines entropy [17].

$$Entropy(p) = -\sum_{k=0}^{L-1} p(k) \log\ p(k) \tag{12}$$

where $p(k)$, is probability density function at the intensity level k and L is total number of gray levels of the image.

The different types of 15 test images with low exposure underwater images and low exposure images are used. The performances of the proposed method is compared with other existing methods HE, BBHE, DSIHE, MMSICHE ,NMHE and ESIHE for better entropy results. From Table I, it is evident that the proposed (SIDCSIHE) method has the highest entropy values as compared to other methods and its value is very near to the input average entropy value (6.269), which indicates that more information is extracted from an input image.

TABLE I. AVERAGE ENTROPY VALUE AND EXECUTION SPEED OF COMPARISION METHODS

Methods	**Entropy**	**Execution speed in sec**
HE	5.534	0.0688
BBHE	6.139	0.0888
DSIHE	6.120	0.0818
MMSICHE	6.193	1.2493
NMHE	6.095	0.1435
ESIHE	6.221	0.1465
SIDCSIHE	**6.227**	**0.0966**

To check its robustness, the proposed method execution time is compared with other methods because most of the studies focus on image quality as well as execution time. The execution of the method is carried out on the computer with 64bit, windows 8 and Intel i3 processor with 4GB RAM. The average execution time as compared to other methods has been tabulated in Table I. The execution time of the proposed method is compared with advanced methods MMSICHE, NMHE and ESIHE as the conventional methods HE, BBHE and DSIHE does not possess better visual quality.

B. Subjective Assessment

The performance of algorithm in contrast enhancement, provides the information about over enhancement and unnatural look of the image, by inspecting the visual quality of the processed image. Although objective assessment provides quantitative information but its quality evaluation can be accomplished by subjective assessment and this is the most direct approach to judge the quality of image from an observer. To prove the robustness and versatility of the proposed methods, the standard images are chosen from different fields, like, underwater images and low exposure images (tank, fish, elk, plane, sanctuary) as shown in Fig. 4 to 8.

Fig. 4(a) is a low contrast image. Fig. 4(b), (c) and (d) are processed by HE, BBHE and DSIHE leads over enhancement, can be seen in the visual appearance and corresponding histogram. Fig. 4(e), (f) are the results of MMSICHE and NMHE individually. These images seem to be gloomy and Fig. 4(f) is too dark, as compared to other images. Fig. 4(g), processed by ESIHE, has better enhancement over other methods. However, its histogram detail seems to equalize more in lower intensity region due to which the tank appears dark as compared to Fig. 4(h) proposed by SIDCSIHE. The image in Fig. 4(h) looks more natural with better visual quality than other methods.

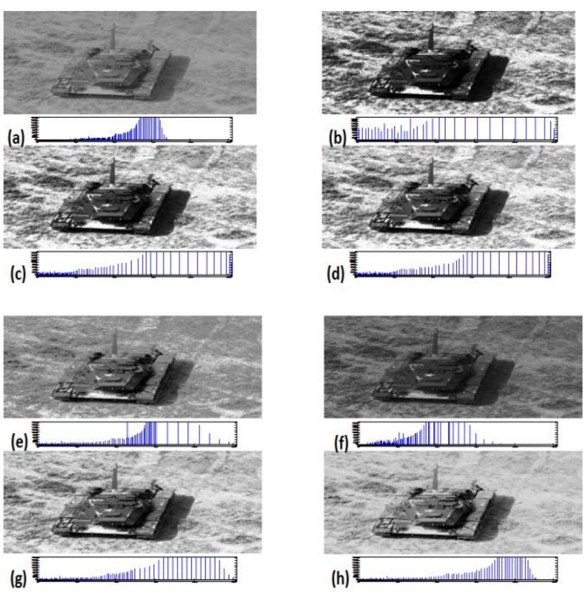


Fig. 4. Result of Tank image (a) original image; (b) HE image; (c) BBHE image ; (d) DSIHE image; (e) MMSICHE image; (f) NMHE image; (g) ESIHE image; (h) SIDCSIHE image.

Fig. 5(a) is an example of underwater low exposure fish image. Fig. 5(b) is processed by HE, which enhances the image in great way but the white pebbles of image have become brighter and cannot be visible clearly.

Fig. 5(c), (d), (e) and (f) are processed by BBHE, DSIHE, MMSICHE and NMHE methods respectively and the methods fail to distinguish the fish from the background. Fig. 5(g), (h) are the results of ESIHE and SIDCSIHE and the images have better enhancement over other methods.

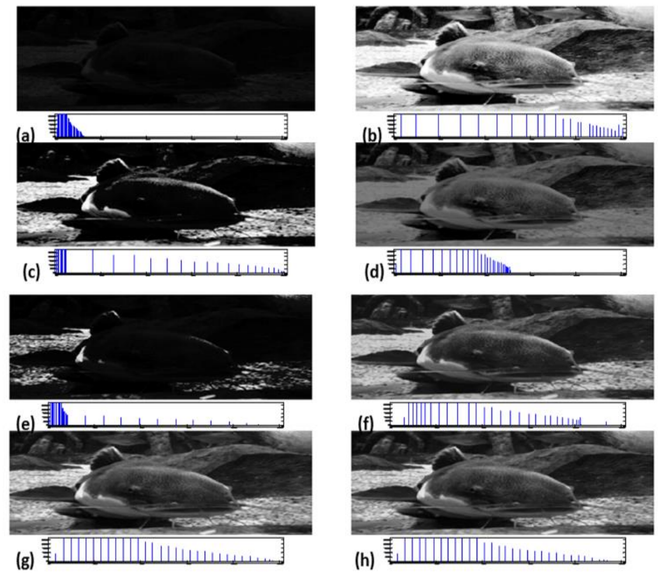


Fig. 5. Result of under water fish image (a) original image; (b) HE image; (c) BBHE image ; (d) DSIHE image; (e) MMSICHE image; (f) NMHE image; (g) ESIHE image; (h) SIDCSIHE image.

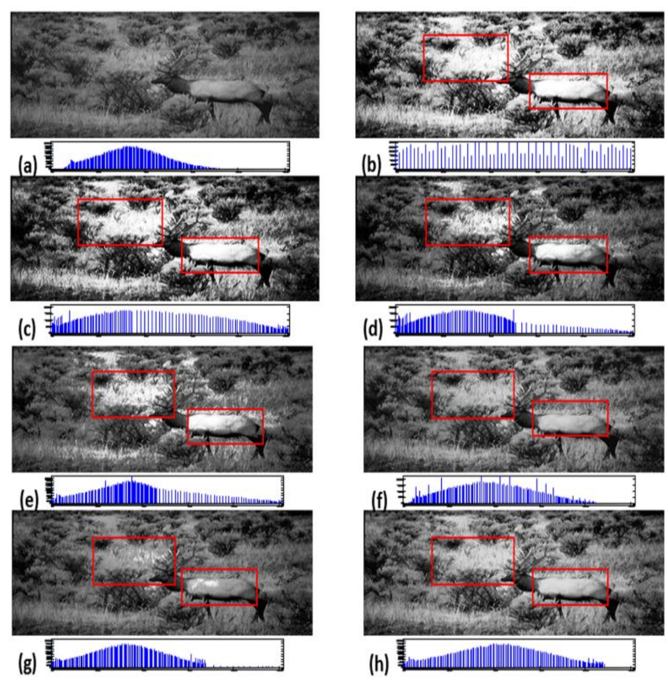


Fig. 6. Result elk image (a) original image; (b) HE image; (c) BBHE image ; (d) DSIHE image; (e) MMSICHE image; (f) NMHE image; (g) ESIHE image; (h) SIDCSIHE image.

The low contrast image is shown in Fig. 6(a). The supremacy of the proposed method (Fig. 6(h)) can be analysed by comparing the Fig. 6(b), (c), (d), (e) and (g) of HE, BBHE, DSIHE, MMSICHE and ESIHE respectively. Due to over enhancement problem information is unclear especially in the skin of elk and grass, which is highlighted square boxes. Fig. 6(f) is the result of applying NMHE, appears dark as compared to Fig. 6(h) obtained by the proposed SIDCSIHE method. In addition to that, Fig. 6(h), have better contrast and visual quality resembling its natural look.

Fig. 7(a) is low contrast plane image. Fig. 6(b), (c), (d), (e) and (g) are results of HE, BBHE, DSIHE, MMSICHE and ESIHE. The texture of the plane and surrounding cloud area in the images are not clear and have unpleasant visual artefacts. Fig. 7(f) processed by NMHE has clear look but lacks the visual effect as compared to Fig. 7(h) the result of proposed method. The proposed method gives image with clear outer surface, which is highlighted in square boxes. The resulting image of the proposed method have natural look by preserving maximum information.

Fig. 8(a) is low contrast sanctuary image. Fig. 8(b)-(g) are results of HE, BBHE, DSIHE, MMSICHE, NMHE and ESIHE, respectively. The methods fail to enhance the texture of mountain, grass and road in all the images except Fig. 8(f) which is highlighted in the square boxes. The same texture information in SIDCSIHE fig 8h is clearly visible and the image looks more natural without any unpleasant artefact.

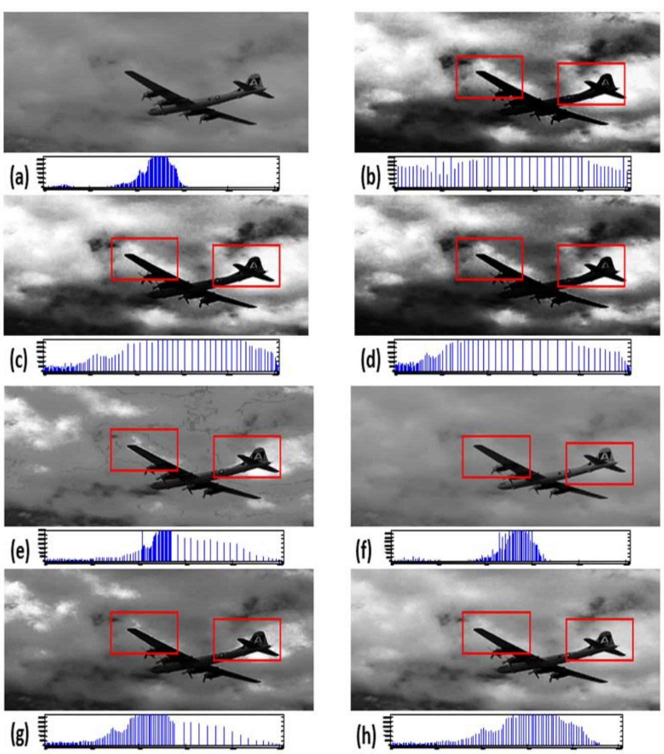


Fig. 7. Result of plane image (a) original image; (b) HE image; (c) BBHE image ; (d) DSIHE image; (e) MMSICHE image; (f) NMHE image; (g) ESIHE image; (h) SIDCSIHE image.

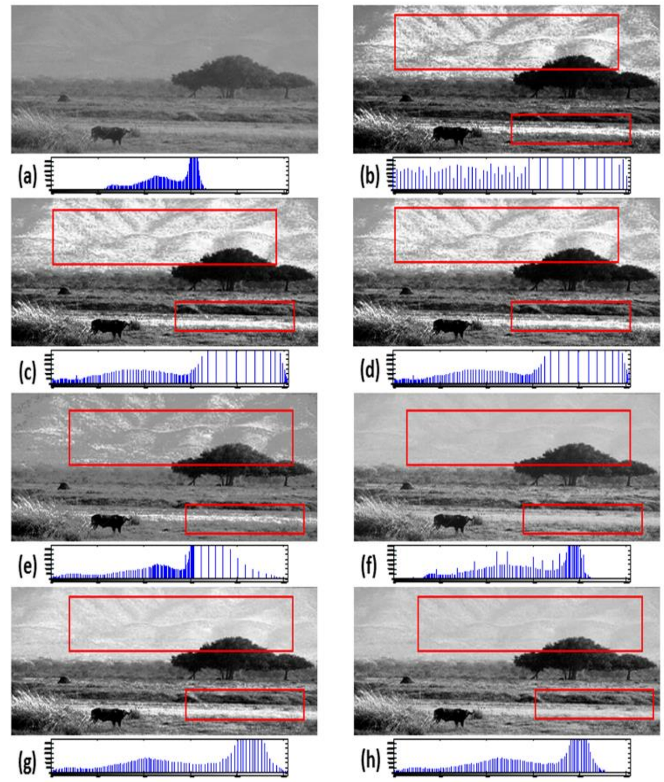


Fig. 8. Result of sanctuary image (a) original image; (b) HE image; (c) BBHE image ; (d) DSIHE image; (e) MMSICHE image; (f) NMHE image; (g) ESIHE image; (h) SIDCSIHE image.

IV. Conclusion

The proposed method has promising performance in terms of both entropy and overall visual quality. The selection of standard deviation intensity value provides new optimal threshold value to split the clipped histogram and equalize sub image effectively and gives control on over enhancement rate. The visual quality, entropy value and execution speed shows the robustness of the proposed method as compared to existing algorithm for low exposure of images.

Looking at the efficiency of the proposed method by protecting detailed information, especially for low exposure underwater image, the proposed method can be extended further to improve the average information by decomposing histogram into multiple segment based on suitable threshold and equalizing each segment independently.

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