Histogram Equalization with Range Offset for Brightness Preserved Image Enhancement

Haidi Ibrahim *haidi_ibrahim@ieee.org*
School of Electrical and Electronic Engineering,
Engineering Campus, Universiti Sains Malaysia,
14300 Nibong Tebal, Penang,
Malaysia

Abstract

In this paper, a simple modification to Global Histogram Equalization (GHE), a well known digital image enhancement method, has been proposed. This proposed method known as Histogram Equalization with Range Offset (HERO) is divided into two stages. In its first stage, an intensity mapping function is constructed by using the cumulative density function of the input image, similar to GHE. Then, during the second stage, an offset for the intensity mapping function will be determined to maintain the mean brightness of the image, which is a crucial criterion for digital image enhancement in consumer electronic products. Comparison with some of the current histogram equalization based enhancement methods shows that HERO successfully preserves the mean brightness and give good enhancement to the image.

Keywords: Digital Image Processing, Image Contrast Enhancement, Histogram Equalization, Brightness Preserving Enhancement

1. INTRODUCTION

Recent trends show that the usage of visual information has becoming more and more prominent in our daily life. In addition to television, camera, camcorder, and personal computer, many high-tech electronic products, such as hand-phone, or even refrigerator, nowadays are being equipped with capabilities to display digital images. Unfortunately, the input images that are provided to (or captured by) these devices are sometimes not really in good contrast. Therefore, a process known as digital image enhancement is normally required to increase the quality of these low contrast images [1].

One of the commonly used digital image enhancement techniques is the Global Histogram Equalization (GHE). This method stretches the dynamic range of the histogram and produces an overall contrast enhancement in the image [2]. GHE is popular because it is effective, simple, and easy to be implemented. GHE uses the Cumulative Density Function (CDF) of the input image as its intensity mapping function. GHE's intensity mapping function can be considered as a scaled version of CDF [3].

Although there are several advantages of GHE, this method is not recommended to be used directly in consumer electronic products. This is because there are several unwanted effects associated with GHE, such as the saturation artifact and washed out appearance [4]. Therefore, in 1997, Kim suggested a simple rule to overcome this problem. This rule requires digital image enhancement methods, which are used in consumer electronic products, to preserve the mean brightness of the original image in the enhanced image [5].

This rule has grabbed attentions of many researchers, and as a consequence, several enhancement methods have been proposed to fulfill this requirement. Several of them are; Brightness Preserving Bi-Histogram Equalization (BBHE) [5], Multipeak Histogram Equalization (MHE) [6], Dualistic Sub-Image Histogram Equalization (DSIHE) [7], Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) [8,9], Recursive Mean-Separate Histogram

Equalization (RMSHE) [9,10], Recursive Sub-image Histogram Equalization (RSHE) [11], Brightness Preserving Dynamic Histogram Equalization (BPDHE) [4,12], Brightness Preserving Weight Clustering Histogram Equalization [13], Bi-Histogram Equalization with a Plateau Limit (BHEPL) [14], and Simple Histogram Modification Scheme (SHMS) [3].

Methods such as BBHE, DSIHE, and MMBEBHE, divide the input histogram into two sections, using one intensity value as their separating point. This separating point is selected based on some criteria, depending on the enhancement method. Although these methods are simple, they can preserve the mean brightness only to a certain extent. For example, BBHE is able to maintain the brightness if and only if the input histogram has a quasi-symmetrical distribution around its separating point [15]. Other methods, such as MHE, RMSHE, RSHE, and BPDHE, divide the input histogram into more than two sections. Although some of these methods are good in preserving the mean brightness, not much enhancement could be obtained due to these separating points. Furthermore, these methods are relatively requiring more computational power in order to select the separating point properly.

In this paper, a new histogram equalization based image enhancement method is proposed. Because this method uses an offset value to maintain the mean brightness, this method is named as Histogram Equalization with Range Offset (HERO). Interestingly, unlike most of the histogram equalization based methods, HERO does not require any histogram portioning process to preserve the mean brightness.

The remainder of this paper is organized as follows. Section 2 describes the basic equations related to GHE, in order to familiarize the reader with the framework of this research. Next, Section 3 presents the algorithm of HERO. Experimental results obtained from this work are presented in Section 4. Finally, Section 5 concludes the findings.

2. GLOBAL HISTOGRAM EQUALIZATION (GHE)

By taking $\mathbf{X}=\{X(i,j)\}$ as the input image with L discrete gray levels denoted by $\{X_0, X_1, ..., X_{L-1}\}$, and $X(i,j)$ presents the intensity of the image at spatial location (i,j) with condition $X(i,j) \in \{X_0, X_1, ..., X_{L-1}\}$, the histogram h is defined as:

$$h(X_k) = n_k, \qquad \text{for} \qquad k = 0,1,..., L-1 \tag{1}$$

where X_k is the k-th gray level and n_k is the number of times the gray level X_k appears in the image. Histogram h presents the frequency of occurrence of the gray levels in the image.

The Probability Density Function (PDF) is defined as the normalized h with respect to the total number of pixels contained in $\mathbf{X}$. If the size of $\mathbf{X}$ is $M \times N$ pixels, PDF for intensity X_k, $p(X_k)$, is defined as:

$$p(X_k) = h(X_k)/(M \times N) \qquad \text{for} \qquad k = 0,1,..., L-1 \tag{2}$$

From Eq. (2), CDF for intensity X_k, $c(X_k)$, is given as:

$$c(X_k) = \sum_{j=0}^{k} p(X_j) \qquad \text{for} \qquad k = 0,1,..., L-1 \tag{3}$$

GHE enhances $\mathbf{X}$ by using CDF as its transformation function. This transformation function, $f(X_k)$, is defined as:

$$f(X_k) = (L-1) \times c(X_k) \qquad \text{for} \qquad k = 0,1,..., L-1 \tag{4}$$

Then, the output image produced by GHE, $\mathbf{Y}=\{Y(i,j)\}$, is given by equation (5).

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

Although GHE successfully increases the contrast in the image, this method does not put any constrain in preserving the mean brightness. Therefore, a simple modification to GHE is introduced in the next section.

3. HISTOGRAM EQUALIZATION WITH RANGE OFFSET (HERO)

The implementation of Histogram Equalization with Range Offset (HERO) is divided into two stages. The main aim of the first stage is to improve the image contrast. On the other hand, the main aim of the second stage is to restore the mean brightness into the output image. Yet, it is worth noting that at the end of the first stage, only the transformation function is created, and no output image is produced. The processes involved in these two stages are explained in the following two subsections.

3.1. STAGE 1: Contrast Enhancement

The procedure in this stage is exactly the same to GHE as described in Section 2. First, the histogram h is constructed from the original input image $\mathbf{X}$ by using Eq. (1). Then, PDF and CDF of $\mathbf{X}$ are found by using Eq. (2) and Eq. (3), respectively. Finally, the transformation function $f(X_k)$ is calculated by using Eq. (4) to become the base function for the contrast enhancement process for HERO.

3.2. STAGE 2: Brightness Restoration

In order to restore the mean brightness effectively, the total brightness value of the input image, B_X, is calculated by using the following equation.

$$B_X = \sum_{x=0}^{x=L-1} x \times h(x) \tag{6}$$

Another total brightness value, B_Y, also been calculated. This value estimates the total brightness value for the output image. This is calculated by using the transformation function obtained in Stage 1.

$$B_Y = \sum_{x=0}^{x=L-1} f(x) \times h(x) \tag{7}$$

Next, the total brightness difference between the input image and the expected image, ΔB, is calculated.

$$\Delta B = B_Y - B_X \tag{8}$$

A positive ΔB value indicates that the expected output image will be brighter than $\mathbf{X}$. Conversely, a negative ΔB value shows that the expected output image will be darker than $\mathbf{X}$.

The idea of brightness restoration technique employed in HERO is depicted in Fig. 1. When the output image is expected to be brighter than the original image (i.e. indicated by a positive ΔB value), the expected histogram h_Y will be translated to the left side in order to reduce the image brightness. On the other hand, when the output image is expected to be darker than the original image (i.e. indicated by a negative ΔB value), the histogram will move to the right side in order to increase the image brightness. In HERO, the shape of the histogram obtained by Eq. (4) is maintained in order to keep the overall contrast in the output image.

The movement of the histogram as shown by Fig. 1 can be obtained by introducing a range offset value, X_{off}. This offset value is used to modify Eq. (4) to create a new intensity transformation function, g, which will be used to create the output image.

$$g(X_k) = f(X_k) + X_{\text{off}} \qquad \text{for} \qquad k = 0, 1, ..., L-1 \tag{9}$$

For the case of positive ΔB, X_{off} needs to be a negative integer in order to move the histogram to the left side. On the contrary, for the case of negative ΔB, X_{off} is presented by a positive integer, and thus the histogram can move to the right side. The intensity values of mapping function g are clipped at 0 and L-1.

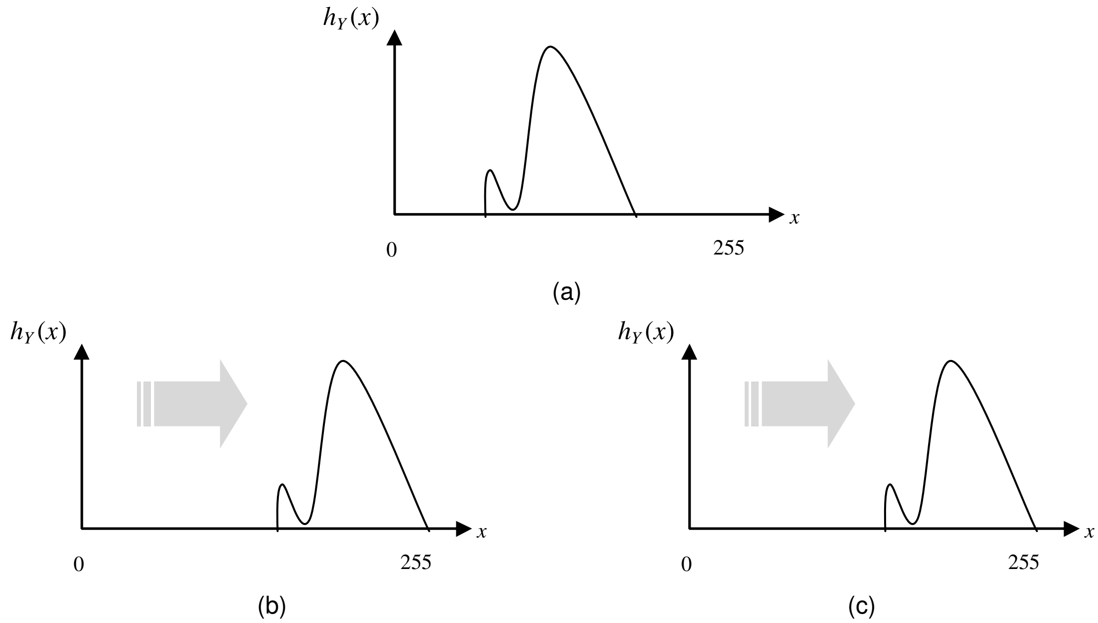


FIGURE 1: (a) The initial expected histogram, h_Y. (b) The correction applied when ΔB is positive. (c) The correction applied when ΔB is negative.

The value of X_{off} in HERO is determined iteratively, starting from X_{off} =0. For every increment, or decrement in the value of X_{off}, the brightness correction value, ΔC, is calculated. Ideally, X_{off} in Eq. (9) will be tuned to obtain the following condition:

$$\Delta C = \left(\sum_{x=0}^{x=L-1} x \times h(x) \right) - \left(\sum_{x=0}^{x=L-1} g(x) \times h(x) \right) \approx 0 \qquad (10)$$

However, the condition stated by Eq. (10) is frequently impossible to be achieved due to quantization applied in digital images. Therefore, one constrain is imposed to HERO to help the process of finding the suitable X_{off} value, effectively. For the positive ΔB, the iteration for the offset finding process will stop when the updated X_{off} value produces ΔC which is equal or less than zero. In opposite, if ΔB is negative, the iteration will stop when the updated X_{off} value produces ΔC which is equal or greater than zero.

4. EXPERIMENTAL RESULTS

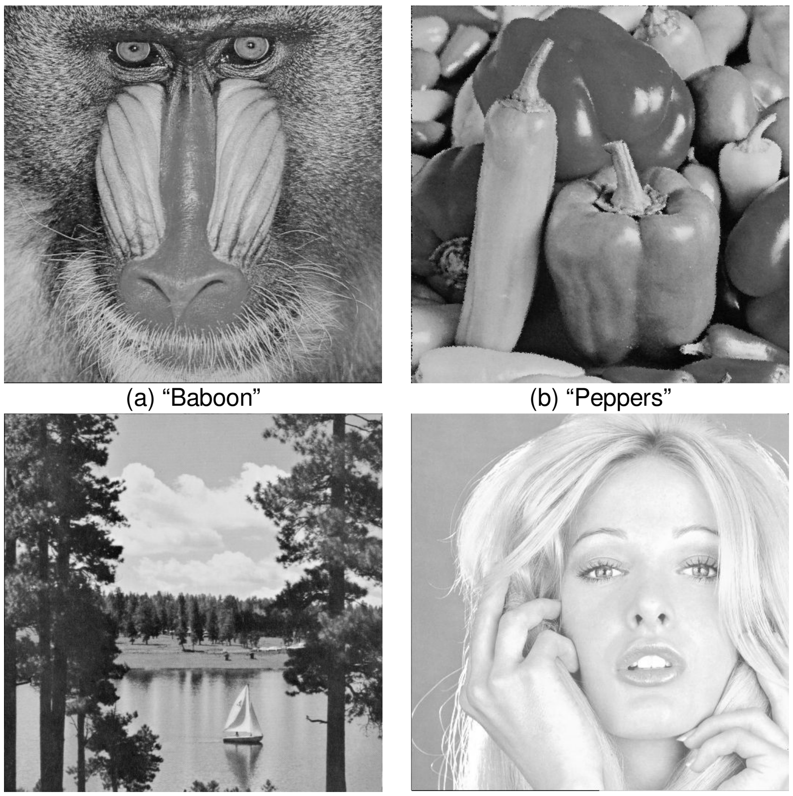
In order to evaluate the performance of HERO, four standard grayscale images of size 512×512 pixels, as shown in Fig. 2, have been used. These images are eight-bit depth images, and therefore L-1= 255. Fig. 2(a) has been chosen because this image has a lot of small details. Fig. 2(b) is selected because it contains multiple objects. Fig. 2(c) is used because the object of interest in this image (i.e. the sailboat) is relatively small as compared with the total image size. Fig. 2(d) is utilized to present an input image with low contrast.

To benchmark the performance of HERO as regards to some state-of-the-art enhancement methods, ten other histogram equalization enhancement techniques have been implemented in this work. They are GHE, BBHE, DSIHE, MMBEBHE, MHE, RMSHE, RSHE, BPDHE, BHEPL and SHMS. These methods present a wide range of brightness preserved histogram equalization methods. For the implementation of RMSHE and RSHE, recursive level of two (i.e. r=2) is chosen. With this parameter setting, both RMSHE and RSHE will divide the histogram into four sub-histograms.

With the intention to evaluate the effectiveness of these contrast enhancement methods in keeping the input mean brightness inside their output images, following the same framework as other researchers in this field, a quantitative measure known as Absolute Mean Brightness Error (AMBE) has been used in this work. If b_X presents the mean brightness of the input image, and b_Y presents the mean brightness of the output image, this measure is defined as:

$$\mathrm{AMBE} = \left| b_X - b_Y \right| \tag{11}$$

Thus, a good enhancement method that is able to preserve the mean brightness will give a small value of AMBE.



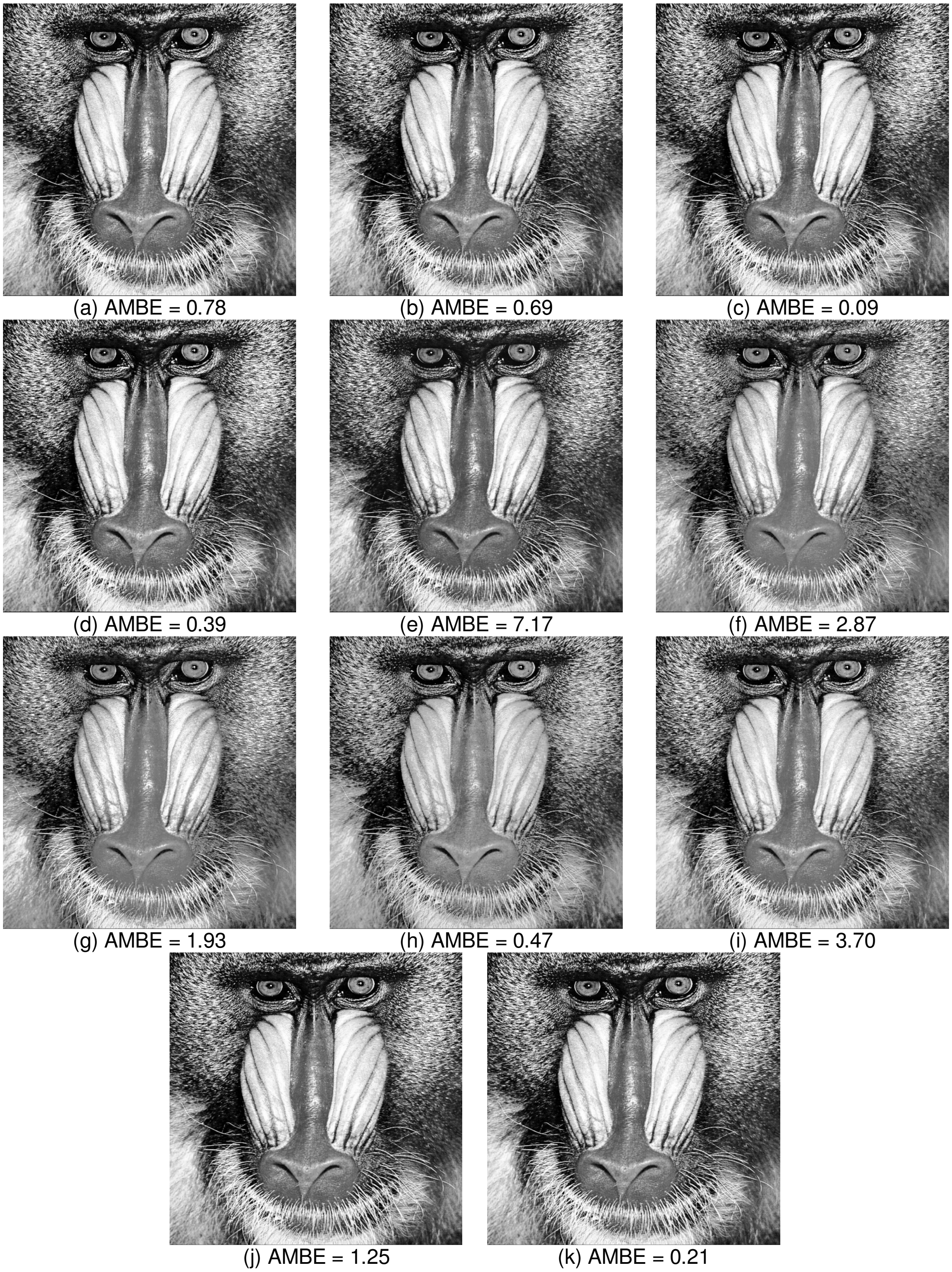
(a) "Baboon" (b) "Peppers"

(c) "Sailboat" (d) "Tiffany"

FIGURE 2: The four test images used in this work for the evaluation purpose.

Contrast Enhancement Method	Average AMBE
GHE	23.64
BBHE [5]	9.52
DSIHE [7]	11.01
MMBEBHE [8,9]	1.50
MHE [6]	12.10
RMSHE [9,10]	6.72
RSHE [11]	6.49
BPDHE [4,12]	0.84
BHEPL [14]	8.96
SHMS [3]	23.60
HERO (the proposed method)	3.43

TABLE 1: The average AMBE value taken from four test images.



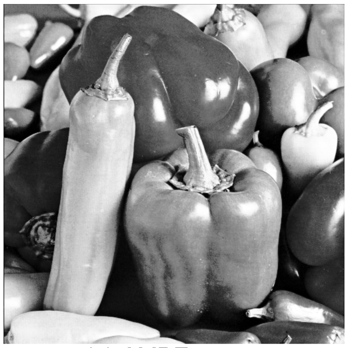
(a) AMBE = 0.78 (b) AMBE = 0.69 (c) AMBE = 0.09

(d) AMBE = 0.39 (e) AMBE = 7.17 (f) AMBE = 2.87

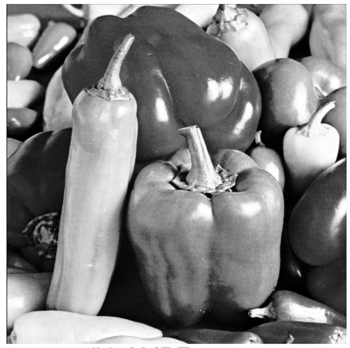
(g) AMBE = 1.93 (h) AMBE = 0.47 (i) AMBE = 3.70

(j) AMBE = 1.25 (k) AMBE = 0.21

FIGURE 3: The enhanced version of “Baboon” by using (a) GHE, (b) BBHE, (c) DSIHE, (d) MMBEBHE, (e) MHE, (f) RMSHE, (g) RSHE, (h) BPDHE, (i) BHEPL, (j) SHMS, and (k) HERO (i.e. the proposed method)

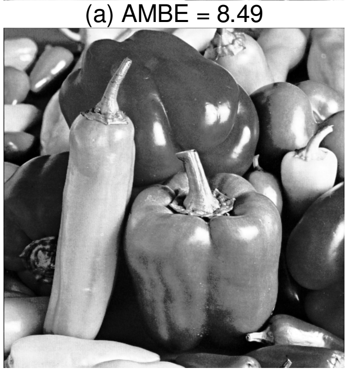


(a) AMBE = 8.49

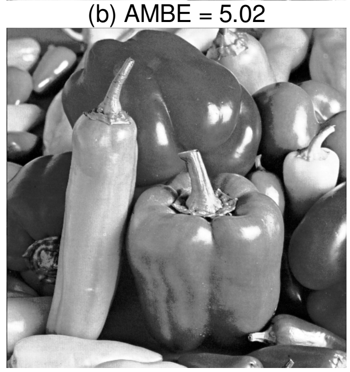


(b) AMBE = 5.02

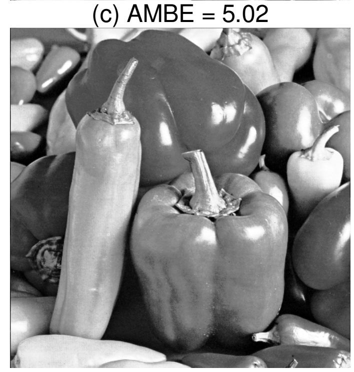
(c) AMBE = 5.02



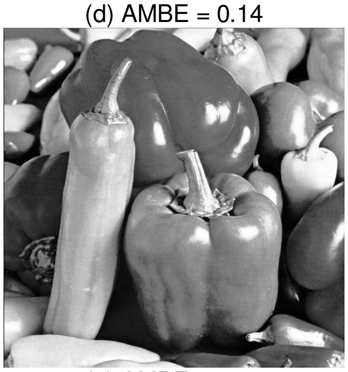
(d) AMBE = 0.14



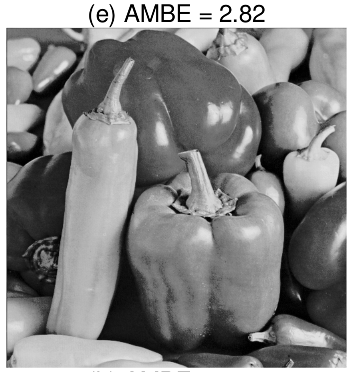
(e) AMBE = 2.82



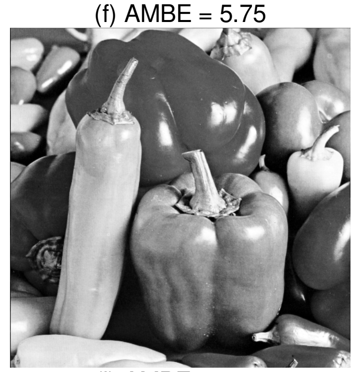
(f) AMBE = 5.75



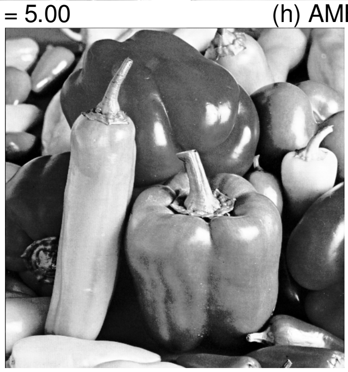
(g) AMBE = 5.00



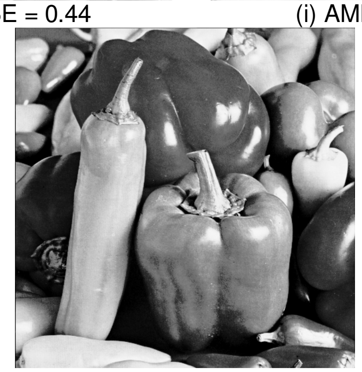
(h) AMBE = 0.44



(i) AMBE = 6.55

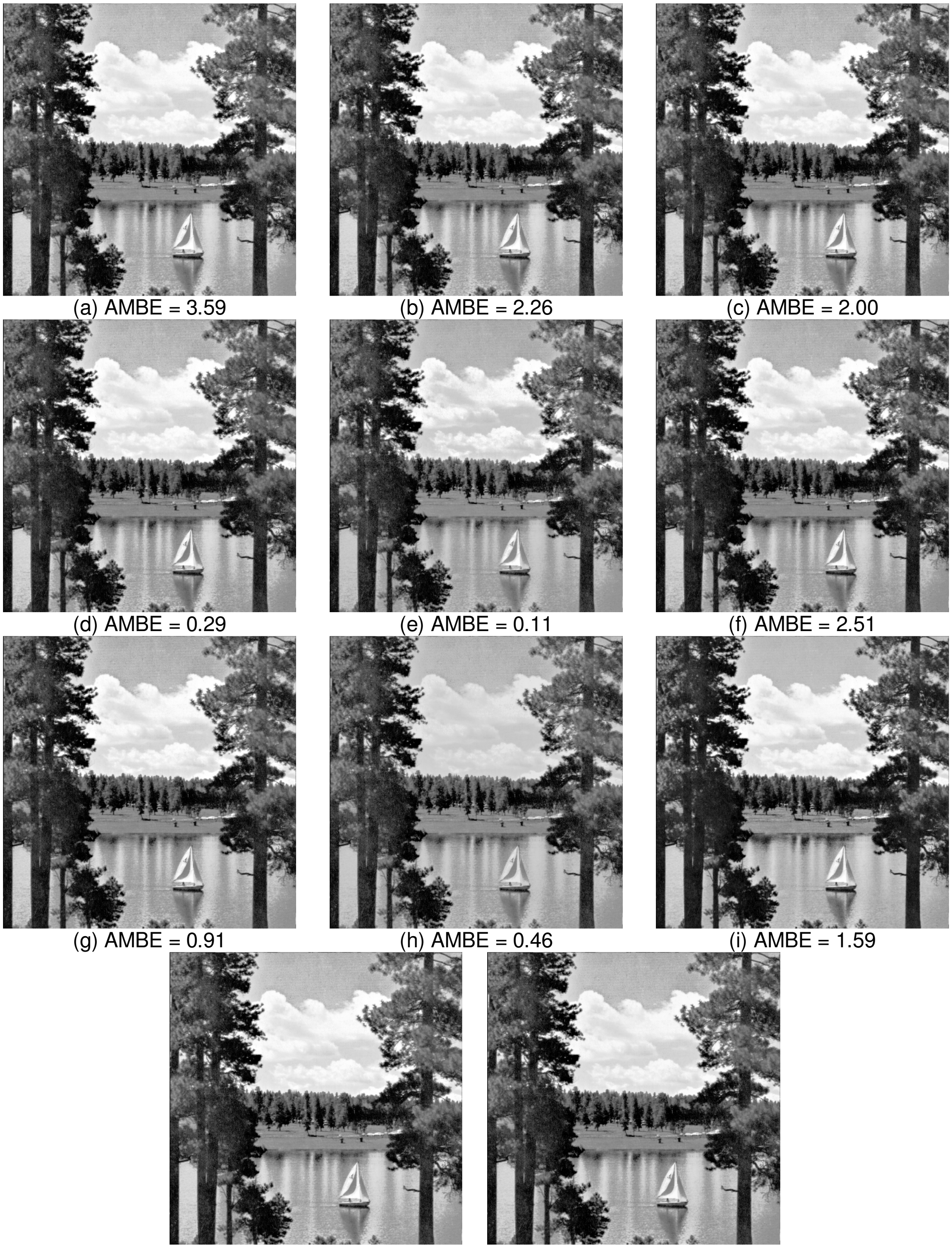


(j) AMBE = 8.01



(k) AMBE = 0.10

FIGURE 4: The enhanced versions of "Peppers" by using (a) GHE, (b) BBHE, (c) DSIHE, (d) MMBEBHE, (e) MHE, (f) RMSHE, (g) RSHE, (h) BPDHE, (i) BHEPL, (j) SHMS, and (k) HERO (i.e. the proposed method).



(a) AMBE = 3.59 (b) AMBE = 2.26 (c) AMBE = 2.00

(d) AMBE = 0.29 (e) AMBE = 0.11 (f) AMBE = 2.51

(g) AMBE = 0.91 (h) AMBE = 0.46 (i) AMBE = 1.59

(j) AMBE = 3.12 (k) AMBE = 0.06

FIGURE 5: The enhanced versions of “Sailboat” by using (a) GHE, (b) BBHE, (c) DSIHE, (d) MMBEBHE, (e) MHE, (f) RMSHE, (g) RSHE, (h) BPDHE, (i) BHEPL, (j) SHMS, and (k) HERO (i.e. the proposed method).

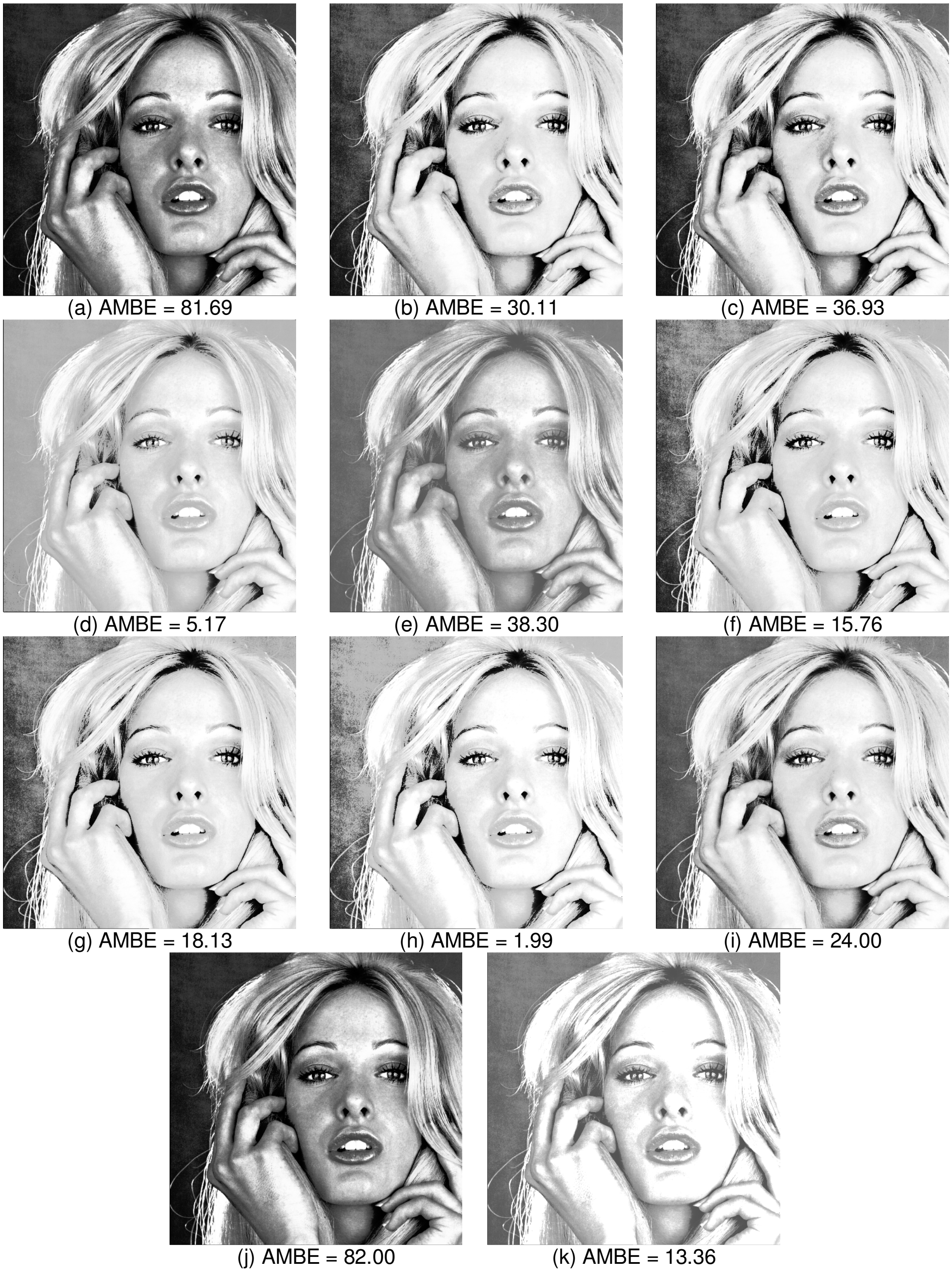


FIGURE 6: The enhanced versions of "Tiffany" by using (a) GHE, (b) BBHE, (c) DSIHE, (d) MMBEBHE, (e) MHE, (f) RMSHE, (g) RSHE, (h) BPDHE, (i) BHEPL, (j) SHMS, and (k) HERO (i.e. the proposed method).

The contrast enhanced version of the images shown in Fig. 2, obtained by using several histogram equalization based methods, including HERO, are presented in Fig. 3 to Fig. 6. As shown by these figures, all enhancement methods implemented in this research successfully increase the contrast in the image. In order to evaluate the performance of these histogram equalization based methods in terms of preserving the mean brightness, the average AMBE values obtained from these four test images are tabulated in Table 1.

Table 1 shows that in average, GHE method produces the highest AMBE value. This is not surprising as GHE does not put any constrain in preserving the brightness. On the other hand, the method that produces the lowest average AMBE value is the BPDHE. This is also not surprising, as this method is relatively more complex and requires more processing time as compared with other methods. The method that produces the second lowest average AMBE value is the MMBEBHE. Yet, similar to BPDHE, MMBEBHE requires histogram partitioning. The proposed method, HERO, has the third lowest average AMBE value. However, despite of this fact, it is worth nothing that as shown in Fig. 3 to Fig. 6, HERO produced the lowest AMBE value for two test images, namely “Peppers” and “Sailboat”. In addition to this, excluding “Tiffany”, HERO produced AMBE values less than one, indicates that the mean brightness of the input image is almost similar to the mean brightness of the output image produced by this method.

5. CONCLUSION

In this paper, an improved version of histogram equalization method has been proposed. By using a range offset, the proposed method successfully maintains the mean brightness of the image. This method is simple, and unlike other brightness preserving histogram equalization based methods, the proposed method does not require any histogram partitioning.

ACKNOWLEDGMENT

This work was supported in part by the Universiti Sains Malaysia’s Short Term Research Grant with account number 304/PELECT/60311013 and by Incentive Grant (Postgraduate Students) with project number 1001/PELECT/8022006.

REFERENCES

[1] Rafael C. Gonzalez, and Richard E. Woods, “Digital Image Processing”, 2nd Edition, Prentice Hall, 2002.

[2] Haidi Ibrahim, and Nicholas Sia Pik Kong, “Image sharpening using sub-regions histogram equalization”, *IEEE Trans. Consumer Electronics,* vol. 55, no. 2, pp. 891-895, May 2009.

[3] Yen-Ching Chang, and Chun-Ming Chang, “A simple histogram modification scheme for contrast enhancement”, *IEEE Trans. Consumer Electronics,* vol. 56, no. 2, pp. 737-742, May 2010.

[4] Haidi Ibrahim, and Nicholas Sia Pik Kong, “Brightness preserving dynamic histogram equalization for image contrast enhancement”, *IEEE Trans. Consumer Electronics,* vol. 53, no. 4, pp. 1752-1758, November 2007.

[5] Yeong-Taeg Kim, “Contrast enhancement using brightness preserving bi-histogram equalization”, *IEEE Trans. Consumer Electronics,* vol. 43, no. 1, pp. 1-8, February 1997.

[6] K. Wongsritong, K. Kittayaruasiriwat, F. Cheevasuvit, K. Dejhan, and A. Soomboonkaew, “Contrast enhancement using multipeak histogram equalization with brightness preserving”, *The 1998 IEEE Asia-Pasific Conference on Circuits and Systems,* pp. 455-458, Chiangmai, Thailand, November 2008.

[7] Yu Wang, Qian Chen, and Baeomin Zhang, "Image enhancement based on equal area dualistic sub image histogram equalization method", *IEEE Trans. Consumer Electronics,* vol. 45, no. 1, pp. 68-75, February 1999.

[8] Soong-Der Chen, and Abd. Rahman Ramli, "Minimum mean brightness error bi-histogram equalization in contrast enhancement", *IEEE Trans. Consumer Electronics,* vol. 49, no. 4, pp. 1310-1319, November 2003.

[9] Soong-Der Chen, and Abd. Rahman Ramli, "Preserving brightness in histogram equalization based contrast enhancement techniques", *Digital Signal Processing,* vol. 14, no. 5, pp. 413-428, September 2004.

[10] Soong-Der Chen, and Abd Rahman Ramli, "Contrast enhancement using recursive mean-separate histogram equalization for scalable brightness preservation", *IEEE Trans. Consumer Electronics,* vol. 49, no. 4, pp. 1301-1309, November 2003.

[11] K. S. Sim, C. P. Tso, and Y. Y. Tan, "Recursive sub-image histogram equalization applied to gray scale images", *Pattern Recognition Letters,* vol. 28, no. 10, pp. 1209-1221, July 2007.

[12] Nicholas Sia Pik Kong, and Haidi Ibrahim, "Color image enhancement using brightness preserving dynamic histogram equalization", *IEEE Trans. Consumer Electronics,* vol. 54, no. 4, pp. 1962-1968, November 2008.

[13] Nyamlkhagva Sengee, and Heung Kook Choi, "Brightness preserving weight clustering histogram equalization", *IEEE Trans. Consumer Electronics,* vol. 54, no. 3, pp. 1329-1337, August 2008.

[14] Chen Hee Ooi, Nicholas Sia Pik Kong, and Haidi Ibrahim, "Bi-histogram equalization with a plateau limit for digital image enhancement", *IEEE Trans. on Consumer Electronics,* vol. 54, no. 3, pp. 2072-2080, November 2009.

[15] Chao Wang, and Zhongfu Ye. "Brightness preserving histogram equalization with maximum entropy: a variational perspective", *IEEE Trans. Consumer Electronics,* vol. 51, no. 4, pp. 1326-1334, November 2005.