Brightness Preserving Dynamic Histogram Equalization for Image Contrast Enhancement

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**Abstract — ** *Histogram equalization (HE) is one of the common methods used for improving contrast in digital images. However, this technique is not very well suited to be implemented in consumer electronics, such as television, because the method tends to introduce unnecessary visual deterioration such as the saturation effect. One of the solutions to overcome this weakness is by preserving the mean brightness of the input image inside the output image. This paper proposes a new method, known as brightness preserving dynamic histogram equalization (BPDHE), which is an extension to HE that can produce the output image with the mean intensity almost equal to the mean intensity of the input, thus fulfill the requirement of maintaining the mean brightness of the image. First, the method smoothes the input histogram with one dimensional Gaussian filter, and then partitions the smoothed histogram based on its local maximums. Next, each partition will be assigned to a new dynamic range. After that, the histogram equalization process is applied independently to these partitions, based on this new dynamic range. For sure, the changes in dynamic range, and also histogram equalization process will alter the mean brightness of the image. Therefore, the last step in this method is to normalize the output image to the input mean brightness. Our results from 80 test images shows that this method outperforms other present mean brightness preserving histogram equalization methods. In most cases, BPDHE successfully enhance the image without severe side effects, and at the same time, maintain the mean input brightness[1].*

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

I. INTRODUCTION

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 purpose of image enhancement is to improve the interpretability or perception of information contained in the image for human viewers, or to provide a "better" input for other automated image processing systems.

There are many image enhancement methods have been proposed. A very popular technique for image enhancement is histogram equalization (HE). This technique is commonly employed for image enhancement because of its simplicity and comparatively better performance on almost all types of images. The operation of HE is performed by remapping the gray levels of the image based on the probability distribution of the input gray levels. It flattens and stretches the dynamic range of the image's histogram and resulting in overall contrast enhancement [2].

Despite of its popularity, HE is not very suitable to be implemented in consumer electronics, such as television, because the method tends to produce undesirable artifacts. One of the reasons to this problem is because HE normally changes the brightness of the input image significantly, makes some of the uniform regions of the output image become saturated with very bright or very dark intensities. Thus, for the implementation of contrast enhancement in the consumer electronics, it is advised that the method should be able to maintain the original input brightness in the output image [3].

There are already many methods have been proposed to fulfill this requirement. The earliest work on this problem has been proposed by Kim in 1997 [3], with a technique known as brightness preserving bi-histogram equalization (BBHE). This method divides the image histogram into two parts as shown in Fig.1. In this method, the separation intensity X_T is presented by the input mean brightness value, which is the average intensity of all pixels that construct the input image. After this separation process, these two histograms are independently equalized. By doing this, the mean brightness of the resultant image will lie between the input mean and the middle gray level.

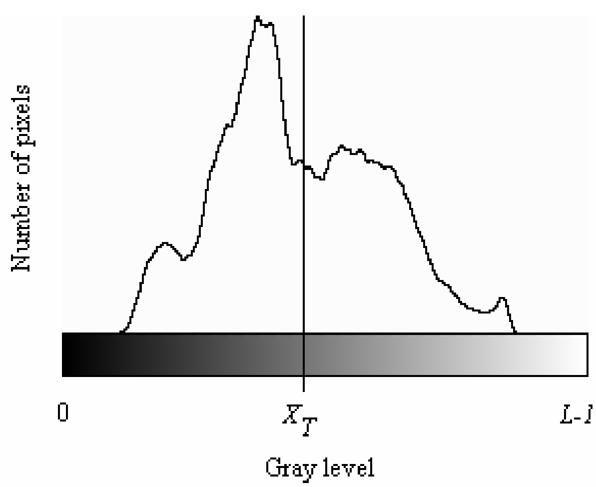

Fig. 1. Bi-histogram equalization. The histogram with range from 0 to L-1 is divided into two parts, with separating intensity X_T. This separation produces two histograms. The first histogram has the range of 0 to X_T, while the second histogram has the range of X_T+1 to L-1.

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Next, in 1999, dualistic sub-image histogram equalization (DSIHE) has been proposed by Wan et al [4]. The algorithm of DSIHE is similar to BBHE, except that the histogram is separated into two histograms based on the median value instead of the mean value. This criterion of X_T will produce two histograms with almost equal number of pixels. It is claimed that DSIHE is better than BBHE in term of preserving an image's brightness and entropy.

Minimum mean brightness error bi-histogram equalization (MMBEBHE) is then proposed by Chen and Ramli to "optimally" maintain the mean brightness [5]. This technique is also an extension to BBHE, but unlike BBHE, the method first will test all possible values of the separating intensity, from 0 to L-1. The differences between the mean brightness of the input and the mean brightness of the outputs that produced from every separating intensity values are calculated. Then, the value of X_T is chosen, by enumeration, as the value that can produce the minimum different between input and output means. The actual output image is obtained by bi-histogram equalize the input image with this value of X_T.

Chen and Ramli also propose another enhancement scheme named recursive mean-separate histogram equalization (RMSHE) [6]. This technique iteratively utilizes the BBHE. First, the technique separates the histogram into two parts based on the average input brightness. Then, the mean of each piece of the resultant sub-histograms is calculated. These sub-histograms are then further divided into two parts based on this average values. This process is repeated for r times, where the value of r is set by the user. Thus, this technique will produce 2^r pieces of sub-histogram. Then, each sub-histogram is equalized independently. It is claimed that RMSHE is good brightness preservation technique when the value of r is large, because the output mean converges to the input mean. However, actually when r is too large, the output histogram will become exactly the input histogram. In this condition, the output image is exactly the copy of the input image, and there is no enhancement at all [7].

Sim et al [8] propose a similar method to RMSHE known as recursive sub-image histogram equalization (RSIHE). The method also produces 2^r pieces of sub-histogram, but unlike RMSHE, the histogram is divided based on median value, rather than the mean value. By using the median values, each sub-histogram will contain exactly the same number of pixels. It is claimed that RSIHE produces relatively better image compared with RMSHE. However, RSIHE shares the same problem with RMSHE, which is, there will be no enhancement could be obtained if we set a very large value of r.

Thus, the weaknesses of RMSHE and RSIHE are the difficulty to find the "optimal" value of r, and also the histogram only can be divided into a multiplication of two (i.e. 2^r) pieces. Therefore, to overcome this problem, there are also ideas on separating the histogram based on the shape of the histogram itself. Wongsritong et al [9], has propose multipeak histogram equalization with brightness preserving (MPHEBP). In this scheme, the histogram is first smoothed with one dimensional smoothing filter. Then, the histogram is divided based on the local maximums of the smoothed histogram. From here, the number of sub-histograms is dependent to the number of the local maximums. Each sub-histogram is then independently equalized using histogram equalization. Wongsritong et al claimed that the performance of MPHEBP in maintaining the mean brightness is better than BBHE.

Yet, enhancement scheme based on dividing histogram into several sub-histograms (i.e. RMSHE, RSIHE, and MPHEBP) tends to not allow some sections of the histogram to expand, as explained by Fig. 2. Thus, Wadud et al [10] has proposed dynamic histogram equalization (DHE) for used in image contrast enhancement. Similar to MPHEBP, the method first smooth the input histogram by using a one dimension smoothing filter. However, in contrast to MPHEBP, the histogram is divided based on the local minimums. Before equalize the sub-histograms, each section are mapped into a new dynamic range. This mapping process is a function of the number of pixels consists in that section, thus the sections with larger number of pixels will occupy bigger range of the dynamic range. However, DHE does not put any constrain on maintaining the mean brightness of the image. Thus, this method may not be suitable to be implemented in television, as the saturation effect may occur in some cases.

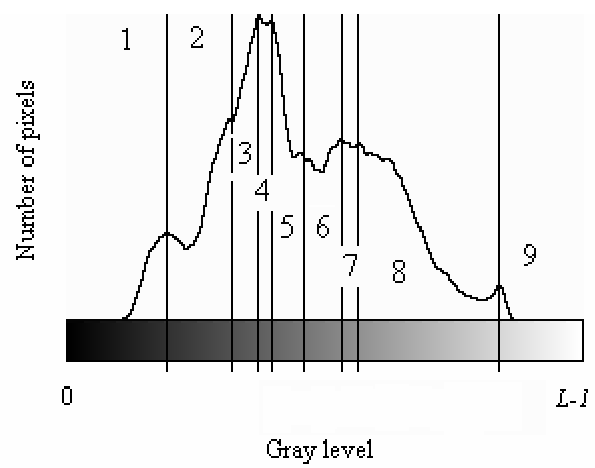


Fig. 2. The histogram of the image before enhancement normally does not occupy all the dynamic range of the gray level. If the histogram is partitioned into more than two subsections, some of the sections will have a very narrow range, such as sections 4 and 7 shown above. Due to small range, these sections will be not be enhanced significantly by HE.

Hence, this paper proposes a technique, known as brightness preserving dynamic histogram equalization (BPDHE). This method is actually an extension to both MPHEBP and DHE. Similar to MPHEBP, the method partitions the histogram based on the local maximums of the smoothed histogram. However, before the histogram equalization taking place, the method will map each partition to a new dynamic range, similar to DHE. As the change in the dynamic range will cause the change in mean brightness, the final step of this method involves the normalization of the output intensity. So, the average intensity of the resultant image will be same as the input. With this criterion, BPDHE will produce better enhancement compared with MPHEBP, and better in preserving the mean brightness compared with DHE.

This paper is organized as follows. Section II describes BPDHE in detail. Then, some experimental results of applying BPDHE are presented in Section III. Section IV presents the conclusion of this work.

II. Brightness Preserving Dynamic Histogram Equalization (BPDHE)

Brightness preserving dynamic histogram equalization (BPDHE) which is proposed in this paper consists of five steps:

1. Smooth the histogram with Gaussian filter.
2. Detection of the location of local maximums from the smoothed histogram.
3. Map each partition into a new dynamic range.
4. Equalize each partition independently.
5. Normalize the image brightness.

The details of each step are described in the following subsections.

A. Smooth the histogram with Gaussian filter.

Because the histogram of the digital image is normally fluctuated and also the probability for some brightness levels is missing, it is difficult to detect the local maximums of the histogram without smoothing the histogram. In this step, first, the disappeared brightness level is filled up by using the linear interpolation.

Then, the histogram is smoothed up by using one dimensional Gaussian filter. The Gaussian filter is defined by the following equation:

$$G(x) = \exp(-x^2 / 2\sigma^2) \qquad (1)$$

where x is the coordinate relative to the centre of the kernel, and σ is the standard deviation.

In this application, we use a Gaussian filter of size 1×9 and σ equal to 1.0762. If we use a smaller filter size, in most cases, the filter not able to reduce the fluctuations of the histogram. As a consequence, the algorithm will detect too much local maximums, thus will partition the histogram into too many subsections. If this happen, less enhancement can be obtained. On the other hand, if we use a bigger filter size, this will result a very flat histogram, and no local maximum can be detected at all.

B. Detection of the location of local maximums from the smoothed histogram.

The smoothed histogram is only used in the process of splitting the original histogram. The histogram is divided into sub-histograms based on local maximums. We choose to use local maximums as the separating intensities rather than local minimums because this selection is better in maintaining the mean brightness. In order to find the local maximums, we follow as what is suggested by [9].

First, the signs of the first derivative of the smoothed histogram are calculated. Since there are still fluctuations in the calculated signs, a process of removing stray signs is applied. In this process, by inspecting three consecutive signs, we change +-+ to +++ and -+- to ---. Then, the local maximums are detected as the points where four successive negative signs are followed by eight successive positive sign.

C. Map each partition into a new dynamic range.

Let m_0, m_1,…,m_n are (n+1) gray levels correspond to the local maximums detected in the previous step. If the original histogram before the smoothing is in the range of [I_{min}, I_{max}], then, the first sub-histogram is in the range of [I_{min}, m_0], the second sub-histogram in the range of [m_0+1, m_1], the third one [m_1+1, m_2], and so on until the last sub-histogram [m_n+1, I_{max}].

However, the equalized version of these sub-histograms does not assure a very good enhancement, because sub-histograms with small range will not be enhanced significantly by HE. Hence, following the same concept as DHE, BPDHE spans each sub-histogram first before the equalizations are taking place. The spanning function used is based on the total number of pixels contained in the sub-histogram. This function is described by the equations given below, as suggested by [10]:

$$span_i = high_i - low_i \qquad (2)$$

$$factor_i = span_i \times \log_{10} M \qquad (3)$$

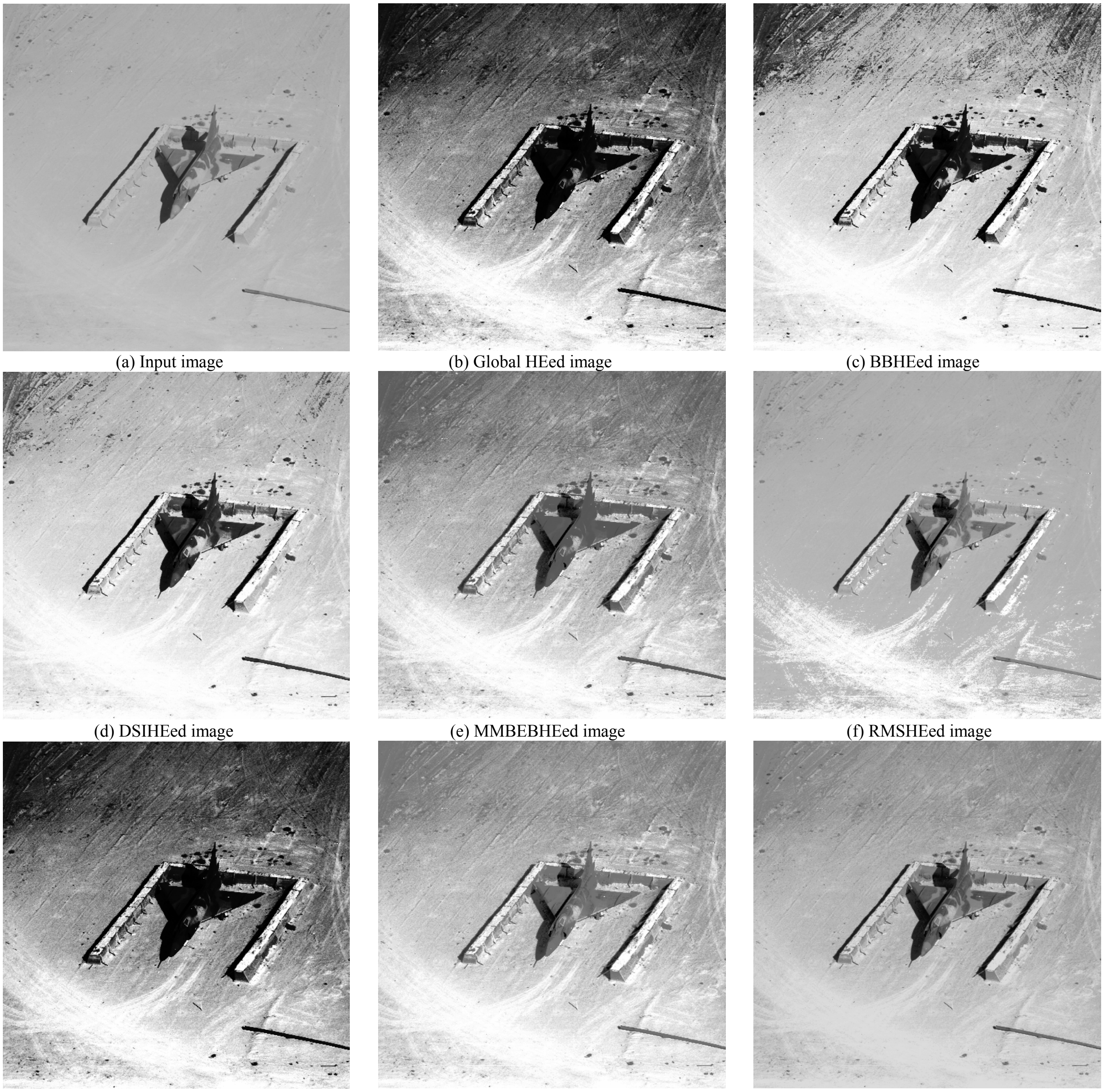
$$range_i = (L-1) \times factor / \sum_{k=1}^{n+1} factor_k \qquad (4)$$

where $high_i$ is the highest intensity value contained in the sub-histogram i, low_i is the lowest intensity value in that section, and M is the total pixels contained in that section. The dynamic range used by the sub-histogram i in input image is given by $span_i$, while the dynamic range used by in output image is $range_i$.

Let the range of the output sub-histogram i is [$start_i$, end_i]. If we set the first sub-histogram of the output image is in the range of [0, $range_1$], then the $start_i$ and end_i (for i> 1) can be calculated as follow:

$$start_i = \sum_{k=1}^{i-1} range_k + 1 \qquad (5)$$

$$end_i = \sum_{k=1}^{i} range_k \qquad (6)$$



(a) Input image (b) Global HEed image (c) BBHEed image

(d) DSIHEed image (e) MMBEBHEed image (f) RMSHEed image

(g) MPHEBPed image (h) DHEed image (i) BPDHEed image

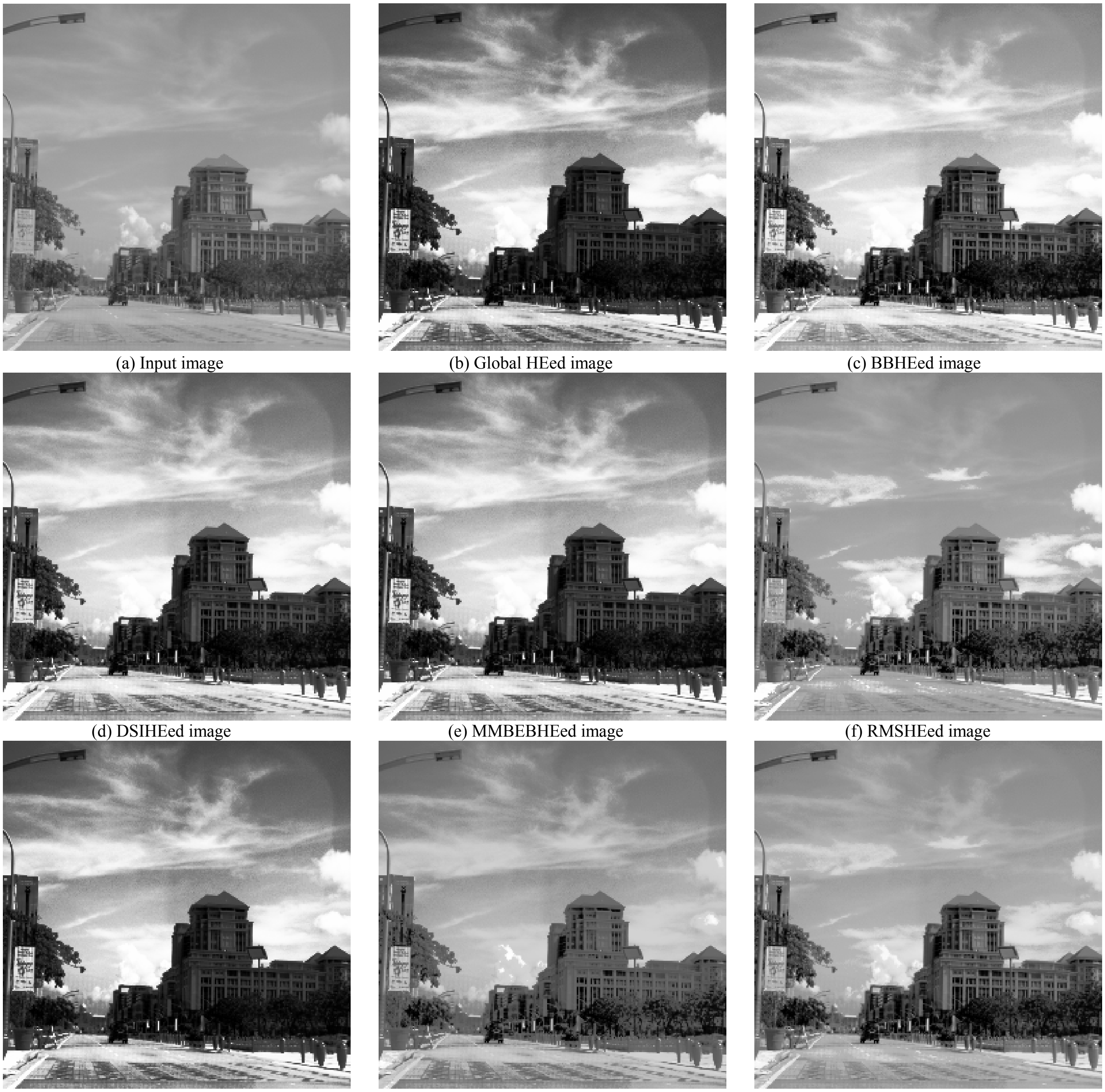
Fig. 3. Results of all methods tested in this work using image of "*Aircraft*". In this case, our object of interest, which is the aircraft, occupies only a small portion of the image and has almost the same intensity with its background. As we can see here, most of the methods suffer from saturation effect. Most of them tend to enhance the take-off trail of the aircraft, while changing the pattern on the aircraft body. Result obtained from our suggested method, as shown in (i), does not have this problem. Although BPDHED enhanced the image, the take-off trail and the aircraft body are not saturated with white or black intensities.

D. Equalize each partition independently.

The next step in BPDHE is to equalize each partition independently. For sub-histogram i with the range of [$start_i$, end_i], the equalization of this section is following the transformation as stated in (7):

$$y(x) = start_i + (end_i - start_i) \sum_{k=start_i}^{x} \frac{n_k}{M} \tag{7}$$

where n_k is the number of pixels with intensity k, and M is the total pixels contained in that section. This equation is actually a general equation for HE. Note that if this equation is used for global histogram equalization, the value of $start_i$ is set to 0, and end_i is set to L-1.



(a) Input image (b) Global HEed image (c) BBHEed image

(d) DSIHEed image (e) MMBEBHEed image (f) RMSHEed image

(g) MPHEBPed image (h) DHEed image (i) BPDHEed image

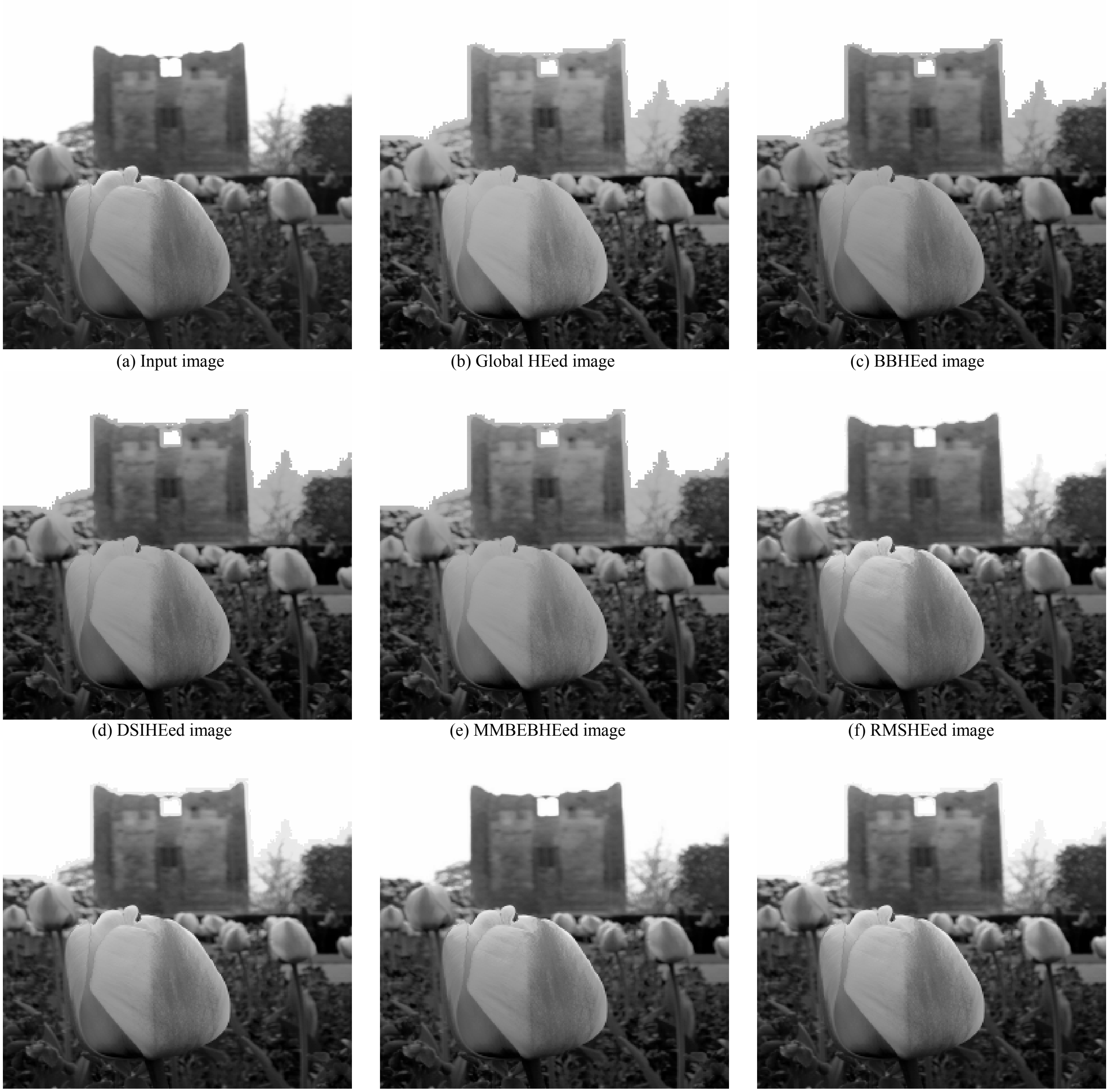
Fig. 4. Results of all methods tested in this work using image of "*Putrajaya*". In the input image, our object of interest is the building. However, most of the methods tend to enhance the clouds significantly, thus changing our focus from the building to the cloud. We don not have this problem with the result obtained from BPDHE. The method has a balanced enhancement between the building and its background. So, our focus is still on the building. Compared with RMSHE and DHE, in this case, the result obtained from BPDHE has the best enhancement of the structure of the building.

E. Normalize the image brightness.

In this step, the mean brightness of the input, M_i, and the mean brightness of the output obtained after the equalization process, M_o, is calculated. In order to shift back the mean brightness to the mean brightness of the input, we apply the brightness normalization, as define by equation (8).

$$g(x,y)=(M_i / M_o) f(x,y) \tag{8}$$

where $g(x,y)$ is the final output image, and $f(x,y)$ is the output just after the equalization process. This normalization will make sure that the mean output intensity will be almost equal to the mean input intensity.



(a) Input image (b) Global HEed image (c) BBHEed image

(d) DSIHEed image (e) MMBEBHEed image (f) RMSHEed image

(g) MPHEBPed image (h) DHEed image (i) BPDHEed image

Fig. 5. Results of all methods tested in this work using image of "*Castle*". In this case, the focus on the input image is the flower, which is located at the front. As the objects behind is out of focus, they appear blurred. The sky on the input image is presented by only one intensity value. Actually, the input image is already has a good contrast. Although all methods successfully enhanced the flower, most of them are also tends to enhance the partial volume effect of the background object. However, this problem is not significantly visible in the output obtained by using BPDHE.

III. RESULTS AND DISCUSSIONS

In addition to BPDHE, we are also implemented seven other methods, which are global HE, BBHE, DSIHE, MMBEBHE, RMSHE, MPHEBP, and DHE, to demonstrate the performance of the proposed method. For the implementation of RMSHE, we set the value of r equal to 3, where the histogram is divided into 8 sub-histograms, based on average values.

We use 80 test images to evaluate the performance of the methods. Some of these results are shown in Fig. 3 to Fig. 5. The results show that BPDHE successfully enhanced the images without introduce undesirable artifacts, such as saturation effect, changing of image focus, and also enhancement of the partial volume effect.

In order to investigate whether the proposed method successfully maintain the input mean brightness, we use an objective measure referred to as Average Absolute Mean

Brightness Error (AAMBE). This measure is defined as follow:

$$AAMBE = \frac{1}{N}\sum_{n=1}^{N}\left|E_n(X) - E_n(Y)\right| \tag{9}$$

where N is the total number of test images, $E_n(X)$ is the average intensity of test image n, while $E_n(Y)$ is the average intensity of the corresponding output image. Smaller value of AAMBE shows that the average intensity of the input and the average intensity of the output are almost equal. So, the method that can preserve the mean brightness of the image is the method with small value of AAMBE.

Table I presents AAMBE measure for all methods used in this work, obtained using 80 input images. From the table, we found that BPDHE can preserve the mean brightness better than global HE, BBHE, DSIHE, MMBEBHE, RMSHE, MPHEBP, and DHE. Note also that the value of AAMBE for BPDHE is only 1.42, which means that the average intensity of the output is differs less than two intensity levels from the average input intensity.

TABLE I
AAMBE MEASURE OBTAINED FROM 80 INPUT IMAGES

Method	AAMBE
Global HE	29.04
BBHE	13.82
DSIHE	24.74
MMBEBHE	1.86
RMSHE	3.05
MPHEBP	15.08
DHE	8.05
BPDHE	1.42

IV. CONCLUSION

In this paper, BPDHE has been proposed, as an extension to MPHEBP and DHE. BPDHE is similar to MPHEBP in terms of separating the histogram based on the local maximums, and similar to DHE in terms of spanning the dynamic range. However, unlike both MPHEBP and DHE, BPDHE utilize brightness normalization in order to keep the input mean intensity. One advantage of BPDHE is that there is no parameter need to be tuned. Experimental results shows that BPDHE can enhance the images without introducing unwanted artifacts, while at the same time maintain the input brightness. Furthermore, similar to other HE based algorithms BPDHE is easy to implement and can be used in real time system because of its simplicity.

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