

Dynamic Contrast Enhancement Using Multiple and Clipped Histogram Equalization

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Abstract: Histogram equalization (HE) is one of the common methods for improving contrast in digital images. However, HE may introduce some unnecessary visual deterioration while enhancing image. One of the solutions to overcome this weakness is by preserving the mean brightness of the output image. This paper proposes a new method, known as dynamic contrast enhancement using multiple and clipped histogram equalization (DCMHE). The proposed method first smoothes the global histogram and assigns each partition to a new dynamic range via optimal thresholds, and then clipping process is implemented to each sub-histogram. At last step, the conventional HE is implemented to each sub-histogram and the output image is normalized to the input mean brightness. Simulation results for several test images show that the proposed method enhances the contrast while preserving mean brightness. *Copyright © 2013 IFSA.*

Keywords: Histogram equalization, Contrast enhancement, Brightness preserving, Clipped histogram equalization.

1. Introduction

Image enhancement is a process involving changing the pixels' intensity of the input image. There are many image enhancement methods have been proposed. A very popular and most effective technique for image enhancement is histogram equalization. Its basic theory lies on mapping the gray levels 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. Despite of its popularity, HE is not very suitable to be implemented in consumer electronics, such as TV, video surveillance and so on. Because the brightness of the input image after HE processed [1-3] is often shifted to the mid gray level, some area of the output image is too bright or dark, namely resulting in excessive contrast enhancement.

There are already many methods with multiple histogram equalization have been proposed to overcome the drawback [4]. Image processed by Bi-HE methods enhances the image contrast significantly and may preserve the brightness to some extent, but it introduces undesirable artifacts. Such as, the earliest improved HE method was proposed by Kim in 1997, named brightness preserving bi-histogram equalization (BBHE) [5]. This method divides the image histogram into two parts. The two histograms corresponding to the two parts are independently equalized. It is mathematically shown that the mean brightness of processed image by BBHE method locates in the middle of the input mean gray level. Next, in 1999, the dualistic sub-image histogram equalization (DSIHE) [6] was proposed by Wan et al. This algorithm is similar to BBHE, except the partition value of histogram is the median value instead of the mean value. The

threshold of the separation is chosen such that two histograms have the equal number of pixels. It is claim that DSIHE is better than BBHE in terms of preserving brightness and entropy of the input image. In 2003 and 2007, Chen and Sims separately proposed recursive mean-separate histogram equalization (RMSHE) [7] and recursive sub-image histogram equalization (RSIHE) [8]. These methods iteratively utilize the BBHE or DSIHE and all produce 2^{γ} pieces of sub-histogram. Then, each sub-histogram is equalized independently. These two methods are good for brightness preserving when the value of γ usually set by users, γ is not too large; otherwise, the output histogram will become exactly the input histogram, and there is no enhancement. In 2010, Chen [9] proposed dynamic quadrants histogram equalization plateau limit (DQHEPL) and bi-histogram equalization median plateau limit (BHEPL-D), which are the extension of the BHEPL [10], and these two methods divides all the histogram of input image into four sub-histograms, so some of the output image may appear excessive enhancement. In 2011, Cheng et al [11] proposed a method for foggy image contrast enhancement, it is sub-histogram equalization method applied to the reality. In 2012, Mohd et al [12] proposed a method named weighted average multi segment histogram equalization for brightness preserving contrast enhancement (WAMSHE), but the ratio between pixels and section of some images is too large, so some section of out image also appear excessive enhancement. All of these methods have one main point in common: they decompose the input image histogram into two or more sub-histogram, and then equalize the histograms of these sub-images indecendently. In contrast, the major difference among these methods is the criteria they used to decompose the input image into two or more sub-images.

The above methods based on sub-image histogram equalization are at the cost of losses enhancement to preserve brightness, but these methods didn't obtain very good result. So, in order to obtain a better result, this paper propose a new method named dynamic contrast enhancement using multiple and clipped histogram equalization (DCMHE), though this method also is based on sub-image histogram equalization, it can be adaptively to determine the range and segmentation number according to the image histogram information, the detail will be given in the section 2. To avoid excessive enhancement phenomenon, we first smooth the global histogram with a one-dimensional filter to find optimal thresholds, then the smoothed histogram will be partitioned into segments via optimal thresholds and remap each partition into a new dynamic range. After that, we will clip each sub-histogram via clipping thresholds and HE is applied to each segment indecendently. In order to preserve the brightness of the image, by the normalization of the output mean, the mean of the resultant image will

be close to the input image. With this criterion, DCMHE is expected to produce better contrast enhancement, and better in preserving the mean brightness compared with other HE methods.

This paper is organized as follows. Section 2 summarizes fundamental theory of histogram equalization and describes the proposed method in detail. Section 3 gives the simulation results and comparisons with other methods. The conclusion of our work is given in section 4.

2. Histogram Equalization (HE)

2.1. Typical Histogram Equalization

For a given image X , the goal of HE method is to uniformly distribute the histogram of image X over the entire range of gray-levels, increasing the image contrast. Let $p(X_k)$ be defined as the probability density function:

$$p(X_k) = \frac{n^k}{n}, \quad (1)$$

for $k = 0, 1, \dots, L-1$, where n^k represents the number of times that the level X_k appears in the input image X and n is the total number of pixels in the input image. Base on the probability density function, the cumulative density function is defined as:

$$c(x) = \sum_{j=0}^k p(X_j) \quad (2)$$

where $X_k = x$, for $k=0, 1, \dots, L-1$. Note that $c(X_{L-1}) = 1$ by definition, HE is a scheme that maps the input image into the entire dynamic range by using the cumulative density function as a transform function. Let's define a transform function $f(x)$ based on the cumulative density function as follows:

$$f(x) = X_0 + (X_{L-1} - X_0) \cdot c(x) \quad (3)$$

Then the output image processed by the HE, $Y = \{Y(i, j)\}$ can be expressed as

$$Y = f(x) = \{f(X(i, j)) | \forall X(i, j) \in X\} \quad (4)$$

The traditional HE has a high performance in enhancing the contrast of an image as a consequence of the dynamic range expansion. But it can also introduce a significant change in brightness of an image, which hesitates the direct application of HE scheme in consumer electronics.

2.2. Dynamic Contrast Enhancement Using Multiple and Clipped Histogram Equalization (DCMHE)

In order to overcome the drawback introduced by the traditional HE, so many variations of HE-based methods have been proposed. In this section, we will describe the method called dynamic contrast enhancement using multiple and clipped histogram equalization (DCMHE) in detail.

2.2.1. Selection of Optimal Thresholds

Because it is difficult to detect the local optimum of the histogram which was not smoothed, we have to gain the smoothing histogram before we choose the local optimum as the optimal thresholds. In order to do so, we use a one dimensional Gaussian filter to smooth the original histogram. The Gaussian filter is defined by the following equation:

$$G(t) = \exp(-t^2 / 2\sigma^2), \quad (5)$$

where t is the coordinate relative to the center of the kernel, and σ is the standard deviation. In this paper, we use a Gaussian filter of size 1x5 and use the local maximum as the optimal thresholds. In order to find the local maximum, we apply the method in [13] and set the initial label of the smoothing histogram as follows (if $(h(k) \geq h(k-1))$ then $b(k) = 1$ else $b(k) = -1$). Since there are still fluctuations in the calculated signs, a process of removing stray signs is applied as the following method:

$$\begin{matrix} + & - & \boxplus & \Rightarrow & + & + & + \\ - & + & \boxminus & \Rightarrow & - & - & - \end{matrix} \quad (6)$$

Then we will find all the values of k from the above sequence which meet the conditions $b(k-9) = 1, \dots, b(k) = 1$ and $b(k+1) = -1, \dots, b(k+9) = -1$ (k_0, k_1, \dots, k_n), as shown in Fig 1.

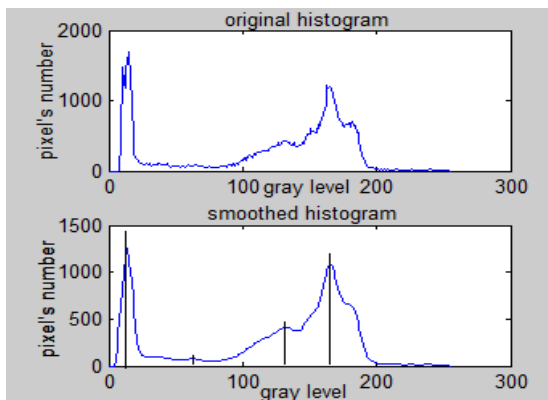


Fig. 1. Smooth histogram and select separated value.

As can be seen from the Fig. 1, there are four points (local maximums) satisfying the conditions; however, at the second point, the local maximum has a very small value difference with the local minimums in its two sides. In order to enhance image better, we need to remove these unobvious local maximums, so we set a threshold f to remove these points.

2.2.2. Map each Partition into a New Dynamic Range

We use I_0, I_1, \dots, I_{n-1} to represent the above sequence of optimal thresholds. If the original histogram before smoothing is in the range of $I_{\min} \sim I_{\max}$, then the histogram will be divided into $(n+1)$ sections, that is, $[I_{\min}, I_0], [I_0 + 1, I_1], \dots, [I_{n-1} + 1, I_{\max}]$, and the number of pixels of each section are $M_0, M_1, \dots, M_{n-1}, M_n$. Because sub-histograms with small range will not be enhanced significantly by HE as shown in Fig. 2, we can use the method in [14] to map each partition into a new dynamic range based on the size of each section and the number of pixels.

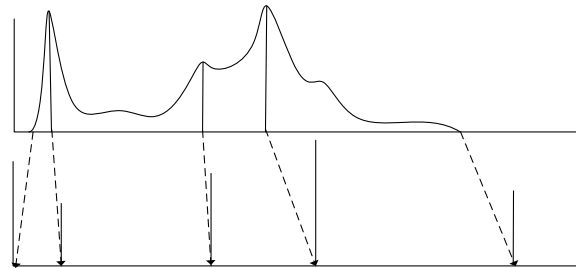


Fig 2. Map each partition into a new dynamic range.

The mapping function is described by the following equations:

$$\begin{aligned} spain_i &= high_i - low_{i-1} \\ factor_i &= spain_i \times \log_{10}(M_i / spain_i) \\ T &= \sum_{i=0}^n factor_i \\ range_i &= (L-1) \times factor_i / T \end{aligned} \quad (7)$$

where $spain_i$ is the range of each section, $high_i$ is the highest intensity value containing in the sub-histogram i , low_i is the lowest intensity value in that section, and M_i is the total pixels containing in that section. Let the $range_i$ represent the size of the output each section. If we set the first sub-histogram

of the output image in the range of $[0, range_0]$, then $start_i$ and end_i can be calculated as follows:

$$\begin{aligned} start_i &= \sum_{k=0}^{i-1} range_k + 1 \\ end_i &= \sum_{k=0}^i range_k \end{aligned} \quad (8)$$

2.2.3. Clipped Histogram Equalization

In order to maintain the stability of preserving the original brightness and avoid over-enhancement, we will further processing sub-histograms respectively, i.e., clipping the sub-histograms by the clipping threshold P_i used in [15]. The value of clipping threshold P_i can be computed by the transformation function:

$$P_i = \frac{1}{k_i - k_{i-1}} \times \sum_{m=k_{i-1}}^{k_i} h(m), \quad (9)$$

where P_i is the mean value of each section, clipping histogram can be done as the following operations:

$$\begin{aligned} h_c(m_i') &= h(m_i) & (h(m_i) \leq P_i) \\ h_c(m_i') &= P_i & (h(m_i) \geq P_i), \end{aligned} \quad (10)$$

where $h_c(m_i')$ represents the clipped histogram, as shown in Fig. 3.

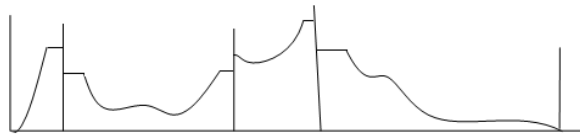


Fig. 3. Clip sub-histogram.

2.2.4. Equalizing Each Segment Independently

After the clipped histogram is obtained, each sub-histogram can be equalized individually by the conventional HE method. Let k' be gray level of output image, which can be computed by the transformation function as follows:

$$k' = h_{lower} + (h_{upper} - h_{lower}) * C_k^{[h_{lower}, h_{upper}]}, \quad (11)$$

where h_{lower} and h_{upper} are lower and upper limit of sub-histograms, $C_k^{[h_{lower}, h_{upper}]}$ represents the cumulative probability density of the level k and can be obtained as follows:

$$\begin{aligned} C_k &= \frac{\sum_{j=m_{i-1}}^k h'(j)}{M_i} \\ M_i &= \sum_{j=m_{i-1}}^{m_i} h'(j) \end{aligned} \quad (12)$$

2.2.5. Normalizing the Image Brightness

In this section, we will try to re-shift the mean brightness of output image to its original position after the equalization process. Assuming that m_i represents the mean brightness of input image $I(x, y)$ and m_o represents the mean brightness of output image $O(x, y)$, we apply the brightness normalization as the following equation:

$$O(x, y) = \frac{m_i}{m_o} I(x, y), \quad (13)$$

This normalization will make sure that the mean brightness of output image will be closer to the original input mean brightness of the image.

3. Results and Discussion

In this section, in addition to the proposed algorithm DCMHE, we also implemented several other improved histogram equalization algorithms mentioned above, the iteration number of RMSHE and RSIHE is let be two, namely the original image is divided into four sub-image.

In order to show the superiority of the proposed algorithm, we used the two measure criterion: the mean absolute error between the output image and the input image (AMBE) in [4] and the standard variance of the difference between the output image and the input image (SD) in [16]. We use AMBE to measure the stability of preserving the mean brightness of images. The smaller the value of AMBE, the better this stability. The AMBE is defined as follows:

$$AMBE = |E[X] - E[Y]|, \quad (14)$$

where $E[X]$ and $E[Y]$ represent the original and enhanced image gray scale averages respectively. In order to measure whether the processed image is enhanced. We use the SD as a measuring standard (the bigger the value of SD, the greater the image contrast), the standard variance of the difference between the output image and the input image (SD) is defined as follows:

$$\begin{aligned} SD &= SD[Y] - SD[X] \\ SD[I] &= \sqrt{\sum_{\min}^{\max} (l - u)^2 \times P(l)}, \end{aligned} \quad (15)$$

where $SD [I]$ represents the SD of image I , $SD[Y]$ and $SD[X]$ represent the SD of output image and input image respectively, I represents the gray value of image I , u represents the mean gray level, $P[I]$ is the probability distribution of gray scale.

From Table 1, we can see that the AMBE value obtained by the proposed algorithm is smaller than other algorithms. It is shown that the gray scale average in the proposed algorithm has very small changes between output image and input image. It is also indicated that the proposed algorithm is able to maintain the stability of image gray scale average very well. Because our algorithm adopts not only the advantages of sub histogram equalization, but also the idea of clipped histogram equalization, the proposed algorithm achieves the good result.

Table 1. The AMBE of input and output image.

	Airplane	Pout	man	Rice
BBHE	12.1257	2.6979	23.7126	8.6479
DSIHE	6.1938	8.1046	17.6388	3.9744
RMSHE	6.1521	5.9960	11.9108	0.2923
RSIHE	6.2408	8.3872	9.5606	0.5201
DQHEPL	4.4864	5.0279	12.7527	3.0582
WAMSHE	0.1966	0.4735	0.1350	0.2301
DCMHE	0.0828	0.1129	0.0168	0.0218

In Table 2, some SD values obtained by the proposed algorithm (DCMHE) are bigger than those achieved by other algorithms (RMSHE, RSIHE, DQHEPL and WAMSHE). Note that the larger the SD value of output image achieves, the better the image is enhanced. However, some SD values obtained by the proposed algorithm (DCMHE) are smaller than those achieved by the algorithms BBHE and DSIHE. This is due to the reason our algorithm is a kind of sub-histogram equalization, it has to be at the cost of image enhancement to preserve the brightness, so the image enhancement effect is influenced.

Table 2. The SD of output and input image.

	Airplane	Pout	man	Rice
BBHE	41.7818	49.5527	8.9911	28.5079
DSIHE	41.9192	50.1927	11.1281	31.3417
RMSHE	11.9431	12.1677	9.9726	0.4771
RSIHE	23.4480	15.2694	2.1166	-0.5304
DQHEPL	11.6272	43.9538	13.9704	23.9391
WAMSHE	5.3798	30.2906	20.3862	26.2009
DCMHE	14.4646	54.0127	6.7917	22.6033

Fig 4 shows that in the shadow of the images processed by the BBHE, RMSHE and RSIHE the

various degree of excessive enhancement appears. So we can not see the outlines of the shadow clearly. In the image f, g and h, we can see the effect of image h is better than the other two images.

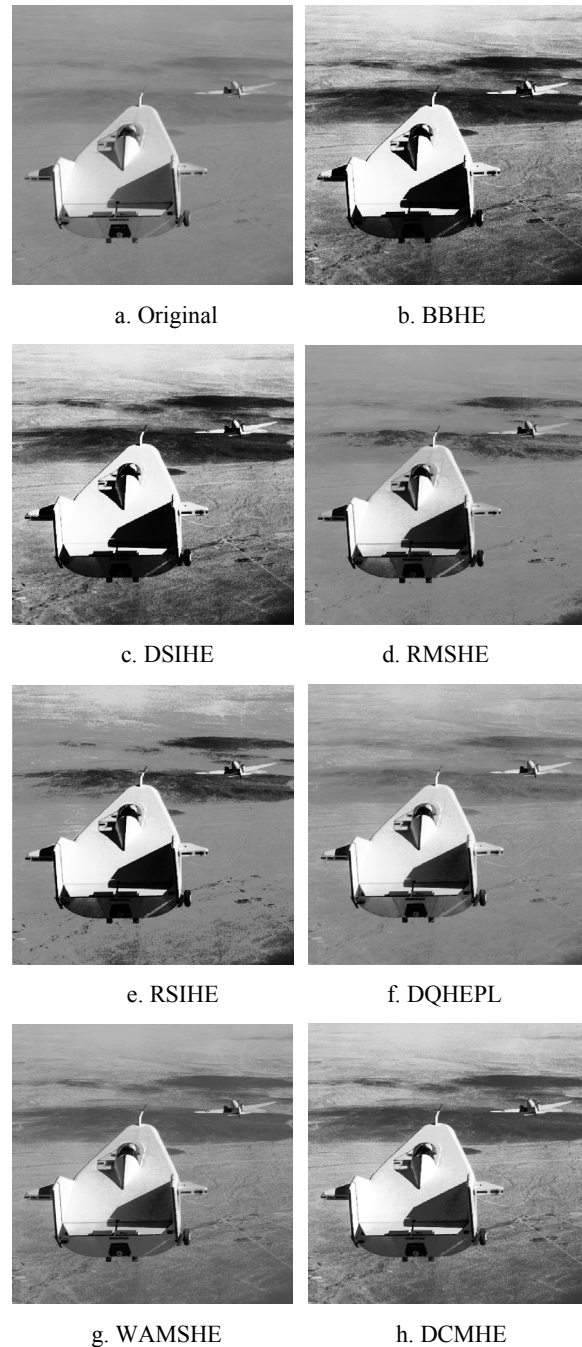


Fig. 4. The result of Airplane image enhancement.

Fig. 5 shows that the images obtained by the RMSHE and RSIHE introduce undesirable artifacts. The image h after processed by the proposed algorithm is better than others, for example, in the picture h the hair contour is more clearly than others, so it has better visual effect.

In the Fig. 6 the backgrounds of image b, c, d, e and g appear different degree of halo phenomenon,

but this phenomenon didn't appear clearly in image h obtained by the proposed algorithm.

In Fig 7, we can see that the effect of images processed by the algorithms RMSHE and RSIHE processed is very poor. Those processed images

almost have no difference from the original image, The algorithms of BBHE DSIHE DQHEPL and WAMSHE enhance the image while introducing a number of noises, but the image h under our algorithm obtains a good effect.



Fig. 5. The result of Pout image enhancement.

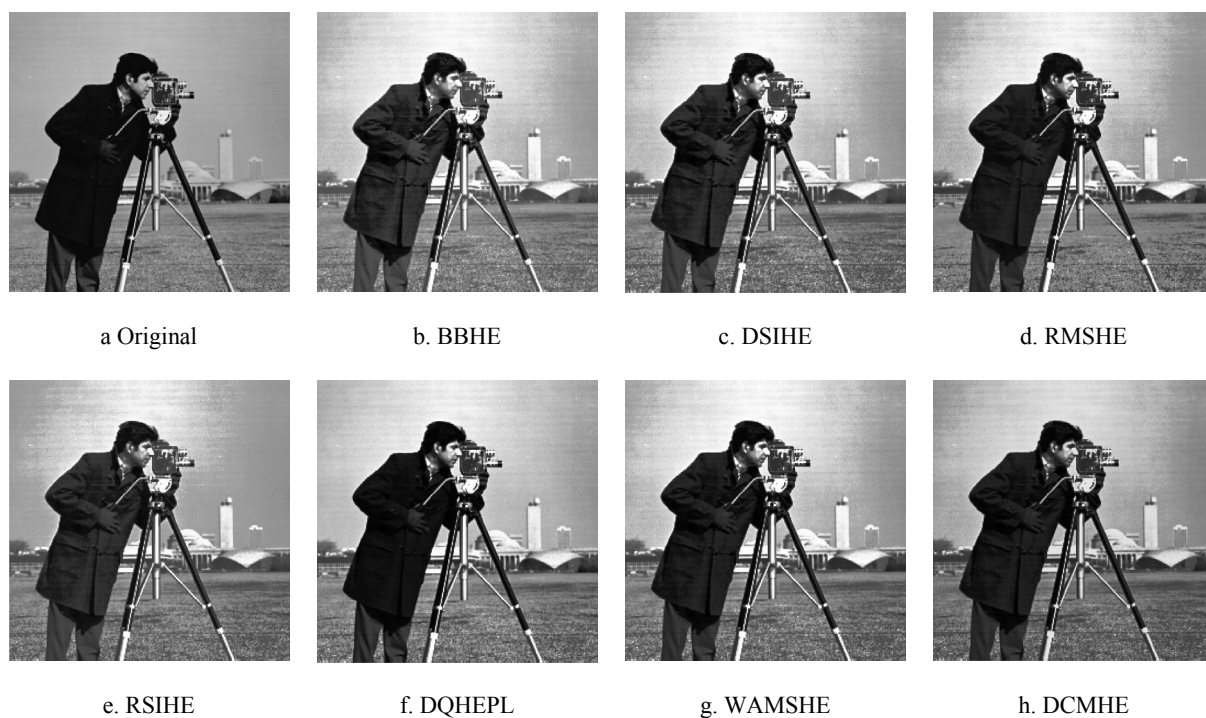


Fig. 6. The result of man image enhancement.

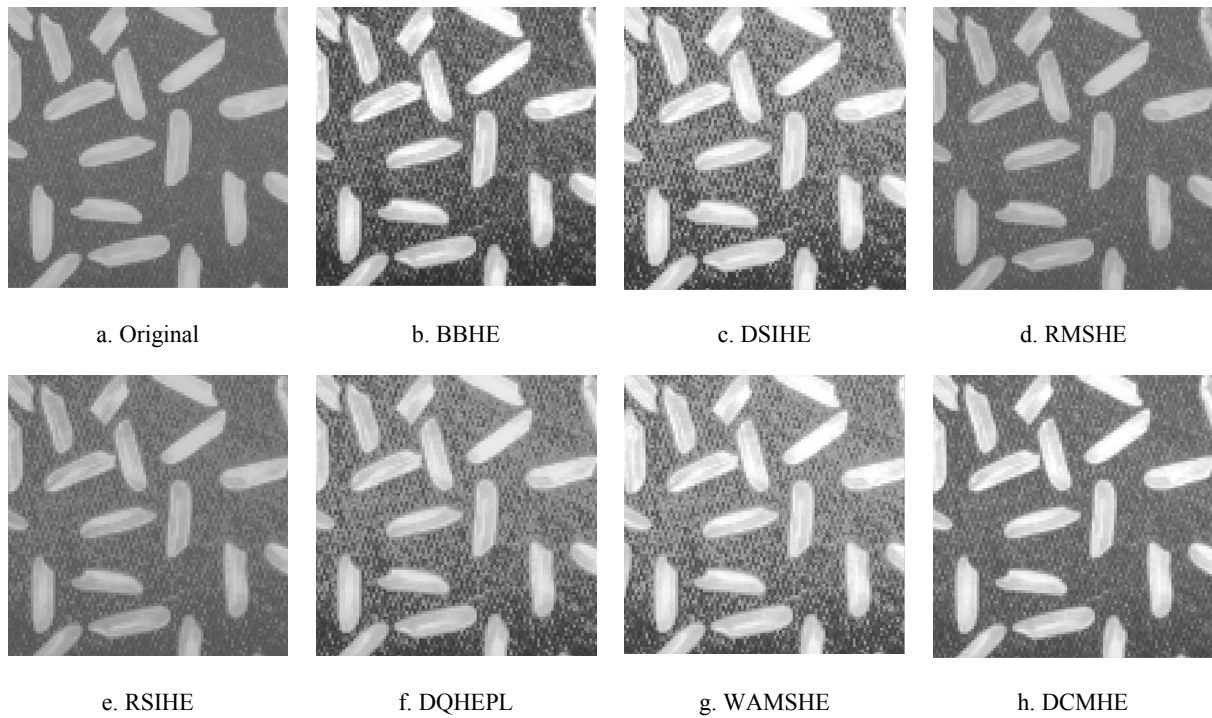


Fig. 7. The result of rice image enhancement.

4. Conclusion

To overcome the defects of traditional histogram equalization algorithm, this paper proposed a dynamic contrast enhancement using multiple and clipped histogram equalization (DCMHE). Experimental results show that this method is able to preserve the brightness of the processed images and yields the images with natural appearance. The subsequent research work is to select a good method to choose the threshold value of f .

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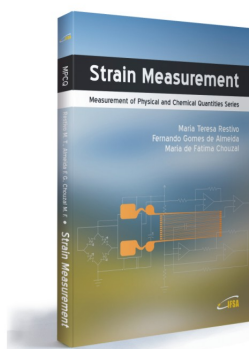


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