Color Image Enhancement Using Brightness Preserving Dynamic Histogram Equalization

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Abstract — *Histogram equalization (HE), although one of the most popular techniques used for digital image enhancement, is not very suitable to be implemented directly in consumer electronics, such as television, because this method tends to produce an output with saturation effect. To overcome this weakness, it is suggested that the mean intensity of the input image be maintained in the output image. Previously, we proposed a method known as brightness preserving dynamic histogram equalization (BPDHE) which can fulfill this requirement for grayscale images. In this paper, we present several possibilities to extend this method for color images*[1].

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

I. INTRODUCTION

Image enhancement is one of the most interesting and important issues in digital image processing field. The main purpose of image enhancement is to bring out details that are hidden in an image, or to increase the contrast in a low contrast image [1]. Image enhancement produces an output image that subjectively looks better than the original image by changing the pixel's intensity of the input image [2]. Generally, image enhancement enlarges the intensity differences among objects and background.

There are many image enhancement techniques have been proposed and developed. One of the most popular image enhancement methods is histogram equalization (HE). HE becomes a popular technique for contrast enhancement because this method is simple and effective. HE technique can be applied in many fields such as in medical image processing [3], radar image processing [4], and sonar image processing [5]. The basic idea of HE method is to re-map the gray levels of an image based on the image's gray levels cumulative density function. HE flattens and stretches the dynamic range of the resultant image histogram and as a consequence, it enhances the contrast of the image and gives an overall contrast improvement. However, HE is rarely employed in consumer electronic applications such as video surveillance [6], digital camera, and television since HE tends to introduce some annoying artifacts and unnatural enhancement, including intensity saturation effect. One of the reasons to this problem is because HE normally changes the brightness of the image significantly, and thus makes the output image becomes saturated with very bright or dark intensity values. Hence, brightness preserving is an important characteristic needed to be considered in order to enhance the image for consumer electronic products [4].

In order to overcome the aforementioned problems, mean brightness preserving histogram equalization based techniques have been proposed in the literature. Generally, these methods separate the histogram of the input image into several sub-histograms, and the equalization is carried out independently in each of the sub-histograms. For example, brightness preserving bi-histogram equalization (BBHE) [4], divides the input histogram into two subsections based on the mean value. Dualistic sub-image histogram equalization (DSIHE), which has been proposed by Wang et al. [7], also separates the input histogram into two subsections, but the separation is based on the median value. Later, minimum mean brightness error bi-histogram equalization (MMBEBHE) has been proposed by Chen and Ramli in [5][8] to preserve the brightness "optimally". MMBEBHE also separates the histogram into two subsections. However, MMBEBHE performs the separation based on the threshold level, which would yield a minimum difference between the input mean and the output mean. Chen and Ramli also have proposed another method called recursive mean-separate histogram equalization (RMSHE) [5][9]. RMSHE recursively divides the histogram into several subsections based on the local mean values. The number of sub-sections, given by 2^r, is set by the user. An almost similar method to RMSHE has been proposed by Sim et. al [10]. This method divides the histogram based on the median value, rather than the mean value.

Previously, we have proposed a new method known as brightness preserving dynamic histogram equalization (BPDHE) [2][3]. Similar to other methods, BPDHE divides the histogram into several subsections and equalize them independently. However, in BPDHE, the division of the histogram is carried out based on the locations of the local maximums of the input histogram itself. Thus, BPDHE is parameter-less, and suitable for the implementation in an automated enhancement system, such as in consumer electronic products. In [2], we showed that BPDHE is superior than some of the brightness preserving histogram equalization based methods, including BBHE, DSIHE, MMBEBHE, and RMSHE.

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It is worth noting that all works in [2]-[10] are all based on grayscale images. But, most of state of the art consumer electronic products, such as television and digital camera, produce color images [11]. Thus, this enhancement scheme should be extended to color images in order to fit the current requirements. However, the color image processing and the grayscale image processing are somehow different [12].

The work in this paper is actually an extension to the work in [2]. The main aim of this paper is to present several possibilities of BPDHE implementations for color images. The intension of this work is not only to give an overview to color image processing but also to find the suitable processing scheme for BPDHE method.

The organization of this paper is as follows. Because the work here is an extension to BPDHE, an overview on BPDHE is given in section II. Section III describes the methodologies we use to process the color images using BPDHE. Then, some experimental results of BPDHE are presented in section IV. The last section serves as the conclusion of this work.

II. Brightness Preserving Dynamic Histogram Equalization (BPDHE)

BPDHE is an extension to both multi-peak histogram equalization (MPHE) [13] and dynamic histogram equalization (DHE) [14]. Both MPHE and DHE break the histogram based on the local minimums. However, unlike MPHE and DHE, BPDHE divides the histogram based on the local maximums. Before the equalization process, BPDHE will map each partition to a new dynamic range, which is similar to DHE. As dynamic range changed, this will cause the change in the mean brightness too. Therefore, the final step is involving the normalization of the output intensity. Thus, the average intensity of the resultant image will be almost the same as the input.

In general, there are five steps involved in BPDHE. The basic descriptions of these steps are:

1. *Smooth the histogram with a Gaussian filter.*
   Histogram of the digital image is normally fluctuated and some of its bins are empty. Thus, the first step is to fill up the empty bins of the histogram by using the linear interpolation. After that, the histogram is convolved with a Gaussian filter to produce a smoother histogram. This step is important in order to generate an approximation to a continuous histogram.
2. *Detect and find the locations of local maximums.*
   The locations of local maximum are detected based on the first derivative of the smoothed histogram. The local maximums are chosen to use instead of local minimums because this selection is better in maintaining the mean brightness. The local maximum detects as four successive positive signs followed by eight successive negative signs. These local maximums are used to split the input histogram into partitions.
3. *Map each partition into a new dynamic range.*
   This step is employed in order to use all the dynamic range available in the image. The mapping of the partitions is based on the number of pixels inside that partition.
4. *Equalize each partition independently.*
   Histogram equalization is carried out in each partition of the histogram, independently. However, the results are then combined together, to form a complete enhanced image.
5. *Normalize the image brightness.*
   Before normalization process is applied, the mean brightness of the input and the mean brightness of the output which are obtained after equalization process are calculated. This step is important in order to maintain the mean brightness of the image.

More details on the implementation of this method can be found in [2].

III. Color Image Processing

As most of the electronic equipments acquire or display image in *RGB* (i.e. red, green, and blue) color space [15], in this work, we assume that our input image is also in *RGB* color space. Thus, each pixels in the input image are presented by three color bands or channel which are red (*R*), green (*G*), and blue (*B*). We assume that after the enhancement process, the output pixels are presented by *R'*, *G'*, and *B'*. In this section, we present seven possible methods to be employed by BPDHE in order to process color digital images. These methods are explained in the following sub-sections.

A. Method 1: Equalize R, G, B Independently

This scheme is one of the mostly used methods for color image processing. Each channels of *RGB* space are processed using BPDHE independently, as shown in Fig. 1. Works in [16] and [17] use this processing scheme.

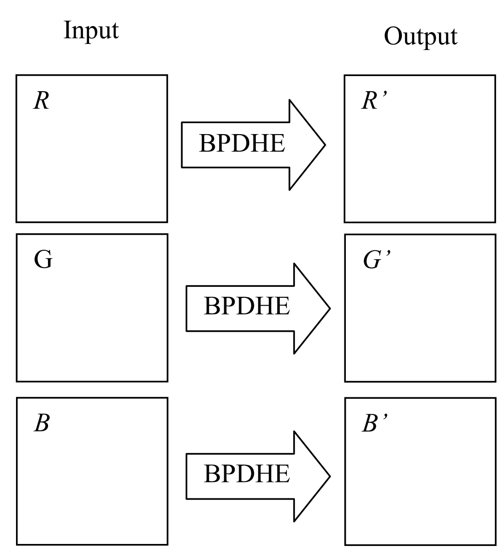

Fig. 1. Block diagram showing the implementation of Method 1.

B. Method 2: Equalize I Channel From HSI Color Space

In order to process color image in *RGB* color space using this scheme, the image first must be transformed to hue, saturation and intensity (*HSI*) color space. In order to make this article self-contained, the equations needed for the transformations are given below [1].

$$I = (R + G + B)/3 \tag{1}$$

$$S = 1 - \frac{[\min(R,G,B)]}{I} \tag{2}$$

and

$$H = \begin{cases} \theta & \text{if} \quad B \le G \\ 360^\circ - \theta & \text{if} \quad B > G \end{cases} \tag{3}$$

where

$$\theta = \cos^{-1}\left\{ \frac{2R - G - B}{2\sqrt{(R-G)^2 + (R-B)(G-B)}} \right\} \tag{4}$$

After we obtained H, S, and I color components, only I channel is processed using BPDHE. The output from BPDHE is denoted by I'. Then, by using the values of H, S, and I', we calculate the value of R', G', and B' using the conversion from *HSI* to *RGB*, which are given by the following equations [1].

If ($0^\circ \le H < 120^\circ$)

$$B' = I'(1 - S) \tag{5}$$

$$R' = I'\left[1 + \frac{S\cos(H)}{\cos(60^\circ - H)}\right] \tag{6}$$

$$G' = 3I' - (R' + B') \tag{7}$$

If ($120^\circ \le H < 240^\circ$)

$$R' = I'(1 - S) \tag{8}$$

$$G' = I'\left[1 + \frac{S\cos(H - 120^\circ)}{\cos(60^\circ + H)}\right] \tag{9}$$

$$B' = 3I' - (R' + G') \tag{10}$$

If ($240^\circ \le H < 360^\circ$)

$$G' = I'(1 - S) \tag{11}$$

$$B' = I'\left[1 + \frac{S\cos(H - 240^\circ)}{\cos(180^\circ + H)}\right] \tag{12}$$

$$R' = 3I' - (G' + B') \tag{13}$$

Work in [18], for example, used this processing scheme.

C. Method 3: Equalize S Channel From HSI Color Space

Similar to Method 2, Method 3 needs to convert the pixels in *RGB* color space to *HSI* color space first. This conversion is using (1) to (4). However, only S channel is processed using BPDHE, produces S'. Then, the value of R', G', and B' are:

If ($0^\circ \le H < 120^\circ$)

$$B' = I(1 - S') \tag{14}$$

$$R' = I\left[1 + \frac{S'\cos(H)}{\cos(60^\circ - H)}\right] \tag{15}$$

$$G' = 3I - (R' + B') \tag{16}$$

If ($120^\circ \le H < 240^\circ$)

$$R' = I(1 - S') \tag{17}$$

$$G' = I\left[1 + \frac{S'\cos(H - 120^\circ)}{\cos(60^\circ + H)}\right] \tag{18}$$

$$B' = 3I - (R' + G') \tag{19}$$

If ($240^\circ \le H < 360^\circ$)

$$G' = I(1 - S') \tag{20}$$

$$B' = I\left[1 + \frac{S'\cos(H - 240^\circ)}{\cos(180^\circ + H)}\right] \tag{21}$$

$$R' = 3I - (G' + B') \tag{22}$$

D. Method 4: Equalize V Channel From HSV Color Space

In order to process color image in *RGB* color space using this scheme, the image first must be transformed to hue, saturation and luminance (*HSV*) color space. In order to do this, we normalize R, G, and B components to the range of [0,1], and these normalized components are denoted as r, g, and b, respectively. Then, the transformations are given by the following equations [19].

$$range = \max(r,g,b) - \min(r,g,b) \tag{23}$$

$$S = \begin{cases} 0 & : \quad \max(r,g,b) = 0 \\ \dfrac{255 \times range}{\max(r,g,b)} & : \quad \text{otherwise} \end{cases} \tag{24}$$

$$H=\begin{cases} underfined & : \ range=0 \\ \dfrac{60°(g-b)}{range} & : \ \max(r,g,b)=r \ \&\&g \geq b \\ \dfrac{60°(g-b)}{range}+360° & : \ \max(r,g,b)=r \ \&\&g < b \\ \dfrac{60°(b-r)}{range}+120° & : \ \max(r,g,b)=g \\ \dfrac{60°(r-g)}{range}+240° & : \ \max(r,g,b)=b \end{cases} \tag{25}$$

$$V=255\times\max(r,g,b) \tag{26}$$

After we obtained *H*, *S*, and *V* components, only *V* channel need to be processed using BPDHE. The output from the process is denoted as *V'*.

In order to perform the conversion from *HSV* to *RGB*, both channel *S* and *V'* need to be normalized to the range of [0,1], and the results are denoted as *s* and *v'*. Then, the following values are calculated:

$$h=\left\lfloor \frac{H}{60} \right\rfloor \bmod 6 \tag{27}$$

$$f=\frac{H}{60}-h \tag{28}$$

$$p=v'\times(1-s) \tag{29}$$

$$q=v'\times(1-f\times s) \tag{30}$$

$$t=v'\times(1-(1-f)\times s) \tag{31}$$

Next, the output color vector (*r'*, *g'*, *b'*) is obtained by:

$$(r',g',b')=\begin{cases} (v',t,p) & : \ h=0 \\ (q,v',p) & : \ h=1 \\ (p,v',t) & : \ h=2 \\ (p,q,v') & : \ h=3 \\ (t,p,v') & : \ h=4 \\ (v',p,q) & : \ h=5 \end{cases} \tag{32}$$

Then, *R'*=255*r'*, *G'*=255*g'* and *B'*=255*b'*. Work in [19], for example, used this processing scheme.

E. Method 5: Equalize Y Channel From YUV Color Space

In this method, the input image, which in *RGB* color space, is first transformed into YUV color space. These transformations are given by the following equations [20].

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix}=\begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{bmatrix}\begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{33}$$

After we obtained *Y*, *U*, and *V* components, only *Y* channel need to be processed using BPDHE. The output from the process is denoted as *Y'*. Then, the corresponding *R'*, *G'*, and *B'* are determined by:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix}=\begin{bmatrix} 1 & 0 & 1.13983 \\ 1 & -0.39465 & -0.58060 \\ 1 & 2.03211 & 0 \end{bmatrix}\begin{bmatrix} Y' \\ U \\ V \end{bmatrix} \tag{34}$$

Work in [21], for example, used this color scheme for their processing.

F. Method 6: Equalize One Band of RGB Color Space

According to the "gray world" assumption, the average intensity values in *R*, *G*, *B* channels should be equal to each other [22]. Method 6 is similar to the "gray world" assumption, and following the work as suggested in [23]. This method works in *RGB* color space. First, the method will check the *R, G,* and *B* channels and select one channel with the smallest intensity range. This selected channel is denoted as *X*, and processed by using BPDHE. The output is denoted as *X'*. Then, the remaining channels are calculated based on the following equations:

$$R'=\begin{cases} X' & : \ X=R \\ \left(\dfrac{R}{X}\right)X' & : \ X\neq R \end{cases} \tag{35}$$

$$G'=\begin{cases} X' & : \ X=G \\ \left(\dfrac{G}{X}\right)X' & : \ X\neq G \end{cases} \tag{36}$$

$$B'=\begin{cases} X' & : \ X=B \\ \left(\dfrac{B}{X}\right)X' & : \ X\neq B \end{cases} \tag{37}$$

G. Method 7: Equalize Only G Channel

This method is our extension to Method 6. Because the *G* channel is a good estimate of the luminance signal [22], we only apply BPDHE to *G* channel, and produce *G*'. Then, the value of *R'* and *B'* are calculated by using the following equations:

$$R'=\begin{cases} 0 & : \ \alpha<0 \\ \alpha & : \ 0\leq\alpha\leq 255 \\ 255 & : \ \alpha>255 \end{cases} \tag{38}$$

$$B' = \begin{cases} 0 & : \quad \beta < 0 \\ \beta & : \quad 0 \le \beta \le 255 \\ 255 & : \quad \beta > 255 \end{cases} \tag{39}$$

where:

$$\alpha = G' + (R - G) \tag{40}$$

$$\beta = G' + (B - G) \tag{41}$$

IV. Experimental Results

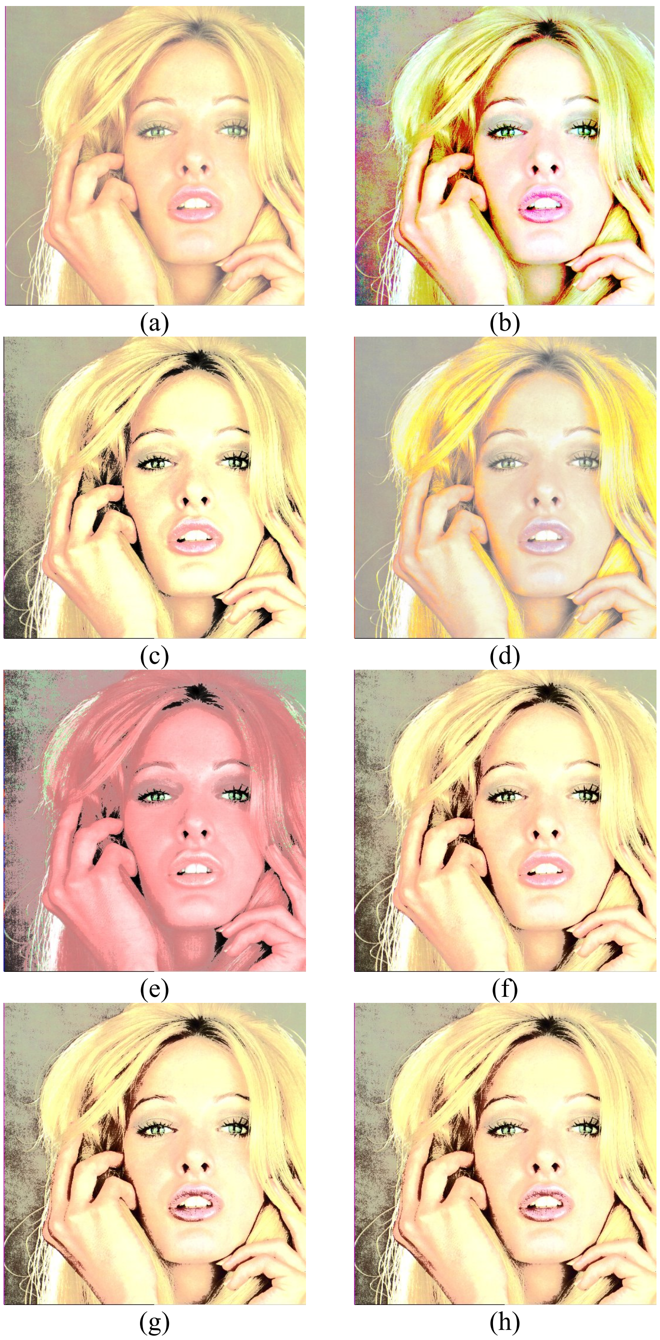

Fig. 2. "*Tiffany*". (a) Input image. Color BPDHEed images using (b) Method 1, (c) Method 2, (d) Method 3, (e) Method 4, (f) Method 5, (g) Method 6, and (h) Method 7. (Color version of this figure can be viewed online).

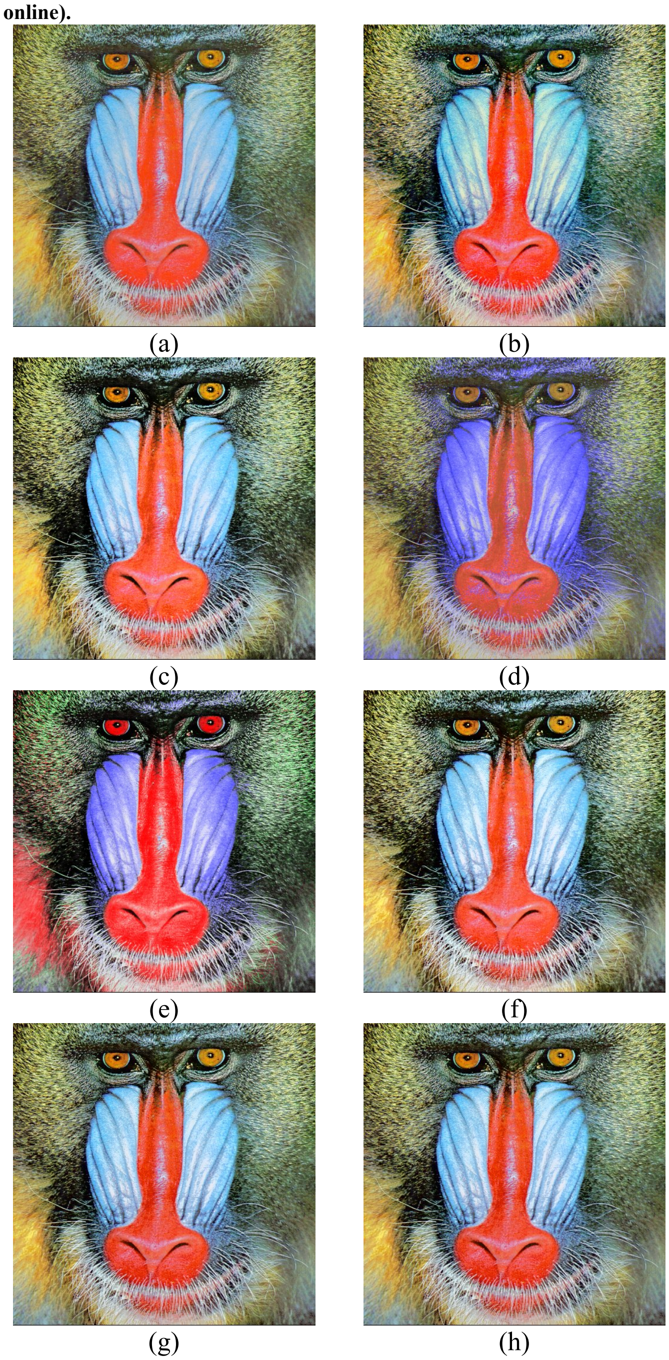

Fig. 3. "*Baboon*". (a) Input image. Color BPDHEed images using (b) Method 1, (c) Method 2, (d) Method 3, (e) Method 4, (f) Method 5, (g) Method 6, and (h) Method 7. (Color version of this figure can be viewed online).

In this experiment, two test images, which are "*Tiffany*" and "*Baboon*", have been used. The results by using color enhancement methods described in Section III are shown in Fig. 2 and Fig. 3. However, the evaluation of the results, in order to find the best scheme for BPDHE, cannot be carried out objectively. The performance measure that is widely used for grayscale brightness preserving histogram equalization based methods, which is the absolute mean brightness error (AMBE), cannot be applied in this work.

AMBE finds the difference between the mean brightness of the input to the mean brightness of the output. Yet, in the work presented in this paper, each method that we use utilizes different color scheme. Each color schemes have their own representation for brightness. Thus, if the performance of these color enhancement methods is judged based on AMBE, the evaluation might not be a valid evaluation.

Thus, we evaluate the results subjectively, based on visual inspection. From Fig. 2 and Fig. 3, it is shown clearly that Method 3 and Method 4 produce unacceptable result. These methods assign inappropriate colors to the objects. Method 1, on the other hand, although produces outputs that look better than the corresponding input, this method slightly changes the color of the image. This can be seen clearly on the background region in Fig. 2(b).

The appearance of the outputs from Method 2, Method 5, Method 6, and Method 7 are seems equivalent to each other and acceptable. However, it is worth noting that Method 2 and Method 5 involve the transformations from *RGB* to another color space, and the conversion back to *RGB* color space. As a consequence, this makes the implementation of these methods for consumer electronic products become more complicated. The implementation also requires more memory spaces (i.e. increase the hardware requirement) and more processing time. The conversions from one color space to another also make the process prone to quantization error.

Thus, for the implementation of BPDHE for color images in consumer electronic products, we suggest that our method, which is Method 7, should be employed. The result from Method 7 is almost similar to Method 6, but this method is less complicated and requires less processing time. This is because Method 7 directly processes the *G* channel; unlike Method 6 which needs to find the channel with smaller intensity range first. In Method 7, the determination of the corresponding R' and B' values is also easy. As shown in (38) to (41), the processes only require simple additions and subtractions, thus require a short processing time.

V. CONCLUSION

In this paper, a short overview and experimentations on color image processing have been presented. Several possibilities on color image enhancement have been explored and implemented to BPDHE. The results show that our proposed method (i.e. Method 7), which is based on *G* color channel, produces the output images that are acceptable and equivalent to other methods. This method is simple, and suitable for consumer electronic products. Yet, in future, a new measure should be introduced in order to evaluate the performance of the methods in more objective manner.

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