Local Brightness Preservation for Dynamic Histogram Equalization

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***Abstract*—This paper presents a novel local brightness preserving dynamic histogram equalization (LBPDHE) algorithm for contrast enhancement. Previous contrast enhancement works have shown the benefits of histogram partitioning before histogram equalization to avoid over or under enhanced images. In addition, brightness preservation has been recognized as one of the most important properties for contrast enhancement schemes. Brightness preservation is important for reducing energy consumption in consumer electronic products, such as liquid crystal displays (LCD) and televisions. The main idea in this paper is the observation that brightness preservation could be performed locally and independently for each partition, instead of globally over the whole histogram as in previous research proposals. Based on eighty test images, experimental results indicate that our proposed method can not only produce good contrast enhanced images, but also achieve the best mean brightness preservation when compared with the other state-of-the-art methods.**

I. INTRODUCTION

Histogram equalization (HE) is a method for enhancing the contrast of images through manipulation of the image's histogram [1], [2], [3]. However, early HE methods, for example [1], often produce unrealistic looking images when photographs are processed. Subsequent methods proposed various refinements to the early methods so that the results are more realistic visually [2], [3]. In additional to producing realistic images, another important requirement for contrast enhancement methods is mean brightness preservation. Image mean brightness should be preserved in many applications for an important reason. Brighter images consume more power on many types of consumer electronics devices, such as backlight power reduction, and medical image diagnosis [4], [5], [6], [7]. Preserving mean brightness is important for these types of devices so that they do not consume more power than necessary after contrast enhancement.

The HE method described in [1] is the earliest version for contrast enhancement and it serves as the basis for performance comparison and algorithmic foundation for other methods. The idea of the HE method is to distribute the gray values so that the cumulative histogram of the output image is linear. More precisely, given the histogram of an input image I, let $[0, L-1]$ denote the full spectrum of gray values. Let n_i and N denote the number of pixels with gray level i and the total number of pixels in I, respectively. Then, the HE method can be defined simply using the transform function $T(i)$, which maps the gray level i in the original image to a new gray level i_{new}, as follows.

$$i_{new} = T(i) = L * \sum_{k=0}^{i} P(n_k) \tag{1}$$

where $P(n_k) = n_k/N$, $0 \leq i \leq L$.

As mentioned before, brightness preservation is an important goal for contrast enhancement methods. The mean brightness of an image is defined as follows.

$$Mean = \sum_{i=0}^{L} i * n_i \tag{2}$$

The HE method often produces unrealistic looking images when photographs are processed. To circumvent the problems, Wadud *et al.* [2] presented a dynamic HE method, called the DHE method, in which the input image histogram is partitioned into several sub-histograms or partitions based on local minimums in the histogram. Each sub-histogram is re-allocated a new range in the histogram based on its distribution, and each new range is then equalized individually. The DHE method is shown to produce much more realistic looking images. However, neither HE nor DHE preserves the brightness of the original images. Both methods produce images that are often much brighter than the originals.

In contrast to HE and DHE, a number of contrast enhancement methods are designed specifically with mean brightness preservation. Kim [3] presented a mean preserving bi-histogram equalization method, called the BBHE method. In the BBHE method, the mean gray value serves as the pivot to partition the image into two sub-images, which are then equalized by using the HE method. Chen and Ramli [8] improved the BBHE method by proposing the recursive mean separate HE method (RMSHE). In [9], Ibrahim and Kong presented a brightness preserving DHE method, called the BPDHE method, which extends the DHE method. The BPDHE method is similar to the DHE method in many respects. The main contribution of the BPDHE method is its brightness preservation step, called normalization, which shifts the mean brightness of the resultant histogram back to the original image brightness mean so that the mean is preserved. Lately, Kim and Chung [10] presented a recursively separated and weighted HE method, namely the RSWHE method, which is shown to produce good contrast enhanced images with better brightness preservation than the other methods, including the BBHE method, the RMSHE method, and the DHE method.

These previous contrast enhancement works have shown the fundamental importance of histogram partitioning for fine grained contrast enhancement and mean shifting for brightness preservation. However, questions remain regarding how best to combine the two techniques. Instead of being performed globally over the whole histogram, the main idea in this paper is the observation that brightness preservation could be performed locally and independently for each partition. Based on the observation, we present a local brightness preserving HE method, called the LBPDHE method. LBPDHE is also based on DHE, but employing a novel local brightness preservation operation. LBPDHE shifts the average mean brightness of each sub-histogram back to the original mean brightness of each original corresponding sub-histogram.

Using the Average Absolute Mean Brightness Error (AAMBE) measure, experimental results based on eighty test images demonstrate that the differential brightness between the original image and resultant image produced by our proposed LBPDHE method is the smallest when compared to the previous related brightness preserving HE-based methods. The rest of this paper is organized as follows. In the second section, the DHE and BPDHE method is discussed in more details, and our proposed LBPDHE method is presented. In the third section, experimental results are presented to demonstrate the brightness preserving advantage of our proposed method. In the final section, the conclusions of this paper are drawn.

II. THE PROPOSED LOCAL BRIGHTNESS PRESERVING HE METHOD

Our proposed LBPDHE method builds on the histogram partitioning technique introduced in DHE, while extending the idea of the brightness preserving operation in the BPDHE method. In DHE, the histogram of the input image is partitioned into sub-histograms, with each sub-histogram being mapped to a new dynamic range and then independently equalized. This partitioning strategy prevents over/under enhancement of any specific portion in the image. More details in the DHE and BPDHE method are introduced in the following, followed by descriptions of our proposed LBPDHE method.

We give more details in DHE now. The histogram is first smoothed by using a 1×3 smoothing filter, and then partitioned by using the minimums in the histogram. Let $m_0, m_1, \ldots, m_n$ be the gray levels that correspond to the $(n+1)$ minimums, separating the original histogram into $(n+2)$ partitions. Let $m_{i,low}$ and $m_{i,high}$ be the lower and upper bounds of sub-histogram *i*. The range of each sub-histogram is mapped to a new range by using a two-step process. In the first-step, the number of pixels in each partition is calculated in a weighted manner.

$$factor_i = (m_{i,high} - m_{i,low})(\log \sum_{k=low}^{high} n_k)^x \tag{3}$$

where n_k is the number of pixels with gray level *k* and *x* is a system parameter. The new dynamic range for each partition is then calculated as follows:

$$range_i = \frac{factor_i}{\sum_{k=0}^{n-1} factor_k} L \tag{4}$$

where $range_i$ is defined to be the new dynamic range for sub-histogram *i*. In the second-step, the HE method is applied to each sub-histogram against its new range for contrast enhancement by applying (1) in each sub-histogram. Note the DHE method does not perform any brightness preservation operation.

Based on the general framework proposed in DHE, the BPDHE method proposed a number of improvements. First, a 1×9 Gaussian filter is used to smooth the input histogram. Secondly, the histogram is partitioned into sub-histograms by using local maximum. Thirdly, the BPDHE method proposed a normalization step to change the brightness in the resultant image. Intuitively, the mean brightness of the resultant histogram is shifted back to the original mean brightness of the input image in a global manner. Let the same notation $i_{new} = T(i)$ denote the collection of mappings obtained in each partition. Let $Mean_{in}$ be the mean brightness of the input image, and $Mean_{he}$ be that of the output image after HE. The normalization step modifies the mapping function $i_{new} = T(i)$ as follows.

$$i_{new} = (\frac{Mean_{in}}{Mean_{he}}) * T(i) \tag{5}$$

From the above equation, it is obvious that the gray values are shifted in a global manner. Thus, the brightness of the output images is close to that of the input image.

We observe that the global shifting in the mapping function in the BPDHE method deviates from the main insight of the DHE method, which calls for localized HE in each partition. Global shifting of brightness in the BPDHE method may change the brightness across partition boundaries. Therefore, we propose an important idea that the brightness preservation could be performed locally for each partition. Since the DHE method produces finer partitions than the BPDHE method, with the use of a 1×3 filter for histogram smoothing, our proposed LBPDHE method is based on the DHE method so that the brightness can be preserved as much as possible. We now give more details on LBPDHE. First, the histogram smoothing and histogram partitioning steps method are the same as those in the DHE method. Then a local brightness preserving normalization step is performed for each sub-histogram individually. Finally, each sub-histogram is independently equalized. Let *k* denote the k_{th} sub-histogram produced by the DHE method. Our proposed local mean brightness preserving normalization step is defined as follows.

$$i_{new} = (\frac{Mean_{in}^k}{Mean_{he}^k}) * T^k(i) \tag{6}$$

where $Mean_{in}^k$ denotes the mean brightness of the original sub-histogram *k* in the input image, and $Mean_{he}^k$ denotes the mean brightness of the resultant output sub-histogram *k*.

III. EXPERIMENTAL RESULTS

We evaluate the performance of our proposed LBPDHE against the HE, BBHE, RMSHE, RSWHE, DHE, and BPDHE methods by using eighty test images, which can be accessed in [11]. All the methods are implemented using the programming language C++ and run on a standard PC with 64x2 4800+ CPU (2.5GHz) and 1.87GB of RAM. The brightness preservation performance of the related algorithms is evaluated both objectively and subjectively.

For objective evaluation, we employ the Average Absolute Mean Brightness Error (AAMBE) measure to assess the brightness preservation performance of the concerned contrast enhancement algorithms. Let $Mean_{in}$ and $Mean_{out}$ be the mean brightness of the input image and the final output image, respectively. The AAMBE value between the input image and the output image is defined as follows.

$$\mathrm{AAMBE} = |Mean_{in} - Mean_{out}| \tag{7}$$

Clearly, the smaller the AAMBE value is, the better an algorithm preserves the mean brightness of the original image.

Table I lists the average AAMBE values and the execution time ratio for the test output images produced by the concerned methods. Clearly, our proposed LBPDHE method has the smallest AAMBE value against the BBHE, RMSHE, RSWHE, DHE, and BPDHE methods. Hence, our proposed method has the best mean brightness preservation performance. Also in Table I, the execution time performance of all the concerned methods are shown. The execution time of all the methods is normalized against the tradition HE method, with HE being 1. Table I indicates that, the execution time needed by the concerned methods is very similar unless the RSWHE method.

For subjective evaluation, we take the "Beans" image to demonstrate the visual quality advantage of our proposed LBPDHE method. Fig. 1(a) shows the original "Beans" image and its corresponding histogram; Figs. 1(b)–(h) respectively illustrate the resultant images and the corresponding histograms produced by the seven concerned methods. From the figures, it is clear that the four resultant images shown in Figs. 1(b)–(d) and Fig. 1(g) show excessive over-enhancement, and therefore seem unnatural. Some over-enhancement also exists in Fig. 1(f). The resultant images produced by the RSWHE method (see Fig. 1(e)) and our proposed LBPDHE method (see Fig. 1(h)) have better brightness preservation and have better visual quality when compared to the other four methods. Even though the RSWHE method and our proposed LBPDHE method yield similar visual quality effects, Table I indicates that the execution time needed by the RSWHE method is forty-six times as much as the one needed by our proposed LBPDHE method. Thus, the RSWHE method might not meet the stringent demand of consumer electronics devices. Further, observing the histograms in Fig. 1(a)–(h), it is clear that the histogram produced by our proposed LBPDHE method is most similar to that of the original image. It implies that our proposed LBPDHE method has the best image brightness preservation.

TABLE I
THE MEASUREMENT AAMBE AND EXECUTION TIME RATIO

Method	AAMBE	Execution time ratio
BBHE	17.1076	1.118
RMSHE	6.583	1.120
DHE	4.8265	1.169
RSWHE	2.5653	67.644
BPDHE	2.0113	1.097
Proposed LBPDHE	1.2356	1.452

IV. CONCLUSIONS

We have presented a local brightness preserving contrast enhancement algorithm, called the LBPDHE method. Our proposed LBPDHE method is an extension to the DHE method, based on the ideas from the BPDHE method. It augments the DHE method with a simple, yet important local mean brightness preserving technique. Based on eighty test images, experimental results show that our proposed LBPDHE method not only has good contrast enhancement, but also achieves the best brightness preservation. Our proposed method will save more power than the other contrast enhancement methods when implemented in consumer electronic products.

ACKNOWLEDGMENT

This work was supported by the National Science Council of Taiwan under contract NSC-98-2923-E-011-001-MY3.

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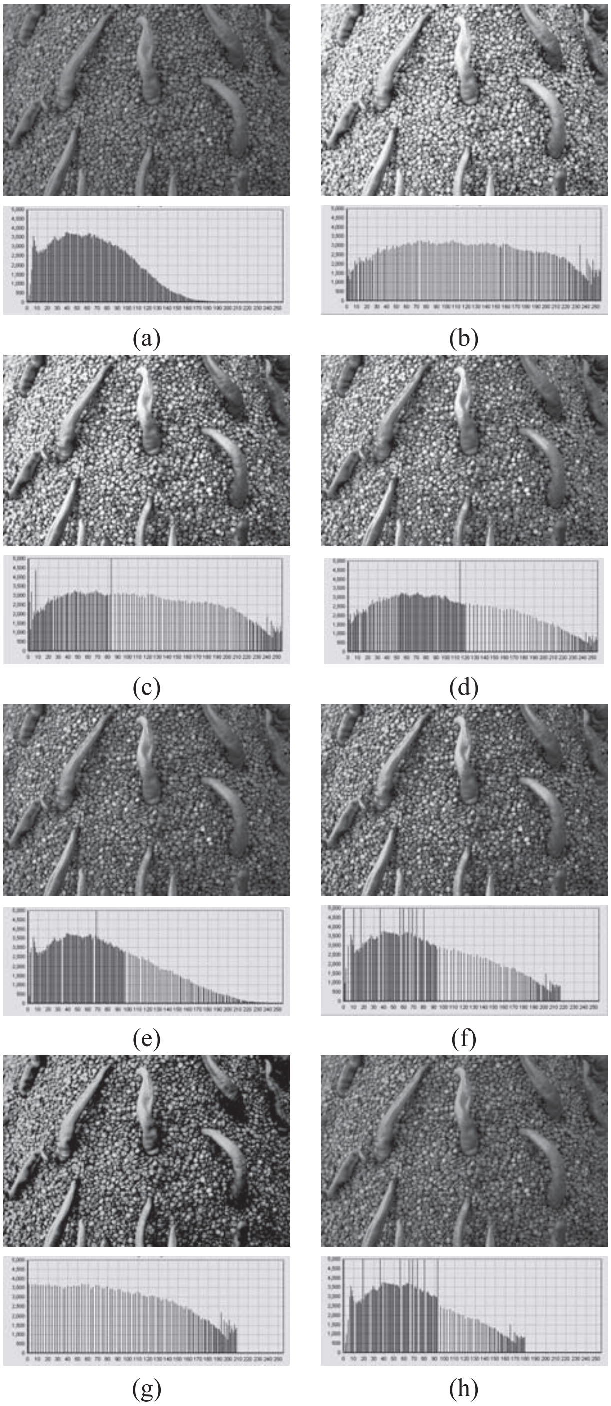

(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 1. Resultant images and histograms produced by the concerned methods for subjective evaluation. (a) The original image. (b) The HE method. (c) The BBHE method. (d) The RMSHE method. (e) The RSWHE method. (f) The DHE method. (g) The BPDHE method. (h) Our proposed LBPDHE method.