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Article

A Novel Contrast Enhancement Technique on Palm Bone Images

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Abstract: Contrast enhancement plays a fundamental role in image processing. Many histogram-based techniques are widely used for contrast enhancement of given images, due to their simple function and effectiveness. However, the conventional histogram equalization (HE) methods result in excessive contrast enhancement, which causes natural looking and satisfactory results for a variety of low contrast images. To solve such problems, a novel multi-histogram equalization technique is proposed to enhance the contrast of the palm bone X-ray radiographs in this paper. For images, the mean-variance analysis method is employed to partition the histogram of the original grey scale image into multiple sub-histograms. These histograms are independently equalized. By using this mean-variance partition method, a proposed multi-histogram equalization technique is employed to achieve the contrast enhancement of the palm bone X-ray radiographs. Experimental results show that the multi-histogram equalization technique achieves a lower average absolute mean brightness error (AMBE) value. The multi-histogram equalization technique simultaneously preserved the mean brightness and enhanced the local contrast of the original image.

Keywords: contrast enhancement; multi-histogram equalization; X-ray radiograph; mean-variance analysis method; absolute mean brightness error (AMBE)

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1. Introduction

Over the last few decades, X-ray images have been widely used in helping physicians make their diagnostic decision. However, the raw X-ray image quality is not always good. Visual image quality has been actively improved using contrast enhancement techniques. The main purpose of image contrast enhancement is to improve the interpretability or perception of information contained in the image for human viewers. Image contrast enhancement is a process that produces an output image that subjectively looks better than the original image by changing the pixel's intensity of the input image. Image enhancement can be used as a preprocessing step in medical image processing, texture synthesis and many other image/video processing applications [1–8]. These techniques also can be used to improve the visual appearance of an image or to convert an image to a form better suited to the subsequent processing, such as segmentation, feature extraction, detection and recognition.

A considerable amount of research has focused on this subject, and numerous histogram modification techniques have been developed [1–18]. Generally speaking, histogram modification techniques can be categorized into two classes: global histogram modification [9,10] and local histogram modification [11,12]. The global histogram equalization (GHE) method is one of the most commonly used methods for image contrast enhancement because of its simplicity and effectiveness. The GHE method employs the cumulative density function of the input image as its intensity mapping function. The basic idea of the GHE method is to re-map the intensities of the input image by using the intensity mapping function. Then, the GHE method can stretch the dynamic range of the image histogram to enhance the overall contrast of the original image. The resulting image may have a uniform distribution of intensity [13]. However, the GHE method suffers from some drawbacks, such as over enhancement, an increase in the noise level, loss in detail and a washed-out effect in some almost homogeneous areas [8].

Many researchers have proposed many useful algorithms to solve these problems involved in the global histogram equalization technique [14–23]. In [14], a brightness preserving bi-histogram equalization (BPBHE) method first separates the input image histogram into two sub-histograms based on the mean of the input image brightness. Then, these two sub-histograms are equalized independently. The mean brightness of the resultant image will lie between the mean brightness and middle grey level of the input image. The BPBHE technique is capable of preserving the original image brightness to a certain extent. In [15], the dualistic sub-image histogram equalization (DSIHE) method also separates the input image histogram into two sub-histograms, but the separation is based on the median value. The minimum mean brightness error bi-histogram equalization (MMBEBHE) is the extension of the brightness-preserving bi-histogram equalization (BPBHE) method. This method separates the image histogram by using the threshold level. The MMBEBHE method yields a minimum brightness difference between the input image and the output image [16]. These methods separate the input image's histograms into two sub-histograms by using one intensity value as their separating point. Although these methods are simple, they can preserve the mean brightness only to a certain extent [17]. Moreover, other solutions can be found in [18–21].

The recursive mean-separate histogram equalization (RMSHE) method is another improvement scheme of the brightness-preserving bi-histogram equalization (BPBHE) method [22]. The recursive mean-separate histogram equalization (RMSHE) method recursively divides the image's histograms

into several sub-histograms based on the local mean values. In [23], recursive sub-image histogram equalization (RSIHE) chooses to separate the image's histograms based on gray level with cumulative probability density equal to 0.5. This method yields better image compensation and provides improving image visual quality. These two recursive methods have improved results compared with previous methods. The mean brightness of the output was similar to that of the input in RMSHE and RSIHE, but the equalization effect was reduced.

In some applications of medical image analysis, local details may be more important than global contrast. For these applications, the global histogram equalization method is inadequate, because it cannot adapt to the local brightness features of the input image. To overcome this drawback, some local histogram equalization methods have been developed. In [24], the dynamic histogram equalization (DHE) technique separates the image's histograms based on local minima. It assigns specific gray level ranges for sub-histograms before equalizing them separately. These sub-histograms further go through a repartitioning test to ensure the absence of any dominating portions. In [25], the brightness-preserving dynamic histogram equalization (BPDHE) method can produce an output image with the mean intensity almost equal to the mean intensity of the input. Therefore, it fulfills the requirement of preserving the mean brightness of the image. The RMSHE, RSIHE and BPDHE methods divide the input image's histograms into more than two sub-histograms. Most of these methods are good at preserving the mean brightness, but not much enhancement could be obtained from most of these methods. Furthermore, these methods require more computational power in order to select the separating point properly [22–26].

In this paper, a new multi-histogram equalization technique is proposed to enhance the contrast on palm bone X-ray radiographs. The remaining sections of this paper are organized as follows. The proposed multi-histogram equalization scheme is described in Section 2. The experiment results and discussion are represented in Section 3. Finally, the conclusion is provided in Section 4.

2. The Proposed Multi-Histogram Equalization Scheme

2.1. Global Histogram Equalization (GHE)

For an input image X with L discrete gray levels, the probability density function $p(x_k)$ is defined as:

$$p(x_k) = \frac{n^k}{n} \quad \text{for} \quad k = 0, 1, 2, \ldots, L-1 \tag{1}$$

where x_k represents a specific intensity in the input image and n^k represents the number of times that the grey level x_k appears in the input image. Additionally, n is the total number of pixels contained in the input image X. Based on the probability density function, the cumulative density function $c(x_k)$ is defined as:

$$c(x_k) = \sum_{j=0}^{k} p(x_j) \quad \text{for} \quad k = 0, 1, 2, \ldots, L-1 \tag{2}$$

GHE is a scheme that enhances the input image X by using the cumulative density function as a transform function. Let us define a transform function $f(x_k)$ based on the cumulative density function as:

$$c(x_k) = \sum_{j=0}^{k} p(x_j) \;\; f(x_k) = x_0 + (x_{L-1} - x_0) \times c(x_k) \quad \text{for} \quad k = 0, 1, 2, \ldots, L-1 \tag{3}$$

Then, the output image produced by GHE, $Y = \{y(i, j)\}$, is given by Equation (4), where i denotes the X-coordinate of the input image and j denotes the Y-coordinate of the input image.

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

Although GHE successfully enhances the contrast in the image, this method does not put any constraint on preserving the mean brightness.

2.2. Multi-Histogram Equalization

In the brightness-preserving bi-histogram equalization (BPBHE) method, the histogram of the input image is separated into two sub-images based on the mean of the histogram of the input image. Then, each sub-image is equalized independently using global histogram equalization, which produces a flatter histogram. In this paper, a multi-histogram equalization technique based on the mean-variance partition method is proposed to enhance the contrast of the input image. The histogram of the input image is separated into multiple subsections based on the mean and standard deviation of the histogram of the input image.

For instance, the histogram of the input image can be separated into four subsections based on the mean and standard deviation of the histogram of the input image. Let μ be the mean and σ be the standard deviation of the image intensities, and $0 \le \mu, \sigma \le L-1$. Based on μ and σ, the input image X can be separated into four sub-images, X_1, X_2, X_3 and X_4, as:

$$X = X_1 \bigcup X_2 \bigcup X_3 \bigcup X_4 \tag{5}$$

$$X_1 = \{x(i, j) \mid x(i, j) \le \mu - \sigma, \forall x(i, j) \in X\} \tag{6}$$

$$X_2 = \{x(i, j) \mid \mu - \sigma < x(i, j) \le \mu, \forall x(i, j) \in X\} \tag{7}$$

$$X_3 = \{x(i, j) \mid \mu < x(i, j) \le \mu + \sigma, \forall x(i, j) \in X\} \tag{8}$$

$$X_4 = \{x(i, j) \mid \mu + \sigma < x(i, j), \forall x(i, j) \in X\} \tag{9}$$

The probability density function $p_l(x_k)$ of sub-image X_l is defined as:

$$p_l(x_k) = \frac{n_l^k}{n_l} \quad \text{for} \quad l = 1, 2, 3, 4 \tag{10}$$

where x_k represents a specific intensity in the sub-image X_l and n_l^k represents the number of times that the grey level x_k appears in the sub-image. Additionally, n_l is the total number of pixels contained in the sub-image X_l. Based on the probability density function $p_l(x_k)$, the respective cumulative density function $c_l(x_k)$ is defined as:

$$c_1(x_k) = \sum_{j=0}^{k} p_1(x_j) \quad \text{for} \quad 0 \le x_k \le \mu - \sigma \tag{11}$$

$$c_2(x_k) = \sum_{j=0}^{k} p_2(x_j) \quad \text{for} \quad 0 \le x_k \le \mu - \sigma \tag{12}$$

$$c_3(x_k) = \sum_{j=0}^{k} p_3(x_j) \quad \text{for} \quad \mu < x_k \le \mu + \sigma \tag{13}$$

$$c_4(x_k) = \sum_{j=0}^{k} p_4(x_j) \quad \text{for} \quad \mu + \sigma < x_k \le L - 1 \tag{14}$$

Then, the respective transform function $f_l(x_k)$ based on the respective cumulative density function can be defined as:

$$f_1(x_k) = (\mu - \sigma) \times c_1(x_k) \quad \text{for} \quad 0 \le x_k \le \mu - \sigma \tag{15}$$

$$f_2(x_k) = (\mu - \sigma + 1) + (\sigma - 1) \times c_2(x_k) \quad \text{for} \quad \mu - \sigma < x_k \le \mu \tag{16}$$

$$f_3(x_k) = (\mu + 1) + (\sigma - 1) \times c_3(x_k) \quad \text{for} \quad \mu < x_k \le \mu + \sigma \tag{17}$$

$$f_4(x_k) = (\mu + \sigma + 1) + (L - \mu - \sigma - 2) \times c_4(x_k) \quad \text{for} \quad \mu + \sigma < x_k \le L - 1 \tag{18}$$

Then, the output image produced by, $Y = \{y(i, j)\}$, is given by Equation (19).

$$Y = f(X) = \{f_l(x(i, j)) \mid \forall x(i, j) \in X_i\} \quad \text{for} \quad l = 1, 2, 3, 4 \tag{19}$$

The histogram of the input image can be separated into six or more than six sections based on the mean and standard deviation of the histogram of the input image. For instance, the histogram of the input image is separated into six sections by the following separate points: $\mu - 2\sigma$, $\mu - \sigma$, μ, $\mu + \sigma$, $\mu + 2\sigma$. In some application, such as medical image analysis, local details may be more important than global contrast. The global histogram equalization (GHE) method is inadequate as it cannot adapt to the local brightness features of the input image. In this paper, the input image can be separated into multiple sections, and each section is equalized independently. It can flatten and stretch the dynamic range of the sub-image histogram resulting in local contrast improvement.

3. Experimental Results and Discussion

The proposed multi-histogram equalization method was implemented by using the Java programming language. A series of experiments were conducted to test the performance of the proposed method. The original grayscale images used in our experiments and their histograms are listed in Figure 1.

For these input images, global histogram equalization (GHE), mean preserving bi-histogram equalization (BPBHE) and the proposed method are performed. The experimental results, including the output images and their histograms performed by global histogram equalization (GHE), are listed in Figure 2. Additionally, the experimental results, including the output images and their histograms performed by mean preserving bi-histogram equalization (BPBHE) and the proposed method, are listed in Figures 3 and 4, respectively.

Figure 1. The original grayscale images and their histograms.

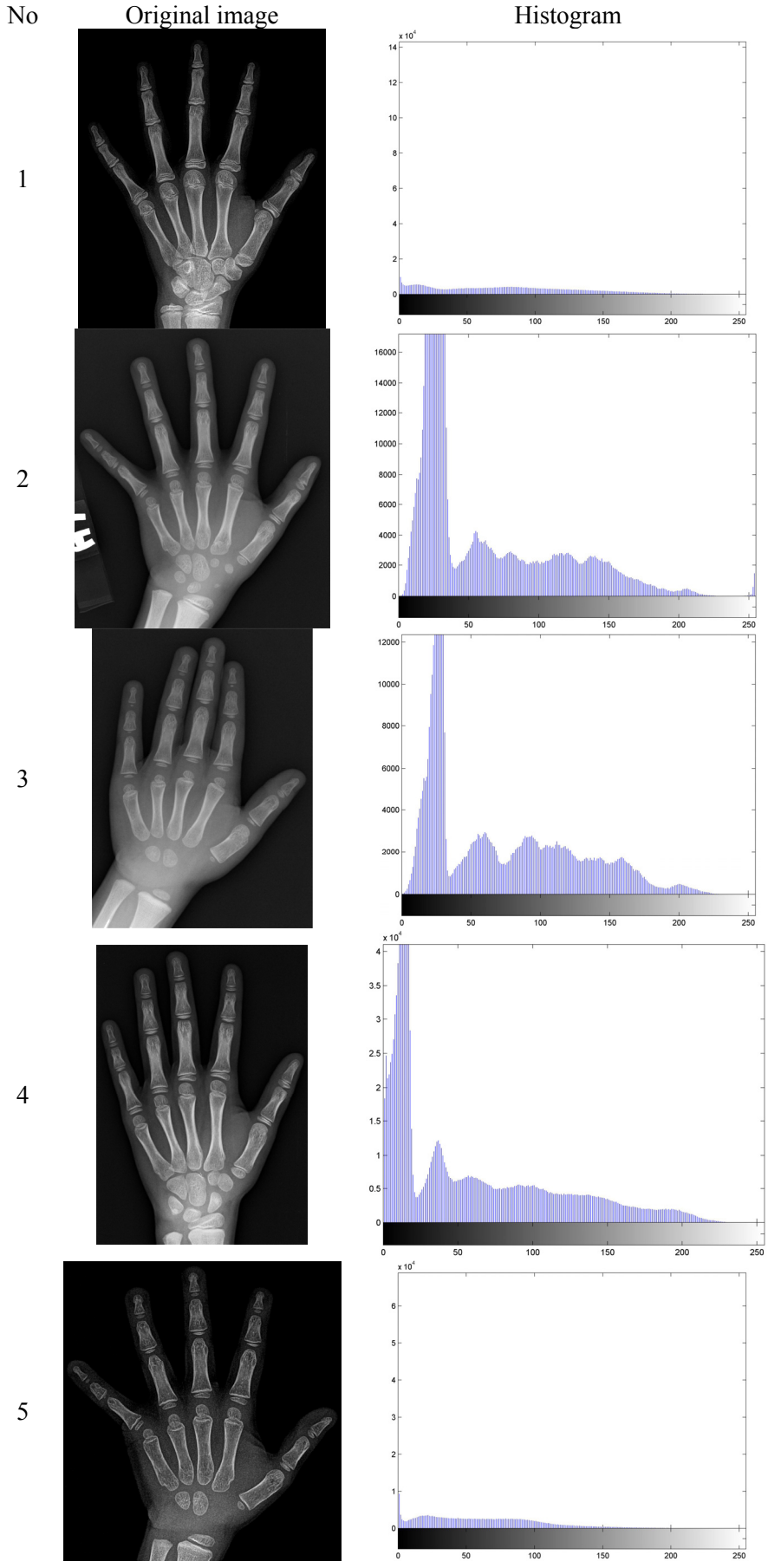


Figure 2. The output images and their histograms (global histogram equalization (GHE)).

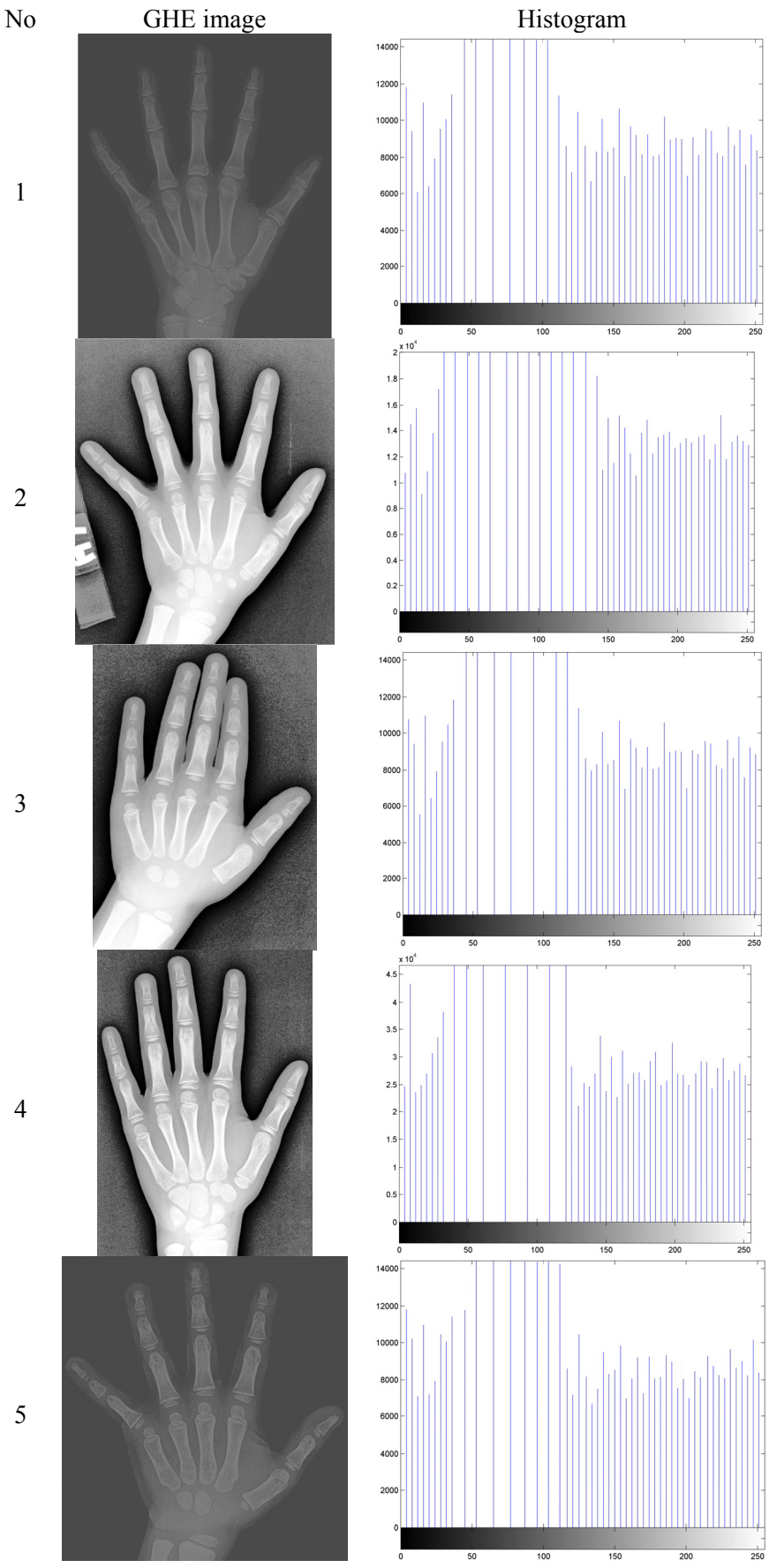


Figure 3. The output images and their histograms (brightness preserving bi-histogram equalization (BPBHE)).

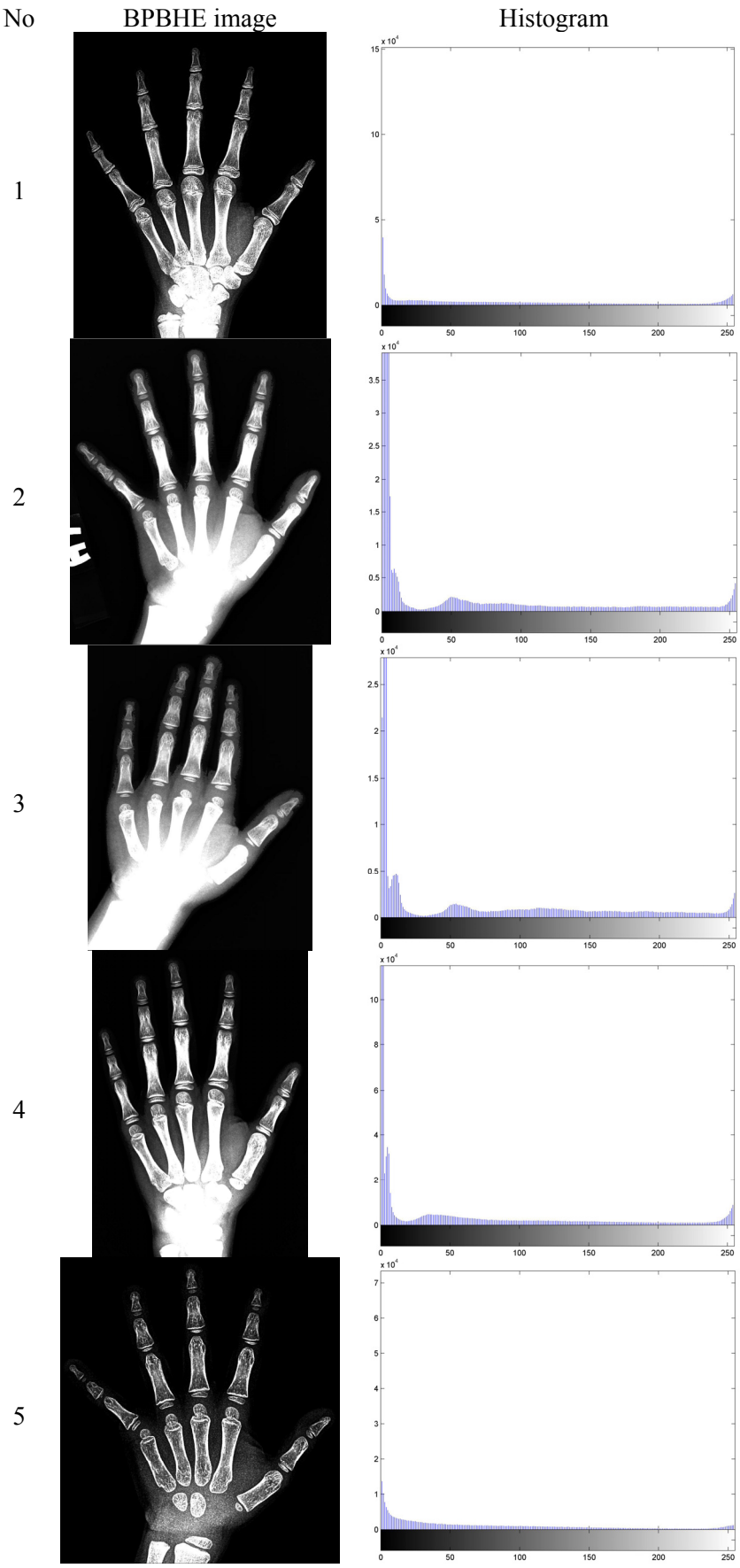
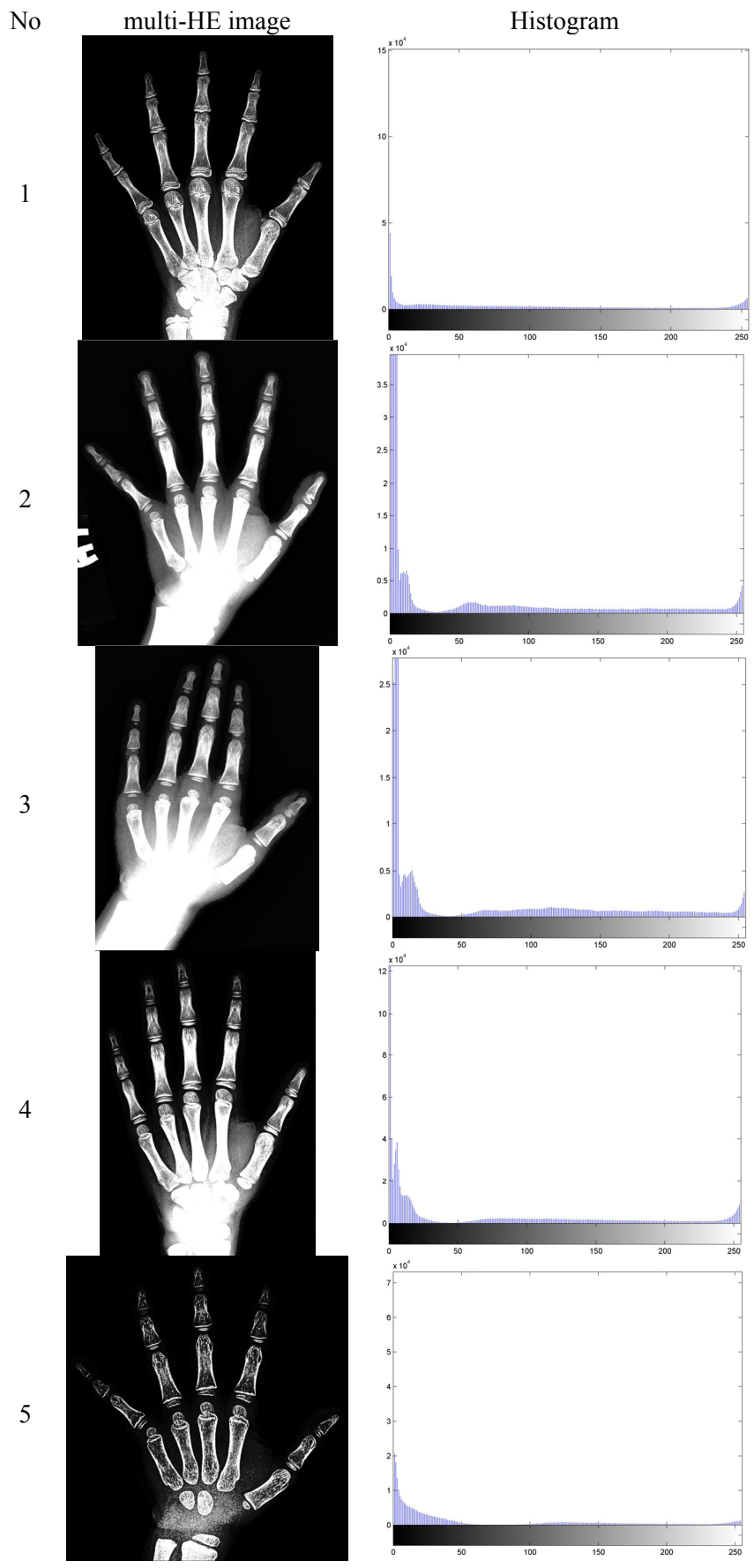


Figure 4. The output images and their histograms (multi-HE).



To evaluate the performance of the proposed method, we chose a widely used metric, *i.e.*, the absolute mean brightness error (AMBE). The AMBE was utilized to investigate whether the proposed method successfully maintains the input mean brightness. The AMBE is defined as Equation (20).

$$AMBE = \left| X_m - Y_m \right| \tag{20}$$

The variable X_m represents the mean brightness of the output image, and the variable Y_m represents the mean brightness of the original image. A good enhancement method that is able to preserve the mean brightness will give a small value of AMBE. The AMBE values performed by GHE, BPBHE and multi-HE are tabulated in Table 1. The average AMBE values taken from the test images are tabulated in Table 2.

Table 1. The absolute mean brightness error (AMBE) value of the output images performed by GHE, BPBHE and multi-HE.

Images	GHE	BPBHE	multi-HE
1	73.28	10.54	10.57
2	69.94	5.57	5.06
3	62.86	11.69	10.50
4	76.35	9.01	6.71
5	72.00	4.40	1.05

Table 2. The average AMBE values of the output images.

Contrast Enhance method	Average AMBE
GHE	70.89
BPBHE	8.24
multi-HE	6.78

4. Conclusions

Contrast enhancement plays a fundamental role in image processing. In this paper, a multi-histogram equalization technique is proposed to enhance the contrast of the palm bone X-ray radiographs. For individual images, the mean-variance analysis method is employed to partition the grey scale image into multiple sub-images. Each sub-image is histogram equalized independently. By using this mean-variance partition method, the proposed multi-histogram equalization technique can achieve contrast enhancement without introducing a significant change in the brightness of the palm bone X-ray radiographs.

Author Contributions

In this paper, a multi-histogram equalization technique based on the mean-variance partition method is proposed to enhance the contrast of the palm bone X-ray radiographs. The proposed multi-histogram equalization method can achieve contrast enhancement without introducing a significant change in the brightness of the palm bone X-ray radiographs.

Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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