Chapter 78
Image Enhancement Algorithm Using Brightness Preserving Multiple-Interval Histogram Equalization

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Abstract For the low illumination image (such as the X light medical image) enhancement processing, proposed one kind of image enhancement method of multiple section histogram equalization for brightness preservation. Using the cumulative function to calculate the average brightness value, the 0–255 gray interval would be divided into four intervals; the histogram equalization algorithm was performed on each interval. The experimental results showed the algorithm which enhanced the image visual effect is good, and a good solution to the traditional histogram equalization overfull-enhancing phenomenon.

Keywords Brightness preservation · Multiple-interval histogram · Average brightness · Histogram equalization

78.1 Introduction

The purpose of image enhancement is to make an enhancement to image visual effect and provide intuitional, clear, and analyzable images. In many image enhancement algorithms, histogram equalization is one of the classic and effective methods of image enhancement [1]. It based on probability theory, revises the histogram of an image with a gray transform function, making the image trend to be uniformly distributed and increasing the dynamic range of image grayscale. Thus, the purpose of image enhancement can be achieved. Although histogram

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equalization algorithm features fast calculation speed and significant enhancement effect, there remain some shortcomings in it; (1) the actual value of the gray distribution histogram of output image is possible to be greatly different from its ideal value and is not the optimal value, although the histogram are approximate to uniform distribution; (2) when the quality of the original image is poor, gray dynamic range is narrow and histogram distribution is extremely nonuniform, the layering effect of the image operated and transformed by the traditional histogram equalization is worse; (3) when the gray range in an image is close to zero, the result is that a bright but diluted image will be obtained if a very narrow dark-pixel interval is mapped to output image in the implementation of equalization algorithm, and this is called as overfull-enhancing phenomenon in the Refs [1, 2].

An image with a gray range of [0, 255] will be too bright after enhanced by histogram equalization algorithm (i.e., after transformation, the bright pixels will be more bright but the dark pixels will be darker), and the basic characteristics of image such as average brightness changes and details lost affect the enhanced image visual effect, thus making the application scope of histogram algorithm limited [3, 4]. According to this, a simple and effective image enhancement algorithm using brightness preserving multiple-interval histogram equalization is proposed. The experimental simulation result shows that the overfull-enhancing phenomenon of the traditional histogram equalization is solved well by this algorithm [5].

78.2 Traditional Histogram Equalization Algorithm

Image enhancement methods include the gray transform, histogram equalization, image filtering, and image sharpening, and so on. The author chooses the histogram equalization algorithm that is classic in air space to be compared with the algorithm in this paper. The basic idea of the traditional histogram equalization is to transform the disequilibrium histograms of the original image to be uniformly distributed. That is, the input image is transformed to have the same number of pixel points at each gray level (i.e., the output histograms are flat and its distribution is uniform) [1]. Histogram equalization processing is a histogram modification based on cumulative distribution function transformation, and the transformation function is assumed to be as follows.

$$s = T(r) = \int_0^r p_r(w)\mathrm{d}w \tag{78.1}$$

In Eq. (78.1), w is an integral variable; $\int_0^r p_r(w)\mathrm{d}w$ is the cumulative distribution function of r [3] and increases from 0 to 1 monotonically; the transformation function $T(r)$ monotonically increases within $0 \le r \le 1$ and also meets $0 \le T(r) \le 1$. Equation (78.1) is applicable to continuous signal processing; in processing discrete digital image, frequency can be approximately used for replacing probability value, namely

$$p_r(r_k) = n_k/n, \quad (0 \le r_k \le 1, \quad k = 0, 1, 2, \ldots, L-1) \tag{78.2}$$

In Eq. (78.2), L is the total number of gray levels; $p_r(r_k)$ is the probability for attaining the value of the kth gray; n_k is the number of the times for the appearance of the kth gray; n is the total number of the pixels in the image. Therefore, the Eq. (78.1) under discrete circumstances can be transformed as follows.

$$s_k = T(r_k) = \sum_{j=0}^{k} n_j/n = \sum_{j=0}^{k} p_r(r_j), \quad (0 \le r_j \le 1, \quad k = 0, 1, 2, \ldots, L-1) \tag{78.3}$$

Through digital image, each gray value is obtained by using Eq. (78.3) to calculate each pixel in the image, and the original gray value is replaced with new gray value. And this is the processing of the traditional histogram equalization [2].

78.3 Multilateral Histogram and Evaluation Indexes Based on Brightness Preserving

78.3.1 Multilateral Histogram Based on Brightness Preserving

Traditional histogram image processing speed is fast, but its effect is poor. Especially, it is easy for low-bright image to be too bright in processing, and also visual effect is reduced. Multilateral histogram algorithm based on brightness preserving is to divide 0–255 gray interval into four intervals according to average brightness and then implement equalization processing on them respectively, and the average brightness formulas is as follows.

$$Y = \mathrm{INT}\left(\sum_{k=0}^{k=255} kp(k)\right) \tag{78.4}$$

In Eq. (78.4), $k \in [0, 255]$ is established; $p(k)$ is the probability for pixel k to appear in the whole image; $\mathrm{INT}(\bullet)$ is a round-off integral function. The histogram equalization formula is as follows.

$$F(i,j) = \mathrm{INT}[(M_{\max} - M_{\min}) \times cdf(f(i,j))/N + M_{\min} + 0.5] \tag{78.5}$$

In Eq. (78.5), $M_{\max}$ and $M_{\min}$ are the upper bound and lower bound of the gray range of the subimage, respectively; N is the total number of the pixels in the corresponding subimage gray range; $cdf(f(i,j))$ is the cumulative function of the number of pixels in the corresponding subimage gray range; i, j are variables of the *x*-ordinate and *y*-ordinate of the original image $f\ (m,\ n)$. Algorithm implementation steps are as follows.

(1) Calculating the average brightness of the image $f\ (m,\ n)$ with Eq. (78.4).
(2) Calculating the maximum $K_{\max}$ and minimum $K_{\min}$ of the pixels of the $f\ (m,\ n)$.
(3) Dividing the original image into two subimages with gray ranges $[K_{\min},\ Y]$ and $[Y,\ K_{\min}]$, respectively, according to the maximum $K_{\min}$, minimum $K_{\min}$ and average brightness Y of the pixels of image $f\ (m,\ n)$, and the solving the average brightness Y_1 and Y_2 of the gray ranges $[K_{\min},\ Y]$ and $[Y,\ K_{\max}]$, respectively, according to step 1 ($Y_1 = \mathrm{INT}\left(\sum_{k=k_{\min}}^{k=Y} kp(k)\right)$, $Y_2 = \mathrm{INT}\left(\sum_{k=Y}^{k=K_{\max}} kp(k)\right)$ and ultimately the gray ranges of the original image $f\ (m,\ n)$ is divided into $[K_{\min},\ Y_1]$, $[Y_1,\ Y]$, $[Y,\ Y_2]$, and $[Y_2,\ K_{\max}]$.
(4) Implementing a histogram equalization within the four gray ranges on the position $f(i,j)$ of each pixel according to the original image $f\ (m,\ n)$, and then outputting the enhancement image $F(m,n)$ with brightness preserving.

78.3.2 Image Evaluation Indexes

Image is evaluated objectively with average brightness difference (ΔY) and contrast increment (ΔC) for this algorithm [3, 4], and the calculation formula is as follows.

Average brightness difference:

$$\Delta Y = Y_F - Y_f = \sum_{k_F=0}^{k_F=255} k_F p(k_F) - \sum_{k_f=0}^{k_f=255} k_f p(k_f) \tag{78.6}$$

Contrast increment:

$$\Delta C = C_F / C_f \tag{78.7}$$

In Eq. (78.6), Y_F is the average brightness of the original image; Y_f is the image after enhancement; ΔY is the difference between the two sides. If the difference is smaller, the brightness of the enhanced image is much closer to the original image, suggesting the image brightness enhanced by the algorithm is preserved better. Otherwise, it is poorer [6].

In Eq. (78.7), C_F is the local contrast mean value of the enhanced image; C_f is the local contrast mean value of the original image; contrast increment ΔC is the local contrast ratio between the original image and the enhanced image. Local contrast is in a sliding window of 3×3, and then the local contrast of each window is calculated according to $(x_{\max} - x_{\min})/(x_{\max} + x_{\min})$, and then their mean value is taken. It is suggested that the enhancement effect is better if contrast increment is larger [1, 7, 8].

78.4 Experimental Results and Analysis

Using MATLAB as experimental research tool, the algorithm of this paper and the classic histogram equalization algorithm are experimentally compared and simulated through writing programs, and the experimental object is standard Lena image. The experimental results are as shown in Fig. 78.1. To illustrate the advantages of the algorithm of this paper in enhancing X-ray medical image, the foot images of the X-ray medical images (pixels are closer to 0 and also gray range is narrow) are used as experimental objects and the experimental results are as shown in Fig. 78.2.

From Fig. 78.1, it can be seen that too-bright or too-dark phenomenon appears in the images enhanced by histogram equalization algorithm, making images too bright and dark, or lose some details, or unnatural and unclear. This shortcoming is especially obvious in the enhancement process of X-ray foot image in Fig. 78.2, making foot bones too bright and going against the judgment of the illness.

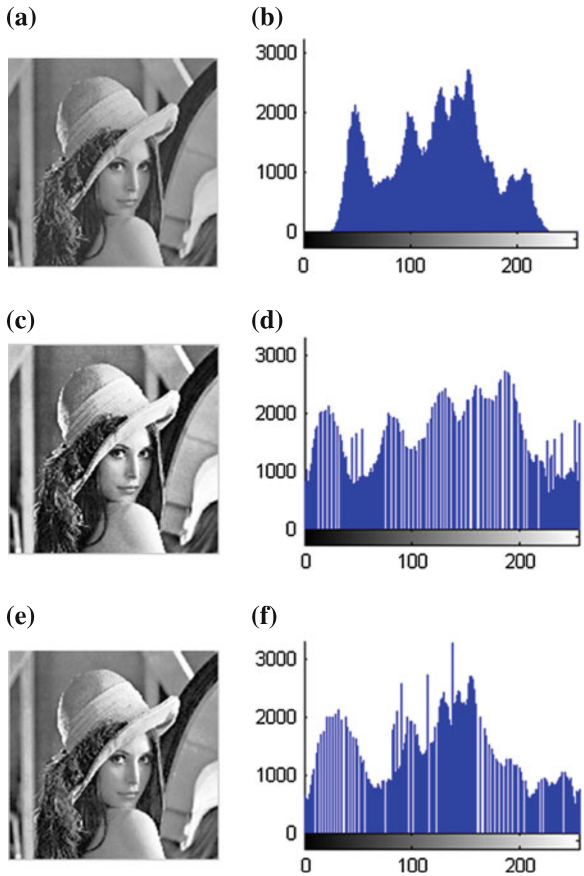

Fig. 78.1 Experimental results of lena images. **a** Original image. **b** The histogram of original image. **c** Classic histogram. **d** The histogram of classic histogram. **e** Algorithm of this paper. **f** The histogram of the algorithm of this paper

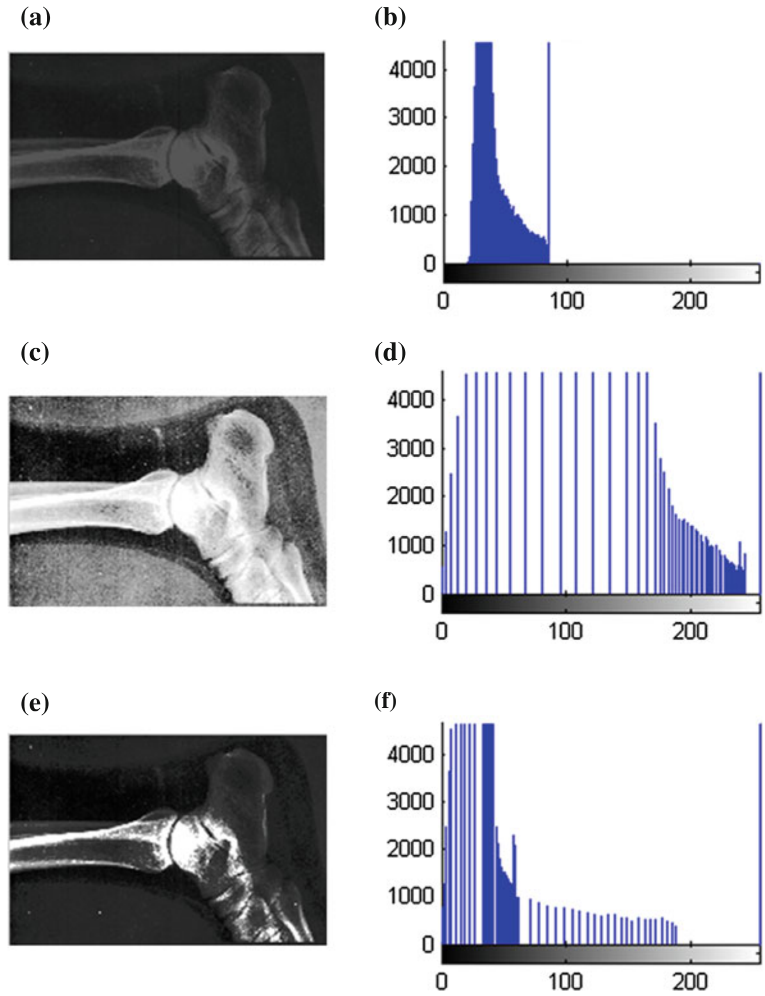

Fig. 78.2 Experimental results of x-ray foot images. **a** Original image. **b** The histogram of original image. **c** Enhancement image of histogram equalization. **d** The histogram of enhancement image of histogram equalization. **e** Enhancement image of the algorithm. **f** The histogram of enhancement of this paper image of this paper

However, in Fig. 78.1, the Lena image after an enhancement process by the algorithm of this paper is clear and nature, the details in the dark part of hair are rich, and also overall brightness remains consistent with that of the original image. In Fig. 78.2, the X-ray foot image processing by the algorithm of this paper is more conducive for doctors to judge than the traditional histogram equalization from the visual effect, and also the image is clearer.

In the above, the advantages of the algorithm of this paper are subjectively analyzed. In the following, average brightness difference (ΔY) and contrast

Table 78.1 Calculation results of average brightness difference (ΔY) and contrast increment (ΔC)

Performance index	Histogram equalization algorithm	Algorithm of this paper
Average brightness difference (ΔY)	5.17	2.28
Contrast increment (ΔC)	2.09	1.79

increment (ΔC) are used for objectively evaluating the algorithm of this paper, and the calculation results are shown in Table 78.1.

From Table 78.1, it can be seen that the algorithm of this paper is smaller than the traditional histogram equalization algorithm in average brightness difference, suggesting the algorithm of this paper is better than the traditional histogram equalization algorithm in brightness preserving. In contrast increment, the traditional histogram equalization algorithm is slightly bigger than the algorithm of this paper in average brightness difference, but the visual effects of the two sides are greatly different. From Figs. 78.1 and 78.2, it can also be seen that the enhancement image by traditional histogram equalization is bigger than that by the algorithm of this paper in contrast stretch, but too big contrast makes the enhanced image nonuniform in brightness, poor in visual effect, and also lose some details. However, the brightness of the image processed by the algorithm of this paper is closer to the original image, and also the visual effect is good.

78.5 Conclusion

According to the gray image enhancement processing, the average brightness value is solved with cumulative function in this paper, and also a multilateral histogram equalization image enhancement method is proposed. Through a comprehensive comparison with the histogram equalization that is classic in air space, the algorithm of this paper is superior to classic histogram algorithm in image enhancement.

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