LETTER

Contrast Enhancement of Mycobacterium Tuberculosis Images Based on Improved Histogram Equalization

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SUMMARY There are often low contrast Mycobacterium tuberculosis (MTB) objects in the MTB images. Based on improved histogram equalization (HE), a framework of contrast enhancement is proposed to increase the contrast of MTB images. Our proposed algorithm was compared with the traditional HE and the weighted thresholded HE. The experimental results demonstrate that our proposed algorithm has better performance in contrast enhancement, artifacts suppression, and brightness preserving for MTB images.

key words: contrast enhancement, tuberculosis, histogram equalization, PDF transformation

1. Introduction

The MTB objects with low contrast often appear in the Ziehl-Neelsen stained images. Autofocus, illumination, camera parameters and other factors bring the influence during the stage of image acquisition. Therefore, the contrast enhancement is essential to avoid missing objects. Histogram equalization is a commonly used contrast enhancement method. The HE method implements contrast enhancement by remapping the gray levels of the image based on the probability density function (PDF) of the input gray levels. However, the HE method has some drawbacks. First, the over-enhancement is often caused by global operation, and the rate of enhancement cannot be controlled. Second, the undesired visual artifacts are often created in the enhancement process. Last, the mean brightness of the input image is significantly changed by the HE method.

Many algorithms have been proposed to improve the HE method. Kim et al. proposed a method based on brightness preserving bi-histogram equalization (BBHE) [1]. This method divided the gray histogram into two sub-histograms based on the mean brightness value of the input image. Then the traditional HE transform was applied to the two sub-histograms respectively, which played a role in brightness preserving for the enhanced image. Wang et al. proposed a similar method named dualistic sub-image histogram equalization (DSIHE) [2]. It is claimed that DSIHE is better than BBHE in term of brightness preserving. The input histogram divided based on its shape was realized [3], [4].

Yang et al. proposed a simple method named bin underflow and bin overflow (BUBO) [5]. The PDF of the image is thresholded using a lower threshold and an upper threshold. This method can control the rate of contrast enhancement by a single parameter. Wang et al. proposed a method called weighted thresholded histogram equalization (WTHE) [6]. This method improved the BUBO in PDF transformation. However, for the MTB images captured from the ZN-stained sputum smear slides, the range of gray levels is narrow, and the background pixels occupy a large part of the image. The background pixels always produce unpleasant visual artifacts after enhancement. Moreover, the low and high contrast objects are simultaneously present in the same image. Thus, the global enhancement will cause over-enhancement to the high contrast objects.

According to the characteristics of the MTB images, the paper proposed a contrast enhancement algorithm based on the improved HE. To avoid over-enhancement, the enhancement operation is only applied to the local areas containing the low contrast objects in the image. The PDF transformation used in WTHE is introduced to control the rate of the contrast enhancement and further reduce the impact of the over-enhancement. The contrast of the neighborhood pixels are considered in histogram computation to prevent the undesired artifacts. The brightness normalization is utilized to preserve the average brightness of the enhanced image. Therefore, the proposed algorithm can produce good results in terms of contrast enhancement, artifacts suppression, and brightness preserving.

2. Methods

2.1 Histogram Computation

The proposed method is implemented by the luminance component Y in the YCbCr color space. The spikes in the histogram are created by a large number of pixels that have the same gray level. These pixels always come from the smooth regions of the input image which would create artifacts/noise in the enhanced image. Therefore, the pixels that have some level contrast with their neighborhood are considered during the histogram computation in this paper. Besides, for the MTB images, the size of MTB objects are very small, and a large part of the image is occupied by the background pixels. The mean gray values between the back-
areas of the gray levels from the selected pixels include the low contrast objects. The pixel values of the low contrast objects are high and close to the background pixels’.

2.2 PDF Transformation and Levels Mapping

Given the histogram, the range of the histogram is found. Let \( W_{\text{max}} \) and \( W_{\text{min}} \) denote the maximum and minimum gray level of the pixels from the histogram respectively. A PDF transformation was utilized in WTHE, which can control the rate of the enhancement and avoid the problem of over-enhancement. Thus, we introduced the PDF transformation for our work, given by

\[
P_T(W_k) = \begin{cases} 
   P_u, & \text{if } P(W_k) > P_u \\
   \frac{P(W_k) - P_l}{P_u - P_l} \cdot P_u, & \text{if } P_l \leq P(W_k) \leq P_u \\
   0, & \text{if } P(W_k) < P_l
\end{cases}
\]  

(3)

where \( P(\cdot) \) and \( P_T(\cdot) \) denote the original and transformed PDF respectively. \( P_u \) is the upper threshold. The levels whose PDF values are higher than \( P_u \) will have their level increment limited to a maximum value \( \Delta_{\text{max}} = (W_{\text{V}_-1} - W_0) \cdot P_u \), where \( (W_{\text{V}_-1} - W_0) \) denotes the value range of the image. Therefore, the over-enhancement can be avoided for the levels with high probabilities. The value of \( P_u \) is given by

\[
P_u = v \cdot P_{\text{max}}
\]  

(4)

where \( v \in [0, 1] \), and \( P_{\text{max}} \) is the maximum value in the original PDF. \( P_l \) is the lower threshold used to cut out the levels whose PDF values are too low. \( r \) is the index of the normalized power law function which is introduced to control the rate of the enhancement. When \( r < 1 \), the low probabilities in the PDF will have higher weights than the high ones. Therefore, the over-enhancement will be restrained to some extent with \( r < 1 \). The traditional HE transform can be considered as the particular case of this PDF transform when \( r = 1 \), \( P_u = 1 \), and \( P_l = 0 \). And when \( r = 1 \) with a simpler thresholding mechanism, the PDF transform is reduced to the BUBO.

The cumulative distribution function (CDF) is then obtained by

\[
C(W_k) = \sum_{W_j=W_{\text{min}}}^{W_k} P(W_j)
\]  

(5)

where \( W_k \) is the gray level ranging from \( W_{\text{min}} \) to \( W_{\text{max}} \). The new gray level is obtained by the following levels mapping

\[
H(W_k) = W_{\text{start}} + W_{\text{out}} \times C(W_k)
\]  

(6)

where \( W_{\text{out}} \) denotes the dynamic range of the output level, and \( W_{\text{start}} \) denotes the start value in levels mapping. In this paper, the \( W_{\text{out}} \) is given by
The mean brightness of the enhanced image is changed after the levels mapping. The brightness normalization is applied to compensate the difference between the brightness.

\[ F_o(i, j) = (M_i/M_o) \tilde{F}(i, j) \]  

where \( M_i \) and \( M_o \) denote the mean brightness of the input image and enhanced image respectively, and \( \tilde{F}(i, j) \) and \( F_o(i, j) \) denote the enhanced image and output image respectively. The mean brightness of the output image can be adjusted by the Eq. (8).

2.4 Quantitative Evaluation

Three quantitative measures are used in this paper to evaluate the performance of the proposed method. EME (measure of enhancement) is introduced to measure the contrast of the image [7], which is given by

\[ EME = \frac{1}{k_1 k_2} \sum_{i=1}^{k_1} \sum_{j=1}^{k_2} 20 \log \left( \frac{I_{\text{max},l}}{I_{\text{min},l}} + c \right) \]  

where the image is divided into \( k_1 \times k_2 \) areas, and \( I_{\text{max},l} \) and \( I_{\text{min},l} \) denote the maximum value and minimum value of the area respectively. \( c \) is a highly small constant greater than zero. The higher is the EME value, the more contrast is the area respectively.

AMEBE (absolute mean brightness error) is utilized to measure the difference of mean brightness between the input and output image, given by

\[ AMBE = |\tilde{F} - F_o| \]  

where \( \tilde{F} \) and \( F_o \) denote the mean brightness of the input and output image respectively.

PSNR (peak signal to noise ratio) is used to measure the quality of the output images. The definition is given by

\[ PSNR = 10 \times \log_{10}(\frac{I^2}{MSE}) \]  

\[ MSE = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} (F(i, j) - F_o(i, j))^2 \]  

where \( MSE \) denotes the mean square error between the input and output image; \( l \) is the maximum of the image; \( M \) and \( N \) indicate height and width of the image respectively.

3. Results and Discussion

The MTB images are captured by the system of computer-aided diagnosis for TB developed by our lab [9]. The captured images are at a resolution of 1360x1024, and the experiment is performed by Matlab 2015a.

The parameters mentioned in the proposed algorithm are set empirically. We use \( T_1 = 4 \) and \( T_2 = 30 \) in the step of histogram computation. For the PDF transformation, the parameters \( v = 0.4 \), \( P_l = 0.0001 \), and \( r = 0.5 \) are set. \( G_{\text{max}} = 4 \) and \( \eta = 0.9 \) are used for levels mapping. According to the size of the image, the parameters of the EME is set \( k_1 = k_2 = 8 \). The experimental results are compared with HE and WTHE. The parameters used in WTHE is set by \( v = 0.1 \), \( P_l = 0.0001 \), \( r = 0.5 \), and \( G_{\text{max}} = 2 \).

From Fig. 2 we can see that HE gives the highest EME and AMBE value in the three methods with the lowest PSNR value. The result shows that the undesired artifacts are presented in the enhanced image, and the mean brightness of the enhanced image is dramatically changed compared with the original image. Figure 2 (b) shows that the image quality of HE is the worst with over-enhancement occurred. WTHE gives lower EME and AMBE value than HE, and higher PSNR value than HE. It is evident that WTHE reduces the over-enhancement and artifacts and preserve the mean brightness of the enhanced image. The proposed method obtains a better result than WTHE in term of contrast enhancement, brightness preserving, and artifacts suppression.

Figure 3 shows the corresponding histograms in Fig. 2. The histogram of the MTB image gives a narrow range of pixels values, and the levels distribute rather closely. The shape of the original histogram is dramatically changed by HE resulting in bad enhancement result. The histogram of WTHE is better than HE’s. However, the shape of the histogram generated by the proposed method is the nearest to the original histogram while enhancing the image contrast.

Figure 4 is the final enhanced result of the color image. It is clear that the enhanced color image of the pro-
Fig. 3  Comparison of the enhancement histograms. (a) shows the original histogram. (b) shows the histogram of HE result. (c) shows the histogram of WTHE result. (d) shows the histogram obtained by the proposed method.

Fig. 4  Comparison of the enhanced result of the color image. (a) is the input color image. (b) is the enhanced result of HE. (c) is the enhanced result of WTHE. (d) is the enhanced result of the proposed method.

The proposed method performed best. The low contrast objects are enhanced while little undesired artifacts are introduced. 50 MTB images are tested to measure the performance of different methods in terms of EME, AMBE, and PSNR. These images have similar characteristics that the pixels of the MTB objects account for a small portion and the range of the gray levels is narrow. The mean results are shown in Table 1.

The proposed method achieves the lowest AMBE value and the highest PSNR value compared with HE and WTHE, which indicates that the proposed method has distinct advantages in brightness preserving and artifacts suppression. Meanwhile, the proposed method is better than WTHE in term of contrast enhancement. Although HE achieves the highest EME value, the over-enhancement and unpleasant artifacts are occurred resulting in low image quality.

4. Conclusion

An algorithm of contrast enhancement for MTB images is presented. The information of neighborhood pixels is introduced to reduce the artifacts, and the mean value of the gray image is used to find the regions including the low contrast objects. The PDF transform is applied to the original PDF to control the rate of the contrast enhancement. Finally, the brightness normalization is used after the levels mapping to preserve the mean brightness of the enhanced image. The experimental results show the effectiveness of the proposed algorithm in comparison to traditional HE and WTHE. The low contrast objects in the input images are enhanced, and the output images are visually pleasing with few artifacts.

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