Image Contrast Enhancement by Global and Local Adjustment of Gray Levels

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SUMMARY Various contrast enhancement methods such as histogram equalization (HE) and local contrast enhancement (LCE) have been developed to increase the visibility and details of a degraded image. We propose an image contrast enhancement method based on the global and local adjustment of gray levels by combining HE with LCE methods. For the optimal combination of both, we introduce a discrete entropy. Evaluation of our experimental results shows that the proposed method outperforms both the HE and LCE methods.

key words: contrast enhancement, histogram equalization, local contrast enhancement

1. Introduction

The enhancement of an image with poor contrast plays an important role in image processing applications. Contrast enhancement attempts to increase global contrast and local details of the degraded image. Numerous methods have been proposed to improve the contrast of images [1]–[9]. Most contrast enhancement methods can be classified into two main categories: global contrast enhancement (GCE) methods and local contrast enhancement (LCE) methods. In a global method, a single mapping derived from the image is used; in a local method, the neighborhood of each pixel is used to obtain a local mapping function [1]. One of the simple but effective GCE methods is the histogram equalization (HE) method [1], [10]. However, the HE method without modification may result in excessive contrast enhancement and saturation artifacts due to stretching of the gray levels over the full gray level range [3]. In some applications, the local details are more important than global contrast. Adaptive contrast enhancement (ACE) method using unsharp masking techniques is a well-known LCE method [8], [9]. The main issue in the ACE method is how to determine a contrast gain (CG) that results in the ringing effect and noise over-enhancement [8]. In order to give the observer a clearer global image with sufficient local contrast detail while processing an image with poor contrast, we propose a new image contrast enhancement method based on the global and local adjustment of gray levels. In the proposed method, we combined the HE and LCE methods. The proposed method defines a nonlinear function with the HE for the CG, which eliminates the ringing effect caused by the ACE method. Experimental results obtained by applying the proposed method and conventional HE and LCE methods to test images are presented to demonstrate the effectiveness of the proposed method.

2. Conventional HE and LCE Methods

We review briefly the conventional HE and LCE methods. The HE method acquires a scale factor from a normalized cumulative distribution of the brightness distribution of the original image, and rescans the original image using the scale factor to redistribute the intensity [1]. Let \( x(i, j) \) be the gray value of a pixel \((i, j)\) in an image with size \( N = I \times J\) in the range from 0 to \( L - 1\). The method gives an enhanced value \( F(x) \) of \( x(i, j) \) as follows:

\[
F(x) = \text{round}\left((L - 1) \sum_{k=0}^{x} h_{x}(k)\right) \text{for } x \in [0, L - 1] \quad (1)
\]

where \( h_{x}() \) is the normalized histogram of the original image, and round( ) denotes a function for rounding off to the nearest integer. First, we rescan the original image and write an output image \( H(i, j) \) with gray levels \( x' = F(x) \). Although the HE method results in a significant change of the mean brightness of the image, it is capable of improving global contrast, and may or may not consider the local details of the image.

The basic idea of the ACE is to enhance the specified features in the image by adopting an unsharp mask used to convolute with the original image. For a particular pixel, the unsharp mask can be calculated by averaging the gray values of pixels over a local area defined as a \((2n + 1) \times (2n + 1)\) window centered at \((i, j)\), where \( n \) is an integer number [8]. Let \( f(i, j) \) denote the enhanced value of \( x(i, j) \). The ACE method with a constant CG gives

\[
f(i, j) = m_{x}(i, j) + C \left[ x(i, j) - m_{x}(i, j) \right] \quad (2)
\]

where \( m_{x}(i, j) = \frac{1}{(2n + 1)^2} \sum_{k=-n}^{n} \sum_{l=-n}^{n} x(k, l) \),

\( m_{x}(i, j) \) is the local mean of a pixel \((i, j)\), and \( C \) is the CG which is usually greater than one. Although the ACE method is simple, using this CG, all high-frequency components are amplified equally which could result in a ringing effect in the vicinity of the edges.

3. The Proposed Method

To increase local details of an image and improve its global
contrast, a new image contrast enhancement method based on the global and local adjustment of gray levels by combining the HE with LCE methods is proposed. In the proposed method, the enhanced gray value \( f(i, j) \) of the gray value \( x(i, j) \) in an image of size \( N = L \times J \) and a \((2n+1) \times (2n+1)\) window centered at \((i, j)\) is given by

\[
f(i, j) = \alpha \left[ m_x(i, j) + \gamma(i, j) \cdot [x(i, j) - m_x(i, j)] \right] + (1 - \alpha) \left[ H(i, j) - \Delta m^h_x \right]
\]

where \( 0 \leq \alpha \leq 1 \) is an adjustment factor for the optimal combination of the HE and LCE, \( m_x(i, j) \) is the local mean of an original image, \( \gamma(i, j) \) is a function for the CG, \( H(i, j) \) is the gray value of the HE enhanced image, \( \Delta m^h_x \) is the deviation between a mean \( m_x \) of the HE processed image and the mean \( m_x \) of the original image for brightness preservation, and is given by

\[
\Delta m^h_x = m^h_x - m_x \tag{4}
\]

and CG \( \gamma(i, j) \) is a nonlinear function given by

\[
\gamma(i, j) = \frac{1}{\alpha} \left( \frac{\sigma_x^2(i, j)}{\sigma_G^2} + \frac{1}{\beta(i, j)} \right) \tag{5}
\]

where

\[
\beta(i, j) = \frac{1}{2} \left( \frac{H(i, j)}{L - 1} \right)^{1/2}
\]

\[
\sigma_x^2(i, j) = \frac{1}{(2n+1)^2} \sum_{k=i-n}^{i+n} \sum_{l=j-n}^{j+n} [x(k, l) - m_x(i, j)]^2
\]

\[
\sigma_G^2 = \frac{1}{N^2} \sum_{i=0}^{L-1} \sum_{j=0}^{J-1} \left[ H(i, j) - m_G \right]^2
\]

\[
m_G = \frac{1}{N^2} \sum_{i=0}^{L-1} \sum_{j=0}^{J-1} H(i, j).
\]

\( \sigma_x^2(i, j) \) is the local variance of the original image, and \( \sigma_G^2 \) and \( m_G \) are the global variance and mean of the HE-enhanced image, respectively. \( \beta(i, j) \) becomes large as the local gray level value decreases; \( \beta(i, j) \) rapidly tends toward a constant value as the local gray level value increases; and \( \beta(i, j) = L - 1 \) when \( H(i, j) = 0 \). Conventionally, the CG \( \gamma(i, j) \) is either a constant or is inversely proportional to the local standard variance [7]. However, in some cases, different gray level values need different CGs (e.g., the low gray level values need higher CGs and the mid- to high-gray level values do not need high CGs). Considering this point, in the proposed method, the CG \( \gamma(i, j) \) is formulated as a nonlinear function of local and global variances of images.

For the adjustment factor \( \alpha \) in Eq. (3), we introduce the discrete entropy \( E_\alpha \):

\[
E_\alpha = - \sum_{r=0}^{h-1} h(r) \log_2 h(r), \quad \forall h(r) \neq 0 \tag{6}
\]

where \( h(r) \) is the globally normalized histogram of the enhanced image \( f(i, j) \). Entropy has been used to measure the content of the image [2], with a higher value indicating images that are richer in details. From Eq. (6), the entropy values are calculated with different values of \( \alpha \in [0, 1] \) in Eq. (3), and the optimal \( \alpha^* \) with maximum entropy value is obtained by

\[
\alpha^* = \arg \max_{\alpha \in [0, 1]} (E_\alpha)
\]

If \( \alpha = 1 \) in Eq. (3), then we directly have the LCE method:

\[
f(i, j) = m_x(i, j) + \gamma \cdot [x(i, j) - m_x(i, j)]
\]

If \( \alpha = 0 \), then we have the modified HE method; that is, the brightness preserving HE method:

\[
f(i, j) = H(i, j) - \Delta m^h_x
\]

To investigate the property of the brightness preservation of the processed image, we used the absolute mean brightness error (AMBE) in Eq. (10). A lower value of AMBE implies better brightness preservation:

\[
\text{AMBE} = |\mu_p - \mu_o|
\]

where \( \mu_p \) and \( \mu_o \) denote means of the proposed and original images, respectively. If the AMBE is calculated using Eqs. (3), (4), and (10), then we have

\[
|\mu_p - \mu_o| = \left[ \alpha \left[ m_x(i, j) + \gamma \cdot [x(i, j) - m_x(i, j)] \right] + (1 - \alpha) \left[ H(i, j) - \Delta m^h_x \right] - m_x \right]
\]

\[
= \alpha m_x + \alpha \gamma \cdot [x(i, j) - m_x(i, j)]
\]

\[
+ (1 - \alpha) \left[ m^h_x - \left( m^h_x - m_x \right) \right] - m_x
\]

\[
= \alpha \gamma(i, j) [x(i, j) - m_x(i, j)] \approx 0 \tag{11}
\]

where \( \alpha \gamma(i, j) [x(i, j) - m_x(i, j)] \) is a high frequency component that can be neglected for the AMBE value of the output image. Therefore the proposed method preserves the original image brightness quite well.

4. Experimental Results

To demonstrate the effectiveness of the proposed method, experiments for the two conventional contrast enhancement methods (HE and ACE) and the proposed method were performed on twelve test images as shown in Fig. 1.

The comparison between the three methods used two quantitative measures supplemented with visual inspection. The first measure is the discrete entropy, which can depict the richness of details to some extent. Another measure is the AMBE, which provides a change in the image global appearance with preference to lower values. The visual assessment was supported by the computed entropy, and the AMBE values are listed in Tables 1 and 2. With respect to the entropy values, the proposed method increased the image content better than the HE and ACE methods. The
entropy values for the HE were always less than those of the original images because the HE method is global, and thus results in a reduction in the details. Comparison of the

![Test images](image1)

![AMBE values](image2)

Comparison of the AMBE values for the three methods revealed that the proposed method outperformed the HE and ACE methods in most cases with very low entropy values. Specifically, it is

| Images | HE  | LCE | Proposed |
|--------|-----|-----|----------|
| Aerial | 43.82 | 0.41 | 1.50     |
| Village | 15.24 | 1.72 | 2.42     |
| House  | 17.87 | 2.14 | 2.65     |
| Desk   | 0.04  | 3.22 | 2.36     |
| Pirate | 14.81 | 0.89 | 1.45     |
| Christena | 0.95 | 1.58 | 1.44     |
| Arctic hare | 81.90 | 3.94 | 2.59     |
| Einstein | 19.85 | 1.06 | 0.01     |
| Fighter | 47.48 | 0.96 | 0.29     |
| Chest 1 | 31.86 | 0.79 | 0.90     |
| Chest 2 | 9.66  | 1.49 | 0.71     |
| Back   | 34.23 | 1.02 | 1.81     |

![Contrast-enhanced results](image3)
better than the HE in terms of enhancing local details and preserving the image outlook with negligible saturation and over-enhancement of artifacts.

The contrast-enhanced images for “Einstein,” “Fighter,” “Chest1,” and “Chest2” are shown in Fig. 2. Figures 2 (a1), 2 (b1), 2 (c1), and 2 (d1) are images obtained from the HE method. The HE-enhanced results show higher contrast in the whole images. However, the contrast of local details is lower, such as in Fig. 2 (a1) in which Einstein is clearly separated from the background frame, but the facial features are lost. Figures 2 (a2), 2 (b2), 2 (c2), and 2 (d2) are the ACE-enhanced results. The window size was chosen as $3 \times 3$ for the local mean and local variance calculation. Comparing Fig. 2 (a1) with Fig. 2 (a2), Einstein’s facial features are clearer than with the HE, but the brightness of the whole image is lower. Figures 2 (a3), 2 (b3), 2 (c3), and 2 (d3) are images obtained from the proposed method which have enough local enhancement of detail and global enhancement for the whole image than with the HE and ACE methods. Figure 2 (a3) shows greater detail (such as the microgroove of the forehead and the cheek of Einstein) based on brightness preservation than the detail shown in Fig. 2 (a1), and the outline and feature of Einstein separated from the background frame is clearer than in Fig. 2 (a2). In Fig. 2 (b3), the outline and feature of the fighter is clearer than in Fig. 2 (b1), and the way the fighter moved on the runway is visible, but Fig. 2 (b2) does not show this. Figures 2 (c3) and 2 (d3) show a different enhancement of the lung field (the mediastinum and lung markings at the same time); these details are clearer than in Fig. 2 (c1), 2 (c2), 2 (d1), and 2 (d2).

5. Conclusion

In this letter, a new brightness preserving contrast enhancement method based on the combination of global adaptive equalization and local dynamic enhancement was proposed. The simulation results show that images enhanced using the proposed method have adequate local enhancement for details and global enhancement for the whole image compared to other contrast enhancement methods.

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