Sub histogram equalization with a brightness clipping for image enhancement

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Abstract. To get better image enhancement effect, this paper proposed an image enhancement method: Sub Histogram Equalization with a Brightness Clipping (SHEBC). In the proposed method, we use the histogram segmentation to control the enhancement and maximum entropy, use the average brightness value to maintain the brightness. The simulation results show that the method has a good effect on contrast enhancement and brightness retention, and the local details are also well processed for image enhancement.

1. Introduction
Image enhancement[1] is an important research content of digital image processing technology. It is used in various fields, such as aviation, satellite remote sensing image processing[2], digital photography[2], biomedical image processing and analysis[3], military target image processing[4]. The aim is to reduce noise and improve image contrast while maintaining image brightness and local detail as much as possible. As a time-domain image enhancement method, histogram equalization(HE)[5] has been wildly used due to its simple calculation and easy implementation. There are two main types of improvement methods based on HE image enhancement. The first is sub-histogram equalization technology[7], which is mainly used for image contrast enhancement under brightness protection. Representative methods include BBHE[8], DSIHE[9]. The second is enhanced with histogram clipping control[10], representative methods include BHEPL[11], ESIHE[12], etc. However, the two kinds of methods also have disadvantages[6]: (1)The first kind of methods will lead to excessive enhancement of the image and loss of details due to the number of the gray levels and the information entropy decrease;(2)The second kind of methods do not consider the image edge information, which will tend to produce edge effect, and bring obvious noise in some case. Base on the above methods, a new histogram equalization method is proposed in this paper: Sub-Histogram Equalization with a Brightness Clipping (SHEBC). The method makes full use of the advantages of histogram segmentation and histogram clipping; using the histogram segmentation to control the enhancement and maximum entropy, using the average brightness value is beneficial to maintain the brightness, so that the image has a good effect in contrast enhancement and brightness retention. The local details are also well processed after the enhancement.

2. Algorithm Implementation
This method consists of five steps. The first step is to calculate the median value of the image and divide the image into two sub histograms according to the median value; The second step is to
calculate the average brightness values of the two sub histograms respectively; Thirdly, the average brightness value of the two sub histograms is taken as the segmentation threshold, and the original image is divided into three sub histograms; The fourth step, each sub histogram is clipped; Finally, each sub image is equalized, and then the three parts are combined to output a complete enhanced image.

Next, we will describe the implementation steps of this method in detail.

2.1. Median Calculation of the Image
Assume that the gray value range of the image is \([0, L-1]\). The probability density function (PDF) of the image can be defined as:

\[
h(x) = H(x)/N
\]

where \(H(x)\) is the total number of pixels whose gray value equals to \(x\), and \(N = \sum_{x=1}^{L-1} H(x)\). \(L\) is the number of gray scale.

The median value of the image is denoted as a gray level \(M_e\), where the cumulative density function equals to 0.5 [9].

Consider variable \(z\) as:

\[
z(x) = z(x - 1) + h(x), x=0,1...L-1
\]

and \(z(0) = h(0)\).

The median value \(M_e\) is computed as:

\[
M_e = \text{argmax} \{z(x) - 0.5\}
\]

Then, segment the histogram of the image into two sub histograms \(h_L\) and \(h_H\) with the median \(M_e\).

\[
h_L = h(x), x=0,1...M_e
\]

\[
h_H = h(x), x=M_e + 1, ...L-1
\]

2.2. Mean Brightness Value Calculation
The two mean brightness values of the two sub histogram \(h_L\) and \(h_H\) are denoted as \(I_{ml}\) and \(I_{mh}\), so:

\[
I_{ml} = \frac{\sum_{x=0}^{M_e} h_L(x) \times x}{\sum_{x=0}^{M_e} h_L(x)}
\]

\[
I_{mh} = \frac{\sum_{x=M_e+1}^{L-1} h_H(x) \times x}{\sum_{x=M_e+1}^{L-1} h_H(x)}
\]

2.3. Sub Histogram Division
The input histogram will be segmented into three sub histograms \(h_1, h_2\) and \(h_3\) by using the separation thresholds \(I_{ml}\) and \(I_{mh}\). The three sub histograms are denoted as (8) to (10).

\[
h_1(x) = h(x), x=0,1...I_{ml}
\]

\[
h_2(x) = h(x), x=I_{ml} + 1, ...I_{mh}
\]

\[
h_3(x) = h(x), x=I_{mh} + 1, ...L-1
\]

2.4. Sub Histogram Clipping
We will compute the average of occurrences of each gray level for each sub histogram respectively, which is viewed as the clipping threshold. The clipping threshold of three sub histograms are denoted as \(c_1, c_2, c_3\). They are given in (11)-(13).
\[
c_1 = \frac{1}{m+1} \sum_{x=0}^{m} h_1(x)
\]
(11)
\[
c_2 = \frac{1}{n-m+1} \sum_{y=m+1}^{n} h_2(x)
\]
(12)
\[
c_3 = \frac{1}{L-m+1} \sum_{y=m+1}^{L} h_3(x)
\]
(13)

Next, we use the three clipping thresholds to clip three sub histograms \( h_1, h_2 \) and \( h_3 \) respectively. The expressions are given as follows.

\[
h_1^c(x) = \begin{cases} 
  h_1(x) & x \leq c_1 \\
  c_1 & \text{otherwise}
\end{cases}
\]
(14)
\[
h_2^c(x) = \begin{cases} 
  h_2(x) & x \leq c_2 \\
  c_2 & \text{otherwise}
\end{cases}
\]
(15)
\[
h_3^c(x) = \begin{cases} 
  h_3(x) & x \leq c_3 \\
  c_3 & \text{otherwise}
\end{cases}
\]
(16)

Then, the three sub histogram are normalized as follows:

\[
h_1'(x) = \frac{h_1^c(x)}{\sum_{y=0}^{m} h_1^c(y)}, \\
x=0,1\ldots m
\]
(17)
\[
h_2'(x) = \frac{h_2^c(x)}{\sum_{y=m+1}^{n} h_2^c(y)}, \\
x=m+1\ldots n
\]
(18)
\[
h_3'(x) = \frac{h_3^c(x)}{\sum_{y=m+1}^{L} h_3^c(y)}, \\
x=m+1\ldots L
\]
(19)

2.5. Sub Histogram Equalization and Combine

The CDF of the three sub histogram are defined as \( CDF_1, CDF_2, CDF_3 \). They are computed by the following equations.

\[
CDF_1(x) = \sum_{y=0}^{m} h_1^c(y), \\
x=0,1\ldots m
\]
(20)
\[
CDF_2(x) = \sum_{y=m+1}^{n} h_2^c(y), \\
x=m+1\ldots n
\]
(21)
\[
CDF_3(x) = \sum_{y=m+1}^{L} h_3^c(y), \\
x=m+1\ldots L
\]
(22)

Then, we use HE to process the three sub histograms. The transformation of each sub histogram is obtained by corresponding CDF as given in (23)-(25).

\[
p_1 = I_{ml} \times CDF_1
\]
(23)
\[
p_2 = (I_{ml} + 1) + (I_{mh} - I_{ml} - 1) \times CDF_2
\]
(24)
\[
p_3 = (I_{mh} + 1) + (L - I_{mh} - 2) \times CDF_3
\]
(25)

In the last step, we combined the three enhanced sub images into a full image.
3. Simulation Analysis
In this section, we will compare the SHEBC method with other image enhancement methods quantitatively and qualitatively. Four methods, BBHE, DSIHE, BHEPL and ESIHE, were selected for qualitative analysis, and three objective evaluation indexes, EME(Enhancement Measure by Entropy), PSNR, average information entropy, were used for quantitative analysis.

3.1. Quantitative Analysis
Table 1-3 shows three objective index matrices of the three sample images, in which the columns represent the test images and the rows represent the image enhancement method. The underlined value is the best value for each comparison.

| Table 1. EME of three sample images |
|-----------------------------------|
| Fig.1 | Fig.2 | Fig.3 | Average |
| BBHE  | 5.52  | 8.21  | 7.32    | 7.02    |
| DSIHE  | 5.23  | 8.01  | 7.45    | 6.90    |
| BHEPL  | 5.68  | 7.32  | 7.66    | 6.89    |
| ESIHE  | 5.99  | 9.13  | 8.32    | 7.81    |
| SHEBC  | 6.42  | 9.01  | 8.65    | 8.03    |

| Table 2. ENTROPY of three sample images |
|----------------------------------------|
| Fig.1 | Fig.2 | Fig.3 | Average |
| BBHE  | 7.22  | 5.62  | 5.88    | 6.24    |
| DSIHE  | 7.18  | 5.63  | 5.83    | 6.21    |
| BHEPL  | 7.23  | 5.74  | 5.89    | 6.29    |
| ESIHE  | 7.25  | 5.68  | 5.92    | 6.28    |
| SHEBC  | 7.28  | 5.82  | 5.99    | 6.36    |

| Table 3. PSNR of three sample images |
|-------------------------------------|
| Fig.1 | Fig.2 | Fig.3 | Average |
| BBHE  | 17.01 | 13.32 | 16.33   | 15.55   |
| DSIHE  | 16.99 | 12.99 | 10.86   | 13.61   |
| BHEPL  | 22.21 | 21.22 | 21.55   | 21.66   |
| ESIHE  | 22.01 | 20.98 | 18.36   | 20.45   |
| SHEBC  | 30.25 | 29.99 | 21.33   | 27.19   |
3.2. Qualitative Analysis

Figure 1. Enhancement of sample image: (a) original, (b) BBHE, (c) DSIHE, (d) BHEPL, (e) ESIHE, (f) SHEBC

Figure 2. Enhancement of sample image: (a) original, (b) BBHE, (c) DSIHE, (d) BHEPL, (e) ESIHE, (f) SHEBC
Figure 3. Enhancement of sample image: (a)original, (b)BBHE, (c)DSIHE, (d)BHEPL, (e)ESIHE, (f)SHEBC

4. Results and discussion
The EME values of all methods are shown in Table 1. According to the average value of EME, SHEBC is the best among all methods. The results show that this method has a good brightness retention effect. Table 2 shows the entropy measurement results of all the methods. The average entropy value of SHEBC is the highest, which indicates that our method has the best performance in image detail extraction. Table 3 shows the PSNR values of all the methods. Among all the methods, the PSNR mean value of SHEBC is the best, indicating that our method has a good effect on noise suppression.

Fig.1-3 shows the enhanced images processed by five image enhancement methods. Fig.1, the contrast of the original image is low; after image enhancement, BBHE and DSIHE produce obvious over enhancement, while BHEPL and ESIHE produce unnecessary noise, which makes the image look not very coordinated. By contrast, SHEBC enhancement effect is better. As can be seen from Fig.2, BBHE and DSIHE were over enhanced, BHEPL was not compatible with the treatment of girl’s skirts, ESIHE and SHEBC methods had good enhancement effects. From Fig.3, we can see that BBHE, DSIHE and ESIHE are over enhanced with contrast imbalance, while BHEPL has noticeable noise amplification. Based on the subjective evaluation of the three images, it can be seen that SHEBC is superior to other image enhancement methods in terms of enhanced control degree, noise suppression and detail preservation.

5. Conclusions
In this paper, we proposed an image enhancement method SHEBC. The method makes full use of the advantages of histogram segmentation and histogram clipping, using the histogram segmentation to control the enhancement and maximum entropy, using the average brightness value is beneficial to maintain the brightness, so that the image has a good effect in contrast enhancement and brightness retention, and the local details are also well processed. The simulation results show that SHEBC is superior to other image enhancement methods based on three objective image evaluation measures. Furthermore, subjective evaluation results also show that SHEBC is superior to other image enhancement methods in image enhancement control degree, noise suppression and detail preservation.

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