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Recursive Plateau Histogram Equalization for the Contrast Enhancement of the Infrared Images

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Abstract. One simple and efficient algorithm based on recursive plateau histogram equalization for the contrast enhancement of the infrared images is proposed in this paper. In this method, the plateau threshold is selected automatically as the average value of the probability density function. Based on the threshold value, the probability density function is divided into two sub-groups. The sub-group whose values are greater than the threshold value is clipped. New threshold value is calculated for another sub-group whose values are less than the old threshold value and the separation process is performed recursively on it. Experimental results show that our method can enhance the contrast of the infrared images better than other histogram equalization based methods. Furthermore, our method is simple enough to make it suitable to be implemented by FPGA for real time image process.

Keywords: Contrast enhancement; Histogram equalization; Plateau histogram equalization; Image enhancement

1. Introduction

Histogram equalization (HE) is a widely used method in image contrast enhancement [1]. Applications of histogram equalization are found in many areas such as medical image processing, texture synthesis, as well as speech recognition. However, the traditional histogram equalization suffers from some problems. One of the well-known problems for histogram equalization is that the brightness of the input image is often changed greatly after enhancement. Additionally, it is especially difficult to achieve a well-balanced enhancement effect over different parts of an image, for example, background and detail parts of the image. Because of the shortcomings, histogram equalization is rarely used in practice. Recently, many improved HE-based techniques have been proposed.

Generally, all these methods belong to two categories: the local HE methods, such as [2], [3] and [4] and the global methods. For the local methods, equalization is based on histogram and statistics obtained from the neighborhood around each pixel. Local methods can usually provide stronger enhancement effects than global methods. However, due to their high computational load, local methods are not best suited for real time enhancement.

The general idea adopted by the global methods is to modify the histogram before the equalization is performed. Through such modifications, artifacts that result from the traditional HE method are reduced. At the same time, the ability to control the degree of enhancement is added.

BBHE is first proposed in [5]. BBHE separates the input histogram into two sections. These two histogram sections are then equalized independently. Similar to BBHE, DSIHE uses the median intensity value as the separating point [6]. MMBEBHE uses the separation point that produces the smallest absolute

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mean brightness error [7]. To preserve the mean brightness better, RMSHE carries out the mean-based histogram equalization more than once recursively [8].

However, all the above methods are not applicable to infrared images, since these methods enhance the image background instead of targets. To overcome this problem, plateau histogram equalization is proposed in [9]. Plateau histogram equalization has been proven to be more effective, which suppresses the enhancement of background by using a plateau threshold value. Examples of plateau histogram equalization include BUBOHE (Histogram Equalization with Bin Underflow and Bin Overflow) [10], WTHE (Weighted and Threshold Histogram Equalization) [11], GC-CHE (Gain-Controllable Clipped Histogram Equalization) [12], SAPHE (Self Adaptive Plateau Histogram Equalization) [13] and MSAPHE (Modified Self Adaptive Plateau Histogram Equalization) [14].

Unfortunately, in order to obtain a good enhancement result, BUBOHE, WTHE and GC-CHE require the user to manually set the parameters' values. Thus, these methods are not suited to be used in an automated image enhancement system. SAPHE selects its parameter value automatically, based on the median value of the local peaks of the corresponding input histogram. However, in some cases, SAPHE fails to detect any local peaks in the image and therefore fails to set its parameter [14].

2. Histogram Equalization

Let $X = \{X(i,j)\}$ denote a given image composed of L discrete gray levels denoted as $\{X_0, X_1, \cdots, X_{L-1}\}$, where $X(i,j)$ represents an intensity of the image at the spatial location (i,j) and $X(i,j) \in \{X_0, X_1, \cdots, X_{L-1}\}$. For a given image X, the probability density function $p(X_k)$ is defined as

$$p(X_k) = \frac{n_k}{n} \tag{1}$$

for $k = 0,1,\cdots,L-1$, where n^k represents the number of times that the level X_k appears in the input image and n is the total number of samples in input image.

Based on the probability density function, the cumulative density function is defined as

$$c(x) = \sum_{j=0}^{k} p(X_j) \tag{2}$$

where $X_k = x$, for $k = 0,1,\cdots,L-1$. Note that $c(X_{L-1}) = 1$ by definition.

Histogram equalization is a scheme that maps the input image into the entire dynamic range (X_0, X_{L-1}), by using the cumulative density function as a transform function. That is, let us define a transform function $f(x)$ based on the cumulative density function as

$$f(x) = X_0 + (X_{L-1} - X_0)c(x) \tag{3}$$

then the output image of the histogram equalization, $Y = \{Y(i,j)\}$, can be expressed as

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

Histogram equalization stretches the contrast of the high histogram regions, and compresses the contrast of the low histogram regions. As a consequence, when the object of interest in an image only occupies a small portion of the image, the object will not be successfully enhanced by histogram equalization. This method also extremely pushes the intensities towards the right or the left side of the histogram and causes level saturation effects.

Plateau histogram equalization based methods try to overcome these problems by restricting the enhancement rate. For histogram equalization methods, the enhancement is obtained from the transformation function. As given in equation (3), it is known that the enhancement from histogram equalization is heavily dependent on $c(x)$. Therefore, the enhancement rate is proportional to the range of $c(x)$. The rate of $c(x)$ is given by the following equation:

$$\frac{d}{dx}c(x) = p(x)$$

Therefore, if we want to limit the enhancement rate, we can do so by limiting the value of $p(x)$.

Plateau histogram equalization modifies the shape of the input histogram by reducing or increasing the value in the histogram's bins based on a threshold limit before the equalization takes place. An appropriate threshold value is selected firstly, which is represented as "T". If the value of $p(X_k)$ is greater than T, then it is forced to equal T, otherwise it is unchanged, as shown below.

$$p_T(X_k) = \begin{cases} p(X_k) & p(X_k) \le T \\ T & p(X_k) > T \end{cases} \tag{5}$$

where, $p_T(X_k)$ is the modified probability density function. Then, histogram equalization is carried out using this modified probability density function.

There is one main problem associated with plateau histogram equalization. Most of the methods need the user to set manually the plateau threshold of the histogram which makes these methods not suitable for automatic systems. Although some methods can set the plateau threshold automatically, the process for deciding one threshold is often complicated.

Selection of plateau threshold value is very important in the infrared image enhancement algorithm of plateau histogram equalization. It would have effect on the contrast enhancement of images. Appropriate plateau threshold value would greatly enhance the contrast of image. In addition, some plateau value would be appropriate to some infrared images, but not appropriate to others. As a result, the plateau threshold value would be selected adaptively according to different infrared images in the process of image enhancement.

3. Recursive Plateau Histogram Equalization

First, we propose one simple and effective way to select the plateau threshold automatically for different input images. The threshold value is given as follows:

$$T_0 = \frac{1}{L}\sum_{k=0}^{L-1} p(X_k) = \frac{1}{L} \tag{6}$$

The above equation shows that the threshold value is actually the average value of the probability density function at the whole dynamic range $[0, L-1]$.

Then, by using the threshold value, the original probability density function $p(x)$ is decomposed into two sub-groups $p_u(x)$ and $p_l(x)$:

$$p_u(x) = \{p(x) | p(x) > T_0\} \tag{7}$$

$$p_l(x) = \{p(x) | p(x) \le T_0\} \tag{8}$$

For the sub-group $p_u(x)$, in order to control the enhancement rate, it is clipped about the threshold T_0:

$$p_{uT_0}(x) = T_0 \tag{9}$$

Here, for the whole input image, $p(x) = p_{uT_0}(x) \cup p_l(x)$. Then, histogram equalization can be applied for contrast enhancement, which is the method for plateau histogram equalization. However, for infrared images with low-contrast, direct use of plateau histogram equalization once can not improve the contrast of images much. Consequently, we need to use plateau histogram equalization more times on the sub-groups.

Now, let us consider sub-group $p_l(x)$, its average value is:

$$T_1 = \frac{1}{M}\sum_{k} p_l(X_k) \tag{10}$$

where, M is the number of elements in the sub-group $p_l(x)$.

Based on the threshold value, we divide $p_l(x)$ into two sub-groups $p_{lu}(x)$ and $p_{ll}(x)$:

$$p_{lu}(x) = \{p_l(x) | p_l(x) > T_1\} \tag{11}$$

$$p_{ll}(x) = \{p_l(x) | p_l(x) \le T_1\} \tag{12}$$

For the sub-group $p_{lu}(x)$, it is clipped about the threshold value T_1 as follows:

$$p_{luT_1}(x) = T_1 \tag{13}$$

then, for the whole input image, the probability density function is composed of three sub-groups,

$$p(x) = p_{uT_0}(x) \cup p_{luT_1}(x) \cup p_{ll}(x) \tag{14}$$

Of course, the clipped process can be applied recursively on sub-group $p_{ll}(x)$. Practically, when the difference between two next threshold values is small, the recursive process can be stopped.

Finally, we need to normalize the probability density function:

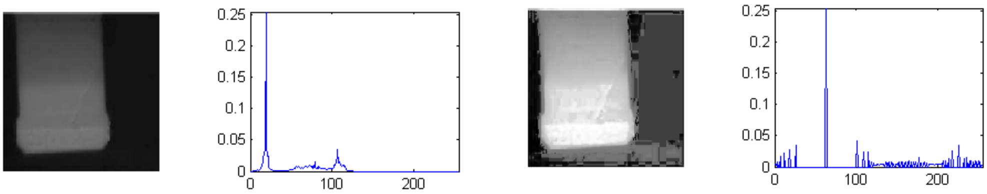
$$p(x) = p(x) / (p_{uT_0}(x) + p_{luT_1}(x) + p_{ll}(x)) \tag{15}$$

Based on this new probability density function, histogram equalization is used for equation (2) and (3).

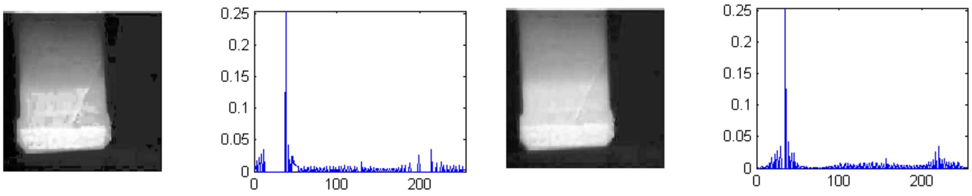
4. Experimental Results

In this section, we test some typical algorithms, including HE、BBHE and WTHE, together with our method (recursive level is 2), on several images.

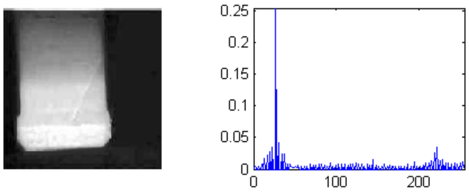
Fig.1 (a) is a glass half filled with hot water. The original histogram has three peaks that respectively represent the background, the upper part and the nether part of the glass. Obviously, the histogram is compact and occupies only a small fraction of the whole gray levels. So, its contrast is low. Fig.1 (b) is the enhanced image by histogram equalization. Although background is enhanced and occupies a wider gray level, the noise is enhanced too. Fig.1 (c) is the image enhanced by BBHE. Since the purpose of BBHE is to preserve the brightness of the input image, the contrast of the output image does not improve greatly. Fig.1 (d) and (e) are two images by WTHE and our method. Both of these two images have better quality of contrast. The targets (glass and hot water) are enhanced. And their histograms are similar except that the background in the histogram of our method occupies a narrower range than WTHE, which prevents the over-enhancement of the background.



(a) Original (b) HE



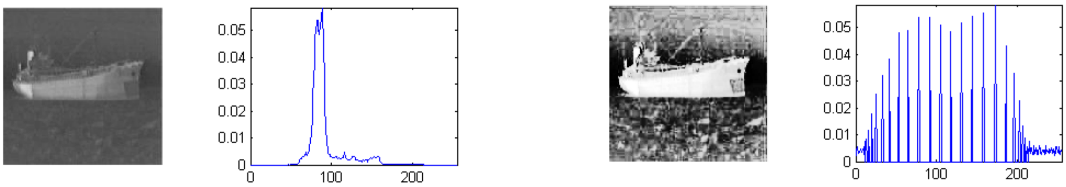
(c) BBHE (d) WTHE



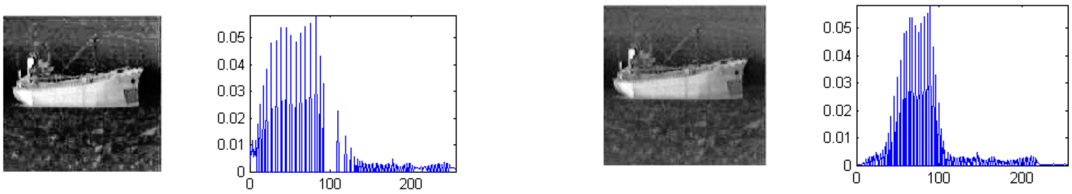
(e) Our method

Fig.1 Result for tested image 1

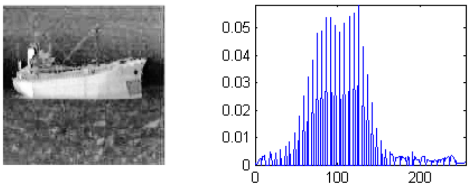
Fig.2 (a) shows one ship in the sea. In the original image, the ship can not be distinguished well from the background "sea". Fig.2 (b) is the enhanced image by HE. Although the ship is enhanced, a lot of noise appears in the background which degrades the quality of the image. Fig.2 (c) shows the enhanced image by BBHE. As expected, the whole contrast of the output image is still low in order to preserve the brightness of the input image. Fig.2 (d) and (e) show images with good contrast enhancement. Moreover, in Fig.2 (e), it is shown that the target (ship) is enhanced more than Fig.2 (d), since the target in the histogram occupies a wider range.



(a) Original (b) HE



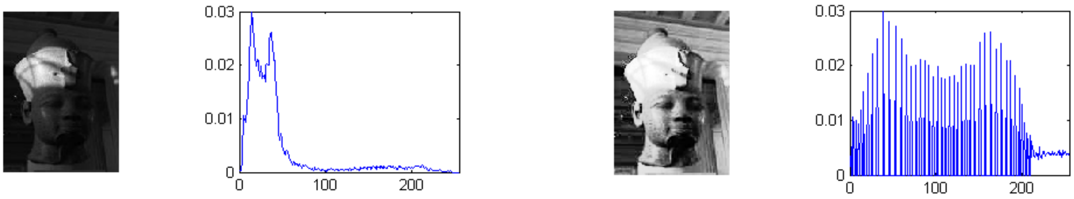
(c) BBHE (d) WTHE



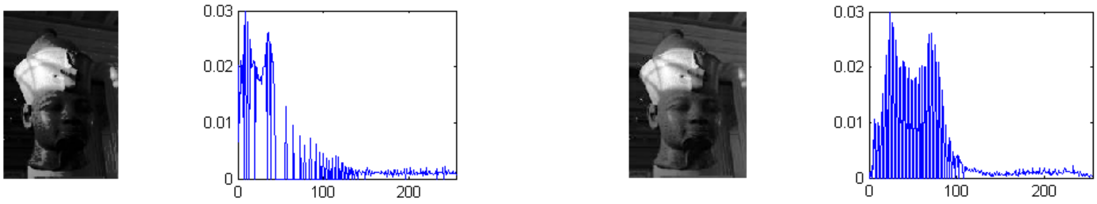
(e) Our method

Fig.2 Result for tested image 2

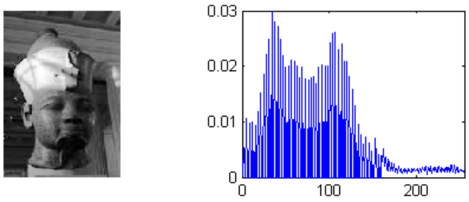
One low-contrast image is shown in Fig.3 (a). Fig.3 (b) shows the image by HE. It is obvious from the image and its histogram that the background and the target are over-enhanced. BBHE can not get one good contrast image at all. Obviously, Fig.3 (d) and (e) show good contrast for the image. In their respective histograms, it is seen that the target gets a wider range in (e) than in (d). Consequently, the target is enhanced and the output quality of the image by our method is better than WTHE.



(a) Original (b) HE



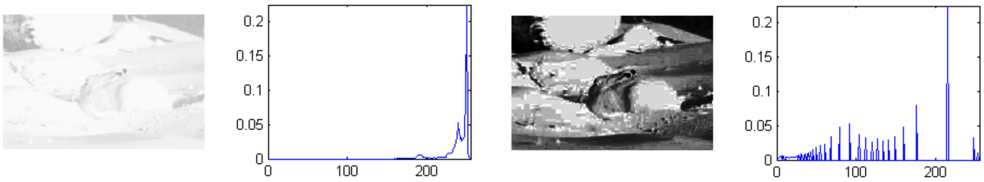
(c) BBHE (d) WTHE



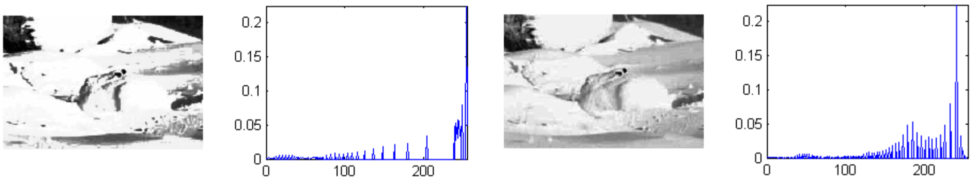
(e) Our method

Fig.3 Result for tested image 3

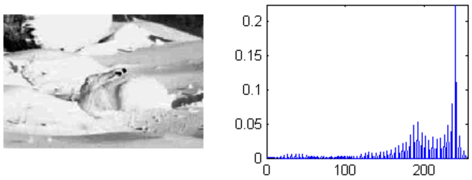
Another low-contrast image with bright background and targets is shown in Fig.4 (a). The image by HE is shown in Fig.4 (b). The mean brightness changed greatly for the output image. However, the contrast does not improve much. Fig.4 (b) shows the image by BBHE. It is seen that the histogram by BBHE is almost the same as the original shown in Fig.4 (a). So, the contrast enhancement of the image is weak. The image by WTHE is shown in Fig.4 (d). The contrast of the image is good, compared to those by HE and BBHE. Fig.4 (e) shows the image by our method. Contrast enhancement is obvious in the image. By looking at the histograms in (d) and (e), we can easily find that the background and targets get a narrower range in (e) than in (d), which reduces the possibility of over-enhancement.



(a)Original (b)HE



(c)BBHE (d)WTHE



(e)Our method

Fig 4 Result for tested image 4

5. Conclusions

Since the infrared images have the property of low-contrast, most HE-based methods can not enhance the targets in the images well. Plateau histogram equalization, on the other hand, can overcome this problem and is widely used in the contrast enhancement of the infrared images. However, plateau histogram equalization suffers from some problems, such as, the automatic selection of the threshold value. Most plateau histogram equalization-based methods set the threshold value manually or need a complicated process, which hesitates the direct use of the method in the automation of the image processing for the infrared images.

Observing the experimental results on several images, we can easily find that our method can enhance the targets in the images effectively, compared to other methods, for example, HE、BBHE and WTHE. Although some methods may output some images with good contrast, the images by our method look more natural. So, our method can work well for the contrast enhancement of the infrared images with low contrast. More importantly, our method is simple enough to make it meet the requirements of automation and real-time.

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