Effective Contrast Enhancement Method by Luminance-Separated Weighted Histogram Equalization

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Abstract

A stronger method for image contrast enhancement is proposed. Histogram Equalization (HE) is a generally used method in image contrast enhancement. Some methods inherit the disadvantage of HE. For example, the average luminance cannot be retained; some parameter is set too large, and does not have adaptive machinery for difference images.

In this paper, we proposed a method to enhance global contrast of an image based on Average Luminance with Weighted Histogram Equalization (ALWHE) for Low Dynamic Range Images (LDRI). We can take the most advantage of that method. Automation of parameter selection can easily be done by iteratively using the proposed method. We present experimental results to compare results of contrast enhancement with other methods.

Key words: Histogram Equalization (HE), Contrast Enhancement, Average Luminance, Average Intensity.

1. Introduction

Digital Cameras that progressively replace conventional cameras store photographs in digital format. As a result, captured images can be more easily processed. Contrast enhancement plays a very important role in increasing visual quality of an image [5, 2, and 14]. Therefore many contrast enhancement techniques have been proposed [10, 3, 6, 9, 8, 4, and 13].

The global and local methods are the two kinds of contrast enhancement techniques. Global method is a useful operation in image processing, because that its efficiency and low computation load. The drawback of a global operator is its incapability of revealing the local variation of details of an image. On the contrary, the advantage of a local operator is its capability of revealing the detail information of an image; however, unless hardware realizations are taken into consideration, local operators are not suitable for enhancing local contrast of videos because the computation load is usually very high.

Histogram Equalization (HE) is a generally used method in image contrast enhancement. The applications of Histogram Equalization are found in many fields, for example medical image processing, natural image processing and texture synthesis. In 2004, Chen, and Ramli used a histogram equalization strategy to change the brightness of an image, and this strategy was found to significantly enhance the contrast [11]. However, that some drawbacks had found in traditional HE method. The traditional HE strategy usually produces annoying artifacts and overstated contrast that makes the image unnatural. Therefore, the bi-histogram equalization (BBHE) [12] and dualistic sub-image histogram equalization (DSIHE) [11] strategies were proposed to solve the problem of brightness preserving, but these methods may fail under certain conditions.

Qing Wang and Raabab K. Ward [7] also addressed the contrast enhancement based on weighted thresholded histogram equalization (WTHE) method for improving traditional HE method. Nevertheless, WTHE also inherits the disadvantage of HE that average luminance cannot be retained. Although a constant parameter $M_{adj}$ can be used to shift the histogram to mitigate fault. But if the $M_{adj}$ value is too larger, gray level of bins would cause out of range. On the other hand, the WTHE also the pre-set maximum gain does not have adaptive machinery for different images.

In this paper, we proposed a method to enhance global contrast of an image based on Average Luminance with Weighted Histogram Equalization for Low Dynamic Range Images (LDRI). In section 2 we introduce a method to enhance global contrast of LDRI. Experimental results comparing our method with several other methods are shown in section 3. Section 4 concludes this paper.

2. The WTHE enhancement method

The weighted thresholded histogram equalization (WTHE) method is modified by traditional histogram equalization. In traditional HE, suppose the probability density function (PDF) of gray level of an image is $P(k)$, the parameter $k$ is gray level. Then the cumulative density function (CDF), $C(k)$ is represented in equation (1).

$$C(k) = \sum_{m=0}^{k} P(m), \text{ for } k = 0, 1, ..., k - 1 \ (1)$$

where $k$ is the total number of gray level bin for the testing image. For low dynamic range images the gray level of bin is equal to 256. After mapped the new gray level $k$ is represented in equation (2).

$$H(k) = (k - 1) \times C(k) \ (2)$$
WTHE method modified the parameter $P(k)$ which weights and thresholds it dynamically as the equation (3).

$$P_{wt} = \Omega(P(k))$$

\[
\begin{cases} 
    P_u, & \text{if } P(k) > P_u \\
    (P(k) - P_l)^r \times P_u, & \text{if } P_l \leq P(k) \leq P_u \\
    0, & \text{if } P(k) < P_l
\end{cases}
\]

Where $P_{wt}$ is the value of weighted and thresholded parameter $P(k)$. $P_u$ equal to $v$ times the maximum of $P(K)$ and the value $v$ is between 0 to 1. $P_l$ is a small constant at about 0.01% for eliminating noise.

Parameter $r$ determines whether to give more weighting to shorter bins. When $v = 1$ and $r = 1$, the algorithm executes to normally HE. Usually $v$ and $r$, both of can be set to 0.5, $r$ and $v$ respectively control the curvature of the curve at left-half side and the end-point of the curve as shown figure 1. Parameter $r$ and $v$ to avoid the unnatural phenomenon is occurred in the result image.

![Figure 1: Control the curvature of the curve.](image)

After the $P_{wt}$ is adjusted, the result image $\hat{F}(i, j)$ is given by equation (4).

$$\hat{F}(i, j) = W_{out} \times C_{wt}(F(i, j)) + M_{adj} \quad (4.1)$$

$$C_{wt}(F(i, j)) = \sum_{m=0}^{k} P_{wt}(m), \quad \text{for } k = 0, 1, \ldots, K - 1 \quad (4.2)$$

Both of the $W_{out}$ and $M_{adj}$ are constants for determining the output range and shifting amount correspondingly for result image.

### 3. The Proposed method

As mentioned in the section 1, there are two problems in WTHE method. We improved the two problems in our method by the average luminance with weighted adaptive machinery. The ALWHE method preserves and modifies the intensity freely. The flowchart of ALWHE is represented in Figure 2.

First, we calculates the average luminance by $I_A = \text{mean}(F(i,j))$ of whole image. Then, we split the original image into two parts depend on $I_A$, namely:

$$G_L = \{F(i, j) | F(i, j) \in [0, I_A]\}$$

Both $G_L$ can be represented as $N_L = \sum_{k=0}^{I_A} n_k$, where $n_k$ stands for number of pixels of gray level $n_k$ in $F(i, j)$. Hence, the PDF of $G_L$ can be represented as $P_L(k) = \frac{n_k}{N_L}$. It is known that PDF of $F(i, j)$ is $P_f(k) = \frac{n_k}{N}$, which correlates with $G_L$ by $P_L(k) = \frac{1}{C(I_A)} P_f(k)$.

We transform $P(k)$ to $P_{wt}(k)$ and normalize it. The $P_{wt}(k)$ is represented as equation (6):

$$P_{wt}(k) = P_{wt}(k) \times C_{wt}(K) \quad (6)$$

where $C_{wt}(F(i, j))$ is the cumulative function of $P_{wt}(k)$, represented in equation (7).

$$C_{wt}(F(i, j)) = \sum_{m=0}^{k} P_{wt}(m), \quad \text{for } k = 0, 1, \ldots, K - 1 \quad (7)$$

Identically, applying $\Omega$ to PDF of $G_L$ and normalizing $P_{wt}(k)$, we obtain

$$P_{Lt}(k) = \frac{P_{Lt}(k)}{C_{Lt}(I_A)}, \quad \text{where } C_{Lt}(k) \text{ is the cumulative function of } P_{Lt}(k) \text{ that can be calculated by}$$

$$C_{Lt}(k) = \sum_{m=0}^{k} P_{Lt}(m) \quad \text{for } k = 0, 1, \ldots, I_A$$

and finally,
\[ P_{NLwt}(k) = \frac{P_{wt}(k)}{C_{NLwt}(I_A)} \]

\[ \hat{P}_{NLwt}(k) = \frac{P_{wt}(k)}{C_{NLwt}(I_A) - C_{wt}(I_A)} \]

We use \( P_{wt}(k) \) of original image \( F(i,j) \) directly to calculate \( P_{NLwt}(k) \) of \( G_L \). Then the algorithm enhance the histogram according to \( P_{NLwt}(k) \). From the concept of HE, the new histogram of \( G_L \) is represented in equation (8):

\[ H_{Lwt}(k) = I_A \times C_{NLwt}(k) = I_A \sum_{m=0}^{k} P_{NLwt}(m) \quad \text{for} \ k = 0,1,2,\ldots,I_A \quad (8) \]

\( I_A \) represents the new separation point, which can be set equal to \( I_A \) to maintain the brightness or modified the brighter or darker of image. Similarly, we evaluated the PDF of \( G_H \) after enhanced, as equation (10).

\[ P_{NLwt}(k) = \frac{P_{wt}(k)}{C_{NLwt}(K-1) - C_{wt}(I_A)} \quad (10) \]

The new histogram of \( G_H \) should be in the segment \([I_A ^*, K - 1]\), therefore the new histogram is

\[ H_{Hwt}(k) = (K - I_A ^*) - 2 \times C_{NLwt}(k) + (I_A ^* + 1) \]

\[ = (K - I_A ^*) - 2 \left( \sum_{m=0}^{k} P_{NLwt}(m) \right) + (I_A ^* + 1) \]

To sum up, the new histogram of \( \hat{H}(k) \) is represented in equation (11).

\[ \hat{H}(k) = \begin{cases} H_{Hwt}(k) & \text{for} \ k > I_A ^* \\ H_{Lwt}(k) & \text{for} \ k \leq I_A ^* \\ \frac{K - I_A ^* - 2 \left( \sum_{m=0}^{k} P_{NLwt}(m) \right)}{C_{NLwt}(K - 1) - C_{wt}(I_A ^*)} \left( \sum_{m=0}^{k} P_{wt}(m) \right) & \text{for} \ k > I_A ^* \\ + (I_A ^* + 1) & \text{for} \ k \leq I_A ^* \end{cases} \]

\[ = \begin{cases} I_A ^* \sum_{m=0}^{k} P_{NLwt}(m) & \text{for} \ k > I_A ^* \\ \frac{K - I_A ^* - 2 \left( \sum_{m=0}^{k} P_{NLwt}(m) \right)}{C_{NLwt}(K - 1) - C_{wt}(I_A ^*)} \left( \sum_{m=0}^{k} P_{wt}(m) \right) & \text{for} \ k \leq I_A ^* \end{cases} \]

The parameters \( r \) and \( v \) can be set to 0.5 and 0.5. The parameter \( P_I \) is implicated in \( P_{H}(k) \) and can be set to 0.01% correspondingly.

**Determination of \( I_A ^* \) - Luminance complementing curve**

We can choose any strict increasing function of \( I_A \) to determine \( I_A ^* \). If \( I_A \) equal to \( I_A ^* \) means that without luminance average adjustment. Due to it is more sensitive of the detail distributes on the mid-tone gray level for human eye. Therefore, we proposed a simple curve to determine \( I_A ^* \) based on S-curve. The curve is formulated as in equation (12).

\[ I_A ^* = x + pK \left( \exp \left( -\frac{x - \frac{K}{2}}{\frac{K}{q}} \right) \right) \]

In equation (12), where \( p \) determines the maximum difference between \( I_A \) and \( I_A ^* \), \( q \) is the curvature of the curve. By experiment we choose \( p = 0.422 \) and \( q = 8 \).

**4. Experiment results**

We use two set of testing images in our proposed method. Figure 3 compares the result image of F-16. The proposed method maintains the average luminance much well than WTHT method. In the testing image of F-16, compare with the original image, some of the clouds is too dark by WTHT method (as the circle). The ALWHT method overcomes the problem without suffering clipping by luminance adjustment, as shown Figure 3.

Another example represents the difference from without or with using luminance average adjustment function in Figure 4. We can see, for example, the detail on the girl’s face becomes clearer than the original image on figure 4c. Luminance average adjustment function coordinates the average luminance closer to the middle-tone region, thus details can be observed easier. The luminance average adjustment functions will adjust the intensity in the darker or lighter regions automatically, without the right contrast ratio in original images.

In theories, the contrast ratio and standard deviation will become higher after using histogram equalization method. Actually it is uncertainly better for getting higher value in contrast ratio and standard deviation. Some parameters for proposed method is listed in table 1. In table 1, the proposed method at the item of luminance average approach to 1. It means that much closed to the original mage and the standard deviation ratio is very less.

Although, the values in contrast, background Variance, detail variance and variance items is less than WTHT method. We can say that the proposed method is stable than WTHT method. In other words, the enhanced degree is balancing in our proposed method.
method. The enhanced degree is stronger than the WTHE method.

5. Conclusion

In this paper we proposed a method based on average luminance with weighted HE (ALWTHE). We addressed a stable method for image contrast enhancement. The advantages of the proposed method are: adjust parameters less; reproduced more detail information and preserved the original light source; and the proposed method could adjust the overexposed or underexposed images.

References


Figure 3 Results images. (a) Original image. (b) The result by WTHE method. (c) The Proposed method.

Figure 4 Difference between used luminance average adjustment function. (a) Original image. (b) After ALWHE without luminance average adjustment. (c) The Proposed method.
Table 1. Some parameters of testing image for proposed method.

<table>
<thead>
<tr>
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<th>Luminance average</th>
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