Fast Image/Video Contrast Enhancement Based on WTHE

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***Abstract*— We present a fast and effective method for image contrast enhancement based on weighted and thresholded histogram equalization (WTHE). In our proposed method, the probability distribution function of an image is modified by weighting and thresholding before the histogram equalization (HE) is performed. We show that such an approach provides a convenient and effective mechanism to control the enhancement process while being adaptive to various types of images. We also discuss applications of the proposed method in video enhancement.**

Keywords—contrast enhancement; histogram; histogram equalization; cumulative distribution function

Topic area—Multimedia processing: image post-processing

I. INTRODUCTION

Histogram equalization (HE) is widely used for image contrast enhancement. Applications of histogram equalization are found in many areas such as medical image processing, speech recognition and texture synthesis. Also in recent years, the application of the HE methods in video enhancement is drawing much interest. It is known, however, that the traditional HE method suffers from the following drawbacks:

(1) It lacks of a mechanism to adjust the degree of enhancement.
(2) It often causes unpleasant visual artifacts, such as over-enhancement, level saturation and raised noise level.
(3) It could dramatically change the character of the image, e.g., the average luminance (mean) of the image.

As a result of the above shortcomings, histogram equalization is rarely used in its original form. Variants of the HE method have been developed by researchers. In recent years, many improved, HE-based enhancement techniques are proposed, such as [1 – 8].

The recently proposed enhancement methods generally belong to two categories: the adaptive (or local) HE methods (AHE), such as [1,2,3], and the improved global methods based on histogram equalization or specification, such as [4 - 8]. The AHE methods use statistical information in the neighborhood of each pixel to perform equalization. In the global HE-based methods, various constraints are added to the equalization procedure to achieve better performance.

AHE methods can usually provide stronger enhancement effects than global methods. However, due to their high computational load, the AHE methods are usually unsuitable for real time video enhancement. Therefore, in our research, we focus more on the global techniques because of their speed. In this paper, we propose a fast global HE-based enhancement scheme. The proposed method provides sufficiently enhanced images with significantly less artifacts, and allows a convenient and effective control over the degree and effect of enhancement.

Section II reviews the traditional HE method and some recently proposed HE-based methods. In section III, we propose a weighted thresholded HE (WTHE) enhancement method and discuss its implementation for video enhancement. Section IV shows experimental results together with comparisons with some contemporary methods. Section V draws conclusions and gives discussions.

II. HE-BASED ENHANCEMENT METHODS

The traditional histogram equalization technique is described as follows:

For a given digital image *F(i, j)* with *N* pixels and a gray level range of [0, *L*-1], its probability density function (PDF) is approximately obtained by

$$P(k) = \frac{n_k}{N}, \qquad \text{for } k = 0, 1, ..., L\text{-}1 \tag{1}$$

where n_k is the number of times level *k* appears in the image.

The cumulative distribution function (CDF) of *F(i, j)* is then obtained by

$$C(k) = \sum_{m=0}^{k} P(m), \quad \text{for } k = 0, 1, ..., L-1 \tag{2}$$

Using the CDF obtained from (2), histogram equalization maps an input level *k* into an output level $\widetilde{k}$, i.e.,

$$\widetilde{k} = (L-1) \times C(k) \tag{3}$$

In the traditional HE described above, the (differential) increment of an output level $\widetilde{k}$ is

$$\Delta\widetilde{k} = (L-1) \cdot P(k) \tag{4}$$

That is to say, the increment at level $\widetilde{k}$ in the equalized PDF is proportional to the magnitude of the original PDF at the corresponding original level *k*. For practical images, where the intensity levels and PDF have discrete values, the traditional HE mapping often results in undesirable effects: over-enhancement for intensity levels with high probabilities and loss of contrast for levels with low probabilities. For an example, HE usually over-enhances the background of the image while causing level saturation (clipping) effects in small but visually important areas. Also, traditional HE often causes the average luminance (mean) of the image to be changed, resulting in undesirable changes in the character of the image.

To overcome the visual artifacts of the HE method and add more flexibility to it, many researchers proposed different improvement schemes.

The adaptive HE (AHE) methods use local image information to enhance the image. Reference [1] proposed an AHE method based on a "modified cumulation function", which provides two parameters, α and β, respectively. Those two parameters allow the user to control the degree and effect of enhancement. An AHE method based on partially overlapping blocks is proposed in [2]. This method requires less computation than the overlapping AHE methods and results in less blockiness than the non-overlapping methods. In [3], a fast propagation-based algorithm is proposed for obtaining the statistical information for image blocks. Histogram stretching is then performed based on non-overlapping blocks using such local statistics.

Reference [4] proposed a global HE-based enhancement method using bin underflow and bin overflow (BUBO). That is, the PDF of the image is thresholded using a lower threshold and an upper threshold. HE is then performed using the thresholded histogram. [5], [6] and [7] discussed the mean-shift problem in the traditional HE and proposed mean-preserving HE methods. In these methods, the histogram is segmented into two sections and equalization is performed separately for each section. The segmentation threshold used in [5] is the mean of the input image; in [6], the threshold is so calculated that the entropy of the enhanced image is maximized; in [7], the threshold is obtained based on the minimum mean brightness error (MMBE).

In some of the references mentioned above [2,3,4,5,8] application of the HE-based techniques in real time video enhancement is discussed, and implementation schemes that are suitable for fast processing are proposed.

The general idea adopted by the recently proposed HE-based methods is to modify the histogram before equalization is conducted. Such modifications reduce visual artifacts resulting from the traditional form of HE, and at the same time the ability to control the degree of the enhancement is added.

However, these methods still have disadvantages to overcome. The AHE methods are usually subject to high computational complexity and sometimes block-related artifacts. The global methods, on the other hand, are usually less effective and flexible than the adaptive methods. Although some of the new methods [1,4] do allow adjustment to the degree of enhancement, the linearity and adaptivity of the control mechanisms are still to be improved. In the next section, we propose a new enhancement method based on the modified global HE approach.

III. THE WTHE CONTRAST ENHANCEMENT SCHEME

In our proposed enhancement method, we perform HE based on a modified histogram. We replace the original PDF $P(k)$ in equation (4) by a weighted thresholded PDF $P_{wt}(k)$, yielding

$$\Delta\widetilde{k} = (L-1)\cdot P_{wt}(k) \qquad (5)$$

$P_{wt}(k)$ is obtained by applying a transformation function $\Omega(.)$ to $P(k)$, that is,

$$P_{wt}(k) = \Omega(P(k)) = \begin{cases} P_u & \text{if } P(k) > P_u \\ \left(\frac{P(k)-P_l}{P_u-P_l}\right)^r \times P_u & \text{if } P_l \le P(k) \le P_u \\ 0 & \text{if } P(k) < P_l \end{cases} \qquad (6)$$

The original PDF is clamped at an upper threshold P_u and a lower threshold P_l, and all values between the upper and lower thresholds are transformed using a normalized power law function with index r>0.

In our level-mapping scheme (5), the increment for each intensity level is decided by the transformed histogram. The index r of the power law function controls the level increment. For an example, with r<1, the power law function gives higher weights to the low probabilities in the PDF than the high probabilities. Therefore, with r<1, the less-probable levels are "protected" and level saturation is less likely to occur. Refer to Fig. 1 for an illustration. In the proposed WTHE method, r is the most important parameter through which the degree of enhancement is controlled.

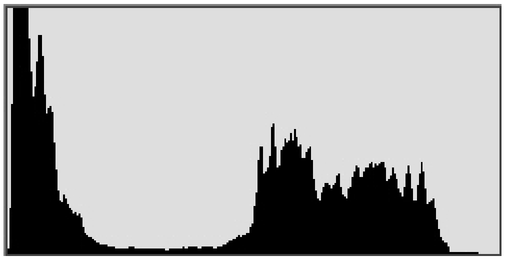
Besides the weighting mechanism described above, in equation (6), the PDF is also thresholded at an upper limit P_u. As a result, all levels with probabilities higher than P_u will have their increments clamped at a maximum value $\Delta_{\max} = (L-1)\cdot P_u$. This further avoids the dominance of the high-probability levels in the output dynamic range. In our algorithm, the value of P_u is decided by

$$P_u = v \cdot P_{\max}, \qquad 0 < v \le 1 \qquad (7)$$

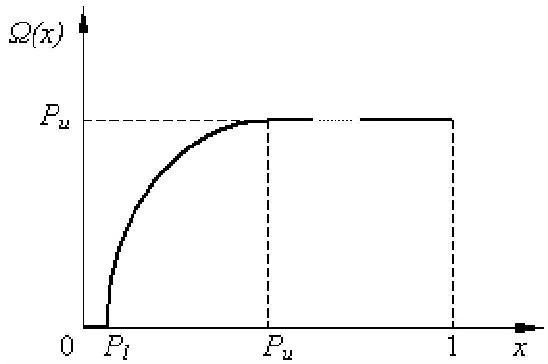
where P_{max} is the peak value (highest probability value) of the original PDF. The real number v defines the upper threshold normalized to P_{max}. For example, with v=0.5, the clamping point is set at 50% of the highest probability observed in the image. A lower value of v results in more high-probability levels being clamped, and thus less likelihood of their dominance in the output range.

The lower threshold P_l in equation (6), on the other hand, is only used to cut off levels with too low probability (and likely to have little visual importance) to better utilize the full dynamic range. In our algorithm, we do not use P_l as a parameter and set it at a very low fixed value (e.g., 0.03%).

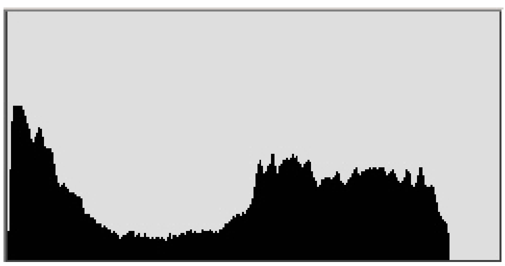
It can be seen from equation (6) that when r=1, P_u=1 and P_l=0 the proposed WTHE method reduces to the original HE. Some other global HE-base methods, such as the BUBO method [4], can also be considered special cases of the proposed WTHE method.



(a) Original Histogram



(b) Transformation function *Ω(x)* with r<1



(c) The weighted thresholded histogram

Fig. 1 Illustration of weighting and thresholding the histogram

In the proposed WTHE method, the power index r is the main parameter to control the enhancement effect. With r<1, more dynamic range is allocated to the less-probable levels, which often protects important visual details. When value of r gradually approaches 1, the effect of WTHE approaches that of the traditional HE. When r>1, higher weight is given to the high-probability levels, and WTHE yields stronger effect than the traditional HE. Although using r>1 is less common due to likelihood of over-enhancement, it is still useful when the majority levels need to be enhanced with extra strength.

Compared with [4], where the thresholds must be manually set, the proposed method uses a threshold that adapts to the highest probability of the image. Such a mechanism provides good adaptivity to different types of images and results in very consistent enhancement effect without manually adjusting the thresholds. Our experiments show that for a large variety of images the value of v can be kept constant whiling achieving satisfactory effect of enhancement.

After obtaining the weighted thresholded PDF $P_{wt}(k)$, the equalization process is similar to the traditional HE. The cumulative distribution function (CDF) is first obtained by

$$C_{wt}(k) = \sum_{m=0}^{k} P_{wt}(m), \quad \text{for } k = 0, 1, ..., L-1 \tag{7}$$

and the HE procedure is then performed as

$$\widetilde{F}(i, j) = W_{out} \times C_{wt}(F(i, j)) + M_{adj} \tag{8}$$

In (8), W_{out} is the dynamic range of the output image. M_{adj} is the mean adjustment factor that compensates for the mean change after enhancement. For a simple case, W_{out} is equal to the full range [0, L-1], and M_{adj}=0. Next we discuss how to control the values of W_{out} and M_{adj} in video enhancement.

For video enhancement, we apply the proposed WTHE method on the luminance (Y) component and leave the chrominance components unchanged. We introduce an enhancement gain control (EGC) mechanism that constrains the ratio between the output and input dynamic range, i.e.,

$$W_{out} = \min(L-1, G_{\max} \cdot W_{in}) \tag{9}$$

in which W_{in} is the dynamic range of the input image and G_{max} is a pre-set maximum gain of dynamic range. The EGC mechanism helps preserve sensation of the original content. It is especially useful for scenes that have narrow (e.g., night scenes) or gradually changing (such as fade-in and fade-out scenes) dynamic ranges. In our experiments, we usually set G_{max} in the range of 1.5 to 3.0.

In deciding the value of W_{out} for a frame, we employ a flywheel mechanism. The value of W_{out} used for enhancing the current frame is the weighted average of the current frame and the previous few frames. This mechanism avoids abrupt change of the output range, which often results in flickering.

M_{adj} in equation (8) is the mean adjustment quantity that reduces luminance change after enhancement. To decide the value of M_{adj}, we first calculate the mean of the enhanced image $\widetilde{F}(i, j)$, assuming M_{adj}=0 for equation (8), and then calculate the difference between the mean of the original and enhanced image. M_{adj} is set to a value closest to the above mean difference that does not cause serious level saturation.

IV. Experimental Results

We tested the proposed WTHE method on a variety of images and video sequences. Here we show some of the results. We also compare to other HE-based methods including BBHE [5], MMBEBHE [7] and BUBOHE [4].

In Fig.2, we show results from BBHE, MMBEBHE and the proposed WTHE with r=0.5 and v=0.5. The corresponding histograms are shown in Fig. 3. Fig. 4 shows a video frame and the enhancement results using BUBOHE [4] and WTHE. The corresponding histograms are shown in Fig. 5. Fig. 6 shows different enhancement effects resulting from the WTHE method by adjusting the parameters. In Fig. 6, the value of r is gradually increased while value of v is fixed at 0.5. Degree of enhancement increases correspondingly. In the middle right image where r=1.0, v is set to 1.0 to show that WTHE has the same effect as the traditional HE. The r>1 case is also shown in two images in Fig. 6.

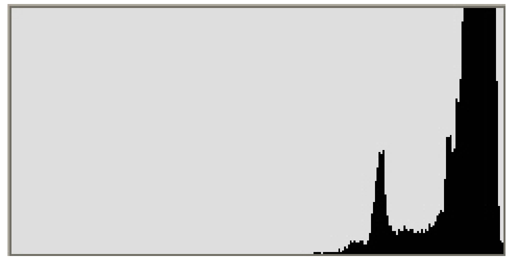
(a) Original “Arctic Hare”

(b) Enhanced by BBHE [5]

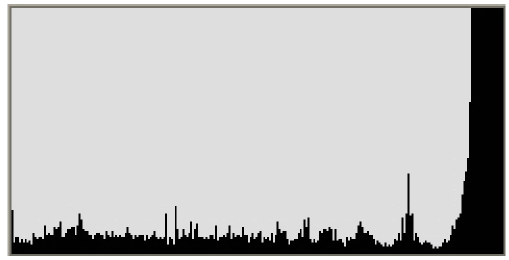
(c) Enhanced by MMBEBHE [7]

(d)WTHE with r=0.5, v=0.5

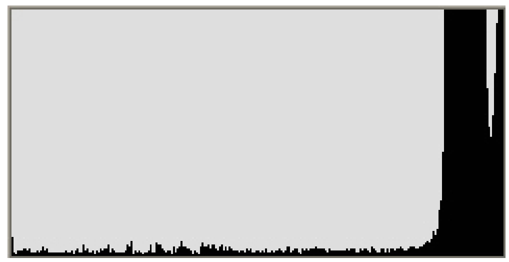
Fig. 2 Arctic Hare and enhancement results



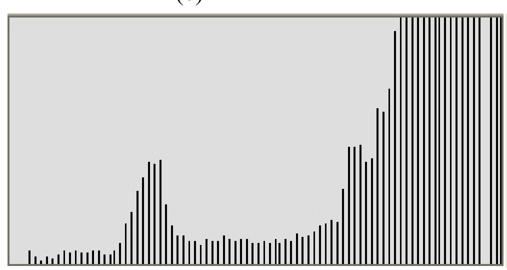
(a) Original



(b) BBHE



(c) MMBEBHE



(d) WTHE

Fig. 3 Histogram of images in Fig. 2

V. CONCLUSIONS

The experimental results show that the proposed WTHE is able to achieve visually pleasant enhancement effects. The over-enhancement and level saturation artifacts are effectively avoided. Compared with most of the other global HE-based enhancement methods, images enhanced using the proposed WTHE method have satisfactory contrast, while being natural and almost artifacts-free. Very importantly, controlling the effect of enhancement in WTHE is convenient and linear by mainly adjusting the power factor r.

The proposed WTHE method provides a good trade-off between two features, flexibility and ease of controlling, which are difficult for global enhancement methods to achieve at the same time. In practice, the proposed global WTHE method is computationally simple and suitable for processor-based implementation. We tested the proposed WTHE algorithm on an embedded real time video processing system and achieved satisfactory results.

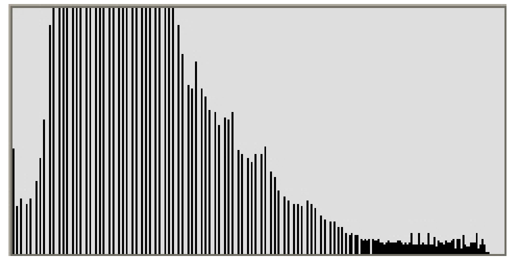
(a) Original video frame: Station Hall

(b)Enhanced by BUBO [4]

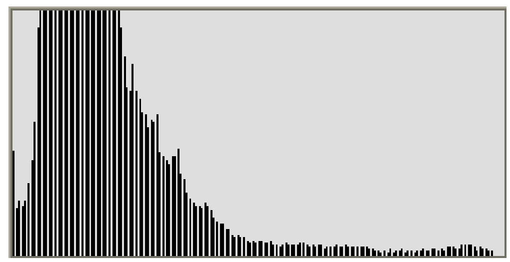
(c) Enhanced by WTHE with r=0.3, v=0.5.

Fig. 4. Enhancement of a video frame

(a)Original histogram



(b)BUBO [4]



(c) Proposed WTHE

Fig. 5 Histogram of images in Fig. 4. Intensity levels are more evenly distributed in Fig. 5(c). Notice the white saturation effect on the clock and screens in Fig. 4(b). Compare to Fig. 4(c). Those areas correspond to about 4% of the highest levels in the histogram.

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Original | r=0.1, v=0.5 | r=0.3, v=0.5

r=0.5, v=0.5 | r=0.8, v=0.5 | r=1.0, v=1.0

r=1.2, v=1.0 | r=1.5, v=1.0 | Traditional HE

Fig. 6. Different degrees of enhancement using WTHE

The image enhanced using r=1.0, v=1.0 (middle right image) is the same as enhanced by traditional HE (bottom right image). The first 2 image in the bottom row are enhanced using r>1 and v=1.0. Although they are over-enhanced overall, they show better contrast in certain areas (e.g., the bottom left corner) than other images.