Efficient Contrast Enhancement Using Adaptive Gamma Correction and Cumulative Intensity Distribution

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***Abstract*—This paper proposes an efficient histogram modification method for contrast enhancement, which plays a significant role in digital image processing, computer vision, and pattern recognition. We present an automatic transformation technique to improve the brightness of dimmed images based on the gamma correction and probability distribution of the luminance pixel. Experimental results show that the proposed method produces enhanced images of comparable or higher quality than previous state-of-the-art methods.**

***Index Terms*—Contrast enhancement, histogram modification, gamma correction, histogram equalization.**

I. Introduction

Contrast enhancement plays an important role in the improvement of visual quality for computer vision, pattern recognition, and the processing of digital images. Several conditions may lead to poor contrast in digital images, including lack of operator expertise and inadequacy of the image capture device. Unfavorable environmental conditions in the captured scene such as the presence of clouds, lack of sunlight or indoor lighting, and so on, may also lead to reduced contrast quality [1]. Essentially, if the overall luminance is insufficient, then the details of the image features will be obscured.

In general, the enhancement techniques for dimmed images can be broadly divided into two categories: direct enhancement methods [2]–[4] and indirect enhancement methods [5], [6]. For direct enhancement methods, the image contrast can be directly defined by a specific contrast term [2]–[4]. However, most of these contrast measures cannot simultaneously gauge contrast in both simple patterns and complex images [4].

Conversely, indirect enhancement methods attempt to enhance image contrast by redistributing the probability density [1]. In other words, the image intensities can be redistributed into the dynamic range without defining a specific contrast term [1]. According to [1], histogram modifications [7]–[12] are the most popular indirect enhancement techniques in regard to dimmed image enhancement due to their easy and fast implementation. Histogram modifications include such techniques as histogram equalization [7]–[11] and gamma correction [7], [12], among others.

The rest of this article is organized as follows. Section II presents our color contrast enhancement method. In Section III, the efficacy of our proposed method is supported through comparison of its experimental results to those obtained through existing methods. Finally, our concluding remarks are presented in Section IV.

II. Proposed scheme

In general, probability density function (PDF) and cumulative distribution function (CDF) can be used to enhance the pixel intensity, but the image brightness may be distorted according to the literatures [8]–[10]. On the other hand, traditional gamma correction method uses a constant power function with exponent γ for the image enhancement [7]. Inspired by the probability and statistical inference, we can determine the γ value based on PDF and CDF. Hence, the proposed gamma transformation can be defined as follows:

$$T(l) = 255 \left(\frac{l}{255}\right)^{1 - CDF(l)}, \quad (1)$$

where $l = l_{\min}, l_{\min}+1, l_{\min}+2, \ldots, l_{\max}$. Unfortunately, the CDF curve of the dimmed image experiences significant fluctuations due to environmental phenomena, according to previous research [8]–[10]. As a result, unfavorable artifacts may be generated by the equation (1).

To solve this problem, we use the weighting distribution function [11] to smooth the fluctuant phenomenon. The weighting distribution function can be expressed as follows:

$$PDF_w(l) = PDF_{max}\left(\frac{PDF(l) - PDF_{min}}{PDF_{max} - PDF_{min}}\right)^{\alpha}, \quad (2)$$

where $l = l_{\min}, l_{\min}+1, l_{\min}+2, \ldots, l_{\max}$, $PDF_w(l)$ represents the weighting probability density, PDF_{max} represents the maximum probability density, PDF_{min} represents the

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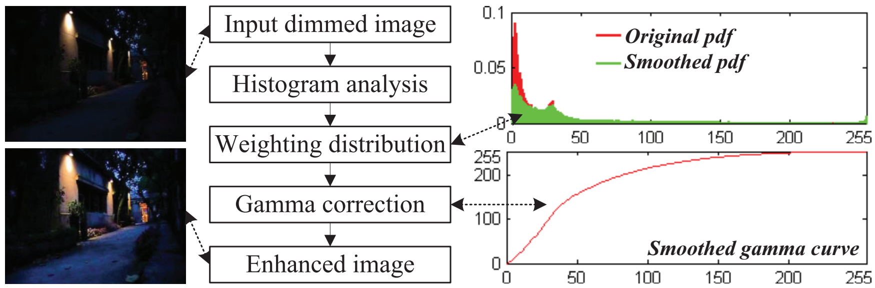

Fig. 1. The flowchart of the proposed image enhancement method.

minimum probability density, and α represents the adaptive parameter that can be experimentally set to 0.5. Using the PDF_w, the original CDF is smoothed and can be expressed as

$$CDF_s(l) = \sum_{h=0}^{l} \frac{PDF_w(h)}{\Sigma PDF_w}, \tag{3}$$

where $l = l_{\min}, l_{\min}+1, l_{\min}+2, \ldots, l_{\max}$, ΣPDF_w represents the sum of the weighting probabilities, and $CDF_s(l)$ represents the smoothed CDF. Finally, the equation (1) can be modified and expressed as

$$T(l) = 255 \left(\frac{l}{255}\right)^{1-CDF_s(l)}. \tag{4}$$

Figure 1 shows the flowchart of the proposed image enhancement method. For the input dimmed image, most of the pixels are densely distributed in the low-level region. Based on the weighting distribution function, the fluctuant phenomenon can be smoothed, thus reducing the over-enhancement of the gamma correction. Note that we are the first group to attain color image enhancement through combination of the CDF, the weighting distribution, and the gamma correction. As a result, it is easily observed that our method can enhance the color image with neither generation of additional artifacts nor distortion of color.

III. Results

This section presents the experimental results for the enhancement of dimmed images. In demonstration of the contribution of this paper, Traditional Histogram Equalization (THE) [7], Brightness Preserving Bi-Histogram Equalization (BBHE) [8], Dualistic Sub-Image Histogram Equalization (DSIHE) [9], Recursive Sub-Image Histogram Equalization (RSIHE) [10], Recursively Separated and Weighted Histogram Equalization (RSWHE) [11], Traditional Gamma Correction (TGC) [7], Dynamic Contrast Ratio Gamma Correction (DCRGC) [12], and the proposed (PRO) method were tested for a variety of natural color images. The test images were broadly obtained in both outdoor and indoor environments.

For outdoor environments, illumination changes may occur in the captured scene due to many factors including the gradual change in the location of the sun, or a sudden switch to dark or cloudy conditions. Conversely, illumination changes presented by indoor environments are relatively simple due to the low variation in lighting conditions. In both cases, the details and colors may not be readily discernable to the human eye.

Three outdoor color images were used in the experiments. The first sample color image, “Road” , is a low-contrast image that features many vehicles passing through a dark country road. The second sample color image, “Lake” , is a medium-contrast image and features people rowing a boat around a lake after sunset. The third sample color image, “Statue of Liberty”, is relatively dark and features a wide sky area around the Statue of Liberty. The sample color image, “Barrel” , is used to evaluate the indoor performance of each method; this low-light scene features three barrels on display in a showroom.

Figure 2 shows the sample color image, “Road” , and the enhancement results of the proposed method compared with other state-of-the-art methods. As indicated in the Fig. 2(b), 2(d) and 2(g), the enhancement results of HE, DSIHE, and DCRGC show serious block artifacts in the background. Of the remaining methods, the PRO method not only preserves the brightness level, but also gives natural contrast enhancement as shown in Fig. 2(h).

The simple color image, “Lake” , is shown in Fig. 3 and features people rowing boats around a dark lake. According to the Fig. 3(b)-(e), and (g), the luminance histogram of the enhancement results is only partially equalized by the HE, BBHE, DSIHE, RSIHE, and DCRGC method. On the other hand, both the RSWHE and PRO methods can stretch the dynamic range of the output luminance histogram over the entire range as shown in Fig. 3(f) and Fig. 3(h).

The luminance histogram of the enhancement results for the “Statue of Liberty” image is not equally stretched by the HE, BBHE, DSIHE, RSIHE, and DCRGC method, resulting in the occurrence of serious block artifacts in the sky area around the enhancement results. Conversely, the RSWHE method can preserve the original image trend without any distortion of features or color, as indicated by Fig. 4(f). Unfortunately, the luminance cannot be improved by the RSWHE method. As shown in Fig. 4(h), the PRO method provides the greatest natural enhancement of the sky without introduction of block artifacts.

The indoor color image, “Barrel” , and the results of its enhancement by each method are shown in Fig. 5. The dynamic range of the original luminance histogram is uniform over

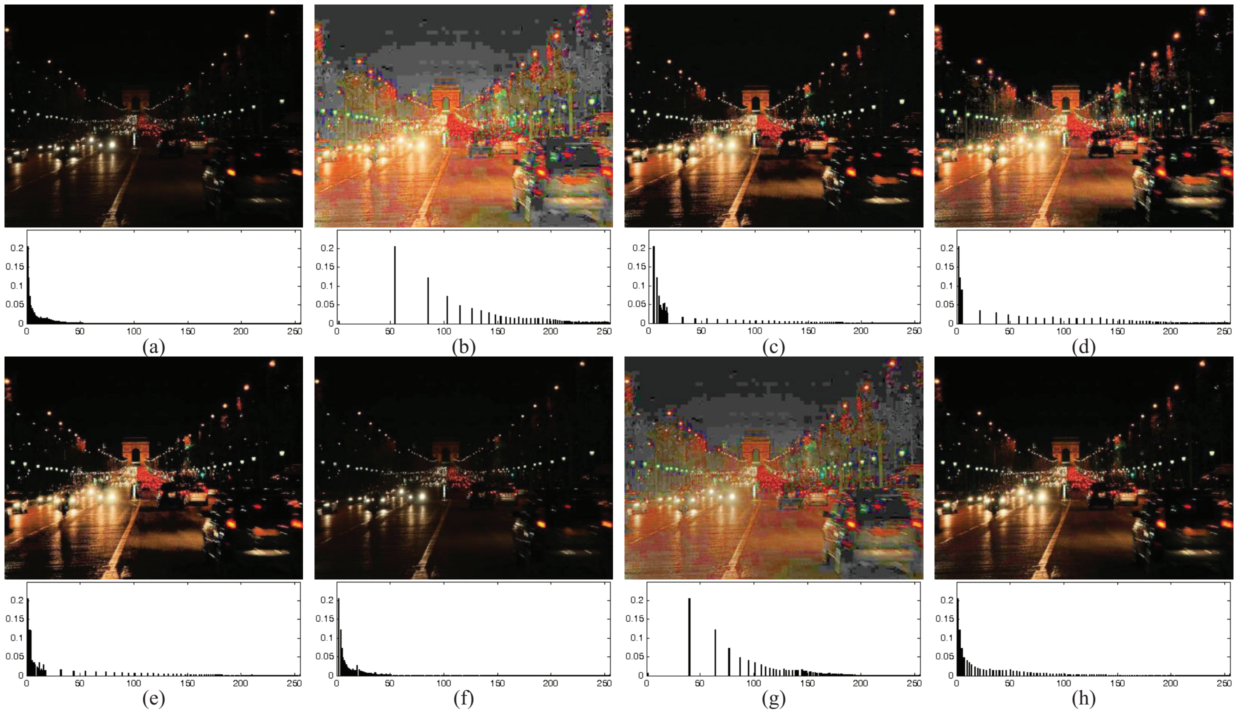

Fig. 2. Comparison of enhancement results with luminance histograms for the color image, "Road": (a) original image; (b) HE result; (c) BBHE result; (d) DSIHE result; (e) RSIHE result; (f) RSWHE result; (g) DCRGC result; (h) PRO result.

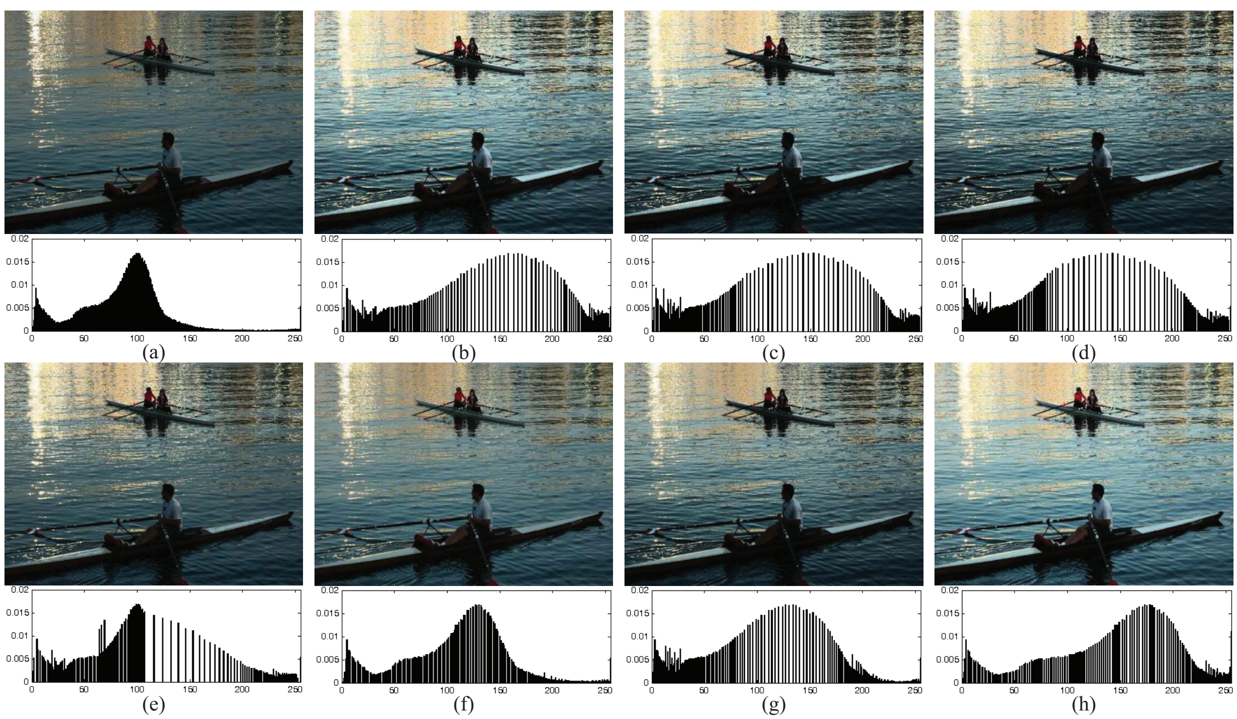

Fig. 3. Comparison of enhancement results with luminance histograms for the color image, "Lake": (a) original image; (b) HE result; (c) BBHE result; (d) DSIHE result; (e) RSIHE result; (f) RSWHE result; (g) DCRGC result; (h) PRO result.

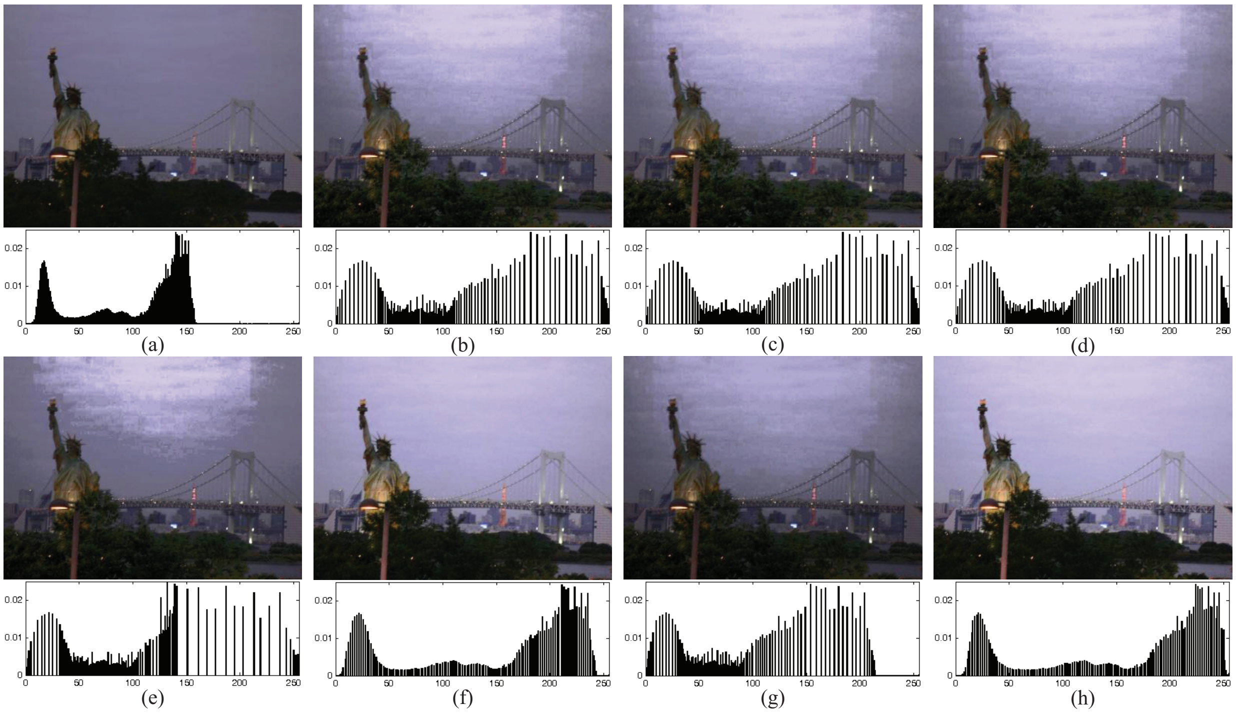

Fig. 4. Comparison of enhancement results with luminance histograms for the color image, "Statue of Liberty": (a) original image; (b) HE result; (c) BBHE result; (d) DSIHE result; (e) RSIHE result; (f) RSWHE result; (g) DCRGC result; (h) PRO result.

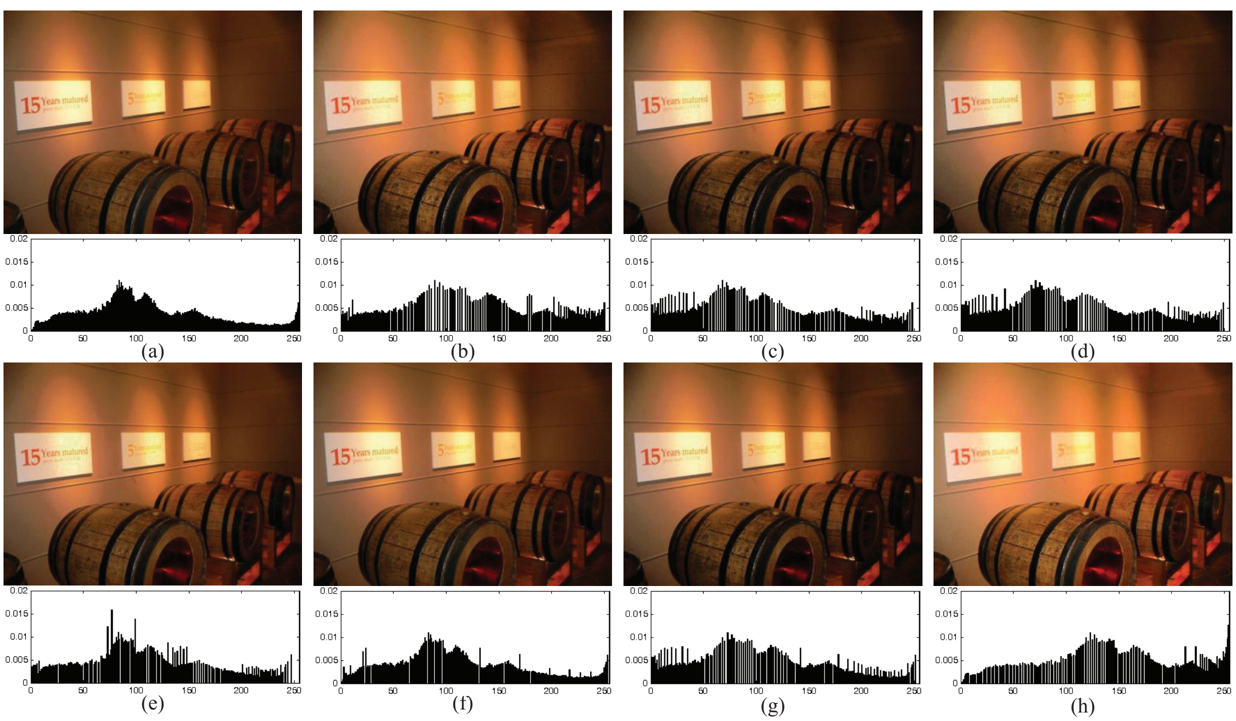

Fig. 5. Comparison of enhancement results with luminance histograms for the color image, "Barrel": (a) original image; (b) HE result; (c) BBHE result; (d) DSIHE result; (e) RSIHE result; (f) RSWHE result; (g) DCRGC result; (h) PRO result.

TABLE I
COMPARISON OF THE PSNR OF VARIOUS METHODS.

Test images	HE	BBHE	DSIHE	RSIHE	RSWHE	DCRGC	PRO
Blakeyed	23.73	24.37	24.59	22.50	35.28	23.21	**44.25**
Bobcat	16.05	26.17	26.31	24.90	28.02	20.76	**28.10**
Butterfish	24.04	24.61	23.85	20.70	31.94	23.73	**36.12**
Colomtn	25.68	22.13	22.12	21.32	26.84	26.83	**27.14**
London	17.57	17.80	17.90	18.81	21.04	23.25	**28.50**
Hsewoods	21.21	22.83	23.07	22.98	30.02	27.70	**30.70**

the entire range in this indoor scene. As shown in Fig. 5(h), the PRO method again enhances the contrast between the three barrels and background while other methods, shown in Fig. 5(b)-(g), cannot attain the proper balance between the image trend preservation and the image enhancement.

The quantitative evaluation of image enhancement is very difficult to measure. In general, the image enhancement quality can be assessed by the Absolute Mean Brightness Error (AMBE) [13], the Discrete Entropy (H) [3], and the Measure of Enhancement (EME) [14], which present an objective criterion for comparison. Unfortunately, previous researches concludes that these measurements cannot give meaningful results for every image [1], [15], [16].

However, quantitative evaluation is still important in addition to qualitative evaluation. Inspired by the measurement of the backlight-scaled TFT-LCD displays [17], we can measure the enhancement quality of backlight-scaled images based on the transmissive backlight estimation and Peak Signal-to-Noise Ratio (PSNR). Unlike the unsuitable measurement [11] that uses the PSNR to assess the enhancement quality between the dimmed input image and the enhanced image, the PSNR of enhanced backlight-scaled images is measured by the clear and bright (full backlight) images in this paper. The reason for its use is that PSNR measurement is used to estimate the similarity between the original image and the enhanced image. In other words, a higher similarity value of PSNR indicates that the enhanced image is more similar to the original image. Table I lists the quantitative PSNR values of each method for these color images, making it apparent that the PRO method obtains the highest PSNR values compared with other state-of-the-art methods.

IV. CONCLUSION

In this paper, we have presented a novel enhancement method composed of three major steps. First, the histogram analysis provides the spatial information of the single image based on probability and statistical inference. In the second step, the weighting distribution is used to smooth the fluctuant phenomenon to avoid generation of unfavorable artifacts. In the third and final step, gamma correction can automatically enhance the image contrast by using the smoothing curve. Experimental image enhancement results demonstrate that our proposed method performs well compared with other state-of-the-art methods.

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