Modified Clipped Histogram Equalization for Contrast Enhancement

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***Abstract*—Histogram equalization (HE) based methodologies are popular and effective ways to improve image contrast and visual quality, but standard HE is not directly applied on consumer electronics. This paper proposes a modified Clipped Histogram Equalization (CHE) for contrast enhancement based on the fundamental of histogram modification. It improves the visual quality by enhancing details both in dark and bright regions through automatically detecting the dynamic range of the image. Experimental results show that the proposed algorithm outperforms state-of-the-art HE based algorithms in improving contrast and giving a visually-pleasing result while avoiding over-enhancement and noise amplification. Its high efficiency makes the proposed method practical for applications on consumer electronic.**

Keywords-contrast enhancement; dynamic range; histogram equalization

I. INTRODUCTION

Histogram Equalization (HE) is an effective contrast enhancement method with low computational cost [1]. However, due to problems of brightness changing, washed-out details and over-enhancement, standard HE is not directly applied on consumer electronics. So, variations of it have been developed.

The first class of HE based techniques focuses on preserving the input brightness. They separate the input histogram into two or more sections before applying equalization or find the target histogram for histogram projection. Initially, brightness preserving bi-histogram equalization (BBHE) [2] and dualistic sub-image histogram equalization (DSIHE) [3] divide the input histogram into two parts based on the mean of gray values and the gray level with cumulative probability density equal to 0.5 respectively. Similarly, recursive mean-separate histogram equalization (RMSHE) [4] and recursive sub-image histogram equalization (RSIHE) [5] correspondingly propose to adopt the separations of BBHE and DSIHE recursively to allow scalable brightness preservation for consumer electronics. Brute iteration scheme is used by the minimum mean brightness error bi-histogram equalization (MMBEBHE) [6] to obtain a threshold of gray level which yields the minimum Absolute Mean Brightness Error (AMBE).

Another category of HE based algorithms locally deploy equalization on input image to effectively improve local contrast. Non-overlapped block histogram equalization (NOBHE) [1] divides input image into non-overlapped blocks and carries out the HE in each block. Block overlapped histogram equalization (BOHE) [1] uses overlapped blocks by sliding the window one pixel at one time. Partially overlapped sub-block histogram equalization (POSHE) [7] is proposed as a tradeoff between NOBHE and BOHE. Although those methods can improve the local contrast, they usually result in over-enhancement to the output image and the researchers do not evaluate their performance on color image.

And the third class of HE based techniques are proposed motivated by histogram modification. It includes contrast limited adaptive histogram equalization (CLAHE) [8], histogram equalization with bin underflow and bin overflow (BUBOHE) [9], weighted and thresholded histogram equalization (WTHE) [10], gain-controllable clipped histogram equalization (GC-CHE) [11], and Bi-histogram equalization with a plateau level (BHEPL) [12]. Manipulation on histogram changes the density function which determines the final dynamic distribution, and thus can improve the contrast locating on specified dynamic range. On the other hand, they can control the amplification of noise and the enhancement rate by sacrificing the amount of contrast. Among those methods, CLAHE also processes image locally and result in images containing unnatural artefacts. The later three methods modify the input histogram with preset parameters. BHEPL requires no user input, but it eliminates the important redistribution process to simplify computation.

In this paper, a modified Clipped Histogram Equalization (CHE) for contrast enhancement is proposed. It is able to effectively enhance the contrast while avoiding over-enhancement and noise amplification. It is also proved to be effective for both grayscale and color images from different scenes. And its high efficiency makes it practical to be implemented on consumer electronics.

This paper is organized as follows. Section II introduces fundamental for histogram modification. Section III presents the proposed modified CHE. Section IV describes the experimental results. And conclusion is given in Section V.

II. FUNDAMENTAL FOR HISTOGRAM MODIFICATION

For intensity x of a given image X with dynamic range $[X_0,X_{L-1}]$, the probability density function $p(x)$ is defined as:

$$p(x)=\frac{n_x}{N}, \quad for\ x=0,1,...,L-1 \tag{1}$$

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where n_x is the number of occurrence of intensity x in the image, N is the total number of pixels in the image.

Then, the cumulative density function, $c(x)$, and the final transformation function, $f(x)$, are defined by (2) and (3).

$$c(x) = \sum_{k=0}^{x} p(k) \quad (2)$$

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

Then, the output image $Y=\{Y(i,j)\}$ can be expressed as:

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

The relationship can be obtained between $c(x)$ and $p(x)$ is:

$$\frac{d}{dx} c(x) = p(x) \quad (5)$$

It indicates that, by modifying the value of $p(x)$, the shape of $c(x)$ is controlled and the enhancement rate can be limited. This is the fundamental for histogram modification based algorithms introduced in Section I.

III. Modified Clipped Histogram Equalization

Compared with other histogram modification based algorithms, the first improvement of the proposed method is that the clipping threshold is determined by dynamic range distribution of the input image. The second one is that the clipped part is redistributed to only the dark and bright regions being inversely proportional to their respectively occupied dynamic range.

For the dark and bright regions, the one occupying narrow dynamic range in the input is assumed to have high histogram bins which means there is more details to be enhanced, and the one occupying wide dynamic range is assumed to have much low histogram bins indicating more noise are there to be suppressed. As an example in Fig.2, the dark region occupied narrow dynamic range compared to the bright region, so it is going to be enhanced more for revealing hidden details, and the bright region to be less enhanced in case of amplifying noise.

The whole procedure of the proposed modified CHE is illustrated in Fig.2 (a)-(d). Firstly, given the histogram of the input image, $h(k)$, its maximum, h_{max}, is found. And the bounders of dark and bright regions respectively are detected using the probability function, $p(x)$, as defined in (6) and (7).

$$gd = \left\{ x \mid \sum_{x=0}^{L-1} p(x) = T \right\} \quad (6)$$

$$gb = \left\{ x \mid \sum_{x=0}^{L-1} p(x) = 1 - T \right\} \quad (7)$$

where, T determines the amount of details expected to be enhanced for dark and bright regions.

Dynamic range of middle tone region dr is defined by (8).

$$dr = gb - gd \quad (8)$$

Combining with h_{max}, the clipping threshold Tc is:

$$T_c = \frac{dr}{(X_{L-1} - X_0)} h_{\max} \quad (9)$$

As Fig.2(c) shows, the clipped histogram $h_c(x)$ is obtained using (10).

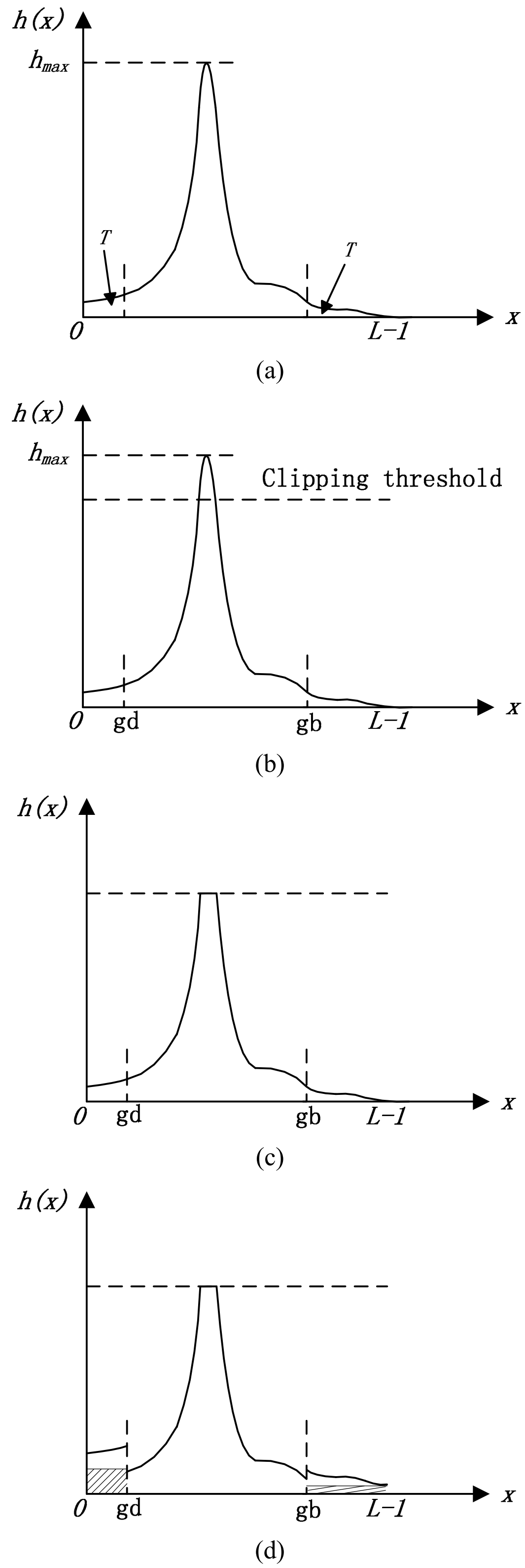


Figure 1. The procedure of the proposed modified CHE.

$$h_c(x) = \begin{cases} T_c, & h(x) \geq T_c \\ h(x), & others \end{cases} \tag{10}$$

The total excessive part, *totalE*, is then accumulated as (11).

$$totalE = \sum_{x=X_0}^{x=X_{L-1}} \left(\max\left(h(x) - T_c, 0 \right) \right) \tag{11}$$

As shown in Fig.2 (d), being inversely proportional to the respectively occupied dynamic range detected by (6) and (7), the *totalE* is divided into two parts for dark and bright regions as defined in (12) and (13).

$$\frac{totalE_d}{totalE_b} = \frac{(X_{L-1} - X_0) - gb}{gd - X_0} \tag{12}$$

$$totalE_d + totalE_b = totalE \tag{13}$$

Then, for redistribution, the final histogram, $h_{final}(x)$, is expressed in (14).

$$h_{final}(x) = \begin{cases} h_c(x) + avgBIncr_d, & x < gd \\ h_c(x), & others \\ h_c(x) + avgBIncr_b, & x > gb \end{cases} \tag{14}$$

where:

$$avgBIncr_d = totalE_d / (gd - X_0) \tag{15}$$

$$avgBIncr_b = totalE_b / \left(X_{L-1} - X_0 - gb \right) \tag{16}$$

Ultimately, the standard HE is applied to map the input into the entire dynamic range, $[X_0, X_{L-1}]$.

IV. Experimental Results

This section performs experiments to demonstrate the performance of the proposed algorithm and also compares the results with those generated by four other algorithms.

First, parameters evaluation is taken on a grayscale image to illustrate the performance of different input parameters. Then, two grayscale and two color images of different scenes are chosen for performance and efficiency comparisons.

A. Parameters Evaluation

From above description, there is a parameter T that determines the clipping threshold. By setting T, the enhancement rate for the output image is controlled. As an extremely case, $T=0.5$ will make the clipping threshold $Tc \approx 0$ and give a modified histogram with most bins having nearly the same height, it will result in an output without dynamic range adjustment. And $T=0$ will result in an output image with the similar dynamic range adjustment by standard HE.

As Fig. 2 shows, grayscale image of "Tank" with resolution of 512×512 pixels is used to evaluate the effects of parameter T. Compare (b), (c), (d) and (e), it can be told that too large T ($T=0.45$) will result in an output image without enhancement as the transformation function indicates shown in Fig. 2(e). A suitable value of T ($T=0.05$ *or* 0.10) is able to reveal details both in dark and bright regions while avoiding over-enhancement and noise amplification at the same time. $T=0.10$ is used as default value to deploy the proposed method on gray and color images with different resolutions under different scenes as shown in the following subsection.

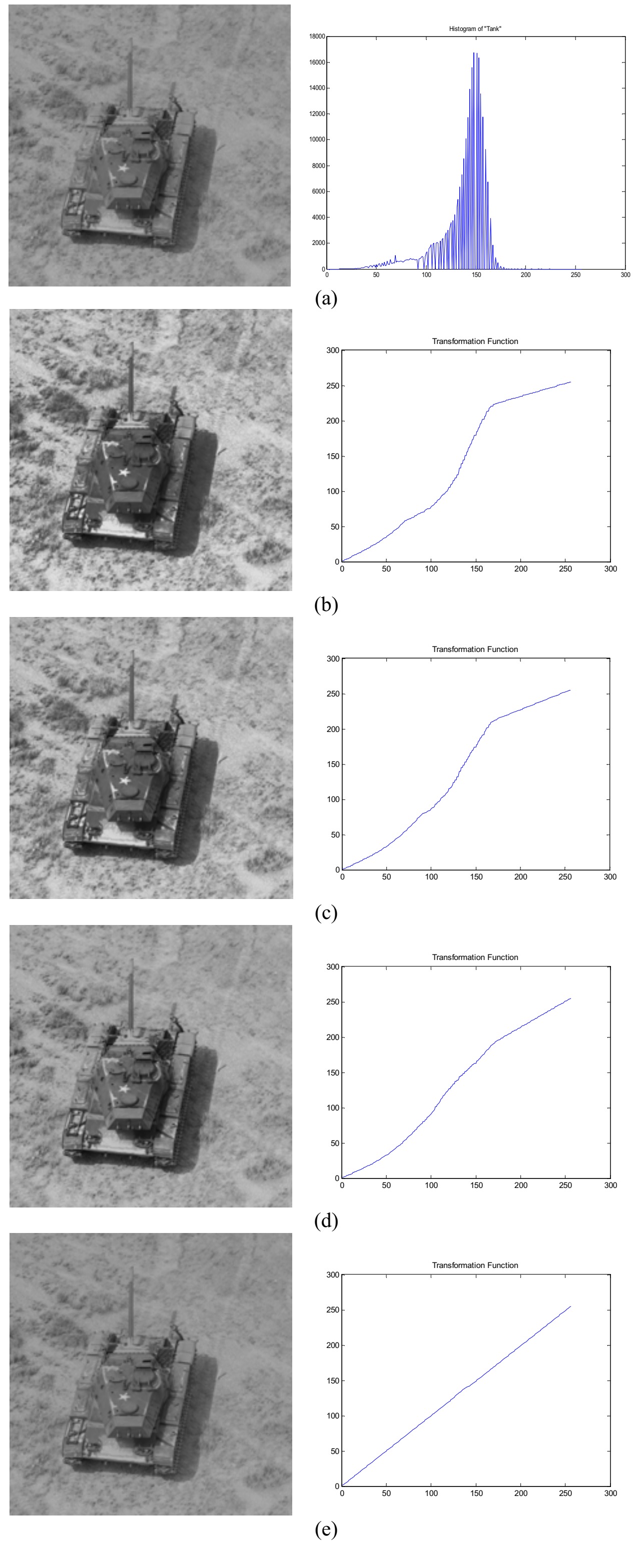


Figure 2. Performance evaluation of the proposed method. (a) Input image and histogram and (b)-(e) results and transformation function produced by different settings of T. (b): T=0.05, (c): T=0.10, (d): T=0.20, (e): T=0.45.

B. Comparative Analysis

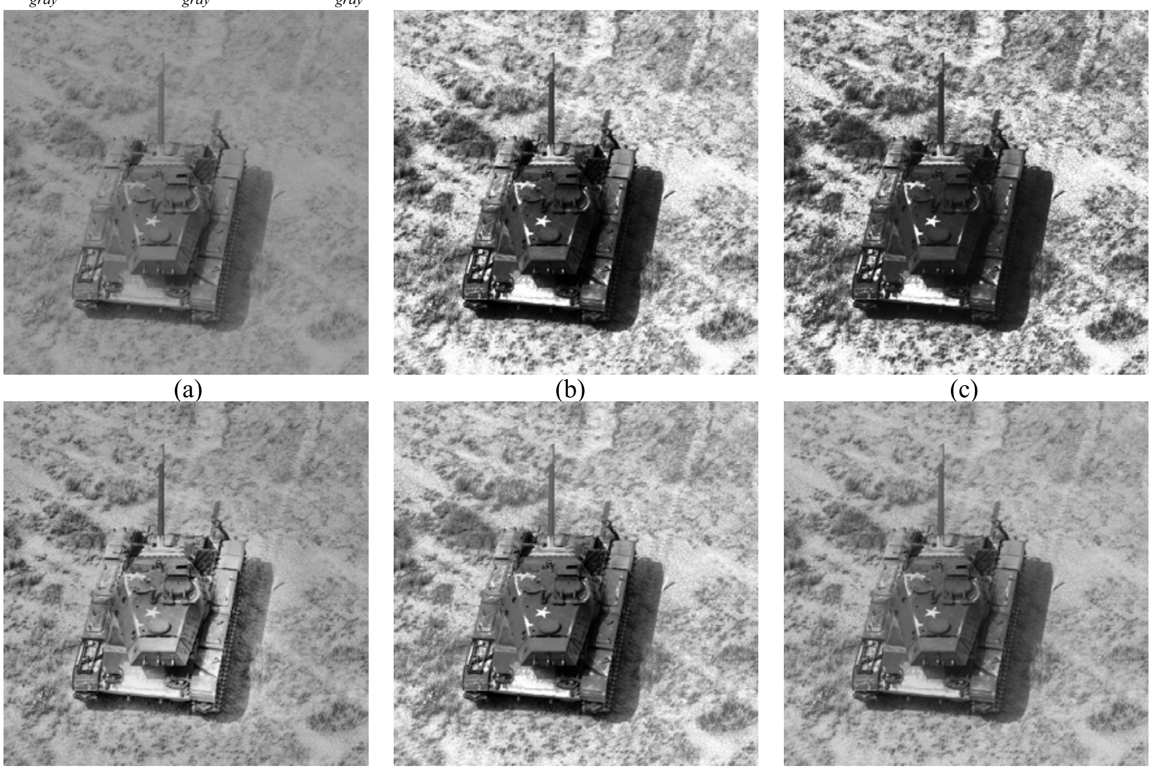
Performance comparisons are carried on both gray and color images between BBHE, MMBEBHE, CLAHE, BHEPL and the proposed method. CLAHE is optimized and integrated into the MATLAB toolbox as *adapthisteq* [13]. In Fig.3 and Fig.4, "Tank" and "Airport" are grayscale images of 512×512 and 1024×1024 pixels respectively. In Fig.5 and Fig.6, "Garage" and "Office" are color images of 800×524 and 903×600 pixels respectively. All methods mentioned in this section are deployed for color images with the same scheme of color conversions defined in (17) and (18).

$$I_{gray} = 0.2989 I_r + 0.5870 I_g + 0.1140 I_b \tag{17}$$

$$O_r = \frac{O_{gray}}{I_{gray}} I_r,\ O_g = \frac{O_{gray}}{I_{gray}} I_g,\ O_b = \frac{O_{gray}}{I_{gray}} I_b \tag{18}$$

where I and O indicate input and output images with subscripts r, g, b and *gray* representing their red, green, blue and luminance components correspondingly.

As shown in Fig.3-4, CLAHE can improve local contrast in both dark and bright regions, but the results are unnatural because of over-enhancement. Absolutely, BBHE and MMBEBHE do not have the ability of revealing details hidden in dark and bright region. BHEPL functions better than BBHE and MMBEBHE. However, the proposed method is effective to enhance contrast and details in both dark and bright regions under different scenes and it also avoids the problems of over-enhancement and noise amplification as the natural look of its output images indicate.



(a) (b) (c)

(d) (e) (f)

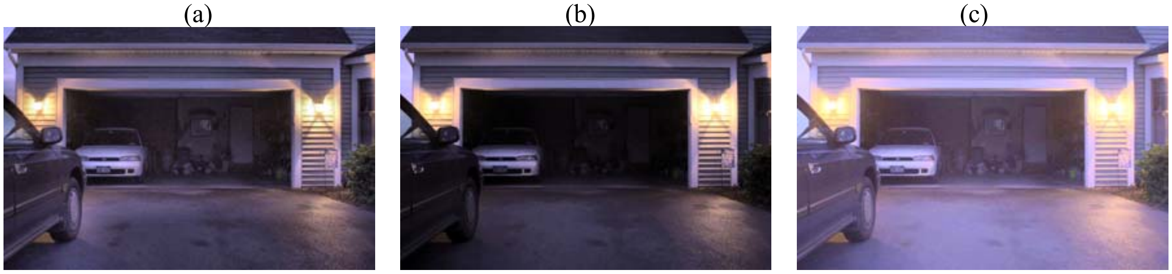
Figure 3. (a): input image of "Tank". (b)-(f): Results by BBHE, MMBEBHE, CLAHE, BHEPL and the proposed method respectively.

(a) (b) (c)

(d) (e) (f)

Figure 4. (a): input image of “Airport”. (b)-(f): Results by BBHE, MMBEBHE, CLAHE, BHEPL and the proposed method respectively.

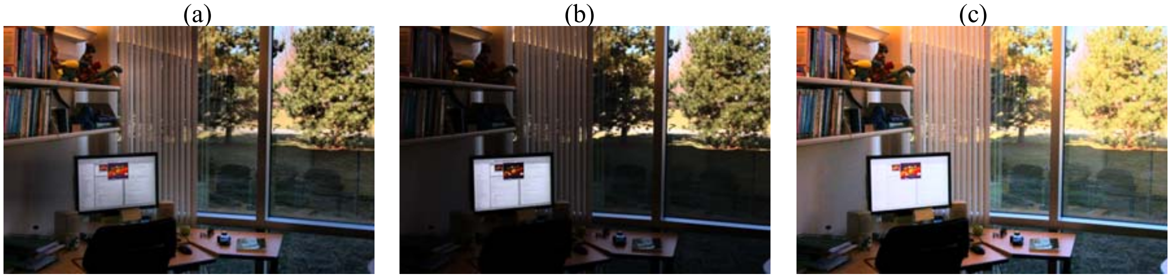
(a) (b) (c)



(d) (e) (f)

Figure 5. (a): input image of “Garage”. (b)-(f): Results by BBHE, MMBEBHE, CLAHE, BHEPL and the proposed method respectively.

(a) (b) (c)



(d) (e) (f)

Figure 6. (a): input image of “Office”. (b)-(f): Results by BBHE, MMBEBHE, CLAHE, BHEPL and the proposed method respectively.

C. Time Consumption

Table I shows the execution time consumed by the four comparative methods and the proposed algorithm for the four sample images with MATLAB environment on a PC with Intel Quad 2.50GHz CPU and 2GB memory. It shows the efficiency of the proposed modified CHE is the highest compared with all the other techniques. Even with high resolution images, the execution time of the proposed method is less than that of CLAHE from the MATLAB toolbox. Thus it is possible for the proposed method to be optimized and implemented for real-time applications on consumer electronics.

TABLE I. EXECUTION TIME

Sample Images	Execution Time (s)				
	BBHE	***MMBEBHE***	***CLAHE***	***BHEPL***	***The proposed method***
Tank	0.153	0.151	0.146	0.148	**0.097**
Airport	2.259	2.378	0.188	2.295	**0.151**
Garage	0.396	0.383	0.097	0.839	**0.030**
Office	0.703	0.658	0.118	0.634	**0. 041**

V. CONCLUSION

In this paper, a modified CHE for enhancing image contrast is presented. It is able to reveal the details in both dark and bright regions while avoiding the problems of over-enhancement and noise amplification. Although parameter is required, default setting provides acceptable performance. Experimental results showed that the proposed method is effective for both grayscale and color images and its efficiency is the highest compared with other techniques including the CLAHE which is a high efficient enhancement algorithm from the MATLAB toolbox. Thus it is possible that the proposed method can be optimized and implemented for real-time applications on consumer electronics.

REFERENCES

[1] R. C. Gonzalez, and R. E., Woods, Digital Image Processing, 2nd ed., Prentice Hall, 2002.

[2] Y. T. Kim, “Contrast enhancement using brightness preserving bi-histogram equalization”, IEEE Trans. Consumer Electronics, vol. 43, no. 1, pp. 1-8, Feb. 1997.

[3] Y. Wan, Q. Chen, and B. M. Zhang, “Image enhancement based on equal area dualistic sub-image histogram equalization method”, IEEE Trans. Consumer Electronics, vol. 45, no. 1, pp.68-75, Feb. 1999.

[4] S. D. Chen, and A. R. Ramli, “Contrast enhancement using recursive mean-separate histogram equalization for scalable brightness preservation”, IEEE Trans. Consumer Electronics, vol. 49, no. 4, pp. 1301-1309, Nov. 2003.

[5] K. S. Sim, C. P. Tso, and Y. Y. Tan, “Recursive sub-image histogram equalization applied to gray-scale images”, Pattern Recognition Letters, vol. 28, pp. 1209-1221, July 2007.

[6] S. D. Chen, and A. R. Ramli, “Minimum mean brightness error bi-histogram equalization in contrast enhancement”, IEEE Trans. Consumer Electronics, vol. 49, no. 4, pp. 1310-1319, Nov. 2003.

[7] Kim Joung-Youn, Kim Lee-Sup, Hwang Seung-Ho. An advanced contrast enhancement using partially overlapped sub-block histogram equalization. IEEE Trans Circuits Syst Video Technol 2001;11(4):475–84.

[8] Stephen M. Pizer, E. Philip Amburn, John D. Austin, Robert Cromartie, Ari Geselowitz, Trey Greer, Bart ter Haar Romeny, John B. Zimmerman, Karel Zuiderveld, Adaptive histogram equalization and its variations, Computer Vision, Graphics, and Image Processing, Volume 39, Issue 3, September 1987, Pages 355-368.

[9] Seungjoon Yang, Jae Hwan Oh, and Yungfun Park, “Contrast enhancement using histogram equalization with bin underflow and bin overflow”, In Image Processing, 2003. ICIP 2003. Proceedings. 2003 International Conference on, vol. 1, pp. 881-884, September 2003.

[10] Qing Wang, and Rabab K. Ward, “Fast image/video contrast enhancement based on weighted thresholded histogram equalization”, IEEE Trans. Consumer Electronics, vol. 53, no. 2, pp. 757-764, May 2007.

[11] T. Kim, and J. Paik, “Adaptive contrast enhancement using gain-controllable clipped histogram equalization”, IEEE Trans. Consumer Electronics, vol. 54, no. 4, pp. 1803-1810, Nov. 2008.

[12] C. H. Ooi, N. S. P. Kong, and H. Ibrahim, “Bi-histogram with a plateau limit for digital image enhancement”, IEEE Trans. Consumer Electronics, vol. 55, no. 4, pp. 2072-2080, Nov. 2009.

[13] http://www.mathworks.cn/help/toolbox/images/ref/adapthisteq.html.