Quadrants Histogram Equalization with a Clipping Limit for Image Enhancement

Zhijun Yao[1] Quan Zhou[2] Xiaofei Yang[1] Chunhua Yang[1] Zhongyuan Lai*[3]

1. The 723 Institute of China Shipbuilding Industry Corporation Yangzhou, China

2. Key Lab of Ministry of Education for Broad Band Communication & Sensor Network Technology, Nanjing University of Posts & Telecommunication Nanjing, China

3. Institute for Interdisciplinary Research Jianghan University Wuhan, China

Abstract—**The paper proposes a novel image enhancement method based on histogram equalization called Quadrants Histogram Equalization with a Clipping Limit (QHECL). The proposed method consists of four steps: (i) The first step is to compute the median value of the input image, which is used to divide the input histogram into two sub histograms. (ii) We calculate the average brightness value of each sub histogram and use the average brightness value to segment each sub histogram respectively. Thus, we can get four sub histograms. (iii) The average of the occupied intensity is computed and viewed as a plateau limit to clip each sub histogram. (iv) Four sub images are enhanced by the tranditional histogram equalization method independently and then are merged into one output ehanced image. The experimental results show that QHECL is better than other contrast enhancement methods according to image subjective evaluation and various image objective evalution measures, i.e. average information content (Entropy), PSNR, absolute mean brightness error (AMBE).**

Keywords: Histogram clipping;Histogram equalization; Image objective evalution measure;Brightness preserving

I. INTRODUCTION

Image enhancement is always a research hotspot of digital image processing technology. Its goal is to reduce noise and improve image contrast while maintaining the image brightness and local details as much as possible. And image enhancement technology has been extensively utilized in various applications, for example, underwater image quality improvement, medical image processing and analysis, digital photography, remote sensing, scientific visualization, and so on. Image enhancement method can be divided into two categories: transform domain enhancement method and spatial domain enhancement method. Histogram Equalization (HE) is one of spatial domain enhancement method and extensively utilized because of its simplicity, ease of implementation and effectiveness [1]. The main idea of HE is to uniformly redistribute the pixel values of the input image, so as to extend the dynamic intensity range and enhance the image contrast. However, the direct use of HE may result in large difference between the mean brightness of the original image and that of the enhanced one. Moreover, it may lead to over enhancement and produce artifacts and edge effect.

To preserve the image brightness, a lot of HE-based image enhancement approaches have been presented in recent years. These methods divide the input original histogram into two sub histograms and equalize them individually. The representative methods include BBHE [2], DSIHE [3], RMSHE [4], RSIHE [5]. These methods can well preserve the image brightness, but cannot always obtain maximum contrast and may lead to over enhancement and detail loss.

Considerable progresses have also been made on the HE-based image contrast enhancement recently. These methods use histogram clipping technique to control over enhancement. The representative methods include BHEPL [7], ESIHE [8] and MMSICHE [9]. BHEPL computes the average of gray level occurrence for each sub image as plateau limit to clip each sub histogram respectively. Like BHEPL, ESIHE uses the average of gray level occurrences to clip histogram too. The difference between BHEPL and ESIHE is the use of different segmentation methods. BHEPL uses the average brightness and ESIHE uses exposure threshold. For MMSICHE, the median of the occupied intensity is set as clipping threshold to clip histogram.

In this paper, we propose a novel method, namely Histogram Equalization with a Clipping Limit (QHECL), on the basis of the above methods. First, we calculate the median of the input image, and divide the input original histogram into two sub histograms in term of this median. Second, the mean intensity value of each sub histogram is computed and viewed as a segmentation threshold to further divide sub histogram into two small sub histograms respectively. Third, clipping process of each sub histogram is implemented respectively. For each sub histogram, the average of intensity occurrences is set as clipping threshold. Finally, we equalize each sub image, and merge them into a complete image. Our method takes the advantages of the histogram division and histogram clipping, and can perform well in both contrast enhancement and brightness keeping. Moreover, the local details are well

* Corresponding author

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preserved after enhancement, which makes the output images look natural.

II. THE PROPOSED METHOD

In this section, we will describe in detail the propsed QHECL method. QHECL consists of four steps, namely Median Calculation and Histogram Divsion, Mean Calculation and Sub Histogram Division, Sub Histogram Clipping and Sub Histogram Equalization. The following subsections will present these four steps.

A. Median Calculation and Histogram Divison

Assume that the gray value range of the input image **I** is [0, L-1], where L is the number of gray scale. Thus, the probability density function (PDF) of the input image, $\mathbf{h}_i(k)$, can be defined as:

$$\mathbf{h}(k)=\frac{\mathbf{H}(k)}{N} \tag{1}$$

where $\mathbf{H}(k)$ is the total number of pixels whose gray value equals to k, and $N=\sum_{k=1}^{L-1}\mathbf{H}(k)$.

The median value of the input image is denoted as an gray level I_d where the cumulative density function equals to 0.5 [3]. For calculating I_d, consider a variable **z** shown in (2):

$$\mathbf{z}(k)=\mathbf{z}(k-1)+\mathbf{h}(k) \quad \text{for} \quad k=0,1,\ldots,L-1 \quad \text{and } \mathbf{z}(0)=\mathbf{h}(0) \tag{2}$$

The median value I_d is computed as (3) by (1) and (2)

$$I_d=\arg\min_k\left|\mathbf{z}(k)-0.5\right| \tag{3}$$

Then, we use the median I_d to segment the input histogram into two sub histograms $\mathbf{h}_L$ and $\mathbf{h}_U$ as given in (4) and (5).

$$\mathbf{h}_L(k)=\mathbf{h}(k), k=0,1,\ldots,I_e \tag{4}$$

$$\mathbf{h}_U(k)=\mathbf{h}(k), k=I_e+1,\ldots,L-1 \tag{5}$$

B. Mean Calculation and Sub Histogram Divison

The two mean intensity values of two sub histograms $\mathbf{h}_L$ and $\mathbf{h}_U$ are denoted as I_{ml} and I_{mu} respectively. Eqs. (6) and (7) expresses the calculation of mean variables I_{ml} and I_{mu}

$$I_{ml}=\frac{\sum_{k=0}^{I_e}\mathbf{h}_L(k)\times k}{\sum_{k=0}^{I_e}\mathbf{h}_L(k)} \tag{6}$$

$$I_{mu}=\frac{\sum_{k=I_e+1}^{L-1}\mathbf{h}_U(k)\times k}{\sum_{k=I_e+1}^{L-1}\mathbf{h}_U(k)} \tag{7}$$

Based on three separation thresholds I_d, I_{ml} and I_{mu}, the input histogram was segmented into four sub histograms $\mathbf{h}_{LL}$, $\mathbf{h}_{LU}$, $\mathbf{h}_{UL}$ and $\mathbf{h}_{UU}$ as given in (8) - (11). The segmentation is graphically illustrated in Figure 1.

$$\mathbf{h}_{LL}(k)=\mathbf{h}(k), k=0,1,\ldots,I_{ml} \tag{8}$$

$$\mathbf{h}_{LU}(k)=\mathbf{h}(k), k=I_{ml}+1,\ldots,I_d \tag{9}$$

$$\mathbf{h}_{UL}(k)=\mathbf{h}(k), k=I_d+1,\ldots,I_{mu} \tag{10}$$

$$\mathbf{h}_{UU}(k)=\mathbf{h}(k), k=I_{mu}+1,\ldots,L-1 \tag{11}$$

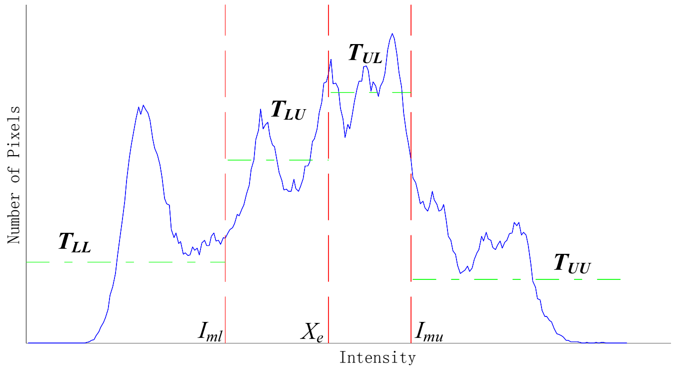


Figure 1. Histogram segmentation and clipping process

C. Sub Histogram Clipping

In order to control over enhancement and obtain natural appearance, we use histogram clipping technique to modify all sub histograms, similar to [8]. In this paper, we compute the avergage of occurrences of each gray level for each sub histogram respectively, which is view as the clipping threshold. These clipping thresholds of four sub histograms are denoted as T_{LL}, T_{LU}, T_{UL} and T_{UU} respectively. These four clipping threshold values are set automatically by using (12) - (15).

$$T_{LL}=\frac{1}{I_{ml}+1}\sum_{k=0}^{I_{ml}}\mathbf{h}_{LL}(k) \tag{12}$$

$$T_{LU}=\frac{1}{I_d-I_{ml}}\sum_{k=I_{ml}+1}^{I_d}\mathbf{h}_{LU}(k) \tag{13}$$

$$T_{UL}=\frac{1}{I_{mu}-I_d}\sum_{k=I_d+1}^{I_{mu}}\mathbf{h}_{UL}(k) \tag{14}$$

$$T_{UU}=\frac{1}{L-1-I_{mu}}\sum_{k=I_{mu}+1}^{L-1}\mathbf{h}_{UU}(k) \tag{15}$$

Then, we use above four clipping thresholds to clip four sub histograms $\mathbf{h}_{LL}$, $\mathbf{h}_{LU}$, $\mathbf{h}_{UL}$ and $\mathbf{h}_{UU}$ respectively by four expressions as follows.

$$\mathbf{h}_{LL}^c(k)=\begin{cases}\mathbf{h}_{LL}(k) & \text{if } \mathbf{h}_{LL}(k)\le T_{LL}\\ T_{LL} & \text{elsewhere}\end{cases} \tag{16}$$

$$\mathbf{h}_{LU}^c(k)=\begin{cases}\mathbf{h}_{LU}(k) & \text{if } \mathbf{h}_{LU}(k)\le T_{LU}\\ T_{LU} & \text{elsewhere}\end{cases} \tag{17}$$

$$\mathbf{h}_{UL}^c(k)=\begin{cases}\mathbf{h}_{UL}(k) & \text{if } \mathbf{h}_{UL}(k)\le T_{UL}\\ T_{UL} & \text{elsewhere}\end{cases} \tag{18}$$

$$\mathbf{h}_{UU}^c(k)=\begin{cases}\mathbf{h}_{UU}(k) & \text{if } \mathbf{h}_{UU}(k)\le T_{UU}\\ T_{UU} & \text{elsewhere}\end{cases} \tag{19}$$

Figure 1 shows the process diagram of clipping with four plateau limits.

Then, the four clipped sub histograms are normalized as follows respectively:

$$\mathbf{h}'_{LL}(k)=\frac{\mathbf{h}^c_{LL}(k)}{\sum_{q=0}^{I_{ml}}\mathbf{h}^c_{LL}(q)},k=0,1,...,I_{ml} \tag{20}$$

$$\mathbf{h}'_{LU}(k)=\frac{\mathbf{h}^c_{LU}(k)}{\sum_{q=I_{ml}+1}^{I_d}\mathbf{h}^c_{LU}(q)},k=I_{ml}+1,...,I_d \tag{21}$$

$$\mathbf{h}'_{UL}(k)=\frac{\mathbf{h}^c_{UL}(k)}{\sum_{q=I_d+1}^{I_{mu}}\mathbf{h}^c_{UL}(q)},k=I_d+1,...,I_{mu} \tag{22}$$

$$\mathbf{h}'_{UU}(k)=\frac{\mathbf{h}^c_{UU}(k)}{\sum_{q=I_{mu}+1}^{L-1}\mathbf{h}^c_{UU}(q)},k=I_{mu}+1,...,L-1 \tag{23}$$

D. Histogram Equalization

The CDF of each sub histogram is denoted as $\mathbf{C}_{LL}$, $\mathbf{C}_{LU}$, $\mathbf{C}_{UL}$ and $\mathbf{C}_{UU}$ respectively . They are computed by the following equations as given in (24)-(27).

$$\mathbf{C}_{LL}(k)=\sum_{q=0}^{k}\mathbf{h}'_{LL}(q),k=0,1,...,I_{ml} \tag{24}$$

$$\mathbf{C}_{LU}(k)=\sum_{q=I_{ml}+1}^{k}\mathbf{h}'_{LU}(q),k=I_{ml}+1,...,I_d \tag{25}$$

$$\mathbf{C}_{UL}(k)=\sum_{q=I_d+1}^{k}\mathbf{h}'_{UL}(q),k=I_d+1,...,I_{mu} \tag{26}$$

$$\mathbf{C}_{UU}(k)=\sum_{q=I_{mu}+1}^{k}\mathbf{h}'_{UU}(q),k=I_{mu}+1,...,L-1 \tag{27}$$

Then, HE is used for all sub histograms. For each sub histogram, the transformation function is obtained by corresponding CDF as shown in (24) - (27). The expressions of all transformation functions can be defined as

$$\mathbf{g}_{LL}=I_{ml}\times\mathbf{C}_{LL} \tag{28}$$

$$\mathbf{g}_{LU}=(I_{ml}+1)+(I_d-I_{ml}-1)\times\mathbf{C}_{LU} \tag{29}$$

$$\mathbf{g}_{UL}=(I_d+1)+(I_{mu}-I_d-1)\times\mathbf{C}_{UL} \tag{30}$$

$$\mathbf{g}_{UU}=(I_{mu}+1)+(L-I_{mu}-2)\times\mathbf{C}_{UU} \tag{31}$$

In the end, four enhanced sub images are merged into into a complete image.

III. Experimental Results

This section will give the experimental comparison between our QHECL method and other image enhancement methods, such as BBHE, ESIHE, DSIHE, RSIHE, RMSHE, BHEPL and MMSICHE. For RMSHE and RSIHE, the recursion level is set to two. In our experiments, four test images: *Boy*, *Couple*, G*irl*, *U2*, are used. In order to test the performance of QHECL, we use three image objective evaluation measures, i.e. AMBE, Entropy, PSNR.

A. Quantitative Comparison

Tables I-III show the matrices of all four objective evaluation measures for four sample images, where the columns represent the test images and the rows represent various image enhancement methods. The values indicated in bold type are the best values for each comparison. The matrix shown in Table I is the AMBE values of all the images for all methods. QHECL is the best according to the average of AMBE value among all the comparative methods. Further, QHECL has the least AMBE value for *Boy*, *Couple*, G*irl* image. It is indicated that QHECL is well suitable for preserving brightness. Table II shows PSNR values of all test images for various image enhancement methods. QHECL gives best results according to the average of PSNR value among all the comparative methods, which indicates that the proposed technique hardly amplifies the noise during the process of image enhancement. The results for the entropy measure are shown in Table III. QHECL gives the highest average of entropy value, which indicates that our proposed method is very suitable for bringing out average information content of the image.

TABLE I. AMBE Measure Obtained From Four Sample Images

	Boy	Couple	Girl	U2	Average
BBHE	21.403	8.277	22.090	14.759	16.632
DSIHE	23.880	3.683	14.321	41.699	20.896
RMSHE	4.612	1.973	0.747	4.319	2.913
RSIHE	10.342	2.532	4.828	17.313	8.754
BHEPL	8.850	5.439	5.823	**3.411**	5.881
ESIHE	15.479	0.678	24.917	33.494	18.642
MMSICHE	2.787	0.751	0.815	4.275	2.157
QHECL	**2.012**	**0.008**	**0.339**	4.563	**1.731**

TABLE II. PSNR Measure Obtained From Four Sample Images

	Boy	Couple	Girl	U2	Average
BBHE	16.591	16.328	13.304	15.633	15.464
DSIHE	16.104	16.418	12.936	10.942	14.100
RMSHE	29.545	23.649	28.024	22.407	25.906
RSIHE	22.270	21.950	19.859	15.680	19.940
BHEPL	23.083	20.918	22.225	21.209	21.859
ESIHE	22.908	21.514	18.283	15.864	19.643
MMSICHE	31.285	27.644	29.342	**24.529**	28.200
QHECL	**34.725**	**28.439**	**29.928**	24.374	**29.366**

TABLE III. Entropy Measure Obtained From Four Sample Images

	Boy	Couple	Girl	U2	Average
Orignal	7.326	7.201	5.594	5.641	6.441
BBHE	7.028	7.008	5.291	5.545	6.218
DSIHE	7.015	7.009	5.293	5.503	6.205
RMSHE	7.121	7.027	5.354	5.455	6.240
RSIHE	7.105	7.047	5.223	5.427	6.200
BHEPL	7.195	7.121	5.529	**5.610**	6.364
ESIHE	7.219	7.123	5.526	5.594	6.365
MMSICHE	7.259	7.127	5.551	5.550	6.372
QHECL	**7.284**	**7.154**	**5.574**	5.569	**6.395**

B. Qualitative Comparison

The analysis of subjective evaluation from Figure 2-5 shows the superiority of BPNMBHE over the other image enhancement methods in all test images according to contrast enhancement, enhancement rate control and natural appearance. From Figure 2 of *Boy* image, we can see that most of the tested methods produce almost equivalent good enhancement results in addition to BBHE and DSIHE, which produce over enhancement phenomena. Figure 3 shows the enhanced images of *Couple* image for all methods. It can be noticed that the results of BBHE and DSIHE are still over enhanced. Although the results of QHECL for *Boy* and *Couple* image are visually comparable to RMSHE, RSIHE, BHEPL, ESIHE and MMSICHE, the proposed method yields best results for three IQMs. In Figure 4 of *Girl* image, the results of enhanced images obviously demonstrate the supremacy of QHECL. It is obviously remarkable that the enhanced images of BBHE, DSIHE and RSIHE produce noise amplification phenomena, and give them a very unpleasant look. The result of ESIHE is over enhanced and has a highest AMBE value. Although the result of QHECL is visually comparable to BHEPL and MMSICHE, the proposed method yields the higher entropy value and PSNR value, and the least AMBE value. From Figure 5(a), the contrast of the original image is low. It is obviously remarkable that the enhanced images of DSIHE, and ESIHE have noise amplification. In contrast, the enhanced image of QHECL provides good contrast enhancement, and meanwhile the noise is suppressed.

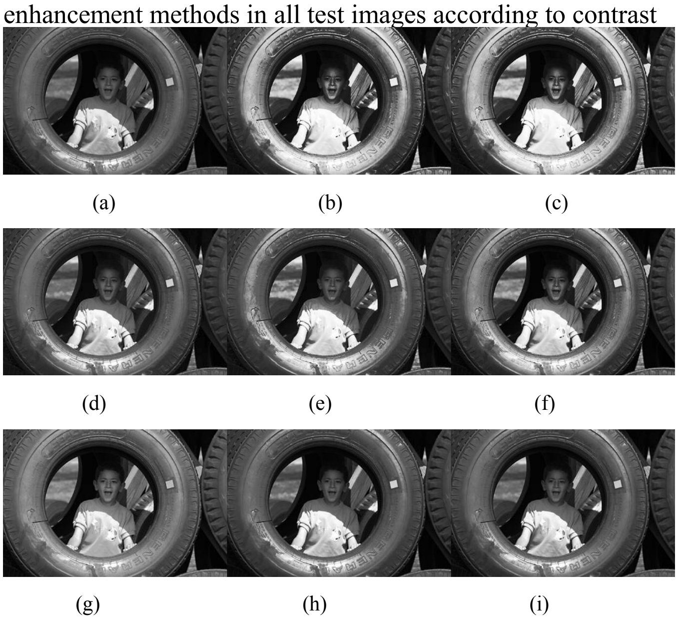


Figure 2. Enhancement results of *Boy* image: (a) Original, (b) BBHE, (c) DSIHE, (d) RMSHE, (e) RSIHE, (f) BHEPL, (g) ESIHE, (h) MMSICHE, (i) QHECL

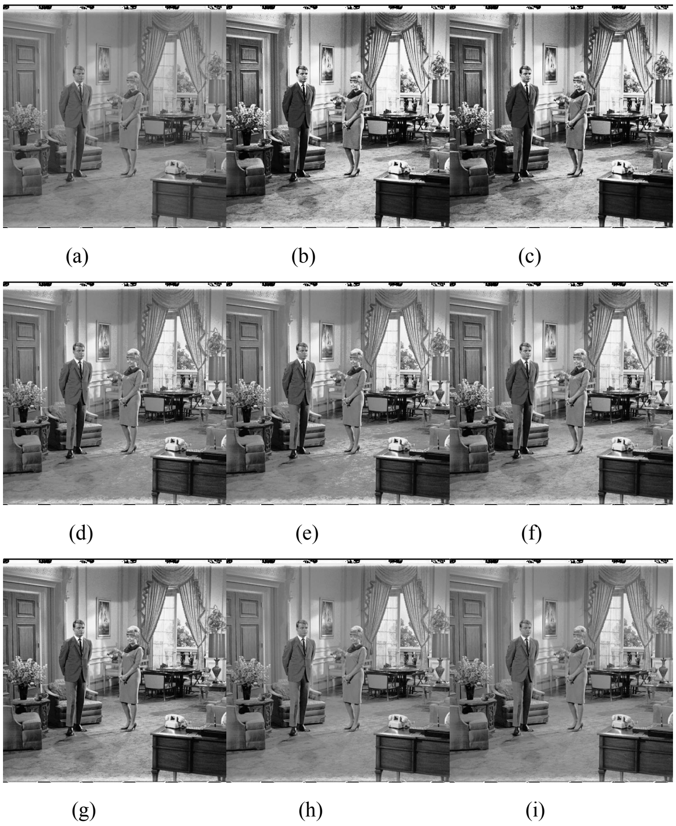
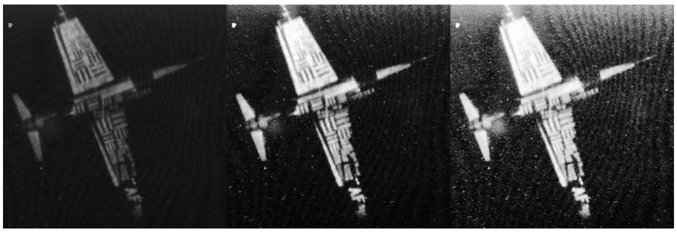
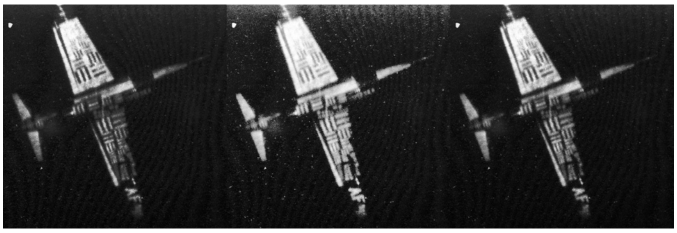


Figure 3. Enhancement results of *Couple* image: (a) Original, (b) BBHE, (c) DSIHE, (d) RMSHE, (e) RSIHE, (f) BHEPL, (g) ESIHE, (h) MMSICHE, (i) QHECL

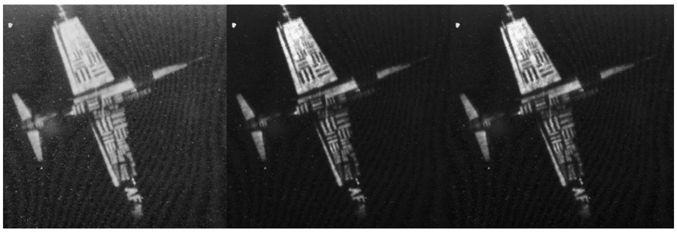
Figure 4. Enhancement results of *Girl* image: (a) Original, (b) BBHE, (c) DSIHE, (d) RMSHE, (e) RSIHE, (f) BHEPL, (g) ESIHE, (h) MMSICHE, (i) QHECL



(a) (b) (c)



(d) (e) (f)



(g) (h) (i)

Figure 5. Enhancement results of *U2* image: (a) Original, (b) BBHE, (c) DSIHE, (d) RMSHE, (e) RSIHE, (f) BHEPL, (g) ESIHE, (h) MMSICHE, (i) QHECL

IV. CONCLUSIONS

The paper presents a novel image enhancement method called QHECL. In the proposed method, the histogram clipping approach is used to control over enhancement and maximize entropy in the histogram equalization process. Sub histogram dividing by the median value and mean brightness is conducive to preserve brightness. Experimental results obviously demonstrate that QHECL is better than other contrast enhancement methods according to three image objective evaluation measures. Subjective evaluation results also demonstrate the superiority of QHECL over other image enhancement methods according to natural appearance

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