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A Novel Method of Determining Parameters of CLAHE Based on Image Entropy

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Abstract

Histogram equalization, which stretches the dynamic range of intensity, is the most common method for enhancing the contrast of image. Contrast Limited Adaptive Histogram Equalization (CLAHE), proposed by K. Zuierveld, has two key parameters: block size and clip limit. These parameters are mainly used to control image quality, but have been heuristically determined by users. In this paper, we propose a novel method of determining two parameters of the CLAHE using entropy of image. The key idea is based on the characteristics of entropy curves: clip limit vs entropy and block size vs entropy. Clip limit and block size are determined at the point with maximum curvature on entropy curve. Experimental results show that the proposed method improves images with very low contrast.

Keywords: *CLAHE, Contrast limited adaptive histogram equalization, Entropy*

1. Introduction

Histogram equalization, which stretches the dynamic range of intensity, is the most popular method for enhancing the contrast of image [1]. The standard procedure of histogram equalization is to remap grayscales of input image so that the histogram of output image approximates that of the uniform distribution, resulting in the improvement of subjective quality for the output image. Histogram equalization, however, introduces some undesirable visual artifacts and over-enhancement. Large peaks of the histogram can be caused in the relatively homogeneous area such as smooth background, and over-enhancement can be caused for the entirely dark or bright images [2, 3].

An adaptive method to avoid this drawback is block-based processing of histogram equalization. In block-based processing, image is divided into sub-images or blocks, and histogram equalization is performed to each sub-images or blocks. Then, blocking artifacts at neighboring blocks are minimized by filtering or bilinear interpolation [4, 5, 6].

Contrast Limited Adaptive Histogram Equalization (CLAHE) [8, 9], proposed by K. Zuierveld [8], as a well-known block-based processing, can overcome the problem of peaks in the histogram, which causes noise-like artifacts in homogeneous region of image with standard histogram equalization. The clip limit, defined as a multiple of the average

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histogram contents, limits the amplification, by which the CLAHE clips the histogram at a predefined value before computing the Cumulative Distribution Function (CDF).

The CLAHE has two key parameters: Block Size (BS) and Clip Limit (CL). These parameters mainly control image quality, but have been heuristically determined by users.

In this paper, we propose a method of determining two parameters of CLAHE using entropy of image. The key idea is based on the characteristics of entropy curves: clip limit vs. entropy and block size vs. entropy. Clip limit and block size are determined at the point with maximum curvature on entropy curve. Experimental results show that the proposed method improves images with very low contrast.

2. Contrast Limited Adaptive Histogram Equalization

Histogram equalization is a gray scale transformation for contrast enhancement. The aim is to get an image with uniformly distributed intensity levels over the whole intensity scale. Histogram equalization might produce the result that is worse than the original image since the histogram of the resulting image becomes approximately flat. Large peaks in the histogram can be caused by uninteresting area. So, histogram equalization might lead to an increased visibility of unwanted image noises. This means that it does not adapt to local contrast requirement; minor contrast differences can be entirely missed when the number of pixels falling in a particular gray range is relatively small.

An adaptive method to avoid this drawback is block-based processing of histogram equalization. In this method, image is divided into sub-images or blocks, and histogram equalization is performed to each sub-images or blocks. Then, blocking artifacts among neighboring blocks are minimized by filtering or bilinear interpolation.

The CLAHE introduced clip limit to overcome the noise problem. The CLAHE limits the amplification by clipping the histogram at a predefined value before computing the CDF. This limits the slope of the CDF and therefore of the transformation function. The value at which the histogram is clipped, the so-called clip limit, depends on the normalization of the histogram and thereby on the size of the neighborhood region. The redistribution will push some bins over the clip limit again, resulting in an effective clip limit that is larger than the prescribed limit and the exact value of which depends on the image.

The CLAHE has two key parameters: block size and clip limit. These parameters are used to control image quality. However, detailed method to determine these parameters was not provided, and they were heuristically chosen by users. When a user determines inappropriate parameters, the results of the CLAHE would be worse than that of HE. Figure 1 shows the result images of the CLAHE with different clip limit and block size, and the result images of HE.


(a)


(b)

(c) (d)

Figure 1. (a) Aerial Image (b) Histogram Equalization (c) CLAHE (CL=0.1, BS=8x8) (d) CLAHE (CL=0.3, BS=64x64)

3. Determining Parameters of the CLAHE

We proposed an effective method to determine two parameters of the CLAHE: block size and clip limit based on the entropy of an image. Image entropy becomes relatively low when histogram is distributed on narrow intensity region while image entropy becomes high when histogram is uniformly distributed. Therefore, the entropy of the histogram equalized image becomes higher than that of the original input image. Key idea of the proposed approach comes from the observation of the curve of image entropy vs. subjective quality of the results of the CLAHE with different parameters.

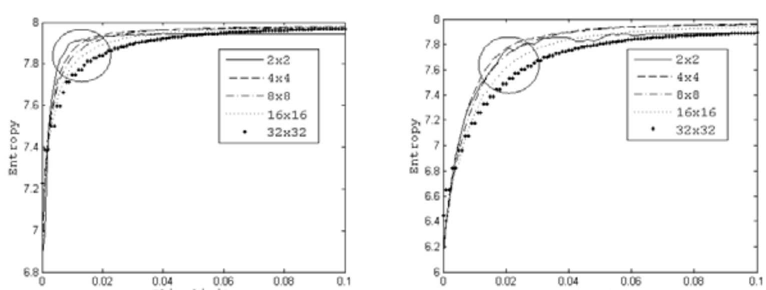
Figure 2 shows the entropy curves of the Aerial image and Crowd image processed by the CLAHE with different parameters. Aerial image is relatively bright and Crowd image is relatively dark so that we can subjectively evaluate the efficiency of histogram equalization.

From the experiments, it is observed that the image quality rapidly changes and the image has subjectively good quality on the circled region of the curves shown in Figure 2. The parameters determined at the point with maximum curvature produce subjectively good quality of the image.

Discrete entropy [6, 7, 10] is defined as.

$$H(x) = -\sum_{i=1}^{N} p(x_i) \log_2 p(x_i) \tag{1}$$

where $p(x_i)$ is the normalized probability of the gray level x_i.



(a) Aerial image (b) Crowd image

Figure 2. Entropy with Different Clip Limit and Block Size

Figure 3 shows that the CLAHE results of Crowd image with different clip limits and 16x16 block size. The image is getting bright when clip limit is increased because input image has very low intensity and larger CL makes its histogram flatter. Figure 4 shows the CLAHE results of Crowd image with different block size and CL=0.026. As the block size is bigger, the dynamic range becomes larger and the contrast of image is also increasing.

(a) (b) (c)

Figure 3. (a) Crowd Image (b) CLAHE (CL=0.005, BS=16x16) (c) CLAHE (CL=0.03, BS=16x16)

(a) (b) (c)

Figure 4. (a) CLAHE (CL=0.026, BS=2x2) (b) CLAHE (CL=0.026, BS=8x8) (c) CLAHE (CL=0.026, BS=32x32)

The image quality mainly depends on the clip limit rather than block size. Therefore, we calculate values of clip limit and block size independently for computation efficiency. First, we compute the entropy curve while changing clip limit from 0 to 0.1 with the fixed block size of 8x8. Because the entropy curve is not monotonic, it is fitted by the equation below:

$$f(x) = c_1 e^{-\lambda_1 x} + c_2 e^{-\lambda_2 x}. \tag{2}$$

For the optimal fitting of a nonlinear function to the given set of data, fitting methods such as fitoutputfun() and fminsearch() in Matlab [11] are used in the experiments. We determine the clip limit, where the point has maximum curvature on entropy vs. clip limit curve. Let clip limit be x(t) and entropy be y(t). Also x(t) and y(t) are assumed to be twice-differentiable. Curvature κ [12] is define as

$$\kappa = \frac{\dot{x}\ddot{y} - \dot{y}\ddot{x}}{\sqrt{(\dot{x}^2 + \dot{y}^2)^3}}. \tag{2}$$

$$x_{\max} = \underset{\arg}{\max}\{\kappa(x)\} \tag{3}$$

Second, we compute the entropy while changing block size from 2x2 to 32x32 with the fixed clip limit determined in the above. We also determine the block size, where the point has maximum curvature on entropy vs. block size curve. Finally, we apply the CLAHE with these clip limit and block size to the input image.

4. Experimental Results

We present the results of the proposed method to determine the CLAHE’s parameters. The proposed method is applied to three different types of images: dark image, normal image, and bright image. We analyzed average intensity, Root Mean Square (RMS) contrast, and entropy of HE and the CLAHE. Average intensity of image indicates its brightness and is defined as below:

$$\overline{I} = \frac{1}{MN}\sum_{i=0}^{N-1}\sum_{k=0}^{M-1} I(i, j) \tag{5}$$

where I(i,j) is normalized intensity of pixel from 0 to 1 at the position (i,j).

RMS contrast, which can make an object in an image distinguishable, is defined as below.

$$Contrast_{RMS} = \sqrt{\frac{1}{MN}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left\{I(i, j) - \overline{I}\right\}^2} \tag{6}$$

where $\overline{I}$ is the average intensity.

Although entropy does not directly represent the enhancement of image quality, it can depict the richness of details. In addition, when average and RMS contrast do not change, entropy is a useful factor to understand the local or global contrast variation in the given image.

Office1(903x600), which is taken under very low light, is very dark image with low average of intensity. As shown in Table 1, its histogram is narrowly concentrated at low intensity region, and its entropy is also very low. Histogram equalization causes over-change of contrast with little change of entropy and keeps the entropy low, resulting in subjectively low quality of the output image. Clip limit is determined as 0.048 and block size is determined as 4x4 by the proposed method. Figure 5 shows that the CLAHE produces the output image subjectively better than HE.

Aerial (764x768) is very bright image with high average of intensity. Its histogram distributes mid-range and high range of intensities. Histogram equalization also causes over contrast and the details in the image are not clear. Clip limit is determined as 0.014 and block size is determined as 2x2 by the proposed method. The CLAHE makes the image brighter and its entropy higher than HE as shown in Table 2. The result shows that the CLAHE produces the output image subjectively better than HE. Figure 6 shows that the CLAHE represents more details than HE due to the increased entropy.

Announce (512x480) has subjectively good quality so that histogram equalization might not be necessary. Table 3 shows that histogram equalization makes it brighter, but a little with contrast and entropy change. Clip limit is determined as 0.008 and block size is determined as 2x2 by the proposed method. Figure 7 shows that HE and the CLAHE have similar quality of the output image generated.

Table 1. Experimental Results of Office1 Image

	Average Intensity	RMS contrast	Entropy
Office1	10.6	0.20	4.87
HE	128.4	0.50	4.58
The proposed Method	81.6	0.47	7.41

Table 2. Experimental Results of Aerial Image

	Average Intensity	RMS contrast	Entropy
Aerial	197.2	0.42	6.87
HE	127.7	0.50	5.92
The proposed Method	136.2	0.50	7.94

Table 3. Experimental Results of Announce Image

	Average Intensity	RMS contrast	Entropy
Announce	103.7	0.49	7.47
HE	127.5	0.50	5.89
The proposed Method	121.8	0.50	7.91

(a) (b) (c)

Figure 5. (a) Office1 Image (b) Histogram Equalization (c) CLAHE (CL=0.048, BS=4x4)

(a) (b) (c)

Figure 6. (a) Aerial Image (b) Histogram Equalization (c) CLAHE (CL=0.014, BS=2x2)

(a) (b) (c)

Figure 7. (a) Announce Image (b) Histogram Equalization (c) CLAHE (CL=0.008, BS=2x2)

5. Conclusion

In this paper, we propose a method of determining two parameters of the CLAHE: block size and clip limit. The key idea is based on the characteristics of entropy curves: clip limit vs. entropy and block size vs. entropy. Clip limit and block size are determined at the point with maximum curvature on entropy curve. In the experiments, the images with relatively low or high intensity are used for enhancement by the proposed approach. We analyze experimental results using the criteria, such as average of intensity, RMS contrast, and entropy. Experimental results of the CLAHE with the parameters, determined by the proposed method, show subjectively better performances when compared to HE.

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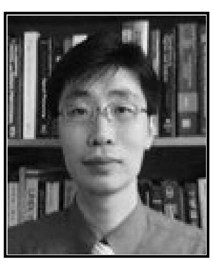

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