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A New Contrast Enhancement Technique by Adaptively Increasing the Value of Histogram

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***Abstract*—The technologies for image contrast enhancement are improved evidently since the popularity of consumer electronics and image processing in the last decade. Based on Histogram Equalization (HE), this paper proposes a simple contrast enhancement scheme named Adaptively Increasing the Value of Histogram (AIVHE). It provides a convenient and effective mechanism to control the rate of contrast enhancement by means of an adaptive parameter, $\alpha(k)$, and a user defined value, β. AIVHE offers a gradually increment by the mean brightness of the image to modify the original probability density function (PDF). The simulation results show that the method can outperform contrast enhancement than other methods.**

Keywords-contrast enhancement; image processing; histogram equalization

I. INTRODUCTION

Contrast enhancement is a display technology that improves the exhibition effect by increasing the dynamic range of gray intensity of the input image. It is an important technology for the improvement of digital image/video quality. We can classify the techniques of contrast enhancement been proposed into two categories: They are Global Enhancement methods and Histogram Equalization based methods.

A. Global Methods

Global Enhancement method is the most prevalent method to be utilized such as Histogram Stretching method (HS) [1], Improved Histogram Stretching method (IHS) [2], localized contrast manipulation method [3], and Automatic Video Contrast Enhancement [4].

HS [1] and IHS [2] are applied to stretch the histogram of image to full dynamic range and suitable to use on centralized histogram of image. Since both methods are work by means of gray levels to calculate input-output mapping curve, so they are sensitive to the noise influence.

The localized contrast manipulation method [3] achieves the enhancement by analyzing local statistical information, and then obtaining the function to transfer the effect of images. The method of Automatic Video Contrast Enhancement [4] performs histogram analysis by computing some statistical information of the image to select the mapping function for enhancing. Both methods achieve contrast enhancement from the view point of characters of image distribution. The lack of both methods is that can not provide the full variety of input-output transfer function.

Global Enhancement methods are relatively simple than other methods. The weakness of these methods is that they can not provide precise image contrast enhancement effect because the inflexibility of these methods and the inability for noise elimination.

B. Histogram Equalization Based Methods

For Histogram Equalization based methods, the original idea named Histogram Equalization, abbreviated as HE [5], is very popular for enhancing the contrast of an image. The method performs the remapping in the gray levels to produce uniform distribution in the order of input images. But it is also being criticized that it always causes unacceptable visual artifacts. There are many solutions been proposed to conquer the weakness of the traditional HE method. The three most famous adaptive histogram equalization methods are improving HE methods [6], [7], spatial processing HE methods [8], [9] and probability density function (PDF) shaping HE methods [10], [11].

In order to improving HE methods, the input histogram is divided into two sub-histograms based on the mean brightness by the method proposed in [6], then the two sub-histograms are manipulated by HE individually. For the method proposed in [7], recursive mean-separate histogram equalization (RMSHE) is proposed to produce $2r$ pieces of sub-histogram by using the BBHE method r times. Although the enhancement effect can be improved, the two methods still produce over-enhancement or unnatural contrast of image in some cases.

Several spatial processing HE methods have been proposed such as Contrast Limited Adaptive Histogram Equalization (CLAHE) [8], and Partially Overlapped Sub-Block Histogram Equalization (POSHE) [9]. Spatial processing HE methods can make premium contrast enhancement effect by heavy computational load.

For improving the traditional HE method that produces over enhancement and abnormal display problems, several PDF shaping HE methods have been proposed. PDF shaping HE methods modify the original PDF to obtain a new PDF, from which to obtain adaptive input-output transfer function to

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enhance image contrast. There are Histogram with Bin Underflow and Bin Overflow (BUBO) method [10] and Adaptively Modified Histogram Equalization (AMHE) method [11]. The former puts constraint on the probability density function (PDF) with the bin underflow and bin overflow thresholds to prevent a significant change of gray levels. In AMHE, The method scales the original shape of the PDF based on the middle value from the maximum and minimum values with original image.

For providing a well designed adaptive contrast enhancement effectively and prevent a significant change of gray levels, this study focuses on the PDF shaping HE techniques to propose a simple contrast enhancement scheme named "Adaptively Increasing the Value of Histogram", abbreviated as AIVHE, to enhance the contrast in a more efficient way.

In section II, we review the most popular methods as the basis of this research. The following section, section III, is a detail description for our proposed AIVHE method. Section IV presents the experimental results and comparisons from other contemporary methods. In the last section, section V, a brief overview of this research and some considerations for future works are present as the concluding remarks.

II. CONTRAST ENHANCEMENT TECHNIQUES

In this section, we review two popular techniques about image contrast enhancement as the basis of this research. They are traditional Histogram Equalization method [5], and BUBO method [10].

A. Traditional HE Method

HE [5] obtains input-output transfer function by means of the histogram of input images. For the digital image input *f(x, y)* in an active area of gray level [0, L-1] with N pixels. The probability density function (PDF) $P(k)$ of the image is defined as (1), where L is the maximum gray level of image:

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

In the equation, n_k is the total number of pixels in the image with gray level k. By means of the cumulative density function (CDF) defined in (2), the input-output transfer function is then defined as the (3), where X_0 and X_{L-1} are the minimum and maximum luminance values.

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

$$f(x) = X_0 + (X_{L-1} - X_0)C(x) \tag{3}$$

Although the transfer function can derive enhanced images by contrast enhancement, HE can not control the effect of enhancement. Moreover, while histogram is centralized in a narrow area, the method tends to produce undesirable artifacts.

B. BUBO Method

To improve the undesirable artifacts caused by traditional HE method, the BUBO method [10] puts constraints to avoid over enhancement by the (4), where C_{BU} and C_{BO} are bin underflow and bin overflow thresholds as defined in (5) and (6).

$$P_{BUBO}(k) = \begin{cases} C_{BO} & ,\text{if } P(k) > C_{BO} \\ P(k) & ,\text{if } C_{BU} \le P(k) \le C_{BO} \\ C_{BU} & ,\text{if } P(k) < C_{BU} \end{cases} \tag{4}$$

$$C_{BU} = (1-\alpha)/N \tag{5}$$

$$C_{BO} = (1+\alpha)/N \tag{6}$$

BUBO is an effective technique for contrast enhancement; but in some cases the method still can not expand gray level distribution to expand dynamic range of input image. Although we can add the function of adjusting parameter into BUBO to expand image for more dynamic range; the method still need to adjust different parameter for input images.

III. AIVHE CONTRAST ENHANCEMENT METHOD

Based on PDF shaping HE methods, this study proposes a new contrast enhancement method, abbreviated as AIVHE. The method reshapes the original PDF to obtain new PDF to prevent a significant change in the gray levels. It also provides a mechanism of adjustment to contrast enhancement by means of adaptive constraint parameter $\alpha(k)$ for adjustment automatically, which is determined by the initial value γ and user defined parameter β.

AIVHE divides the original PDF into upper and lower blocks on the basis of P_{bas}. A value of maximum threshold P_h is then be set to restrict the variation of the $P_{AIVHE}(k)$, and then limit the value of $P_{AIVHE}(k)$ be not greater than P_h. AIVHE reshapes original PDF and obtain the $P_{AIVHE}(k)$ by (7).

$$P_{AIVHE}(k) = \begin{cases} P_h & ,\text{if } P(k) \ge P_h \\ P(k) - \alpha(k)(P(k) - P_{bas}) \times \beta & ,\text{if } P_{bas} < P(k) < P_h \\ P(k) + \alpha(k)(P_{bas} - P(k)) \times \beta & ,\text{if } P(k) \le P_{bas} \end{cases} \tag{7}$$

The value of P_{bas} in the equation is set as the average PDF (normalized total number of pixels divided by maximum gray level, 1 / L). The value can prevent output from unnecessary effect. The value of threshold, P_h, is set as double of P_{bas} to divide $P_{AIVHE}(k)$ into two equal areas to obtain effective image contrast enhancement effect. The value of weight parameter, β, is defined to adjust the enhance effect by user. The β is a real number in the range of [0, 1]. The function of HE is produced when the value of β is set by zero and P_{bas} is the mean value of the maximum and the minimum values of $P(k)$. The effect of contrast enhancement will be decreased by increasing the value of β.

$$\alpha(k)=\begin{cases}\left(1-\dfrac{X_m-k}{X_m}\right)^2\times(1\text{-}\gamma)+\gamma & \text{, if } k\le X_m\\[2ex]\left(1-\dfrac{k-X_m}{(L-1)-X_m}\right)^2\times(1\text{-}\gamma)+\gamma, & \text{if } k>X_m\end{cases}\tag{8}$$

The adaptive constraint parameter $\alpha(k)$ in the (7) is tunned automatically based on the mean brightness X_m as shown in (8) to increment the value to mean brightness gradually. It changes each gray region for pixel distribution proportion of steps, and produces input-output transfer function based on mean brightness to obtain more output pixels to distribute to dark and bright regions.

The initial value γ is a real number in the range of [0, 1]. By setting the initial value γ for $\alpha(k)$, the pixel distribution of PDF in the dark region and bright region is decided. For instance, by setting the initial value γ of $\alpha(k)$ to zero will produce black and white stretching effects in both regions. On the other hand, the number of pixels will be increased in the mean brightness by increasing the value to produce a smooth input-output transfer curve.

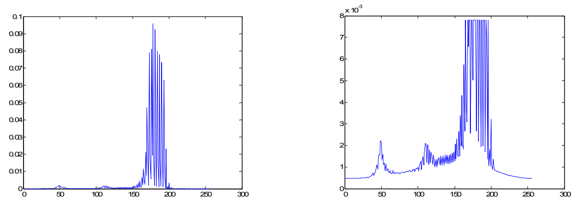
To determine the optimum value of β and γ, we are going to determine a constant β and γ that can produce natural contrast enhancement result when input image is low contrast and can prevent to produce over enhancement result when input image is high contrast. The value of β is set to small real number that can produce desirable contrast enhancement result and we set the value of γ to small real number that can produce natural histogram distribution result. By adopting various values for β and γ to identify the effect of the parameter, the final simulation results show that the both adequate values of β and γ are 0.35. The initial values will produce most clear images in most cases. AIVHE control dark and bright regions stretching degree of the image by γ of $\alpha(k)$, and control the degree of whole contrast enhancement effect of the image by β.

Fig. 1 present a reshaped PDF result from a over-centralized PDF distribution, the figure shows that the entire image is divided into two blocks by the mean brightness. By increasing the value of $\alpha(k)$ from the both side to the mean brightness as shown in Fig. 1(b), it can prevents to produce unacceptable visual artifacts. In Fig. 2(b), we can find that more black and white stretch is achieved and the condition of significant change in gray levels is prevented.

By the $P_{AIVHE}(k)$, the cumulative density function, $C_{AIVHE}(k)$, is straight forward accumulated. Since the accumulation of $C_{AIVHE}(k)$ does not amount to 1, we have to normalize $C_{AIVHE}(k)$ to gray level [0, L-1] and then output the image by the (9).

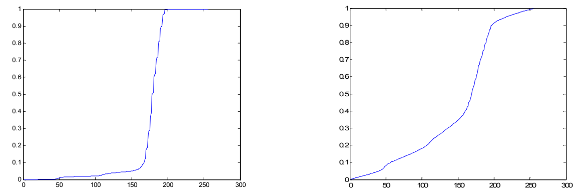
$$f(k)=(L-1)\times\left(\frac{C_{AIVHE}(k)}{C_{AIVHE}(L-1)}\right)\tag{9}$$

Fig. 3 is the original image that derives the PDF of Fig. 1. We can observe from the images in Fig. 3 that AIVHE can show the detail of original image clearly by enhancing the contrast more smoothly and widely.



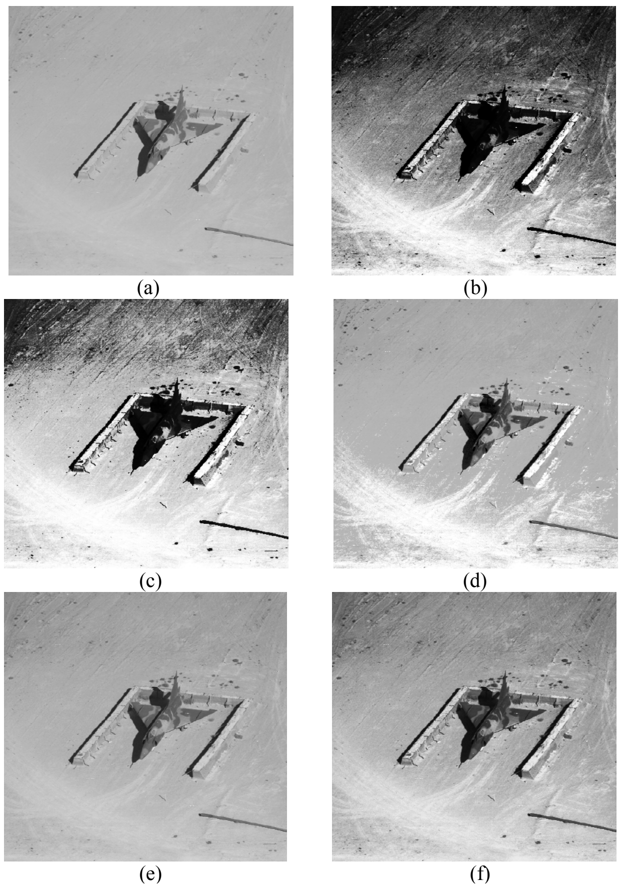
(a) (b)

Figure 1. (a) the original PDF of input image, (b) the PDF reshaped by AIVHE with β = 0.35 and γ = 0.35



(a) (b)

Figure 2. (a) input-output transfer function of HE, (b) input-output transfer function produce by AIVHE with β = 0.35 and γ = 0.35



(a) (b) (c) (d) (e) (f)

Figure 3. (a) original image (b) Enhanced by HE (c) Enhanced by BBHE (d) Enhanced by RMSHE, (e) Enhanced by BUBO, $\alpha = 0.7$ (f) Enhanced by AIVHE, $\beta = 0.35$, $\gamma = 0.35$

IV. Experiment Results

This study tested the proposed AIVHE method on different images. Some other contrast enhancement methods, such as HE [5], BBHE [6], RMSHE [7] and BUBO [10], are simulated for comparison, too. The parameters of each method are selected according to the suggestion of the researches. For the RMSHE, we set the value of r with 2, and the value of α in BUBO is set to 0.7. To observe the effects of contrast enhancement achieved by these methods, the process of luminance component is done but the process of chrominance component is omitted for the completion of the image contrast enhancement processing.

Fig. 4 shows another image example enhanced by the different methods. The image produced by AIVHE as shown in Fig. 4(f) conquer the challenge and exhibit a much clear image. Fig. 5 is all histograms of the images shown in Fig. 4, we can find that although HE, BBHE and RMSHE methods expand the histogram to the entire dynamic range [0, L-1], the image is not well enhanced by the methods because they can not prevent the significant change of gray levels. In Fig. 5(f), the result shows that AIVHE utilized more dynamic range than BUBO shown in Fig. 5(e).

Fig. 6 shows some other results of contrast enhancement for AIVHE, all of the enhancement results show that the method of AIVHE can achieve ideal effect of contrast enhancement by means of a new concept of white and black stretching based on HE method to obtain suitable dark and bright region distribution.

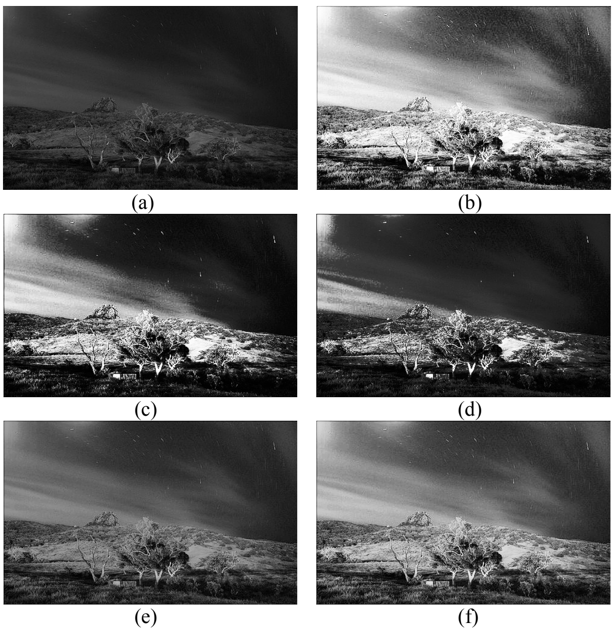


Figure 4. Contrast enhancement results of intensity image, (a) input image, (b) Enhanced by HE (c) Enhanced by BBHE (d) Enhanced by RMSHE (e) Enhanced by BUBO (f) Enhanced by AIVHE

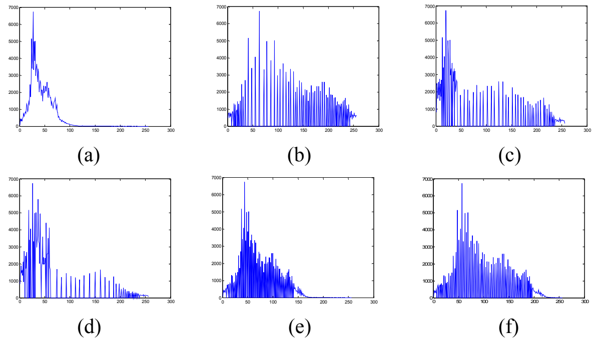


Figure 5. Histogram of Fig. 4, (a) input image, (b) Enhanced by HE (c) Enhanced by BBHE (d) Enhanced by RMSHE (e) Enhanced by BUBO (f) Enhanced by AIVHE

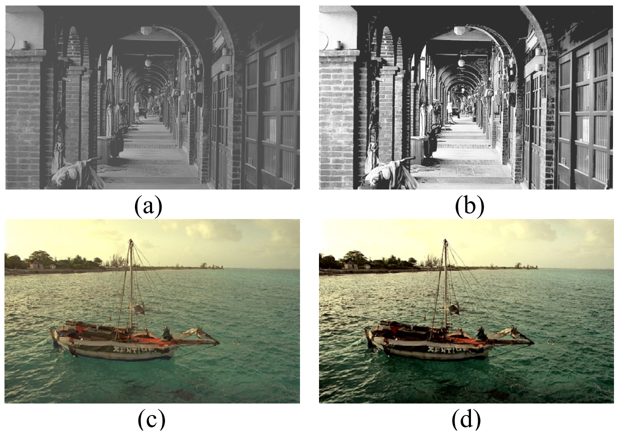


Figure 6. Other contrast enhancement results, (a) and (c) are input image, (b) and (d) Enhanced by AIVHE

V. Concluding Remarks

In this study, we propose a new method named AIVHE for image contrast enhancement to enhance image display quality. The simulation results show that the method can enhance image contrast effectively. The input image can produce the effect of contrast enhancement effectively by automatic adaptive increment, the parameter $\alpha(k)$. In the meantime, the method can obtain more gray level distribution of dark and bright regions and also increase gray levels effectively. The truth shows that AIVHE can not only provide natural image contrast enhancement effect, but also enhance display quality, furtherer prevent from produce excess strengthen or artifacts for image output.

An important feature of AIVHE is that the functions proposed in the study are all designed under the consideration of hardware implementation, and then use the mechanism of adjustable contrast enhancement effect, It might be suitable to be applied for consumer electronics such as mobile phone, digital camera, LCD TV etc..

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