Fast Contrast Enhancement Based on A Novel Dynamic Histogram Equalization Algorithm

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Abstract —**In this paper, a novel contrast enhancement algorithm based on the Histogram Equalization algorithm is presented. The proposed approach enhances image/video contrast without losing the original histogram characteristics. The algorithm is expected to process the video resolution efficiently but does not to overshoot the equalization with annoying side effects by using the difference information from the input histogram. The experimental results show that the proposed Dynamic Histogram Equalization (DHE) algorithm not only keeps the original histogram features but also enhances the contrast with much less computational efforts for large resolution. Furthermore, the proposed DHE algorithm can be easily applied to the FPGA hardware.**

***Keywords* — Contrast Enhancement; Histogram Equalization; Dynamic Histogram Equalization; FPGA**

I. Introduction

Contrast enhancement techniques are widely used for image/video processing in order to achieve a wider dynamic visual range. Among the many commonly used enhancement techniques, the histogram modification algorithm is the most popular approach to achieving a wide dynamic range, especially for Histogram Equalization (HE). This method is the most commonly used algorithms for performing contrast enhancement because of its simplicity and effectiveness [1]. HE will distribute pixel values uniformly and results in an enhanced image with linear cumulative histogram. HE has also been applied to many practical applications, such as video enhancement, digital surveillance, medical image processing, speech recognition, and texture synthesis [2]–[3].

In the past few years, many studies have focused on image/video contrast enhancement [4]–[5]. Mean preserving Bi-Histogram Equalization (BBHE) was proposed to overcome the brightness preservation problems [4]. BBHE separates the input image/video histogram into two parts based on input mean before equalizing them independently. Later, Equal Area Dualistic Sub-Image Histogram Equalization (DSIHE) was proposed to separate the histogram by entropy value [5]. Chen [6] proposed an extension of BBHE which was referred to as Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) to provide maximal brightness preservation. Although the above algorithms can perform the highest contrast enhancement in image/video signals, however, these algorithms actually result in undesired side effects [7].

However, Ultra-HD (UHD) TV, producing a 7,680×4,320 pixel resolution (a.k.a. 4K-2K) and the next generation High Efficiency Video Coding (HEVC), will soon need very high throughput performance [8]. Most research in contrast enhancement still focuses on how to maximize the contrast ratio using entropy theory [9]; however, when the resolution increases to 4K-2K, it will become impossible to process the video contrast enhancement in real-time. For example, when the resolution is 4,096×2,160 and the color depth is 16-bit, 23.73 GBs of data flow must be processed per second. Therefore, it is necessary to rethink how to using the traditional histogram modification to further improve the computational time and enhancement quality.

In this paper, a novel Dynamic Histogram Equalization (DHE) algorithm based on the derivative method is proposed to enhance the contrast without losing the original histogram characteristics. The algorithm is expected to perform the contrast enhancement very fast in order to satisfy the huge computational requirements of the UHD and to avoid the overshot problem [7]. In order to keep original histogram features, the DHE will first extracts the difference information from the input histogram, and then apply extracted derivative parameters to control the overall processing. By contrast, the proposed DHE results can not only obtain a more nature contrast enhancement than other histogram modification algorithms in objectively.

This paper is organized as follows. Section 2 briefly introduces the theory of Histogram Equalization. In Section 3, the proposed fast Dynamic Histogram based on derivative method will be described. The experimental results are shown in Section 4, while Section 5 concludes the paper.

II. HISTOGRAM EQUALIZATION THEORY

In this section, the definitions of Histogram Equalization, Bi-Histogram Equalization and Dualistic Sub-Image Histogram Equalization are addressed; detailed definitions can be found in [1], [4], [6].

A. Histogram Equalization

In the following, only discrete cases will be considered. Let $F = X(x, y)$ denote a input frame that is composed of gray pixel levels in the range of $[0, L\text{-}1]$. The transformation function $C(r_k)$ in a input image is defined as

$$s_k = C(r_k) = \sum_{i=0}^{k} P(r_i) = \sum_{i=0}^{k} \frac{n_i}{n} \tag{1}$$
$$\text{where } 0 < s_k \le 1 \text{ and } k = 0, 1, 2, \ldots, L-1.$$

Equation (1), n_i presents the amount number for each k^{th} gray level appears in F, and n is the total numbers of pixels in the input image. $P(r_i)$ presents as the Probability Density Function (PDF) of the input gray level k. Based on the PDF, the Cumulative Density Function (CDF) is defined as $C(r_k)$. Consequently, the HE equalizes the histogram distribution of the input stream into its dynamic range by employing the CDF as a transform function that is defined as

$$F^{th} = \{ f(X(x,y)) \mid \forall X(x,y) \in F \}, \tag{2}$$

where $f(X)$ is the transform function and F^{th} denotes the frame number that appears in the video sequences. Fig. 1(b) shows the histogram distribution of Fig. 4 after histogram equalization with the resolution in 2160x4096 pixels (color depth is 16bit). Although the HE introduces a significant improvement in image/video contrast, it gives rise in more artifacts and undesirable side effects [7].

B. Bi-Histogram Equalization

Although histogram equalization is widely used for contrast enhancement in a variety of applications due to its simple function and effectiveness, there is one drawback that the brightness of an image can also be changed after equalization. This is mainly because of the flattening property of the histogram equalization. For this problem, Y.T. Kim proposed a Mean Preserving Bi-histogram Equalization (BBHE) method [4] to remain the brightness of result image, so that the shape of result histogram would not become so much different from source histogram. It will first decompose the gray level image into two sub image, as X_L and X_U which is depend on the mean value X_m to separate the input image. Then two sub images will perform the histogram equalization independently. Finally the BBHE combines these two sub images into one result image.

Denoted by X_m the mean of the image X. Based on the mean value (critical point), the input image is decomposed into two sub images X_L and X_U as $X = X_L \cup X_U$, and assume $X_M \in \{X_0, X_1, \cdots X_{L-1},\}$ where

$$X_L = \{X(x,y) \mid X(x,y) \le X_m, \forall X(x,y) \in X\}, \tag{3}$$

and

$$X_U = \{X(x,y) \mid X(x,y) > X_m, \forall X(x,y) \in X\}. \tag{4}$$

And X_L and X_U can also be expressed as:

$$X_L \in \{X_0, X_1, \ldots, X_m\}, \quad X_U \in \{X_{m+1}, X_{m+2}, \ldots, X_{L-1}\}. \tag{5}$$

Next, the respective probability density functions of the sub images X_L and X_U can be defined as

$$P_L(X_k) = \frac{n_L^k}{n_L}, \text{ where } k = 0, 1, 2, \ldots, m \tag{6}$$

and

$$P_U(X_k) = \frac{n_U^k}{n_U}, \text{ where } k = m+1, m+2, \ldots, L-1, \tag{7}$$

in which n_L^k and n_U^k represent the respective numbers of X_k in $\{X\}_L$ and $\{X\}_U$, and n_L and n_U are the total numbers of samples in $\{X\}_L$ and $\{X\}_U$, respectively. Note that $n_L = \sum_{k=0}^{m} n_L^k$, $n_U = \sum_{k=m+1}^{L-1} n_U^k$ and $n = n_L + n_U$. The cumulative density functions for $\{X\}_L$ and $\{X\}_U$ are defined as

$$C_L(x) = \sum_{j=0}^{k} P_L(X_j) \tag{8}$$

and

$$C_U(x) = \sum_{j=m+1}^{L-1} P_U(X_j) \tag{9}$$

where $X_k = x$. Note that $c_L(X_m)=1$ and $c_U(X_L\text{-}1)=1$ by definition.

Similar to the histogram equalization where a cumulative density the following transform functions exploiting the cumulative density functions

$$f_L(x) = X_0 + (X_m - X_0) C_L(x) \tag{10}$$

and

$$f_U(x) = X_{m+1} + (X_{L-1} - X_{m+1}) C_U(x). \tag{11}$$

Based on these transform functions, the decomposed sub images are equalized independently and the composition of the resulting equalized sub images constitute the output of the BBHE. The final output image of the BBHE can be expressed as

$$Y = f_L(X_L) \cup f_U(X_U) \tag{12}$$

where

$$f_L(X_L) = \{f_L(X(i,j)) \mid \forall X(i,j) \in X_L\} \tag{13}$$

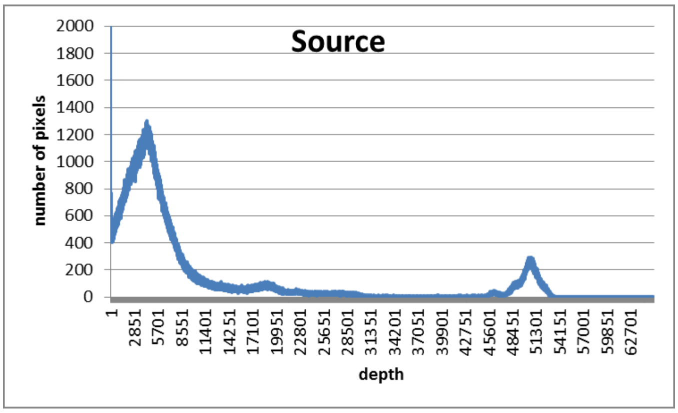
and

$$f_U(X_U) = \{f_U(X(i,j)) \mid \forall X(i,j) \in X_U\}. \tag{14}$$

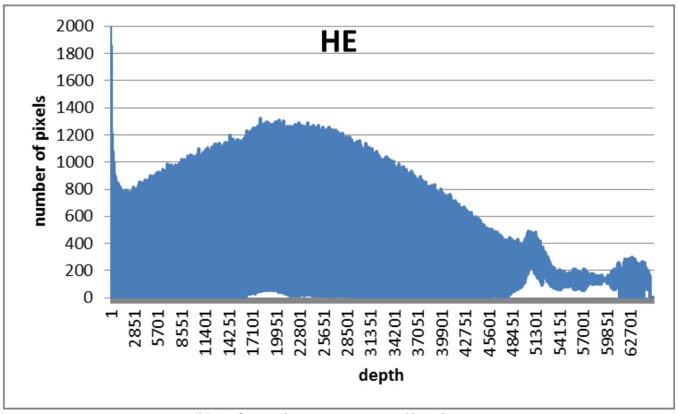
Fig. 1(c) shows the histogram distribution of the Fig. 4 after bi-histogram equalization with the resolution in 2160x4096 pixels (color depth is 16bit). Compared to Fig. 1(b), the distribution is obviously separated into two parts, however, over enhancement in both methods from Fig. 4(b) and Fig. 4(c) can still be observed.

C. Dualistic Sub-image Histogram Equalization

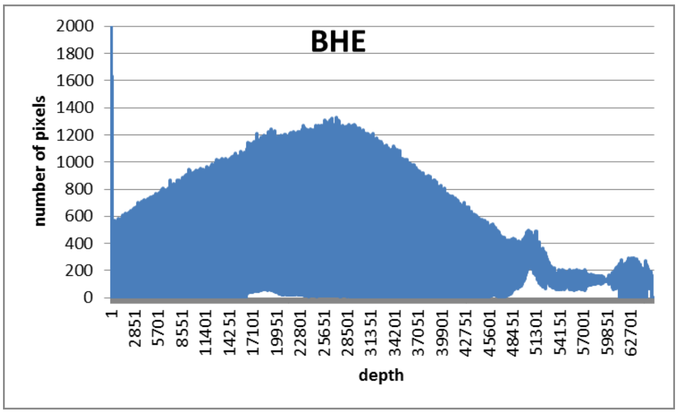
In a similar way, Dualistic Sub-Image Histogram Equalization separates input image into two sub images by critical points which is searched from BHE, then process BHE once again with these two sub images respectively [5]. In other words, the algorithm DSIHE will separate the input image with three critical points and perform histogram equalization for each sub image.



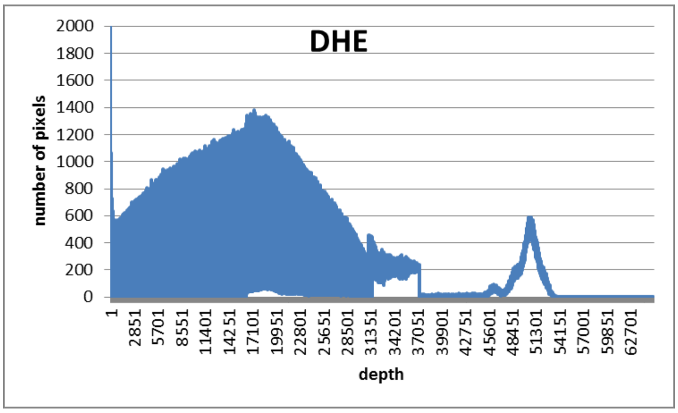
(a) Original Histogram of Fig. 4



(b) After Histogram Equalization



(c) After Bi-Histogram Equalization



(d) After proposed Dynamic Histogram Equalization

Fig. 1. Histogram distribution of the Fig. 4 for each method.

III. DYNAMIC HISTOGRAM EQUALIZATION

In order to keep original histogram shape without losing its simple characteristics, the proposed DHE algorithm employs a derivative operation. The mathematical derivative model is defined as

$$\begin{aligned} D1 &= \frac{\partial f}{\partial k} = n_k - n_{k-1}, \\ D2 &= \frac{\partial^2 f}{\partial^2 k} = n_{k-1} + n_{k+1} - n_k, \end{aligned} \tag{15}$$

where $k = 0, 1, 2, \ldots, L - 1,$

where D1 and D2 represent 1^{st} and 2^{nd} derivative results from the input image's histogram distribution, respectively. Equation (15) can be implemented by simple hardware due to its simplicity.

Next, the DHE algorithm finds inflection points from the 1^{st} and 2^{nd} derivative results for the reason to separate the histogram. Fig. 2 shows the pseudo-code of the derivative algorithm. The two critical points are searched for and determined using the following two rules. First, searching for the first inflection point value from the 1^{st} derivative results where the histogram distribution increases in time. Then, obtain the second inflection point value from the 1^{st} derivative results while the histogram distribution falls in time. Next, two critical points will be defined according to the extracted inflection point. Then, the DHE algorithm uses the selected critical points to separate the input histogram into three sub images as BHE did with the mean value. Finally, histogram equalization will be applied to each sub image.

```
PROCEDURE Derivative_Function IS
    Input: Frame Histogram Table his = (r0, r1, …,rL-1)
    Output: Critical value = (c0, c1)
    Register: Inflection point = (i0, i1)
    Register: 1st derivative Table D1 = (d10, d11, ..., d1L-1)
    Register: 2nd derivative Table D2 = (d20, d21, ..., d2L-1)
BEGIN
    I1 = i0
    I2 = i1

    FOR i IN 0 TO L-1 LOOP
      D1(i) = his(i+1) – his(i)
    FOR i IN 0 TO L-2 LOOP
      D2(i) = D1(i+1) – D1(i)

    FOR i IN 0 TO L LOOP
      IF D2i = max(D2) AND I1 = 0 THEN
            I1 = i
      ELSE IF D2i = min(D2) AND I2 = 0 THEN
            I2  =i
    END LOOP;

    Critical(0) = I1/2
    Critical(1) = I2 + 2*(L – I2)/3
    RETURN Entropy value;

END PROCEDURE;
```

Fig. 2. Algorithm to search critical value from 1st and 2nd derivative results. (|$D2_i$| denotes the absolute value of 1st derivative.)

IV. Experimental Results

In order to demonstrate the performance of the proposed contrast enhancement algorithm, the HE, BHE and proposed DHE with UHD resolution samples are simulated in order to further display the ability of the proposed fast approach. Fig. 3 and 4 show the simulation results with the UHD resolution 4096x2160 in 16-bit high color depth of original photo, after HE, after BHE and after DHE. It can be easily observed from Fig. 3 that both HE and BHE reveal some annoyed effects, such as overhead brightness enhancement and white noise. Although HE and BHE provide great improvement in contrast enhancement, they cannot be accepted by human visual sensitivity because of the large artifacts that they introduced. By contrast, the proposed contrast enhancement algorithm performs more naturally than other methods.

Because of its simple derivative operation, the DHE algorithm can be applied by the FPGA system. The performance of the proposed algorithm using several examples of UHD resolution photos was verified in the C Language. Finally, it has been implemented on Terasic DE3 FPGA by using Verilog HDL to prove the concept practicality.

In Fig. 5., Terasic DE3 received and transmitted image stream by HSMC-HDMI daughter board which received data from computer by HDMI RX and transmitted data to monitor by HDMI TX. And DHE module will process the received image, then output result image in real-time.

(a) Original

(b)Histogram Equalization

(c) Bi-Histogram Equalization

(d) Dynamic Histogram Equalization

Fig. 3. Comparison results between different methods (Test1-2160×4096@16bit).

(a) Original

(b) Histogram equalization

(c) Bi-Histogram Equalization

(d) Dynamic Histogram Equalization

Fig. 4. Comparison results between different methods (Test4-4096×2160@16bit).

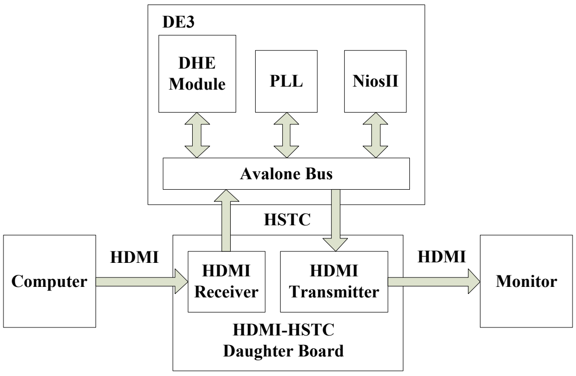


Fig. 5. DE3 results and block diagram for practical CE aspects

V. CONCLUSION

In this paper, a fast dynamic histogram equalization algorithm to perform contrast enhancement was proposed for large resolution. The experimental results show that the proposed DHE algorithm can preserve the original histogram features without overshooting the results efficiently. Furthermore, the simplicity of the DHE algorithm can ensure contrast enhancement in many electric appliances with large resolution requirements.

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