

# QUANTIZED BI-HISTOGRAM EQUALIZATION

Yeong-Taeg Kim

Signal Processing R&D Center, Samsung Electronics Co., Suwon, Korea  
(voice) +82-331-200-3186, (fax) +82-331-200-3147, (e-mail) kimyt@rnd.sec.samsung.co.kr

## ABSTRACT

Histogram equalization is a widely used scheme for contrast enhancement in a variety of applications due to its simple function and effectiveness. One possible drawback of the histogram equalization is that it can change the mean brightness of an image significantly as a consequence of histogram flattening. Clearly, this is not a desirable property when preserving the original mean brightness of a given image is necessary. As an effort to overcome such drawback for extending the applications of the histogram equalization in consumer electronic products, bi-histogram equalization has been proposed by the author [1, 2] which is capable of preserving the mean brightness of an image while it performs contrast enhancement. The essence of the bi-histogram equalization is to utilize independent histogram equalizations separately over two subimages obtained by decomposing the input image based on its mean. In this paper, a simplified version of the bi-histogram equalization is proposed, which will be referred to as the *quantized bi-histogram equalization*. The proposed algorithm provides much simple H/W structure than the bi-histogram equalization since it is based on the cumulative density function of a quantized image. Thus, the realization of bi-histogram equalization in H/W can be much feasible, which leads to versatile applications in the field of consumer electronics.

## 1 INTRODUCTION

Histogram equalization is a well-known method for enhancing the contrast of a given image in accordance with the sample distribution [3, 4]. Useful applications of the histogram equalization scheme include medical image processing and radar image processing [5, 6]. In general, histogram equalization flats the density distribution of the resultant image and enhances the contrast of the image as a consequence. In spite of its high performance in enhancing contrasts of a given image, however, it is rarely employed in consumer electronics such as TV since the straight use of histogram equalization may change the original brightness of an input image, deteriorate visual quality, or, introduce some annoying artifacts. Note that the mean brightness of the resultant output image approaches to the middle gray level as the output density of the histogram equalizer uniforms. In theory, it can be shown for the histogram equalization of an analog image that the mean of the equalized image is the middle gray level regardless of the input mean, which is not a desirable property in some applications where mean preserving is necessary.

In [1, 2], a novel extension of the histogram equalization, which is referred to as the *bi-histogram equalization*

(BHE), has been proposed to overcome the aforementioned problems of the histogram equalization. The ultimate goal of the BHE is to preserve the mean brightness of a given image while enhancing the contrast of an image. The BHE firstly decomposes an input image into two subimages based on the mean of the input image. One of the subimages is the set of the samples less than or equal to the mean whereas the other one is the set of the samples greater than the mean. Then the BHE equalizes the subimages independently based on their respective histograms with the constraint that the samples in the formal set are mapped into the range from the minimum gray level to the input mean and the samples in the latter set are mapped into the range from the mean to the maximum gray level. Thus, the resulting equalized subimages are bounded each other by the input mean, which has an effect of preserving mean brightness.

When implementing a histogram based algorithm in H/W, the realization of a cumulative function is essential. A typical implementation of a cumulative function for 8-bit image is depicted in Fig. 1, which is composed of 255 comparators, 256 counters, and 255 dividers. Since the realization of the BHE is also based on this structure, it can be understood that the associated H/W complexity for the BHE would be also high. In this paper, a simplified version of the bi-histogram equalization is proposed which will be referred to as the *quantized bi-histogram equalization* (QBHE). The proposed algorithm provides much simple H/W structure than the bi-histogram equalization since it utilizes the cumulative density function of a quantized image, which requires less number of comparators, counters, and dividers. Thus, the realization of histogram equalization in real application can be much feasible.

## 2 QUANTIZED BI-HISTOGRAM EQUALIZATION

Let  $\mathbf{X} = \{X(i, j)\}$  denote a given image composed of  $L$  discrete gray levels  $\{X_0, X_1, \dots, X_{L-1}\}$ , where  $X(i, j)$  represents an intensity of the image at the spatial location  $(i, j)$  and  $X(i, j) \in \{X_0, X_1, \dots, X_{L-1}\}$ . Consider the following quantization operation  $Q(\cdot)$  which quantizes the  $L$  discrete gray levels into  $K$  discrete levels denoted as  $\{Z_0, Z_1, \dots, Z_{K-1}\}$  as

$$Q(X(i, j)) = Z_q, \text{ if } Z_{q-1} < X(i, j) \leq Z_q, \quad (1)$$

where  $Z_{K-1} = X_{L-1}$  and  $\{Z_0, Z_1, \dots, Z_{K-1}\} \subset \{X_0, X_1, \dots, X_{L-1}\}$  are assumed.

Denoting by  $M$  the mean of the image  $\mathbf{X}$  which is assumed as  $M \in \{X_0, X_1, \dots, X_{L-1}\}$ , the input image is

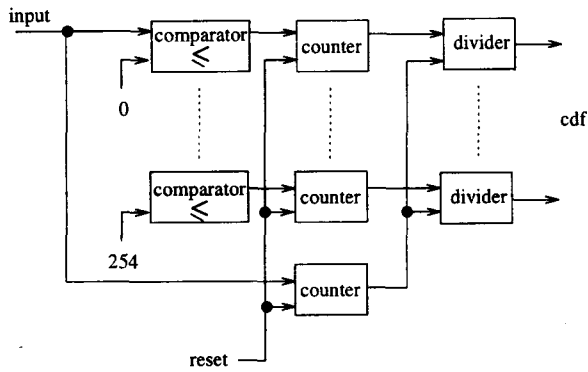


Figure 1. A typical H/W realization of a cumulative density function.

decomposed into two subimages  $\mathbf{X}_L$  and  $\mathbf{X}_U$  as

$$\mathbf{X} = \mathbf{X}_L \cup \mathbf{X}_U \quad (2)$$

where

$$\mathbf{X}_L = \{X(i, j) | X(i, j) \leq Z_m, \forall X(i, j) \in \mathbf{X}\} \quad (3)$$

and

$$\mathbf{X}_U = \{X(i, j) | X(i, j) > Z_m, \forall X(i, j) \in \mathbf{X}\}, \quad (4)$$

where  $Z_m = Q(M)$ .

For the subimage  $\mathbf{X}_L$ , let us define the *quantized cumulative density function (qcdf)* as

$$c_L^Q(Z_q) = \frac{n_L^q}{n_L} \quad (5)$$

for  $q = 0, 1, \dots, m$ , where  $n_L$  denotes the total number of samples in  $\mathbf{X}_L$ , and where  $n_L^q$  represents the number of samples satisfying

$$Q(X(i, j)) \leq Z_q, \forall X(i, j) \in \mathbf{X}_L. \quad (6)$$

Similarly, the qcdf for the subimage  $\mathbf{X}_U$  is defined as

$$c_U^Q(Z_q) = \frac{n_U^q}{n_U} \quad (7)$$

for  $q = m + 1, m + 2, \dots, K - 1$ , where  $n_U$  denotes the total number of samples in  $\mathbf{X}_U$ , and where  $n_U^q$  represents the number of samples satisfying

$$Q(X(i, j)) \leq Z_q, \forall X(i, j) \in \mathbf{X}_U. \quad (8)$$

By definition, it directly follows that  $c_L^Q(Z_m) = 1$  and  $c_U^Q(Z_{K-1}) = 1$ .

Note that the cdfs given in (5) and (7) contain partial information of the entire cumulative density functions. Conversely speaking, all the cumulative density function values for  $X_0, X_1, \dots, X_{L-1}$  are not included in the information behind the cdfs given in (5) and (7). In order to perform equalization properly, we need to evaluate the function value at every input gray level in some fashion. For this purpose, a linear interpolation is used. That is, for  $x \in \mathbf{X}_L$  where  $x \leq Z_m$ , if  $Q(x) = Z_q$  then  $c_L(x)$  is obtained by the following linear interpolation

$$c_L(x) = c_L^Q(Z_{q-1}) + (c_L^Q(Z_q) - c_L^Q(Z_{q-1})) \frac{x - Z_{q-1}}{Z_q - Z_{q-1}} \quad (9)$$

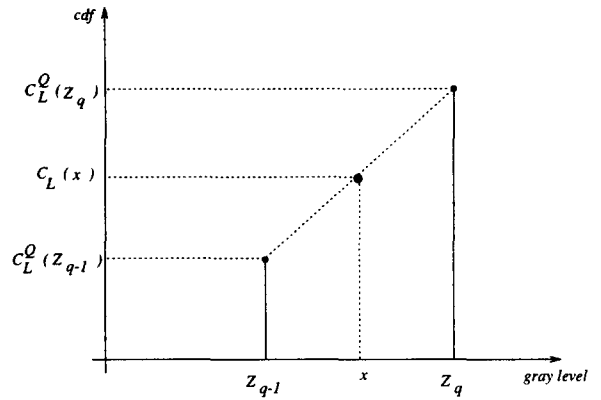


Figure 2. Linear interpolation of the cdf value for  $x$  when  $Q(x) = Z_q$  based on the given values  $c_L^Q(Z_{q-1})$  and  $c_L^Q(Z_q)$ .

with  $Z_{-1} = 0$ . This can be easily understood from Fig. 2. Similarly,  $x \in \mathbf{X}_U$  where  $x > Z_m$ , if  $Q(x) = Z_q$  then  $c_U(x)$  is approximated as

$$c_U(x) = c_U^Q(Z_{q-1}) + (c_U^Q(Z_q) - c_U^Q(Z_{q-1})) \frac{x - Z_{q-1}}{Z_q - Z_{q-1}} \quad (10)$$

with  $c_U(Z_m) = 0$ .

Once the cdf values are estimated for all input gray levels, the next process is much like the histogram equalization, where a cumulative density function is used as a transform function. Let us define the following transform functions exploiting the cumulative density functions as

$$f_L(x) = X_0 + (Z_m - X_0)c_L(x) \quad (11)$$

and

$$f_U(x) = Z_m^* + (X_{L-1} - Z_m^*)c_U(x), \quad (12)$$

where  $Z_m^*$  is the next upper gray level in  $\{X_0, X_1, \dots, X_{L-1}\}$  to  $Z_m$ . For instance, if  $X_{l-1} \leq Z_m < X_l$ , then  $Z_m^* = X_l$ . Based on these transform functions, the decomposed subimages are equalized independently and the composition of the resulting equalized subimages constitutes the output of the QBHE. That is, the output image of the QBHE,  $\mathbf{Y}$ , is finally expressed as

$$\mathbf{Y} = f_L(\mathbf{X}_L) \cup f_U(\mathbf{X}_U), \quad (13)$$

where

$$f_L(\mathbf{X}_L) = \{f_L(X(i, j)) | X(i, j) \in \mathbf{X}_L\} \quad (14)$$

and

$$f_U(\mathbf{X}_U) = \{f_U(X(i, j)) | X(i, j) \in \mathbf{X}_U\}. \quad (15)$$

If we note that  $0 \leq c_L(x), c_U(x) \leq 1$ , it is easy to see that  $f_L(\mathbf{X}_L)$  equalizes the subimage  $\mathbf{X}_L$  over the range  $(X_0, Z_m)$  whereas  $f_U(\mathbf{X}_U)$  equalizes the subimage  $\mathbf{X}_U$  over the range  $(Z_m^*, X_{L-1})$ . As a consequence, the input image  $\mathbf{X}$  is equalized over the entire dynamic range  $(X_0, X_{L-1})$  with the constraint that the samples less than the input mean are mapped to  $(X_0, Z_m)$  and the samples greater than the mean are mapped to  $(Z_m^*, X_{L-1})$ .

Referring to Fig. 1, let us turn our attention to the H/W complexity of the proposed algorithm. Note that the proposed algorithm requires  $K - 1$  comparators,  $K$  counters, and  $K - 1$  dividers, in realizing the cdfs in H/W as can be seen from (6) and (8). Hence, for  $K \ll L$ , it



Figure 3. The original image.

can be seen that significant save in H/W can be attained. The extra complexity required for the implementation of the proposed algorithm compared to the BHE is the interpolation function embedded in (11) and (12), which is much smaller than the degree of H/W reduction by the proposed algorithm.

### 3 SIMULATION RESULTS

To demonstrate the performance of the proposed algorithm, simulation results of the proposed algorithm are demonstrated in this section. A given 8-bit original image is shown in Fig. 3, and Fig. 4 illustrates the result of histogram equalization. The result of BHE is shown in Fig. 5, and the results of the proposed algorithm for  $K = 32$ , 8 and  $K = 4$  are shown in Figs. 6 to 8, respectively. If we compare the images shown in Figs. 3 and 5, it can be noted that there occurs a significant brightness change after the histogram equalization, i.e., the image has been darkened significantly by the histogram equalization. The original mean brightness is 209 whereas the mean brightness of the image shown in Fig. 4 is 125. However, observe that the brightness of the original image is preserved well by both BHE and QBHE as can be seen from Figs. 5 to 8. The respective mean brightness of the images shown in Figs. 5 to 8 are 182, 183, 189, and 200. We can observe that the degree of contrast enhancement of the QBHE is decreasing as  $K$  decreases. However, note that the results of QBHE for  $K = 32$  and  $K = 8$  are highly comparable to the result of BHE which utilizes entire cumulative density function. If we recall that the proposed algorithm requires much less H/W complexity than the BHE for small  $K$ , simulation result clearly indicates that the proposed algorithm is much fascinating than the BHE when applying to real consumer products.

### 4 CONCLUSION

In this paper, a newly developed contrast enhancement algorithm referred to as the *quantized bi-histogram equalization* (QBHE) is proposed. The QBHE is a novel extension



Figure 4. The result of histogram equalization.

of a typical histogram equalization, which utilizes cumulative density function of a quantized image for the purpose of H/W reduction and performs independent histogram equalizations over two subimages obtained by decomposing the input image based on its mean. The ultimate goal behind the QBHE is to preserve the mean brightness of a given image effectively with less H/W complexity while enhancing the contrast of a given image. Simulation results demonstrate the brightness-preserving property of the QBHE while enhancing contrasts. Hence, many applications can be made possible by utilizing the proposed algorithm in the field of consumer electronics, such as TV, VTR, or, camcorder.

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Figure 5. The result of BHE.



Figure 7. The result of QBHE with  $K = 8$ .



Figure 6. The result of QBHE with  $K = 32$ .



Figure 8. The result of QBHE with  $K = 4$ .