A Literature Review on Histogram Equalization and Its Variations for Digital Image Enhancement

Nicholas Sia Pik Kong, Haidi Ibrahim, and Seng Chun Hoo

***Abstract*—Global Histogram Equalization (GHE) is a well-known image enhancement method. Despite of its simplicity and popularity, GHE still has limitations. GHE usually causes the shifting of the mean luminance of the image, produces artifacts and unnatural enhancements, and does not consider local information in its process. Therefore, these limitations lead to the development of several histogram equalization (HE) methods. This paper surveys some of HE based methods. These methods generally fall into three main families of HE, namely Mean Brightness Preserving HE (MBPHE), Bin Modified HE (BMHE), and Local HE (LHE).**

***Index Terms*—Image enhancement, contrast enhancement, histogram equalization.**

I. Introduction

Histogram is one of the important features which are very related to image enhancement. The histogram does not only gives us a general overview on some useful image statistics (e.g. mode, and dynamic range of an image), but it also can be used to predict the appearance and intensity characteristic of an image. If the histogram is concentrated on the low side of the intensity scale, the image is mostly a dark image. On the other hand, if the histogram is concentrated on the high side of the scale, the image is mostly a bright image. If the histogram has a narrow dynamic range, the image usually is an image with a poor contrast [1].

In order to define a histogram, first, assume that $X=\{X(i, j)\}$ is an image that is composed of L discrete gray levels denoted by $\{X_0, X_1,\ldots, X_{L-1}\}$. Here, $X(i, j)$ represents the intensity of the image at spatial location (i, j) with the condition that $X(i, j)\in \{X_0,X_1,\ldots,X_{L-1}\}$. As the intensities are all in discrete values, the histogram of a digital image is a discrete function. Then, the histogram h is defined as:

$$h(X_k) = n_k, \qquad \text{for } k=0, 1, \ldots, L\text{-}1 \tag{1}$$

where X_k is the k-th gray level and n_k presents the number of times that the gray level X_k appears in the image. In other words, the histogram is the frequency of occurrence of the gray levels in the image [2].

Alternatively, as used by Wang et al. [3], and Wang and Ye [4], the histogram also can be defined as the statistic probability distribution of each gray level in a digital image. For a given image **X**, the Probability Density Function (PDF) for intensity X_k, $p(X_k)$, is given by:

$$p(X_k) = n_k / N, \qquad \text{for } k=0, 1, \ldots, L\text{-}1 \tag{2}$$

where N is the total number of samples in the image. By comparing equation (2) with equation (1), the PDF is actually a normalized version of the histogram. Usually, the histogram of an image **X** is presented as a graph plots of $h(X_k)$ versus X_k, or $p(X_k)$ versus X_k.

There are many Histogram Equalization (HE) methods for digital image contrast enhancement. One of the well-known HE methods is Global Histogram Equlization (GHE), which is also known as Tradisional HE [5] and [6], Classical HE [2] and [7], Conventional HE [8]-[10], and Typical HE [11]-[13]. The basic idea of GHE method is to remap the gray levels of an image based on the image's gray levels cumulative density function.

GHE uses the information of the whole intensity values inside the image for its transformation function and thus this method is suitable for global enhancement [14]. Its goal is to redistribute the intensity of an image uniformly over the entire range of gray-levels (i.e. the image's cumulative histogram is linear) which is very effective for enhancing low contrast detail of an image [15] and maximize the entropy of an image [2] and [4].

GHE attempts to "spread out" the intensity levels belongs to an image to cover the entire available intensity range [16]. GHE flattens and stretches the dynamic range of the resultant image histogram and as a consequence, the enhanced image will optimally utilize the available display levels [17]. This then yields an overall contrast improvement.

A. GHE Algorithm

The sum of all components of a normalized histogram or PDF results a Cumulative Density Function (CDF) of an image. Based on the PDF in equation (2), the CDF for intensity X_k, $c(X_k)$, is defined by the following equation:

$$c(X_k) = \sum_{j=0}^{k} p(X_j) \quad \text{for } k=0, 1, \ldots, L\text{-}1 \tag{3}$$

where by definition, $c(X_k)$=1. GHE is a scheme that maps the input image into the entire dynamic range, $[X_0,X_{L-1}]$, by using CDF as its transformation function. Now, let $x=X_k$. The transform function, $f(x)$, is defined based on the CDF as:

$$f(x) = X_0 + (X_{L-1} - X_0).c(x) \quad \text{for } k=0, 1, \ldots, L\text{-}1 \tag{4}$$

From here, the output image produced by GHE, $\mathbf{Y}=\{Y(i, j)\}$, can be expressed as in the following equation:

$$\mathbf{Y} = f(\mathbf{X}) = \{ f(X(i, j)) \mid \forall X(i, j) \in \mathbf{X}\} \tag{5}$$

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B. Limitations of GHE

Although GHE is suitable for an overall contrast enhancement, practically there are some limitations associated with GHE. Although GHE successfully stretches and expands the dynamic range of the image [1], the histogram is far from being flat. The histogram of the output image may contain many empty bins (A bin is defined as a series of equal intervals in a dynamic range of an image employed to describe the divisions in a histogram.) because the histogram is actually a shifted version of the original histogram [7]. Thus, the entropy value of the GHE enhanced image is almost similar to the original version, and not maximized as expected in theory.

GHE also usually causes level saturation (clipping) effects in small but visually important areas [5]. This happen because GHE extremely pushes the intensities towards the right (bright) or the left (dark) side of the histogram. If the input image is dominated by dark intensity pixels, the histogram is pushed to the right side, and thus bright saturation effect will be clearly visible. On the other hand, if the input is dominated by bright intensity pixels, the output normally suffers from dark saturation effect. This saturation effect, not only degrades the appearance of the image, but also leads to information loss [14].

GHE does the enhancement globally, without considering the local contents of the image. GHE method is effective in enhancing the low contrast image when the input image contains only one big single object, or when there is no appearance contrast change between the object and the background in the image [18]. For other images, GHE mapping often result in undesirable effects such as over enhancement for intensity levels with high probabilities, and loss of contrast for levels with low probabilities [5], [14], [18], [19] and [20]. Thus, the enhancement might be biased towards the depiction of parts of the image which are unimportant for the viewer such as the background area of the image [21] and [22]. As a consequence, GHE algorithm is not applicable to many image modalities, such as infrared image, because this algorithm usually enhances the image's background instead of the object that occupies only a small portion of the image [23].

Furthermore, GHE often causes the shifting on the average (i.e. mean) luminance of the image [3], which is a well-known mean-shift problem [20]. Therefore, GHE is rarely employed in consumer electronic products such as video surveillance, digital camera, and digital television, where the brightness preserving characteristic of the enhancement method is crucial [4]. A dark movie scene displayed on television, for example, should be maintained dark in order to keep its artistic value. Besides, the excessive change in brightness level introduce by GHE leads to annoying artifacts and unnatural enhancement. The noise in the image is also enhanced or magnified [24]. Thus, although GHE can increase the brightness level in the image, this technique might significantly degrade the quality of the image.

II. Extensions of Histogram Equalization Technique

The limitations of GHE as mentioned in Subsection I.*B* have encouraged many researchers to actively develop various extensions to Histogram Equalization (HE) method. Generally, variations of HE can be classified into four groups as shown in Fig. 1. In addition to GHE, they are Mean Brightness Preserving HE, Bin Modified HE, and Local HE. Hence, this paper provides a literature review on some of the extensions of HE. Subsection II. *A* will discuss about the Mean Brightness Preserving HE methods. Then, the Bin Modified HE will be presented in Subsection II. *B*. After that, Subsection II. *C* will give in details about the Local HE.

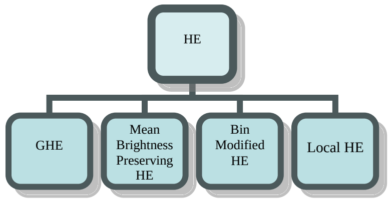

Fig. 1. Block diagram of HE's extensions.

A. Mean Brightness Preserving Histogram Equalization (MBPHE)

MBPHE is a novel extension to HE. This type of enhancement method is specially developed for the use in consumer electronic products such as digital television, digital camera and camcorder. The idea of keeping the mean brightness of an image for consumer electronic products is first introduced by Kim [12]. By preserving the mean brightness, this is not only can maintain the artistic value of the image, but it is also proven that this methodology can reduce the saturation effect, and able to avoid unnatural enhancement and annoying artefacts on the output image.

Commonly, MBPHE decomposes the input image into two or more sub-images, and then it equalizes the histograms of these sub-images independently. The major difference among the MBPHE methods is the criteria used to decompose the input image. Examples of MBPHE methods are Brightness Preserving Bi-HE (BBHE) [12], Quantized Bi-HE (QBHE) [11], Dual Sub-Image HE (DSIHE) [3], Minimum Mean Brightness Error Bi-HE (MMBEBHE) [25] and [26], Recursive Mean-Separate HE (RMSHE) [13] and [26], Recursive Sub-Image HE (RSIHE) [10], Recursive Separated and Weighted HE (RSWHE) [20], Multipeak HE (MPHE) [27], Dynamic HE (DHE) [14], Multi-HE (MHE) [2] and [28], Brightness Preserving Weight Clustering HE (BPWCHE) [29], Brightness Preserving Dynamic HE (BPDHE) [30], and HE with Range Offset (HERO) [31].

B. Bin Modified Histogram Equalization (BMHE)

GHE stretches the contrast of the high histogram region, and compresses the contrast of the low histogram regions [29]. As a consequence, when the object of interest in an image only occupies a small portion of the image, this object will not be successfully enhanced by GHE. Thus, to overcome this limitation, an extension of HE, which is the Bin Modified Histogram Equalization (BMHE) has been introduced.

BMHE modifies the shape of the image histogram by reducing or increasing the value in the histogram's bins based on a threshold limit before the equalization is taking place. Examples of BMHE based methods are Bin

Underflow and Bin Overflow HE (BUBOHE) [32], Weighted and Thresholded HE (WTHE) [5] and Self-Adaptive Plateau HE (SAPHE) [23].

C. Local Histogram Equalization (LHE)

It is known that GHE cannot adapt with the local brightness features of the input image [14]. As a consequence, GHE normally fails to enhance the input image with illumination problem. This is because GHE does the enhancement globally, without considering the local content of the image which is usually contains small or hidden details inside it. GHE uses only one single CDF, which is obtained from the entire pixels in the image, to construct its transform function. Thus, the same transform function is being used by all pixels in that image.

To overcome this limitation, an extension to HE known as Local Histogram Equalization (LHE) has been introduced. The main idea of LHE is to define a local transform function for each pixel based on its surrounding neighbouring pixels [5].

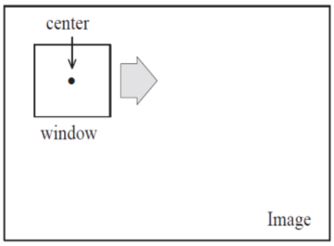

Fig. 2. The basic concept of LHE operation.

Generally, LHE uses a small window to define a Contextual Region (CR) for the center pixel of that window. The relationship between the image and the window is illustrated in Fig. 2. Only the block of pixels that fall in this window is taken into account for the calculation of CDF. Thus, as the window slides, the CDF is modified.

The CDF is the main contributor for the HE transform function. Hence, in LHE, the transform function of a pixel is depending on the statistics of its neighbors in CR. Because the transform function changes as a response to the changes in the contents of CR, LHE is also popularly known as Adaptive Histogram Equalization (AHE) [6] and [33]. Examples of LHE methods are Non-Overlapped Block HE (NOBHE) [1], Block Overlapped HE (BOHE) [1], [19] and [21], Interpolated Adaptive HE (IAHE) [34], Weighted Adaptive HE (WAHE) [34], Contrast Limited Adaptive HE (CLAHE) [34] and [35], Variable Region Adaptive HE (VRAHE) [36], Local Information HE (LIHE) [37], Spatio-Temporally Adaptive HE (STAHE) [19], Partially Overlapped Sub-Block HE (POSHE) [38], Conditional Sub-Block Bi-HE (CSBHE) [39], and Multiple Layers Block Overlapped HE (MLBOHE) [40].

III. Remarks

In this paper, extensions to HE which are MBPHE, BMHE, and LHE, have been presented. MBPHE methods aim to preserve the overall mean brightness of the original image in the enhanced image, mostly for the implementation in consumer electronic products. After having an extensive review on MBPHE, it is realized that although many MBPHE methods have been developed, most of them give too much constrain on preserving the mean brightness, rather than enhances the image. Therefore, not much contrast improvement could be obtained from these methods. By altering the input histogram, BMHE methods are able to control the enhancement rate, thus avoid over amplification of noise in an image. However, in order to obtain a good enhancement result, the threshold which is needed to be selected optimally by the user, is difficult to be determined. LHE methods are suitable to be used to reveal small and hidden image content. However, these methods require long processing time, sensitive to noise, and produce unnatural enhancement.

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