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RESEARCH ARTICLE

Low-complexity Histogram Modification Algorithm for Contrast Enhancement

V.Magudeeswaran[1], M.Krishnamurthy[2]
[1]Department of ECE, P.S.N.A college of Engineering and Technology, Dindigul-624622, India
[2]Department of ECE, P.S.N.A college of Engineering and Technology, Dindigul-624622, India

Corresponding Author email: *magudeeswaran@gmail.com*

Abstract— Histogram equalization is widely used in different ways to perform contrast enhancement in images. In this paper, a new Histogram modification algorithm is proposed for contrast enhancement of images. Histogram Equalization (HE) is one of the most popular technique used for digital image enhancement, but it is not suitable to be implemented directly in consumer electronics, such as television, because this method tends to produce an output with saturation effect. To overcome this weakness, Low-complexity Histogram Modification Algorithm is proposed that works well with both video and still images, and it enhances the images without making any loss in image details.

Key Terms: - Contrast enhancement; Histogram equalization; Dynamic histogram specification; Histogram modification

I. INTRODUCTION

Contrast enhancement is an important area in image processing for both human and computer vision. It is widely used for medical image processing and as a pre-processing step in speech recognition, texture synthesis, and many other image/video processing applications [1]-[4]. There are several reasons for an image/video to have poor contrast: the poor quality of the used imaging device, lack of expertise of the operator, and the adverse external conditions at the time of acquisition. These effects result in under-utilization of the offered dynamic range. As a result, such images and videos may not reveal all the details in the captured scene, and may have a washed-out and unnatural look. Contrast enhancement targets to eliminate these problems, thereby to obtain a more visually-pleasing or informative image or both. Different methods have already been developed for this purpose [5] - [17].

A very popular technique for contrast enhancement of images is Histogram Equalization (HE) [4]-[7]. It is the most commonly used method due to its simplicity and comparatively better performance on almost all types of images. HE performs its operation by remapping the gray levels of the image based on the probability distribution of the input gray levels [5]. Generally, we can classify these methods in two principle categories – global and local histogram equalization [6]. Global Histogram Equalization (GHE) [4] uses the histogram information of the entire input image for its transformation function. Though this global approach is suitable for overall enhancement, it fails to adapt with the local brightness features of the input image. If there are some gray levels in the image with very high frequencies, they dominate the other gray levels having lower frequencies. In such a situation, GHE remaps the gray levels in such a way that the contrast stretching becomes limited in some dominating gray levels having larger image histogram components and causes significant contrast loss for other small ones. Local Histogram Equalization (LHE) [4] uses a small window that slides through every pixel of the image sequentially and only the block of pixels that fall in this window are taken into account for HE and then gray level mapping for enhancement is done only for the center pixel of that window. Thus, it can make remarkable use of local information also. However, LHE requires high computational cost and sometimes causes over-enhancement in some portion of the image. Another problem of this method is that it also enhances the noises in the input image along with the image features. Nonetheless, most of the time, these methods produce an undesirable checkerboard effects on enhanced images [4].

Histogram Specification (HS) [4] is another method that takes a desired histogram by which the expected output image histogram can be controlled. However specifying the output histogram is not a smooth task as it varies from image to image. A method called Dynamic Histogram Specification (DHS) is presented in [9], which generates the specified histogram dynamically from the input image. This method can preserve the original input image histogram characteristics. However, the degree of enhancement is not that much significant.

Some researchers have also focused on improvement of histogram equalization based contrast enhancement such as Mean Preserving Bi-histogram Equalization BBHE [17], Equal area Dualistic Sub-image Histogram Equalization (DSIHE) [7] and Minimum Mean Brightness Error Bi-histogram Equalization (MMBEBHE) [8]. BBHE separates the input image histogram into two parts based on input mean. After separation, each part is equalized independently. This method tries to overcome the brightness preservation problem. DSIHE method uses entropy value for histogram separation. MMBEBHE is the extension of BBHE method that provides perform good contrast enhancement, they also cause more annoying side effects depending on the variation of gray level distribution in the histogram. Recursive Mean-Separate Histogram Equalization (RMSHE) [3] is another improvement of BBHE. However, it also is not free from side effects.

The aforementioned contrast enhancement techniques perform well on some images but they can create problems when a sequence of images is enhanced, or when the histogram has spikes, or when a natural looking enhanced image is strictly required.

In addition, computational complexity and controllability become an important issue when the goal is to design a contrast enhancement algorithm for consumer products. In summary, our goal in this paper is to obtain a visually pleasing enhancement method that has low-computational complexity and works well with both video and still images. To overcome the aforementioned problems we have proposed a GCE Histogram modification algorithm in this paper.

The rest of the paper is organized as follows. Section II gives some of the existing methods, and the proposed method is described in Section III.

II. HETECHNIQUES

In this section, we review some of the existing HE approaches in brief. Here we discuss about GHE, LHE, DHS and some methods based on histogram partitioning.

A. Global Histogram Equalization (GHE)

Contrast of images is determined by its dynamic range, which is defined as the ratio between the brightest and the darkest pixel intensities. The histogram provides information for the contrast and overall intensity distribution of an image. Suppose input image f(x, y) composed of discrete gray levels in the dynamic range of [0, L-1]. The transformation function C(rk) is defined as

$$S_k = C(r_k) = \sum_{i=0}^{k} p(r_i) = \sum_{i=0}^{k} \frac{n_i}{n} \quad (1)$$

Where $0 \le sk \le 1$ and k = 0, 1, 2, …, L-1

In (1), ni represents the number of pixels having gray level ri, n is the total number of pixels in the input image, and P(ri) represents as the Probability Density Function (PDF) of the input gray level ri. Based on the PDF, the Cumulative Density Function (CDF) is defined as C (rk). This mapping in (1) is called Global Histogram Equalization (GHE) or Histogram Linearization. Here sk can easily be mapped to the dynamic range of [0, L-1] multiplying it by (L-1). The result image of HE is enhanced in contrast. However, it also has unnatural look because of over enhancement in brightness.

Fig. 1(b) shows that GHE provides a significant improvement in image contrast, but along with some artifacts and undesirable side effects such as washed out appearance in the gray levels of the flower. In (1), larger values of nk cause the respective gray levels to be mapped apart from each other forcing the mappings of the smaller nk values to be condensed in a small range with the possibility of duplications. This is the main source of such side effects and loss of image details.

Fig. 1 (a) Original image (b) GHEed image

B. Local Histogram Equalization (LHE)

While GHE takes into account the global information and cannot adapt to local light condition, Local Histogram Equalization (LHE) performs block-overlapped histogram equalization [6], [10]. LHE defines a sub-block and retrieves its histogram information. Then, histogram equalization is applied for the center pixel using the CDF of that sub-block. Next, the sub-block is moved by one pixel and sub-block histogram equalization is repeated until the end of the input image is reached. Though LHE cannot adapt well to partial light information [9], still it over-enhances some portions depending on its mask size.

Fig. 2(a) shows the results of applying LHE to Fig 1(a). In Fig. 2(a), the background noises are much enhanced depending on the block size. Actually, using a perfect block size that enhances all part of an image is not an easy and smooth task to perform.

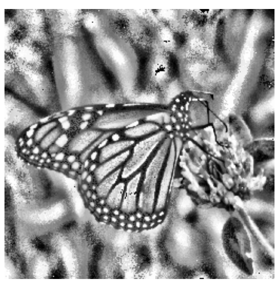

Fig.2 (a) LHEed image (d) DHSed image

C. Histogram Specification (HS)

Histogram specification is a technique that transforms the histogram of one image into the histogram of another image. This transformation can be easily accomplished by recognizing that if instead of using an equally spaced ideal histogram (as in histogram equalization), one is specified explicitly. Histogram specification is applied when we want to transform the histogram of image into a specified histogram to achieve highlighted gray level ranges.

$$v_k = C(z_k) = \sum_{i=0}^{k} p(r_i) = s_k \tag{2}$$

Where k = 0, 1, 2, …, L-1.

Note that, sk and vk represent the CDFs of histograms of the input image and the specified histogram respectively.

D. Dynamic Histogram Specification (DHS)

This approach selects some Critical Points (CP) from the image histogram. Then based on these CPs and other components of the histogram, it creates a specified histogram. Then HS is applied on the image based on this specified histogram. DHS enhances the image keeping some histogram characteristics since the specified histogram is created from the input image histogram. However, as it does not change the dynamic range, the overall contrast of the image is not much enhanced. Moreover, sometimes it causes some artifacts in the images.

E. Dynamic histogram equalization (DHE)

In spite of processing the whole histogram with the transformation function at a time, DHE divides it in to a number of sub-histograms until it ensures that no dominating portion is present in any of the newly created sub-histograms. Then a dynamic Gray Level (GL) range is allocated for each sub-histogram to which its gray levels can be mapped by HE. This is done by distributing total available dynamic range of gray levels among the sub histograms based on their dynamic range in input image and Cumulative Distribution Function (CDF) of histogram values.

Fig. 3(b) shows the results of applying DHE to Fig 3(a). As a result, there will be no significant loss in image details.

Fig. 3 (a) Original image (b) DHE image

III. HISTOGRAM MODIFICATION FRAMEWORK

Histogram-based contrast enhancement techniques utilize the image histogram to obtain a single-indexed mapping T[n] to modify the pixel values. In HE and other histogram-based methods; mapping function is obtained from the histogram or the modified histogram, respectively. HE finds a mapping to obtain an image with a histogram that is as close as possible to a uniform distribution to fully exploit the dynamic range. A histogram can be regarded as an un-normalized discrete probability mass function of the pixel intensities. The normalized histogram p[n] of an image gives the approximate Probability Density Function (PDF) of its pixel intensities. Then, the approximate Cumulative Distribution Function (CDF), C[n], is obtained from p[n]. The mapping function is a scaled version of this CDF. HE uses the image histogram to obtain the mapping function; whereas, other histogram-based methods obtain the mapping function via the modified histogram. The mapping function in the discrete form is given as

$$T[n] = \left\lfloor (2^B - 1)\sum_{i=0}^{n} P[j] + 0.5 \right\rfloor \tag{3}$$

Where B is the number of bits used to represent the pixel values, and $n \in [0, 2^B - 1]$. Although the histogram of the processed image will be as uniform as possible, it may not be exactly uniform because of the discrete nature of the pixel intensities.

It is also possible to enhance the contrast without using the histogram. Black stretching and white stretching are simple but effective techniques used in consumer-grade TV sets. Black stretching makes dark pixels darker, while white stretching makes bright pixels brighter. This produces more natural looking black and white regions; hence, it enhances the contrast of the image.

A. Low-complexity histogram Modification algorithm

In this section, a low-complexity histogram modification algorithm is presented. The pseudo-code of the algorithm is given in algorithm. It deals with histogram spikes, performs B&W stretching, and adjusts the level of enhancement adaptively so that the dynamic range is better utilized while handling the noise visibility and the natural look requirements.

Algorithm: GCE Histogram Modification Algorithm

Input: Input image: f,

B&W stretch parameters: b, w, and $1/1+\alpha$

Level of enhancement: g

Output: Modified histogram: $\tilde{h}$

1 Initialize k;

2 for each row m do

3 for each column n do

4 $k = k + f[m,n] - f[m,n-2]$;

5 if $k = k + f[m,n] - f[m,n-2]$ >Threshold then

6 $++h_i[f[m,n]];$

7 $++count$;

8 end

9 end

10 end

11 Normalize gk to get k^* ;

12 $u = \min\{count/256, u_{\min}\}$;

13 for each bin n do

14 if b<n<w then

15 $\tilde{h} = (1-k^*)u + k^* h_i[n]$;

16 else

17 $\tilde{h} = 1/1-\alpha\left[(1-k^*)u + k^* h_i[n]\right]$;

18 end

19 end

B. Adjusting the Level of Enhancement

As described in Section III, it is possible to adjust the level of histogram equalization to achieve natural looking enhanced images. The modified histogram is a weighted average of the input histogram and the uniform histogram. The contribution of the input histogram in the modified histogram is $k^* = 1/1+\lambda$. The level of histogram equalization should be adjusted depending on the input image's contrast. Low contrast images have narrow histograms and with histogram equalization, contouring and noise can be created. Therefore, k is computed to measure the input contrast using the aggregated outputs of horizontal two-lagged difference operation (step 4). Afterwards, k is multiplied by a user-controlled parameter g, then gk is normalized to the range [0, 1] (step 11) to get k^*. It is a good practice to limit the maximum contribution of a histogram, since this will help with the worst-case artifacts created due to histogram equalization. By choosing the maximum value that can take on as a power of two, the normalization step can be done using a bit-shift operation rather than a costly division. To ensure that h_i and u have the same normalization, umin is obtained using the number of pixels that are included in the histogram (step 12). is used to ensure that very low bin regions of the histogram will not result in very low slope in the mapping function; it will increase the slope in these regions, resulting in increased-utilization of dynamic range.

B&W stretching is performed using (14) (step 17). Parameters b, w, and α can be adapted with the image content. And w is usually derived from the histogram as the minimum and maximum intensities. For noise robustness, should be chosen as the minimum gray-level that is bigger than some predefined number of pixels' intensities, w can be chosen similarly. It is a good practice to impose limits on b and w. The stretching parameter should also be adapted with image content. For dark images white stretching can be favoured, while for bright images black stretching can be favoured. α May also depend on the input image's contrast.

IV. CONCLUSION

A general framework for image contrast enhancement is presented. GCE Histogram Modification Algorithm enhances the image without making any loss in image details. However, if user is not satisfied, he/she may control the extent of enhancement (i.e., the amount of loss of details he/she is ready to accept) by adjusting only one parameter. Moreover, the method is simple and computationally effective that makes it easy to implement and use in real time systems.

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