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Review of Contrast Enhancement Techniques Based on Histogram Processing

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***Abstract*—** Image enhancement is one of the basic steps used in digital image processing. Here the image is manipulated to make it more suitable than the original image for specific purposes. It is used to modify the contrast of an image. Here the intensity of the input image is manipulated to make the best use of available grayscale values. A wide range of contrast enhancement methods available work upon the histogram of an image to make the image visually suitable for either viewing or further development. We need to study and review different contrast enhancement techniques primarily operating on the histogram of an image. Depending on the nature of the technique these are classified into global and local contrast enhancement techniques. This paper focuses on a comparative study of contrast enhancement techniques and draws conclusions considering their pros and cons.

***Keywords*—** Contrast enhancement, histogram equalization

I. INTRODUCTION

Image enhancement is the process that manipulates the image to make it suitable for a specific purpose. It is used to improve the visual appearance of the image. Image enhancement improves the contrast of an image to make the subject stand out of the background. Image enhancement is one of the most interesting areas of digital image processing. Image enhancement methods are broadly divided into two categories: spatial-domain methods and frequency-domain methods. Spatial-domain methods directly manipulate the pixels of the image. On the other hand, frequency-domain methods operate on the Fourier transform of an image.

Image enhancement plays an important role in many fields such as medical image processing, remote sensing, television and broadcast industry, industrial X-ray image processing, microscopic image processing, urban surveillance systems etc. It is mainly used to improve the visual clarity of an image and improve the dynamic range needed in most automation systems. Generally, the original acquired image has poor dynamic range and distortion due to imaging device fault or adverse external conditions at the time of acquisition. The contrast enhancement technique helps here by improving the dynamic range of the image for simultaneous display.

There are various contrast enhancement techniques available in the spatial domain due to their direct pixel manipulation approach. Among these, many techniques make use of the histogram of the image. These techniques analyze some properties of the histogram and apply some methods and manipulate it and make the image visually more appealing. Again, the histogram modification techniques are broadly divided into two types: global contrast enhancement and local contrast enhancement based on which histogram is taken into consideration. One of the most widely used histogram modification technique is the Histogram Equalization (HE). The main goal of HE is to remap the grayscales so that the resultant histogram obeys a uniform distribution [1]. The global contrast enhancement methods consider the image as a whole and perform the enhancement operations. As a result, the contrast is improved by stretching the intensity distribution. But the major drawback of global enhancement techniques is they don’t adapt to local brightness [1]. On the other hand, the local contrast enhancement methods use different contrast enhancement functions to each area of the image. But these techniques often result in enhancing the noise pixels. Due to these complementary characteristics, depending on the situation many techniques are developed for both global and local contrast enhancement.

This paper is organized as follows: Section II describes the different contrast enhancement techniques. Section III gives a comparative discussion of the techniques and section IV summarizes the related works into a table. At last, we conclude the paper in section V.

II. METHODOLOGY

Histogram Equalization (HE)

Histogram equalization is widely used in contrast enhancement due to its simple function and lesser computational complexity. It works by stretching the gray levels of the input image over the entire dynamic range. For this purpose, it uses the cumulative density function as a transform function. The main problem of histogram equalization is that the brightness of the image changes after the operation is performed. Hence it is not suitable for the consumer electronics where preserving the original brightness and enhancing the contrast are important [2,3].

Brightness Preserving Bi-Histogram Equalization (BBHE)

To overcome the drawbacks of histogram equalization, a brightness preserving bi-histogram equalization method was proposed. The BBHE firstly decomposes an input image based on the mean of the input image. One sub-image has intensity values less than or equal to the mean intensity value and the other has intensity values greater than the mean value. Then the sub-images are equalized independently. The ranges of their respective histograms are from minimum gray level to mean value and from mean value to the maximum gray level. Thus, the mean brightness of the image is preserved [4].

Dualistic Sub-Image Histogram Equalization (DSIHE)

The HE method stretches the gray levels with heavy probability density over a large scale of dynamic range, which often causes the average luminance of the image to shift significantly. To overcome this problem a dualistic sub-image histogram equalization method is proposed. This method also divides the image into two sub-images like BBHE. But unlike BBHE, where the mean brightness of the input image considered to divide the input image, DSIHE separates the histogram based on the gray-level with cumulative probability density equal to 0.5. The result is obtained after composing the two sub-images into one. This algorithm enhances the visual information as well as prevents the original image gray level from a great shift [5].

Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE)

This method is similar to the BBHE and DSIHE method. But instead of using mean or cumulative density function to divide the input image into sub-images, it divides the histogram such that the brightness difference between the input image and output image is minimum. Once the input image is divided based on the threshold value, the sub-images are equalized using the classical HE method. This method allows us to obtain the brightness of the output image without generating the output image [6].

MMBEBHE technique consists of three steps:

1. Calculate the absolute mean brightness error (AMBE) for each of the threshold levels.
2. Find the threshold level, XT that yield minimum MBE.
3. Separate the input histogram into two based on the XT found in step 2 and equalized them independently as in BBHE.

Step 1 uses considerable computation power when the gray levels are large, which is a major drawback for real-time applications.

Recursive Mean-Separate Histogram Equalization (RMSHE)

RMSHE is a generalization of HE and BBHE in terms of brightness preservation. Instead of subdividing the input image only once, it allows us to recursively divide the histogram based on the mean value of the divided histogram. After dividing the histogram, HE is performed for each part. For recursion level 0 no sub-image is generated and the method performs the same as HE. For recursion level 1 the image is divided into 2 sub-images and the method performs as BBHE. The preservation of the brightness of output image increases as the number of recursion levels increases. It is analyzed mathematically that the output image's mean brightness will converge to the input image's mean brightness as the number of recursive mean separation increases. Besides, the recursive nature of RMSHE also allows scalable brightness preservation, which is very useful in consumer electronics [7].

Multi Histogram Equalization (MHE)

Multi histogram equalization subdivides the input image into several sub-images and the applies histogram equalization to each part. The image decomposition is based on the histogram of the image. The histogram is divided into classes, determined by threshold levels, where each histogram class represents a sub-image. The decomposition process can be seen as an image segmentation process executed through multi-threshold selection [8].

Brightness Preserving Dynamic Histogram Equalization (BPDHE)

BPDHE divides the histogram based on the local maxima. Then each partition is mapped to a new dynamic range and equalization is performed. As the intensities are mapped to new values, after equalization normalization is done to preserve the average brightness [9].

The steps involved in BPDHE are

1. Smooth the histogram with a Gaussian filter:

It is done to fill the empty bins of the histogram and get a smoother histogram.

2. Detect and find the locations of local maximums:

The locations of the local maximum are detected based on the first derivative of the smoothed histogram.

3. Map each partition into a new dynamic range:

This step is employed to use all the dynamic range available in the image.

4. Equalize each partition independently:

Histogram equalization is carried out in each partition of the histogram, independently.

5. Normalize the image brightness:

This step is done to maintain the mean brightness of the image.

Plateau Histogram Equalization (PHE)

Plateau Histogram equalization, unlike the above contrast enhancement techniques, is used in mapping the raw data pixels into a range suitable for simultaneous display. It is mainly used in infrared imagery devices for mapping the 14-bit raw pixel data into 8 bits for display purposes. It is a modification of histogram equalization, where an appropriate threshold value is selected first, which is represented as 'T'. If the value of P(k) is greater than T, then it is forced to equal to T, otherwise, it is unchanged, where P(k) is the histogram of an image. Then the HE is used for image enhancement. It has been effective in suppressing the enhancement of the background of a low light image [10,11].

Double Plateaus Histogram Equalization (DPHE)
Double plateaus histogram equalization is an improved version of Plateau histogram equalization where two plateau thresholds T_{up} and T_{down} are used to modify the histogram. The values that are greater than the upper threshold T_{up} are set to T_{up} and those whose values are smaller than lower threshold T_{down}, but larger than zero are set to T_{down}. The rest remains unchanged. Then the HE is done. Here the upper threshold is set for avoiding over enhancement of background and noise and the lower threshold is set to preserve the details [12].

Adaptive Double Plateaus Histogram Equalization (ADPHE)
In DPHE the threshold values are constant for every input image, which often falls to enhance the input image. The adaptive double plateaus histogram equalization adaptively chooses the threshold values so that the normalized coefficient of variation of the histogram (NCVH) is close to 0.5. The main idea of the proposed algorithm is to control the contrast enhancement effect by constantly adjusting the plateau thresholds until the NCVH is limited to a desired level [13].

Contrast Limited Adaptive Histogram Equalization (CLAHE)
The CLAHE is a local contrast enhancement (LCE) technique. It operates on the local histograms and does not consider the global histogram. The idea behind LCE is that our eyes adapt to the local context of mages to evaluate their contents, hence it makes sense to modify the local brightness values. In CLAHE, the image is divided into a grid of rectangular regions in which the optimal contrast must be calculated. The deal with the over enhancement of noise pixels a clip limit is used to restrict the over enhancement. The regions are again clipped to form the enhanced image. The main advantage of CLAHE is its modest computational requirement [14].

Partially Overlapped Sub-Block Histogram Equalization (POSHE)
POSHE is a modified version of block overlapped histogram equalization, where the histogram is calculated for every pixel. Using partially overlapped blocks reduces the computational complexity and eliminate blocking effects. Local histogram equalization is performed over the whole block. After LCE performed over the whole image, then divide each pixel value in the output image array by its sub-block histogram equalization frequency. If any blocking effect is generated then eliminate it with a blocking effect reduction filter. POSHE is faster than LCE. The enhancement is more favorable than the original image and global contrast enhancement (GCE) [15].

Balanced CLAHE and Contrast Enhancement (BCCE)
Balanced CLAHE and contrast enhancement is based on CLAHE and Dynamic range compression (DRC). It is mainly used for visualization of HDR infrared images. LCE is used for visualization of low-contrast details, while DRC is used to exploit the entire output dynamic range in the presence of large intensity variations. It is mainly used in infrared microscopy, night vision for driver assistance, area surveillance etc [16].

Adjacent-Block-Based Modification for Local Histogram Equalization (ABMHE)
LCE methods often create unnecessary artifacts. The block-based local histogram equalization techniques deal with it but are prone to blocking effect. To overcome these problems the ABMHE is proposed, which achieves much better results than GCE techniques. The input image is classified into three kinds of sub-blocks by counting the number of pixels with a higher gradient magnitude than a threshold in all subblocks. Then, the histogram of each sub-block is analyzed and the extended local histogram is generated based on its adjacent sub-blocks. Finally, the corresponding histogram equalized sub-block is obtained using the extended local histogram, and the output image is calculated by averaging the equalized sub-blocks in the corresponding position [17]. This method is effective in reducing artifact effects, enhancing detailed information, restraining the non-uniformity and achieving better contrast enhancement results.

III. RESULTS AND DISCUSSION

HE method is the most primitive and simple enhancing method available with the least computational complexity. But it stretches the dynamic range around the intensities with the highest PDF. Hence the brightness of the output image is greatly shifted. BBHE, on the other hand, divides the input image based on the mean value, which preserves the mean brightness of the image. Due to lesser computational complexity, it is used in consumer electronics. DSIHE works in the same way, except that it uses the Cumulative density function to divide the input image. This prevents the image intensity value from a great shift. MMBEBHE also divides the image into two sub-images, but in a way that the brightness difference between the input and out image is minimum. It requires a significant amount of computation and hence is not suitable for consumer realization. RMSHE divides the image recursively based on the mean value of the intensity values. As the level of recursion increases the output image attains the brightness of the input image. MHE divides the image into classes based on threshold values like a segmentation process. BPDHE divides the image based on local maxima and then performs histogram equalization independently. This can be realized in consumer electronics. PHE is a simple method to threshold the input intensity values so that the over enhancement of noise and significant details loss of the foreground can be prevented while mapping raw data for visualization. DPHE is an enhanced version of PHE where two threshold values are used. It provides a better result than PHE. These are primarily made for infrared imagery systems. ADPHE, unlike DPHE, where the threshold values are fixed for all types of images, provides flexibility to adaptively select the threshold values. Besides these GCE methods, there are some LCE methods available that provide better results than GCE methods. CLAHE divides the image into sub-regions and performs local histogram equalization (LHE) and uses the clip limit to prevent over enhancement of noise. POSHE enhances the image better than the GCE and block-based enhancement methods with lesser computation. It is effective in reducing the blocking effect. BCCE is another LCE method which is used in night vision, infrared imagery, but not suitable for those areas where the linear relationship between the digital level and the measured radiation must be maintained [16]. ABMHE is another method that is effective in reducing the blocking effect. While most of the LCE methods are more efficient in enhancing contrast, they don't consider the brightness of the whole image and often result in enhancing noise.

IV. TABLE

Table 1. Summary of different contrast enhancement methods

Authors	**Title**	**Methods**	**Results**
R. C. Gonzalez	Digital Image Processing	Histogram Equalization	Simple and faster. But does not preserve original brightness
Y.-T. Kim	Contrast Enhancement Using Brightness Preserving Bi-Histogram Equalization	Brightness Preserving Bi-Histogram Equalization	Preserves mean brightness. Suitable for consumer electronics
Y. Wang, Q. Chen, B. Zhang	Image Enhancement Based on Equal Area Dualistic Sub-Image Histogram Equalization Method	Dualistic Sub-Image Histogram Equalization	Prevents the mean brightness from a great shift.
Soong Der Chen, Rahman Ramli	Minimum Mean Brightness Error Bi-Histogram Equalization in Contrast Enhancement.	Minimum Mean Brightness Error Bi-Histogram Equalization	Ensures that the brightness difference between input and output image is minimum. But the computational cost is high. Hence can't be realized into consumer electronics.
S.-D. Chen, A. R. Ramli	Contrast Enhancement Using Recursive Mean-Separate Histogram Equalization for Scalable Brightness Preservation	Recursive Mean-Separate Histogram Equalization	As the recursion level increases brightness preservation increases. But the computational cost is high.
D. Menotti et al.	Multi-Histogram Equalization Methods for Contrast Enhancement and Brightness Preserving	Multi-Histogram Equalization	Computational cost is high due to multiple runs of histogram equalization.
Nicholas SiaPik Kong, Haidi Ibrahim	Color Image Enhancement Using Brightness Preserving Dynamic Histogram Equalization	Brightness Preserving Dynamic Histogram Equalization	Divides the image based on local maxima and performs enhancement. It can be realized in consumer electronics.
V. E. Vickers	Plateau Equalization Algorithm for Real-Time Display of High-Quality Infrared Imagery	Plateau Histogram Equalization	Thresholds the input intensity to prevent noise. Mainly used in infrared visualization
B.-J. Wang et al.	A Real-Time Contrast Enhancement Algorithm for Infrared Images Based on Plateau Histogram	Plateau Histogram Equalization	Thresholds the input intensity to prevent noise. Mainly used in infrared visualization
K. Liang et al.	A New Adaptive Contrast Enhancement Algorithm for Infrared Images Based on Double Plateaus Histogram Equalization	Double Plateaus Histogram Equalization	Same as Plateau Histogram equalization except that it uses two threshold values. Used in infrared visualization.
S. Li et al.	An Improved Contrast Enhancement Algorithm for Infrared Images Based on Adaptive Double Plateaus Histogram Equalization	Adaptive Double Plateaus Histogram Equalization	The threshold values are adaptively changed. It provides better results than Double Plateaus Histogram Equalization.
K. Zuiderveld	Contrast Limited Adaptive Histogram Equalization	Contrast Limited Adaptive Histogram Equalization	Divides the image into sub-regions and performs histogram equalization locally. Better to enhance local details, but a cost of computation power.
J.-Y. Kim, L.-S. Kim, S.-H.	An Advanced Contrast Enhancement	Partially Overlapped Sub-Block	Better in reducing blocking effect at a lesser

Hwang	Using Partially Overlapped Sub-Block Histogram Equalization	Histogram Equalization	computation cost.
F. Branchitta et al.	Dynamic-Range Compression and Contrast Enhancement in Infrared Imaging Systems	Balanced CLAHE And Contrast Enhancement	Suitable for use in night vision devices, but not in situations where the linearity between radiation and digital levels should be maintained.
Y. Wang, Z. Pan	Image Contrast Enhancement Using Adjacent-Blocks-Based Modification for Local Histogram Equalization	Adjacent-Blocks-Based Modification for Local Histogram Equalization	Effective in reducing blocking effect while preserving brightness.

V. CONCLUSION

Image enhancement algorithms offer a wide variety of approaches for modifying images to achieve visually acceptable images. The choice of such techniques is a function of the specific task, image content, observer characteristics, and viewing conditions. While some methods are good at preserving the average brightness, some are more focused on preserving local variations in intensity. Some are suitable for consumer realization and some perform well at the cost of computation. Though the computational cost is not discussed here, it may play a critical role in choosing an algorithm for real-time application. Though GCE and LCE methods have their area of interest, a good method is often a combination of both.

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