Histogram and Its Applications to Image Processing

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***Abstract*—This paper presents the assignment of course EE7403. The histogram would be mainly discussed where a literature review would be made to discuss the applications of the histogram in the state-of-art imaging processing field. First, the basic definition and properties of histogram would be introduced. Then the advantages and disadvantages of histogram equalization would be addressed using detailed examples and analysis. Furthermore, the other applications of the histogram and their basic principles and applications would also be introduced. Finally, the conclusions would be made.**

I. The Definition of Histogram

Any image is composed of pixels with different gray levels. The distribution of gray levels in an image is an important and unique feature. This histogram describes the distribution of gray levels in the image, showing how much of the image is occupied by each gray level. The histogram of an image is a gray level and describes the number of pixels with that gray level in the image, where the horizontal coordinate is the gray level, and the vertical coordinate is the frequency. Mathematically, the histogram of a digital image $f(x,y)$ with gray level range [0, L] is a discrete function, and defined as:

$$p_f(f) = \frac{n_f}{n}$$

Here the f represents the gray level, n_f is the number of pixels with that gray level, and n is the total pixels to proceed in the selected area. Apparently, the histogram of the image is non-negative and the total summation of frequency of occurrence of gray-level equals 1, as:

$$\sum_{f=0}^{L} p_f(f) = 1$$

The gray value of the image is a discrete variable, so the histogram represents a discrete probability distribution. After reviewing the definition of the histogram, the properties of the histogram would be introduced in the next section.

II. The Properties of Histogram

We employ the properties of histograms in image processing. These properties include:

- The histogram helps to detect image acquisition issues including overexposure, underexposure, brightness contrast, and dynamic range
- The histogram reflects the distribution pattern of gray levels in an image. This describes the number of image elements per gray-level but not contain information regarding the position of these elements
- Any particular image has a unique histogram corresponding to it, but different images can have the same histogram
- If an image consists of two disjoint regions and the histogram of each region is known, the histogram of the whole image is the sum of the histograms of the two regions
- In addition to providing useful image statistics, the information inherent in the histogram can also be used for image cutting and compression.

After introducing the properties of the histogram, in the next section, the histogram equalization and some related examples in applications would be further discussed.

III. Histogram Equalization

A. The Definition of Histogram Equalization

Histogram equalization (HE) is the process of converting one image to another with a balanced histogram with the same number of pixel points at each gray level, utilizing a grayscale transformation [1].

The understanding from the distribution graph is that the values of the y-axis in the original image are expected to expand as much as possible in the new distribution. The transformation process is a mapping of the original distribution $f(x,y)$ using a cumulative distribution function to generate a new uniformly stretched distribution g where:

$$g = T(f)$$

The fundamental principle of HE is to transform the histogram of the original picture into a uniformly distributed form, which expands pixel gray values in the whole scale and therefore to balance brightness which increases the contrast of the whole picture.

The histogram equalization algorithm is as follow:

$$c(f) = \sum_{t=0}^{f} p_f(t) = \sum_{t=0}^{f} \frac{n_t}{n}, \quad f = 0,1,\ldots,L$$

$$g = T(f) = round\left[\frac{c(f) - c_{\min}}{1 - c_{\min}} L\right], \quad c(f) \geq c_{\min}$$

Here t is a dummy variable of the summation. $c_{\min}$ is the smallest positive value of all histogram equalization obtained, *round* means to integrate and get an integer. g is approximately uniformly distributed in [0, L].

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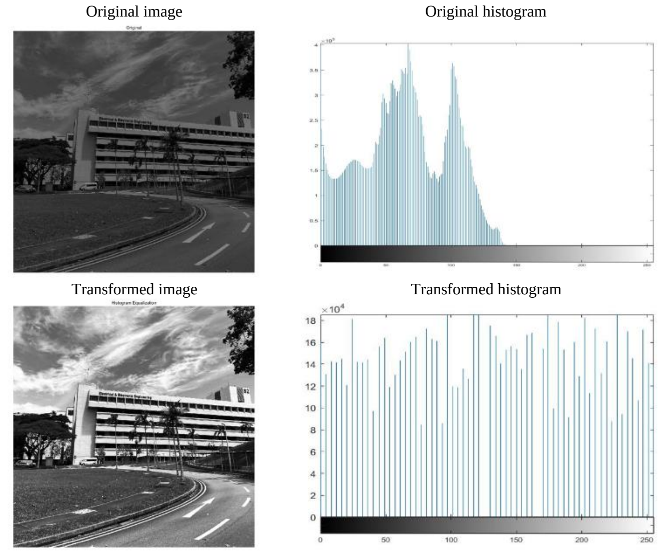

Fig. 1: Histogram equalization applied to low contrast image

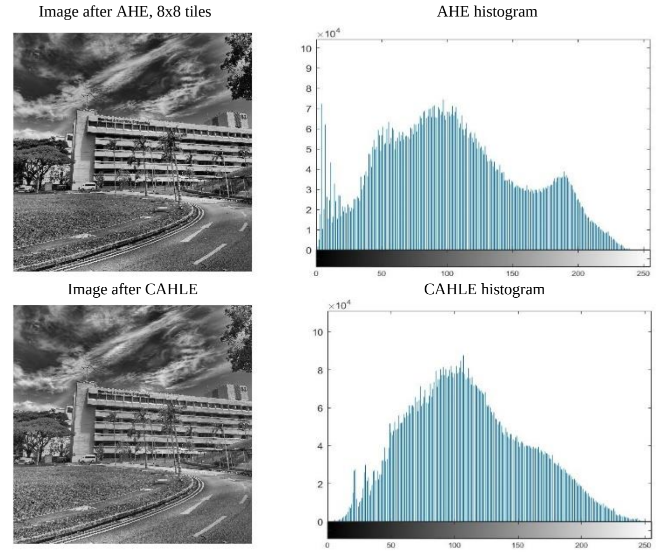

Fig. 2: Adaptive Histogram equalization & CAHLE

In the image processing, the HE is frequently utilized to adjust contrast of the pictures, especially when the comparison of the whole image is low which made it difficult to extract the useful data we need. Using the properties of HE, the critical information of the image could be obviously while the overall contrast of the whole image would not be affected.

Fig. 1 shows an example of employing the global histogram equalization algorithm. The original input image has low contrast where after equalization the processed image shows a more dynamic range, from 0 to 255. The picture after transform shows more details compared with the original one.

B. *Merits and Limitations of Histogram Equalization*

The advantages of histogram equalization are:

- Simple and easy to enhance the global contrast, especially when the background and foregrounds of images are both bright or dark. The images with shadows can be clearly observed using dynamic range expansion
- The histogram equalization is reversible, allowing recovery of the original histogram if the equalization function is known with not complicate computation.

While histogram equalization can significantly simply improve image quality, it is a globally modified approach that every pixel value of the image is modified with the exact same transform function. There may be some disadvantage:

- The local details of the image are likely to be lost, affected by the properties of other regions. For example, in the high-brightness region of the image, after the global histogram equalization adjustment, it is difficult to see the detailed texture of the seal clearly because it is too bright and appears as a bright white.
- Histogram equalization often produces unrealistic effects and unwanted results such as apparent image gradients when applied to images with low color depth.

To solve the potential shortcoming of the global HE method, many optimized methods had been proposed. Modifications of the methods employ sub-histograms to emphasize local contrast instead of the global. Two mainly used methods would be discussed in the following.

Adaptive histogram equalization (AHE) [2] is different from conventional histogram equalization. The adaptive histogram equalization calculates several histograms according to the distinct part of the image. Then redistribute the grey level values of the image in each of these parts. Compared with global equalization, the adaptive histogram equalization is better at improving the local contrast and enhancing the definitions of edge in each region of an image.

Another optimized method is called contrast-limited adaptive histogram equalization (CLAHE) [3]. Various from the AHE method, CLAHE sets contrast limitations during the processing. The limitation constraints each neighbored distinct parts of the image from which a transformation function is derived. This method was designed to prevent the over-amplification of noise which using the AHE method may occur. Fig. 2 shows the result based on the two mentioned methods. The CAHLE method avoids image discontinuity and over-enhancement of noise pints.

Besides the above modifications of the original algorithm, there are commonly used methods including multipeak histogram equalization (MPHE) [4] and multiple beta optimized histogram equalization (MBOBHE) [5]. Some other methods were also proposed focusing on various features of the pictures, such as BBHE [6], DSIHE [7], RMSHE [8], MMBEBHE [9], RSIHE [10], RSWHE [11], and more.

Overall, the selection of methods is task-dependent and each of these optimized methods has its own merits as well as certain limitations. Fig. 3 shows the comparison of processed images by HE, BBHE, DSIHE, RMSHE, RSIHE, MMBEBHE, and RSWHE-M methods [12].

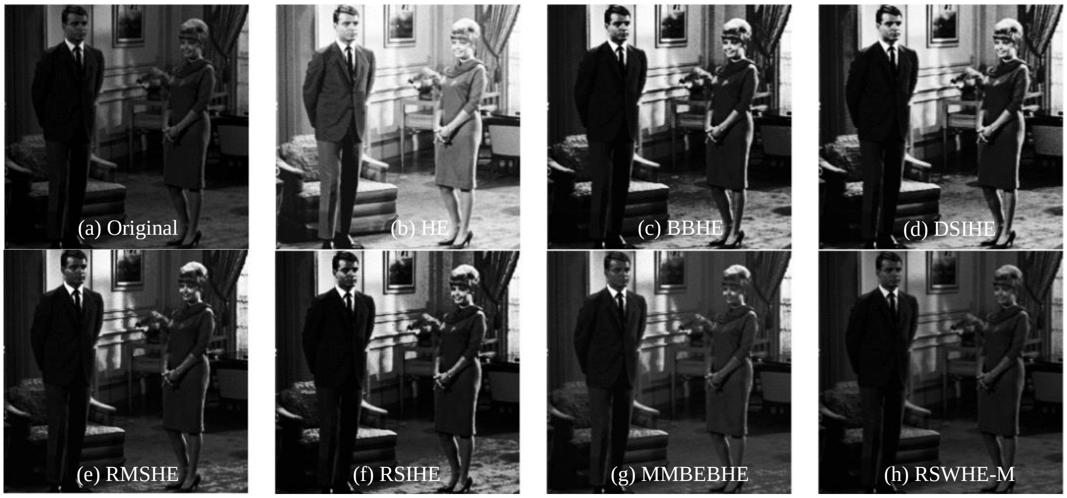

Fig. 3: Results of all methods tested on the image of 'Couple' [12]

IV. Applications of Histogram

A. Hough Transform

Hough transform (HT) is a simple but powerful tool to detect straight lines, circles, and curves in images. The main idea of this was to use polar coordinates to represent the lines in Hough transform:

$$r(\theta) = x\cos\theta + y\sin\theta$$

Here the 'r' and θ were utilized to represent the lines in the image. All points would on the same line in the image fall into the same point (a_i, b_i) in the parametric space. The transform is implemented by quantizing the Hough parameter space into finite intervals or accumulator cells. Each (x_i, y_i) is transformed into a discretized (r, θ) curve. While each (x_i, y_i) lies on the curve, the corresponding accumulator would increment. Finally, the resulting peaks in the accumulator (or if the number in the accumulator exceeds a certain level) would be extracted as corresponding straight lines in the image.

The correlation between Hough transform and histogram is that they both adopt a similar concept of the accumulator. Also, they both convert image data into digital data for further processing. Before the computing of Hough transform, edge detectors like canny edge detection should be first deployed. Using an edge detector and then remove the noise of the pictures help to get a clear boundary description. Then the Hough transform detects the separate line segments of the images and thereby identifies the true geometric structure.

There are many applications of Hough transform in image processing, one of these fields is face detection and recognition. Many researchers proposed different face recognition algorithms based on this. Biswas et., al. proposed a novel approach of using Hough transform peaks for detecting the orientation angles and then calculating the histogram from the transform. In this approach, the images would be divided into several non-overlapping blocks of equal size. The orientation of these blocks is then computed and finally, the classification would be done on the obtained histogram combined to form the final feature vector set.

Sufyanu et., al. [14] proposed another approach called Extended Histogram of Gradients (ExHoG) for human detection. Their method featured having good classification ability between a dark object against a bright background and vice versa. The study converted the original image of the human face into an integrated histogram before deploying the Hough transform. This step simplified the procedure of extracting features and minimizing the error during matching. Then the canny edge detector was employed on the rotated histograms to reduce the dimensions of the image. The result of the studies showed high accuracy based on established benchmarking datasets INRIA, Caltech, and Daimler.

On the subspace of the ExHoG algorithm, Satpathy et al [19]. proposed a quadratic classification approach for human detection. The unreliable dimensions were reduced to alleviate the poor classify performance and avoid the overfits of training data when exploiting the Minimum Mahalanobis Distance classifier (MMDC). Using the Asymmetric Principal Component Analysis (APCA) to solve the problem that conventional Principal Component Analysis may perform poorly in classifying unreliable data due to the asymmetry issue in human detection training sets.

In addition to the field of face recognition, there are many other more applications of the Hough transform, such as traffic and transport applications using the hierarchical additive Hough transform (HAHT) [15], biometrics, and man-machine interaction using generalized Hough transform (GHT) [16], object tracking using a mixture of uniform and Gaussian Hough (MOUGH) [17], and more.

Lots of these research works on Hough transform are motivated by its features like noise immunity, the ability to deal with occlusion, and the expandability of the transform [18]. These methods had been successfully applied on many binary images and are expected to be applied to color images in further works. The applications of the Hough transform had been used in numerous fields.

V. CONCLUSION

In this paper, the progress of the first assignment of EE7403 was presented. First, the definition of the histogram was introduced, as well as its properties. Then the histogram equalization was discussed, here we listed several merits and limitations of such methods. Based on the global histogram equalization, many optimized methods were proposed, such as AHE, CLAHE. Each of these methods focused on various features of the original pictures and should be exploited in task-dependent.

In the next part, we introduced the application of histogram on Hough transform, especially in human detection. The literature review was based on several types of research that employ the Hough transform and its derivative optimized methods.

Overall, the histogram is very simple yet powerful in image processing and could be applied in numerous areas. In this paper, only limited applications were discussed.

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