Image Enhancement using Histogram Equalization and Spatial Filtering

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Abstract: ***Image Enhancement is one of the important requirements in Digital Image Processing which is vital in making an image useful for various applications which can be seen in the areas of Digital photography, Medicine, Geographic Information System, Industrial Inspection, Law Enforcement and many more Digital Image Applications. Image Enhancement is used to improve the quality of poor images. The focus of this paper is an attempt to improve the quality of digital images using Histogram Equalization and Spatial Filters in MATLAB version 7.12.0.635 (R2011a) software and the results obtained are discussed highlighting the performance of each method.***

Keywords: Image Enhancement, Histogram Equalization, Spatial Filtering, MATLAB**.**

1. Introduction

Image Enhancement is the process of manipulating an image so that the result is more suitable than the original for a specific application. The word *specific* is important here because it establishes at the outset that enhancement techniques are problem oriented. Thus, for example, a method that is quite useful for enhancing X-ray images may not be the best approach for enhancing satellite images taken in the infrared band of electromagnetic spectrum. Regardless of the application or method used, however, image enhancement is one of the most visually appealing areas of image processing [1].

Digital image processing is an ever expanding and dynamic area with applications into our everyday life such as medicine, space exploration, authentication, automated industry inspection and many more areas. Image Processing basically includes analysis, manipulations, storage and display of graphical images from sources such as photographs, drawings and so on. Image Enhancement basically includes noise reduction from the image [2]. Image Enhancement is one of the basic requirements for making an image useful for various statistical analysis and particle identification that form the basis of various tests and measurements in Digital Photography, Biomedical Tests and Measurements, Microscopic Image Enhancement and many more Digital Imaging Applications [2].

Image enhancement is basically improving the interpretability or perception of information in images for human viewers and providing better input for other automated image processing techniques. The principal objective of image enhancement is to modify attributes of an image to make it more suitable for a given task. During this process, one or more attributes of the image are modified. The choice of attributes and the way they are modified are specific to a given task. Moreover, observer-specific factors, such as the human visual system and the observer's experience, will introduce a great deal of subjectivity into the choice of image enhancement methods. Image enhancement is used in the following cases: Removal of noise from image, Enhancement of the dark image and highlight the edges of the objects in an image [3]. The goal of image enhancement is to improve the image quality so that the processed image is better than the original image for a specific application or set of objectives [4].

2. Image Histogram

In general, a histogram is the estimation of the probability distribution of a particular type of data. An image histogram is a type of histogram which offers a graphical representation of the tonal distribution of the gray values in a digital image. By viewing the image’s histogram, we can analyze the frequency of appearance of the different gray levels contained in the image [5]. The figure below shows an image with its histogram representation. The pixels in the image have a wide histogram representation indicating that the image is of a high quality.

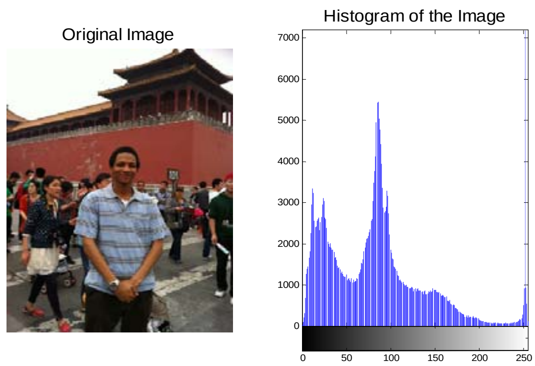

Figure 1: A colored image with Histogram representation

2.1 Histogram Processing

The *histogram* of a digital image with intensity levels in the range [0, $L-1$] is a discrete function $h(r_k) = n_k$, where r_k is the kth intensity value and n_k is the number of pixels in the image with intensity of r_k [1]. It is common practice to normalize a histogram by dividing each of its components by the total number of pixels in the image, denoted by the product MN, where, as usual, M and N are the row and column dimensions of the image. Thus, a normalized histogram is given by $p(r_k) = n_k/MN$, for $K = 0,1,2,\ldots\ldots, L-1$. Loosely speaking, $p(r_k)$ is an estimate of the probability of occurrence of intensity level r_k in an image [1]. The sum of all components of a normalized histogram is equal to 1. The histogram of bad images is usually narrow while that of good images are wide. To change a bad image to a good one, the histogram is thus modified. The figure below shows an example of a histogram representing a bad and a good image [1].

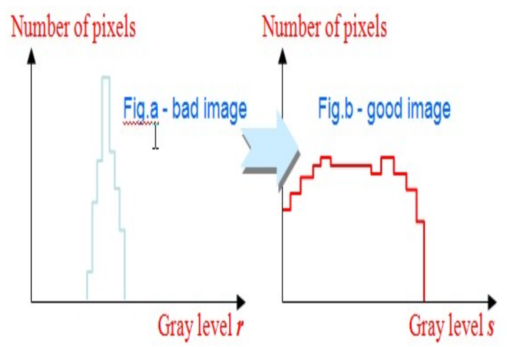

Figure 2: Histogram of a good and a bad image [9].

2.2 Histogram Equalization

Histogram equalization is used to enhance the contrast of the image, it spreads the intensity values over full range. Histogram equalization technique can't be used for images suffering from non-uniform illumination in their backgrounds as this process only adds extra pixels to the light regions of the image and removes extra pixels from dark regions of the image resulting in a high dynamic range in the output image [2]. The goal of histogram equalization is to spread out the contrast of a given image evenly throughout the entire available dynamic range, in this case between 0 and 1 [6].

In histogram equalization technique, it is the probability density function (pdf) that is being manipulated. To make it simple, what histogram equalization technique does is that, it changes the pdf of a given image into that of a uniform pdf that spreads out from the lowest pixel value (0 in this case) to the highest pixel value ($L-1$). This can be achieved quite easily if the pdf is a continuous function. However, since we are dealing with a digital image, the pdf will be a discrete function. Lets suppose we have an image x, and let the dynamic range for the intensity r_k varies from 0 (black) to $L-1$ (white). This pdf can be approximated using the probability based on the histogram $p(r_k)$ as follows [10]:

$$\mathrm{pdf}(x) = p(r_k) = \frac{\text{total pixels with intensity } r_k}{\text{total pixels in image } x}$$

From this pdf, we can then obtain the cumulative density function (cdf) as follows [10]:

$$\mathrm{cdf}(x) = \sum_{k=0}^{L-1} p(r_k)$$

Where $p(r_k$ is the probability for pixel of intensity. The output of a pixel from the histogram equalization operation is then equal to the cdf of the image or mathematically [10].

$$p(s_k) = \sum_{k=0}^{L-1} p(r_k)$$

To get the value of the pixel, p (s_k) needs to be multiplied by $L-1$ and then round it to the nearest integer [6].

3. Spatial Filtering

This refers to an image operators that change the gray value at any pixel (x,y) depending on the pixel value in a square neighborhood centered at (x,y) using a fixed integer matrix of the same size. The integer matrix is called a filter, mask, kernel or a window. The mechanism of special filtering consists simply of moving the filter mask from pixel to pixel in an image. At each pixel (x,y), the response of the filter at that pixel is calculated using a predefined relationship (linear or nonlinear). The size of mask must be odd (i.e. 3x3, 5x5, e.t.c.) to ensure it has a center. The smallest meaningful size is 3x3 [7]. The figure below shows the spatial filter mask [8].

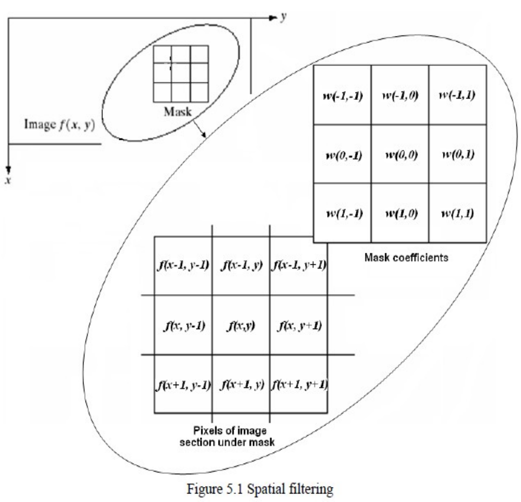

Figure 3: Spatial Filtering

3.1 Linear Spatial filtering (Convolution)

The process consists of moving the filter mask from pixel to pixel in an image. At each pixel (x,y), the response is given by a sum of products of the filter coefficients and the corresponding image pixels in the area spanned by the filter mask. For the 3x3 mask as shown in figure 3, the result (or response), R of linear filtering [7].

R=
w(-1,-1)f(x-1,y-1)+w(-1,0)f(x-1,y)+….+w(0,0)f(x,y)+…+ w(1,0)f(x+1,y)+w(1,1)f(x+1,y+1)

In general, linear filtering of image *f* of size *MxN* with a filter mask of size *mxn* is given by the expression [8].

$$g(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x+s, y+t)$$

Where a = (m-1)/2 and b = (n-1)/2 [8]. To generate a complete filtered image, this equation must be applied for x=0,1,2,……..*M*-1 and y =0,1,….,*N*-1 [7].

3.2 Nonlinear Spatial filtering

The operation also consists of moving the filter mask from pixel to pixel in an image. The filtering operation is based conditionally on the values of the pixels in the neighborhood, and they do not explicitly use coefficients in the sum-of –products manner. For example, noise reduction can be achieved effectively with a nonlinear filter whose basic function is to compute the median gray-level value in the neighborhood in which the filter is located computation of the median is a nonlinear operation [7].

4. Smoothing Spatial Filters

Smoothing filters are used for blurring and noise reduction. Blurring is used preprocessing tasks such as removal of small details from an image prior to (large) object extraction, and bridging of small gaps in lines or curves. Noise reduction can be accomplished by blurring with a linear filter and also by nonlinear filtering [1].

4.1 Smoothing Linear Filters

The output (response) of smoothing, linear filter is simply the average of the pixels contained in the neighborhood of the filter mask. These filters sometimes are called averaging filters. Also, they are also referred to as lowpass filters [1]. Noise and edges consist of sharp transitions in gray-levels. Thus smoothing filters are used for noise reduction; however, they have the undesirable side effect that they blur edges. The two figures below shows two 3x3 averaging filters [7].

$$\frac{1}{9} \times \begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array} \qquad \frac{1}{16} \times \begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline 2 & 4 & 2 \\ \hline 1 & 2 & 1 \\ \hline \end{array}$$

Figure 4: Two 3 x 3 smoothing (averaging) filter masks [8].

The Averaging linear filtering of an image *f* of size *M*x*N* with a filter mask of size *mxn* is given by the expression [7];

$$g(x,y) = \frac{\sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x+s, y+t)}{\sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t)}$$

To generate a complete filtered image, this equation must be applied for x = 0,1,2,…,*M*-1 and y=0,1,2,….*N*-1 [7]. The denominator in the above equation is simply the sum of the mask coefficients and, therefore, it is a constant that needs to be computed only once [1]. The following figure below shows an example of applying standard average filter [7].

Figure 5: Effect of averaging filters (a) Original Image (b)-(f) Results of smoothing averaging filter mask of size n=3,5,9,15 and 35respectively.

4.2 Order-Statistics (Nonlinear filters)

Order-statistic filters are nonlinear spatial filters whose response is based on ordering (ranking) the pixels contained in the image area encompassed by the filter, and then replacing the value of the center pixel with the value determined by the ranking result. The best known filter in this category is the *median filter*, which as its name implies, replaces the value of a pixel by the median of the intensity values in the neighborhood of that pixel (the original value of the pixel is included in the computation of the median). Median filters are quite popular because, for certain types of random noise, they provide excellent noise reduction capabilities, with considerably less blurring than linear smoothing filters of similar size. Median filters are particularly effective in the presence of impulse noise, called *salt-and-pepper* noise because of its appearance as white and black dots superimposed on an image [1].

5. Sharpening Spatial Filters

Sharpening aims to highlight fine details (e.g. edge) in an image, or enhance detail that has been blurred through errors or imperfect capturing devices. Imaging blurring can be achieved using averaging filters, and hence sharpening can be achieved by operators that invert averaging operators [7].

5.1 Partial Derivatives of Digital Functions

The first order partial derivatives of the digital image *f(x,y)* is [7];

$$\frac{\partial f}{\partial x} = f(x+1,y) - f(x,y) \text{ and } \frac{\partial f}{\partial y} = f(x,y+1) - f(x,y)$$

The first order must be [7];

- Zero along flat segments (i.e. constant gray values)
- Non-zero at the outset of gray level step or ramp (edges or noise).
- Non-zero along segments of continuing changes i.e. ramps).

The second order partial derivatives of digital images are [7];

$$\frac{\partial^2 f}{\partial x^2} = f(x+1,y) + f(x-1,y) - 2f(x,y)$$

$$\frac{\partial^2 f}{\partial y^2} = f(x,y+1) + f(x,y-1) - 2f(x,y)$$

Second derivative must be;

- Zero along flat segments.
- Non-zero at the outset and of gray-level step or ramp
- Zero along ramps.

5.2 Laplacian Filter

The Laplacian operator of an image *f(x,y)* is [7];

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$

The above equation can be implemented using the 3x3 mask as shown below [7].

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

Since the Laplacian filter is a linear spatial filter, we can apply it using the same mechanism of the convolution process. This will produce a Laplacian image that has grayish edge lines and other discontinuities, all superimposed on a dark, featureless background [7]. The figure below shows an example of using Laplacian filter to sharper an image [8].

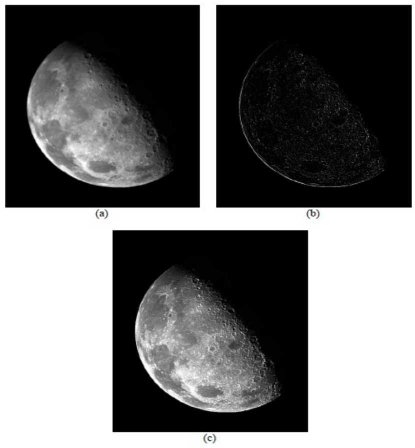

Figure 6: Example of applying Laplacian filter (a) Original Image (b) Laplacian Image (c) Sharpened Image.

6. Experimental Results

This section presents the performance of Image Enhancement by Histogram Equalization and use of spatial filters which are thus classified into two types. The first type is the Smoothing Spatial Filters which include; averaging filters and median filters. The second type is the Sharpening Spatial Filters which include Laplacian linear filter.

MATLAB version 7.12.0.635 (R2011a) was used on two images to perform the Image Enhancement. Histogram Equalization was carried on the first image which was taken in Tianjin, P.R China with a pixel size of 500x667. Spatial filtering was carried out on the second image which was taken in Beijing, P.R. China with a pixel size of 500x699. The figure below shows an image before and after histogram equalization was performed.

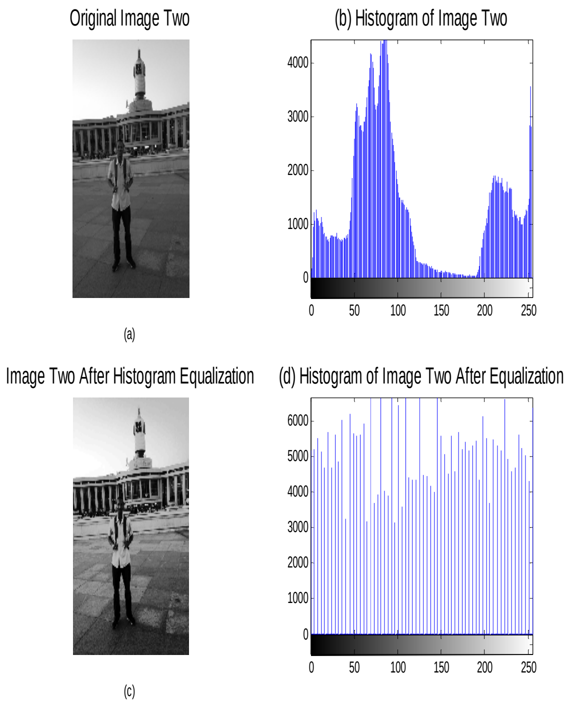

Figure 7: (a) Original Image (b) Histogram of Original Image (c) Image after Histogram equalization (d) Histogram of the equalized image

It was observed in figure 7(a) that, the original image has a low contrast and the histogram of the image has intensity values which do not spread over a full range. In figure 7(c), after histogram equalization was performed on the image, a high contrast was achieve making the intensity values spread over a full range as seen from figure 7(d) in the histogram of the image.

The figure below shows averaging filter applied on an image

Figure 8: (a) Original Image (b) Results of smoothing with averaging filter mask of 3x3 (c) Results of smoothing with averaging filter mask of 5x5

It was observed in figure 8 (b) that, smoothing with averaging filter mask of 3x3 produced a slight blurring effect for the Original image, figure 8(a). In figure 8 (c), when smoothing with averaging filter mask of 5x5 was performed on the original image, blurring effect became more visible as compared to figure (b).

The figure below shows an image after addition of Gaussian Noise as well as Salt and Pepper Noise together with the results of averaging filter.

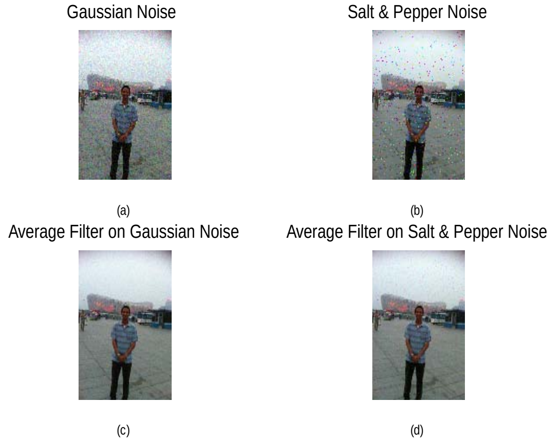

Figure 9: (a) Image corrupted by Gaussian Noise (b) Image corrupted by Salt and Pepper Noise (c) Result of applying averaging filter on Gaussian Noise (d) Result of applying averaging filter on Salt and Pepper Noise

In Figure 9 (a), Gaussian noise was added to an image, in figure 9 (b), Salt and Pepper was added to an image. After applying averaging filter, it was observed that, in figure 9 (c) Gaussian Noise was removed. Also in figure 9 (d), the Salt and Pepper Noise was removed but the averaging filter blurred both the image with Gaussian Noise as well as that with Salt and Pepper Noise and the noise reduction was poor.

The figure below shows an image after addition of Gaussian Noise as well as Salt and Pepper Noise together with the results of median filter.

Figure 10: (a) Image corrupted by Gaussian Noise (b) Image corrupted by Salt and Pepper Noise (c) Result of applying median filter on Gaussian Noise (d) Result of applying median filter on Salt and Pepper Noise

In Figure 10 (a), Gaussian noise was added to an image, in figure 10 (b), Salt and Pepper was added to an image. After applying median filter, it was observed that, in figure 10 (c) Gaussian Noise was removed. Also in figure 10 (d), the Salt and Pepper Noise was removed but the image was first converted from colored to a grayscale image. The median filter performed better than averaging filter for the removal of salt and pepper noise.

The original image together with a Laplacian image and a sharpened original image are shown below.

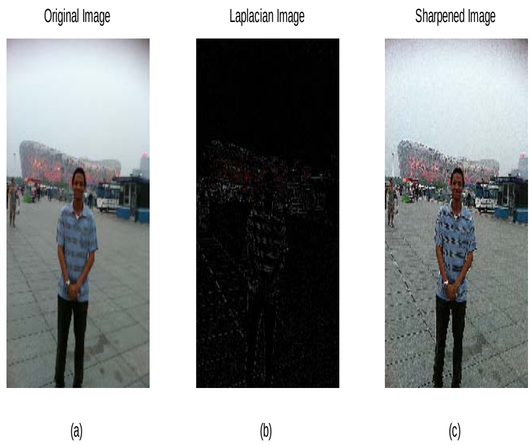

Figure 11: (a) Original Image (b) Laplacian Image (c) Sharpened Image

After Laplacian filter was performed on an image, it was observed in figure 11 (b) that, the image was converted to grayscale and edges of the image were obtained and in figure 11 (c), it was observed that the image was sharpened.

7. Conclusions

This paper made an attempt to study Image Enhancement by Histogram Equalization and spatial filtering. The performance of these techniques was carried out with two images using MATLAB version 7.12.0.635 (R2011a). Histogram Equalization was carried out on the first image and two types of spatial filters were applied on the second image.

It was observed from the results of histogram equalization, a high contrast was achieved for the image making the intensity values spread over a full range. From the results of smoothing with average filter mask of 3x3, the image produced a slight blurring effect for the Original image. When smoothing with averaging filter mask of 5x5 was performed on the original image, blurring effect became more visible as compared to averaging filter mask of 3x3.

From the results of Image corrupted by both Gaussian Noise and Salt and Pepper noise, after applying averaging filter, it was observed that Gaussian Noise was successfully removed. Also the Salt and Pepper Noise was removed as well but the averaging filter blurred both the image with Gaussian Noise as well as that with Salt and Pepper Noise and the noise reduction was poor. From the results of Image corrupted by both Gaussian Noise and Salt and Pepper noise, after applying median filter, it was observed that Gaussian Noise was removed. Also, the Salt and Pepper Noise was removed but the image was first converted from colored to a grayscale image. The median filter performed better than averaging filter for the removal of salt and pepper noise. The Laplacian filter was applied to an image obtaining the Laplacian Image as well as sharpening of the image was achieved.

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