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Practical Digital Image Enhancements using Spatial and Frequency Domains Techniques

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Abstract-*The principal objective of digital image enhancement is to process an image so that the result is more suitable than the original image for a specific and unique purpose / application. Image enhancement approaches fall into two broad categories: Spatial domain methods and Frequency domain methods. This paper presents an implementation details of the results of the image processing application software designed using Matlab as a tool for some given ordinary images using the above mentioned methods. The designed software produces image histogram, histogram equalization of an image. Low pass and high pass filters could be applied to the imageries too. Finally having tested the application with several images, it was found to be relatively effective in both ways as contained in the results herein.*

Key words- Histogram, histogram equalization, spatial domain, frequency domain

I. INTRODUCTION.

Image enhancement is by definition to process an image so that the result is more suitable than the original image for a specific purpose. It encompasses histogram processing and equalization of an image. The two methods for enhancement are spatial domain as well as frequency domain methods. The term spatial domain refers to the image plane itself. The approaches in this category are based on direct manipulation of pixels in an image. While the frequency domain refers to the plane of 2D discrete Fourier transform of an image. Frequency domain filters are used to enhance digital images by manipulating the Fourier transform of the image [1]. This paper practically employs the spatial as well as the frequency domain techniques to show their relative effectiveness on some ordinary digital images. The paper is concluded as follows. Section II contains the mathematical background; Section III contains the implementation details and the results while Section IV shows the conclusion.

II. II. MATHEMATICAL BACKGROUND

2.0 Histogram:

A Histogram for a digital image is basically the number of pixels that have colors in each of a fixed list of color ranges that span the image's color space. The histogram of a digital image with gray levels in the range [0, L-1], is a discrete function [1]

$$p(r_k) = n_k / n \quad \text{...} (1)$$

where r_k is the kth gray level; n_k is the number of the pixels with grey level r_k; n is the total number of pixels in the image.

Histograms are the basis for numerous spatial domain processing techniques. Histogram manipulation can be used effectively for image enhancement. The histogram is a graph showing the number of pixels in an image at each different intensity value found in that image [2].

*2.0.1 Histogram Equalization (H.E.) of an Image***:**

HE, is one of the most commonly used methods for image contrast enhancement. It is a technique by which the dynamic range of the histogram of an image is increased by assigning the intensity values of pixels in the input image such that the output image contains a uniform distribution of intensities. Each pixel is assigned a new intensity value based on its previous intensity level. it is used to improve contrast with the aim of obtaining a uniform image histogram. This technique can be used on a whole image or just on a part of an image. We suppose the gray level r is a continuous quantity and normalized in the range [0,1], with r=0 representing black and r=1 representing white. Consider the enhancement transform function to be given as s=T(r). Assume that the transformation function T(r) satisfies the following two conditions [1]:

T(r) is a single-valued and monotonically increasing for r in the interval [0,1];

$$0 \leq T(r) \leq 1 \text{ for } 0 \leq r \leq 1 \text{.......................................} (2)$$

The requirement in (1) guarantees that the inverse transformation exists, and the monotonicity condition preserves the increasing order gray scale image output.

A transformation function that is not monotonically increasing could result in at least a section of the intensity range being inverted, thus producing some inverted gray levels in the output image. Finally, condition (2) guarantees that the output gray levels will be in range [0,1].

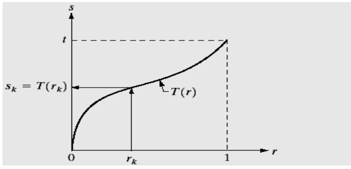

Figure 1: Gray-level transformation function that is both single-valued and monotonically increasing [1].

2.1 Image Enhancement in the Spatial Domain

In the case of digital image data, spatial filtering in the domain of image space is usually achieved by local convolution with an n x n matrix operator as follows.

$$y(i,j) = \sum_{k=i-w}^{i+w} \sum_{l=j-w}^{j+w} f(k,l)\, h(i-k, j-l)$$

……….(3) where *f*: input image; *h*: filter function; *g*: output image

a. Low Pass Filters

Low-pass filters attenuate high frequency components in the frequency domain, and result in image blurring. Low Pass Filters are also called smoothing or averaging filters. The basic idea behind low pass filtering is to replace the value of a pixel in an image by the average of the grey levels of the pixels contained in the neighborhood of the filter mask. The result of applying this filter is to blur the image and also reduce the noise in the image.

b. High Pass Filters

High-pass filters attenuate low-frequency components (resulting in sharpening edges and other sharp details). These filters use spatial differentiation to sharpen an image. The strength of the response to the derivative operator is proportional to the degree of discontinuity of the image at the point at which the operator is applied, thus image differentiation enhances edges and other discontinuities [3].

2.2 Image enhancement in the Frequency Domain

2.2.1 Frequency Domain Filters

We simply compute the Fourier transform of the image, multiply the result by a filter (rather than convolve in the spatial domain), and take the inverse transform to produce the enhanced image. The frequency domain refers to the plane of the two dimensional discrete Fourier transform of an image. The purpose of the Fourier transform is to represent a signal as a linear combination of sinusoidal signals of various frequencies. Frequency is directly related to rate of change. The frequency of fast varying components in an image is higher than slowly varying components. Frequency domain filters are used to enhance digital images by manipulating the Fourier transform of the image [4]. The basic steps involved in filtering an image in the frequency domain are:

1. Compute $f(x,y) * (-1)^{(x+y)}$ Let the centre of the UV domain be at (M/2, N/2)

2. Compute $F(u,v) = \Im(f(x,y) * (-1)^{(x+y)})$

3 .Compute G(u,v) = H(u,v) F(u,v); H(u,v) is called a filter.

4. Filtered image = $\Im^{-1}[G(u,v)]$

2.3 Basic Filters in the frequency Domain

2.3.1 Low Pass Filters:

A filter is called a low-pass one if it attenuates high frequencies while “passing” low frequencies. Smoothing is mainly a low pass operation in the frequency domain.

1. Edges and sharp transitions in the gray levels of an image contribute significantly to the high-frequency content of its Fourier Transform.
2. Smoothing is achieved by attenuating a specified range of high- frequency components.
3. Transform in the frequency domain follows

$$G(u,v) = H(u,v)F(u,v)$$

We call it low-pass filter in the frequency domain. We give the values for H for the three different filters below

1. Ideal Low pass filter (ILPF)

$$H(u,v)=\begin{cases}1 & \text{if } D(u,v)\le D_0\\ 0 & \text{if } D(u,v)>D_0\end{cases}$$

2. Butterworth Low-pass Filters (BLPF)

$$H(u,v)=\frac{1}{1+[D(u,v)/D_0]^{2n}}$$

We call it Butterworth Low-pass Filter (BLPF) with order *n* and cutoff frequency at a distance from the origin. The BLPF transfer function does not have a sharp discontinuity that establishes a clear cutoff between passed and filtered frequency.

3. *Gaussian Low-pass Filters (GLPF)*

$$H(u,v)=e^{-D^2(u,v)/2\sigma^2}$$

*2.3.2 High Pass Filters***:**

When a filter attenuates low frequencies and "passes" high frequencies it is a high-pass filter.

1. Edges in the gray levels are with high-frequency components of its Fourier Transform.
2. Sharpening is achieved by attenuating the low-frequency components without disturbing high-frequency information in the Fourier transform.
3. High-pass filter function can be obtained using the relation.

$$H_{hp}(u,v)=1-H_{lp}(u,v)$$

1. Ideal High Pass filter (IHPF)

$$H(u,v)=\begin{cases}0 & \text{if } D(u,v)\le D_0\\ 1 & \text{if } D(u,v)>D_0\end{cases}$$

2. Butterworth High Pass Filter (BHPF)

$$H(u,v)=\frac{1}{1+[D_0/D(u,v)]^{2n}}$$

3. Gaussian High Pass Filter

$$H(u,v)=1-e^{-D^2(u,v)/2\sigma^2}$$

III IMPLEMENTATION AND RESULTS

A system was developed using MATLAB that accepts input images and then processes them for the desired outputs.

3.0.1 Spatial Domain

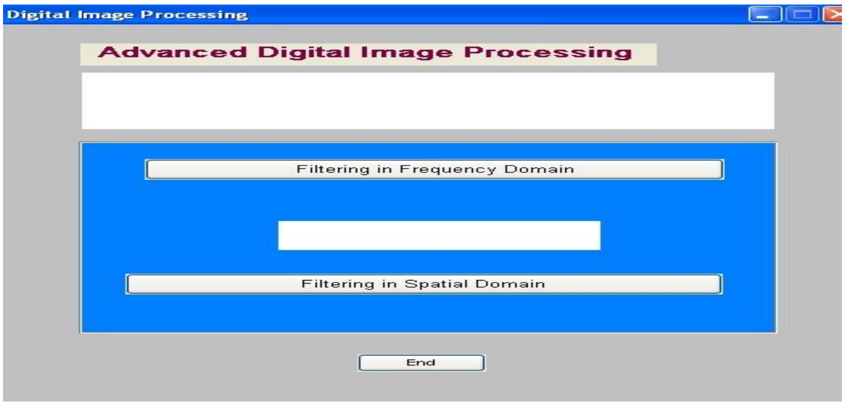

Figure 2, The initial GUI.

When the user clicks on the spatial Filtering button, a GUI screen is loaded which can then be used to load an original image, then transform it into a gray scale image as shown in figure 3.

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Figure 3. Original image loaded and its Gray Scale form.

The histogram of the same figure is as follows:

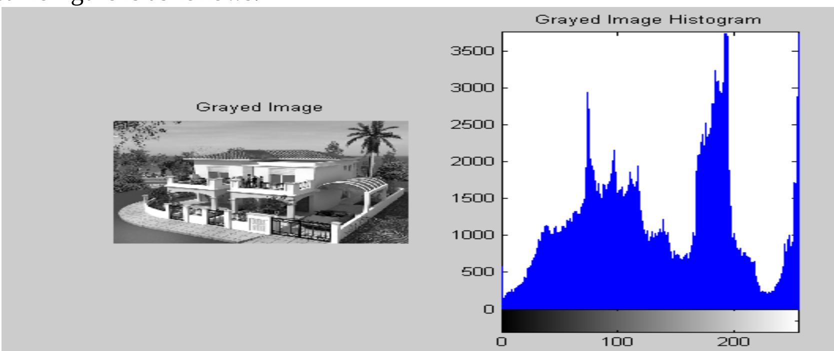

Figure 4. Histogram of the Image

While the histogram equalization is as follows:

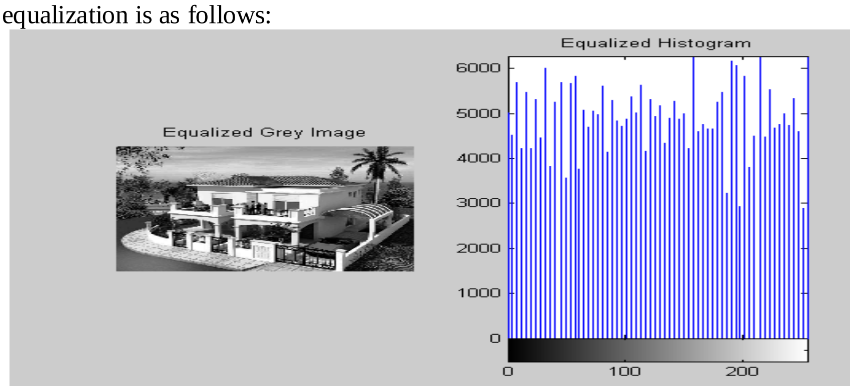

Figure 5.Histogram Equalization

Low pass and high pass filtering results are as follows:

Figure 6: Low and High Pass filtering

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3.0.2 Frequency Domain.

This part shows how the program runs to process the filtering in frequency domain. Figure 7 shows the main GUI screen for this application.

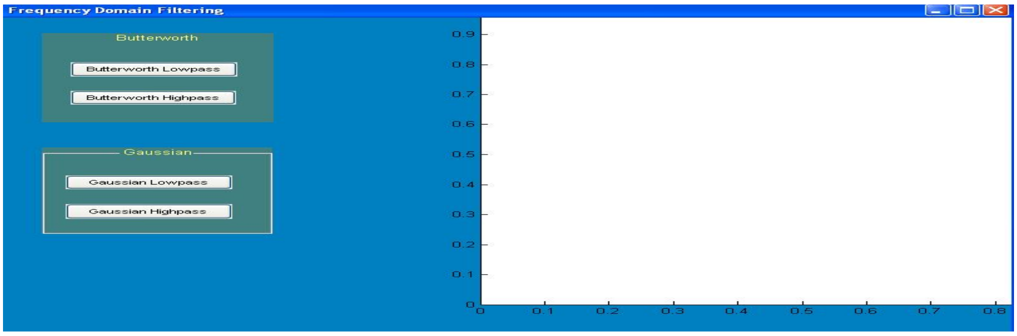

Figure 7. Frequency Domain Filtering GUI

Figure 8: Butterworth Low pass Filtered Image

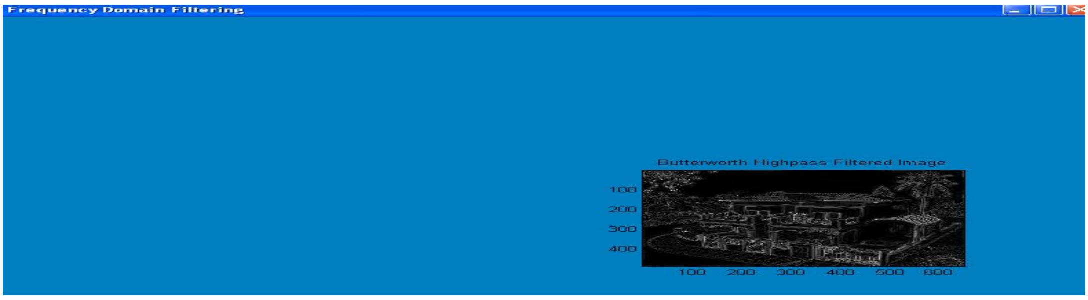

Figure 9: High Pass Butter Worth Filtered Image

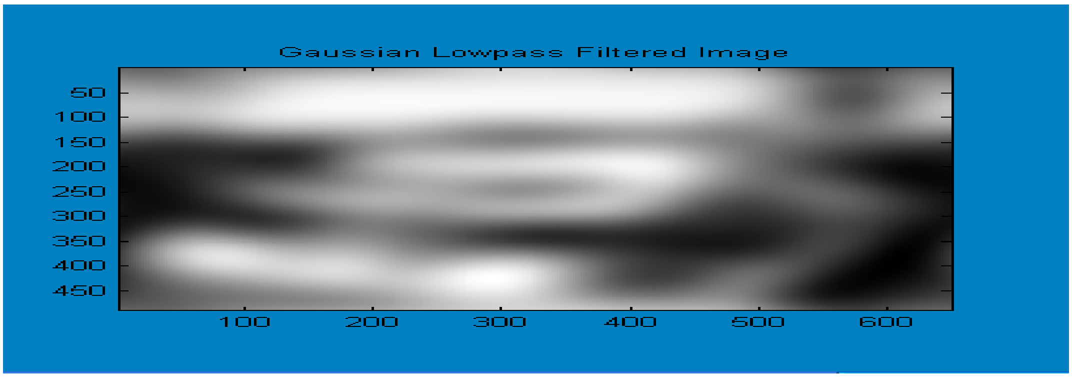

Figure 10: Gaussian Low Filtered Image

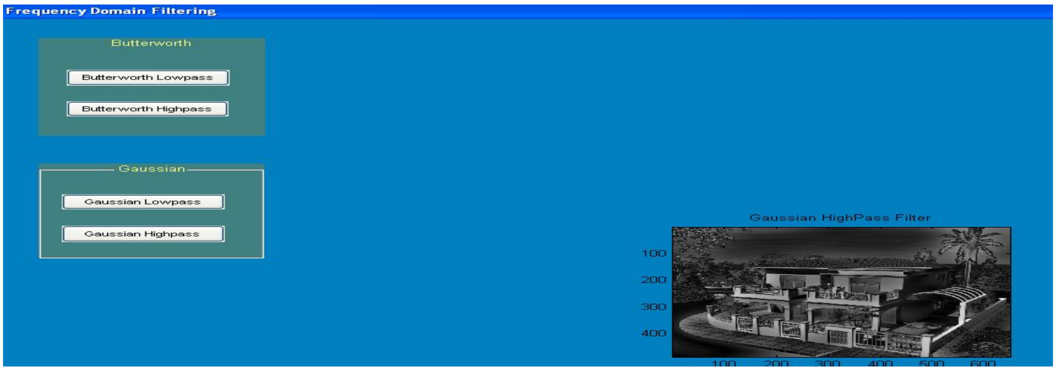

Figure 11: Gaussian High Pass Filtered Image

IV. CONCLUSION

It is clearly seen that Low pass filtered images are more blurred than the original but as the cut-off frequency increases, the difference between the filtered and the original image becomes smaller i.e. the blurring is less noticeable. We also noticed that the Gaussian filter has the least blurring while the ideal filter has the most blurring at any cutoff. It can be observed that the High pass filtered images are very dark and as the cut-off frequency increases, the sharpness of the image also decreases.

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