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Image Enhancement in Frequency Domain by Using Lowpass and Highpass Filters

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ABSTRACT

Digital image processing (or DIP) is the processing of digital images by utilizing digital computers. The main application area in DIP is to enhance or improve the pictorial information for human interpretation. While image acquisition some of the undesirable information is removed by utilizing various preprocessing techniques. Filtering is one such solution with the help of which digital images can be enhanced by removing noise. The goal of this research work is to show the Highpass and Lowpass filtering techniques. These are those filtering techniques which are utilized in Wavelet and Fourier Transformations. Highpass and lowpass filters help in reconstructing the original/new image by utilizing subband coding in Wavelet Transform. Lowpass filter will create a Gaussian smoothed blur image, whereas, high pass filter will normally increase the level of contrast between a dark and bright pixel in order to generate a sharpen image.

Keywords—*Image enhancement; Digital image processing; Lowpass filter; Highpass filter; Fourier Transform; Fast Fourier Transform (FFT).*

I. INTRODUCTION

Interest in DIP (digital image processing techniques) stems from 2 principal areas, enhancement of pictorial information for human interpretation and understanding the image knowledge for illustration, transformation, and storage of autonomous or self-governing machine perception. The aim of image enhancement is to improve the image standards as perceived by various human beings by means of several enhancement techniques/algorithms. Image enhancement can be performed in the spatial domain as well as in frequency domain [1].

An image is represented by a 2-D function $f(x$ where and are the spatial or plane coordinates, and is the amplitude at any coordinate pair $(x,$ It is also known as the gray level values or intensity of the image at that particular coordinate pair. When all these parameters i.e. and are discrete finite quantities then it becomes a digital image. The digital image processing field refers to the manipulation of different digital images with the help of digital computers [2-3]. But, a few of the digital images have a blurred look because of noise and so they need to be enhanced. Therefore, various filtering techniques are utilized in order to enhance digital images by filtering the noise and several other discontinuities from them. A filter also sharpens the digital images and plays an important role in edge detection [4].

II. RELATED WORK

Randall B [5] introduced noise in a digital image which decreases the quality of the image. Lowpass filters are then utilized in order to get the smoothed image. The results also show the reduction in noise levels. Omeed [6] demonstrated how to use the kernel structure with Highpass and lowpass filters. The whole process is implemented in Java. Handley [7] described that how to employ low-pass filters in order to get smoothed image. A Lowpass filter generally calculates the pixel average and all of its 8-connected neighbors. Kenny Hunt [8] introduced that lowpass filtering is basically the convolution which attenuates the high-frequency components of an image whilst allowing the components of low frequency to pass. By the literature survey, we come to recognize that Highpass and lowpass filters are doing convolution between the two sets of the array. These two array sets are filtering mask and image elements. In this research work, our focus is on the enhancement of digital images by utilizing frequency domain filters.

III. FAST FOURIER TRANSFORM (FFT)

Fourier Transform is an image processing tool which is generally used to divide an image into cosine and sine transforms. The transformation's output represents the digital image in Frequency domain or in terms of Fourier. This transformation is utilized when access to the geometric characteristics are required in spatial domain [9]. It is very easy to process and examine the several frequencies of the image with Fourier transform. The FFT has contributed its role the field of image processing for a lot of years. The two-dimensional Fourier Transform is the effective tool and is utilized to enhance, encode, restore, and describe the digital images. The FFT is employed in a lot of image processing applications as its computational cost is not so much. Fourier transform is also helpful in text recognition.

Let f be a continuous 1-D function of a real variable x. The Fourier Transform is represented by F of f is defined by the following formula [10]:

$$F(u) = \int f(x)e^{-j2\pi ux}\ dx \dots \dots \dots \dots (1)$$

Where

The inverse Fourier transform is defined as:

$$f(x) = \int F(u)e^{j2\pi ux}du \dots \dots \dots \dots (2)$$

The 2-D Fourier transform is given by [1]:

$$F(u,v) = \iint f(x,y)e^{-j2\pi(ux+vy)}\ dx\ dy \dots \dots \dots \dots (3)$$

Inverse Fourier transform of a 2-D Fourier transform is defined as:

$$f(x,y) = \iint F(u,v)e^{j2\pi(ux_{vy})}du\,dv \ldots\ldots\ldots\ldots (4)$$

A. Filters

The Filters in image processing are categorized into two parts on the basis of image enhancement techniques in spatial and frequency domain. These are further categorized for image sharpening and image smoothing [11]. Filters are of three types: Lowpass, Highpass, and Bandpass filters. In this research work, the focus is on frequency domain filtering using Fast Fourier Transform. In the frequency domain, the operator uses the Fourier domain filter function plus image. The digital image is multiplied with the chosen filter function in the following manner:

$$G(u,v) = F(u,v)H(u,v) \ldots\ldots\ldots\ldots (5)$$

Where F(u is the input image, H (u is the corresponding filter function and G (u is the resultant filtered image [11]. In order to get the result in spatial domain inverse, Fourier transform has to be applied on G(u. The process is shown in the following figure:

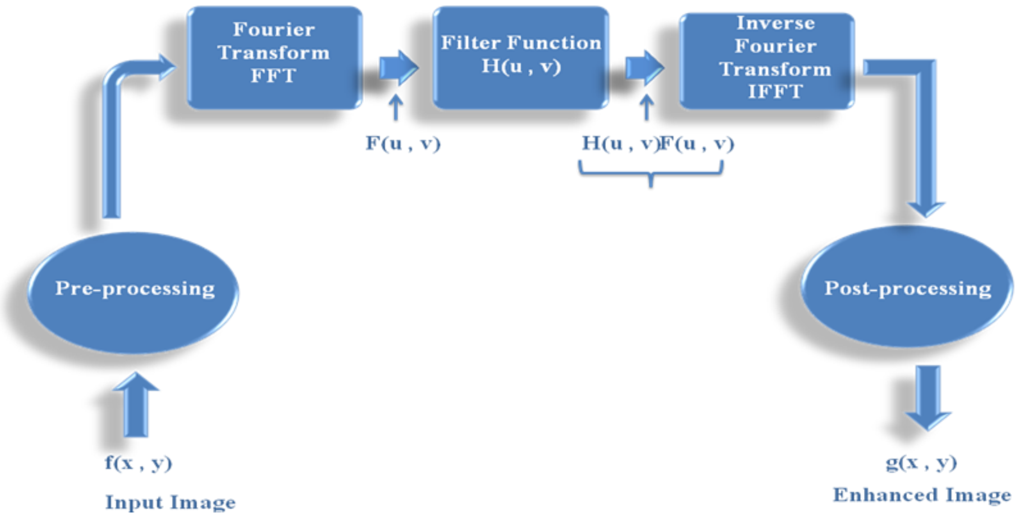

Fig. 1. Filtering process in frequency domain

Attenuating the high-frequency components will give a smoother image in the spatial domain and the process of attenuating the low-frequency components give you sharp images. That is, it will enhance the edges of the image.

3.1 Lowpass Filters (Image Smoothing*)*

A low-pass filter allows passing the low-frequency components and cut-off high-frequency components which are greater than the cut-off frequency. The level of attenuation for every frequency depends on the design of the filter. Smoothing is basically a lowpass filtering operation [6] [12]. Lowpass filters in the frequency domain are an Ideal lowpass filter, Gaussian lowpass filter and Butterworth lowpass filter.

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3.1.1 Ideal Lowpass Filter

An ideal low-pass filter eliminates all those frequencies which are greater than the cut-off frequency or a specified distance D0 whilst passing those frequencies which are below the cut-off frequency [13].

Mathematically, it is defined as [1] [14]:

$$\mathrm{H(u,v)} = \begin{cases} 1, & \text{if } D(u,v) \leq \mathrm{D_0} \\ 0, & \text{if } D(u,v) > \mathrm{D_0} \end{cases} \dots\dots\dots\dots (6)$$

where $\mathrm{D(u}$ is the distance from the frequency center to the point $\mathrm{(u}$ and it is calculated as:

$$\mathrm{D(u,v)} = \left[\left(\mathrm{u} - \frac{\mathrm{M}}{2}\right)^2 + \left(\mathrm{v} - \frac{\mathrm{N}}{2}\right)^2\right]^{\frac{1}{2}} \dots\dots\dots\dots (7)$$

3.1.2 Butterworth Lowpass Filter

These are used to remove the high-frequency signal noise with the minimum loss of the signal frequencies at a specific distance with order n [1] [15].

$$\mathrm{H(u,v)} = \frac{1}{1 + \left[\mathrm{D(u,v)}/\mathrm{D_0}\right]^{2\mathrm{n}}} \dots\dots\dots\dots (8)$$

3.1.3 Gaussian Lowpass Filter

Gaussian Transfer function is defined by the flowing equation [1] [16]:

$$H(u,v) = e^{\frac{-D^2(u,v)}{2D_0{}^2}} \dots\dots\dots\dots (9)$$

IV. HIGHPASS FILTERS (IMAGE SHARPENING)

The image can be filtered or smoothed by attenuating the components of high-frequency of its corresponding Fourier transform [17]. Edges and several other manipulations in intensities are linked with the high-frequency components, so image sharpening can be accomplished with Highpass filters in the frequency domain [18] [19]. Highpass filters attenuate the components of low-frequency without distracting high-frequency components in the Fourier transform. As lowpass filters, Highpass filters are categorized into three types: Ideal Highpass filter, Gaussian Highpass filter, and Butterworth Highpass filter.

Highpass filters ($\mathrm{H_{HP}(u,}$ can be obtained from lowpass filters ($\mathrm{H_{LP}}$ $\mathrm{(u,}$ by utilizing the following equation [1] [20]:

$$H_{HP}(u,v) = 1 - H_{LP}(u,v) \dots\dots\dots\dots (10)$$

V. EXPERIMENTAL RESULTS

The results obtained by various Highpass filters are shown in figure 2.

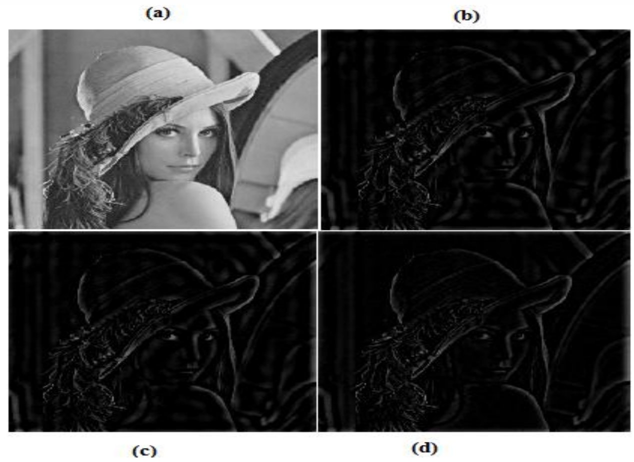

Fig. 2. Results obtained by Highpass filters. (a) Original Image (b) Ideal HPF (c) Butterworth HPF (d) Gaussian HPF

In experimental results, Root Mean Square Error (RMSE), Peak Signal to Noise Ratio (PSNR) is calculated. The RMSE value of Ideal Highpass filter is 15.9687, Butterworth Highpass filter is 15.6647 and Gaussian Highpass filter is 13.3284. The PSNR value of Ideal Highpass filter is 36.1321, Butterworth Highpass filter is 37.7247 and Gaussian Highpass filter is 39.3126. By analyzing these calculated values we can conclude that Gaussian Highpass filter has lower Root Mean Square Error (RMSE) value and higher Peak Signal to Noise Ratio (PSNR), which is very effective to sharpen the digital image while implementing transformation.

The results obtained by various lowpass filters are shown in figure 5.

Fig. 3. Results obtained by Lowpass filters. (a) Original Image (b) Ideal LPF (c) Butterworth LPF (d) Gaussian LPF

In experimental results, Root Mean Square Error (RMSE), Peak Signal to Noise Ratio (PSNR) is calculated. The RMSE value of Ideal low-pass filter is 8.5381, Butterworth lowpass filter is 8.2641 and Gaussian lowpass filter is 7.5989. The PSNR value of Ideal low-pass filter is 38.6386, Butterworth lowpass filter is 38.9281 and

Gaussian lowpass filter is 39.6184. By analyzing these calculated values we can conclude that Gaussian lowpass filter has lower Root Mean Square Error (RMSE) value and higher Peak Signal to Noise Ratio (PSNR), which is very effective to smooth the digital image while implementing transformation.

The RMSE and PSNR values of highpass and lowpass filters are tabulated in Table 1 and Table 2 respectively and Analysis of RMSE and PSNR values corresponding to two filter categories are shown in fig. 4 and fig. 5 respectively.

Table 1 RMSE value analysis of lowpass and highpass filters

Filter Type	Low-Pass Filter	High-Pass Filter
Ideal Filter	8.5381	15.9687
Butterworth Filter	8.2641	15.6647
Gaussian Filter	7.5989	13.3284

Table 2 PSNR value Analysis of lowpass and highpass filters

Filter Type	Low-Pass Filter	High-Pass Filter
Ideal Filter	38.6386	36.1321
Butterworth Filter	38.9281	37.7247
Gaussian Filter	39.6184	39.3126

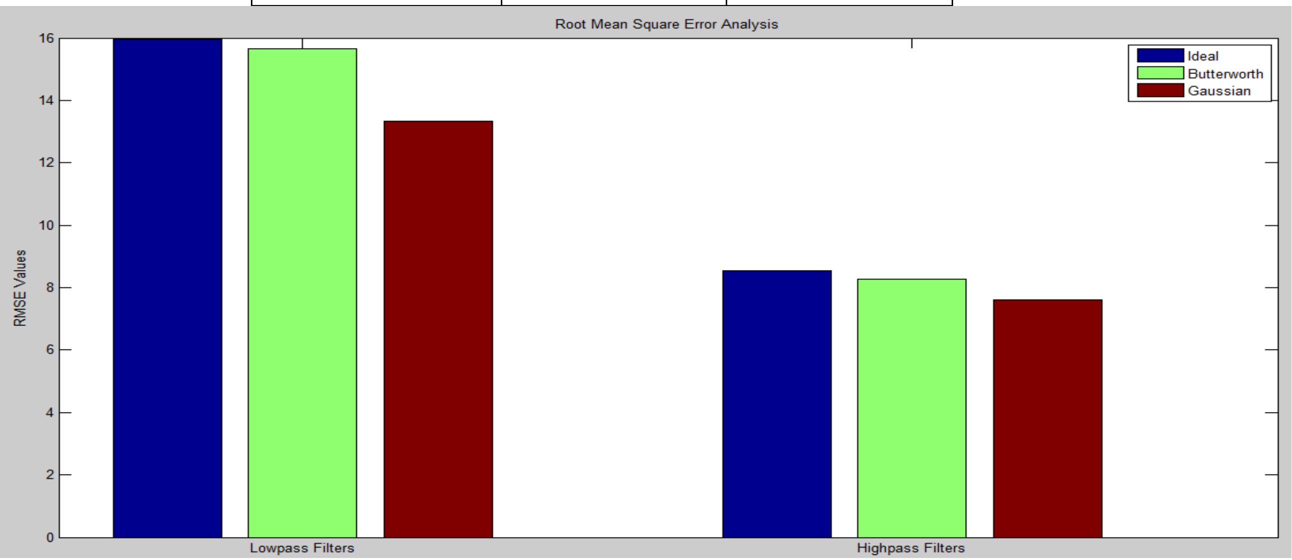

Fig. 4. RMSE analysis of Highpass and Lowpass filters

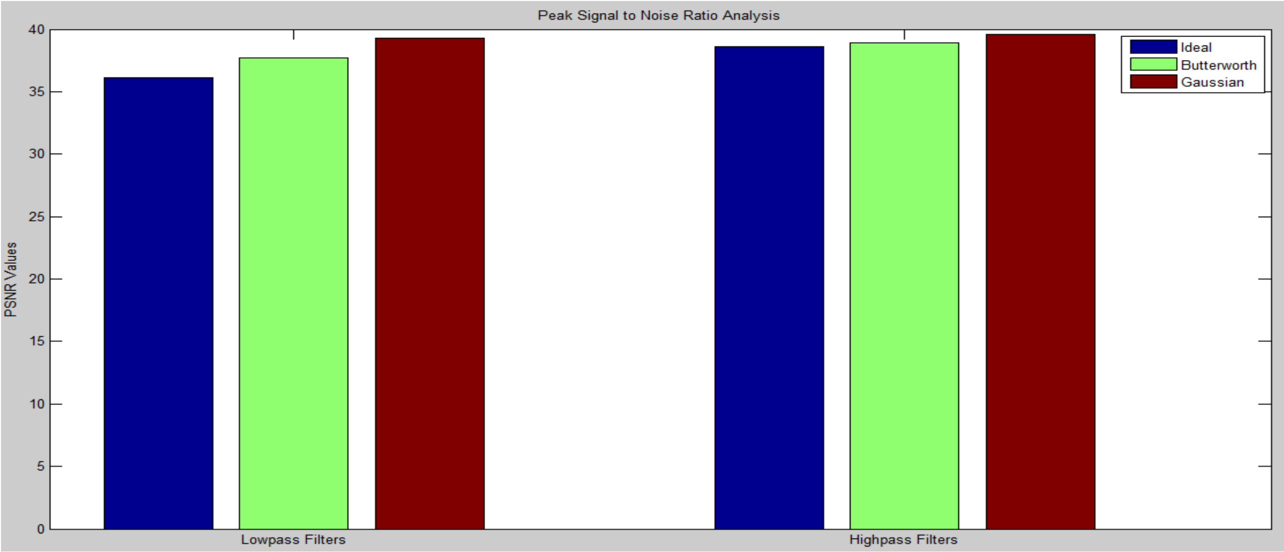

Fig. 5. RMSE analysis of Highpass and Lowpass filters

VI. CONCLUSION

In this research work, we have implemented Highpass and Lowpass filters both in the frequency domain by utilizing Fourier transform. The implemented results of Highpass filters and lowpass filters show that lowpass filters preserve the image detail by removing noise whereas edge details are preserved by highpass filters, so lowpass and highpass are basic image processing filters utilized in the image enhancement transformations. In both filter categories, Gaussian lowpass and Highpass filter are the most effective as shown in experimental results. The maximum PSNR and minimum RMSE values show the effectiveness of Gaussian filter on an image. In future, this method can be utilized for the enhancement of illumination and reflectance effects.

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