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Image Smoothing and Sharpening using Frequency Domain Filtering Technique

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Abstract – Images are used in various fields to help monitoring processes such as images in fingerprint evaluation, satellite monitoring, medical diagnostics, underwater areas, etc. Image processing techniques is adopted as an optimized method to help the processing tasks efficiently. The development of image processing software helps the image editing process effectively. Image enhancement algorithms offer a wide variety of approaches for modifying original captured images to achieve visually acceptable images. In this paper, we apply frequency domain filters to generate an enhanced image. Simulation outputs results in noise reduction, contrast enhancement, smoothing and sharpening of the enhanced image.

Index Terms – Digital Image Processing, Fourier Transforms, High-pass Filters, Low-pass Filters, Image Enhancement.

1. INTRODUCTION

Image processing is a form of signal processing in which the input is an image, such as a photograph or video frame and the output may be either an image or a set of characteristics or parameters related to the image. Most image-processing techniques involve treating the image as a two-dimensional signal and applying standard signal-processing techniques. It deals with the improvement of pictorial information for human interpretation and processing of image for storage, transmission and representation for machine perception.

Image processing can be defined as analysis of picture using techniques that can basically identify region of interest from all those images in bitmapped graphic format that have been scanned or captured with digital camera. Image enhancement techniques aims at realizing the improvement in the quality of a given image. An image can be enhanced by changing any attribute of the image. There exist many techniques that can enhance an image without spoiling it. Enhancement methods can be broadly divided into two categories i.e. spatial domain technique and frequency domain technique.

Spatial domain deals with direct manipulation of pixels of an image whereas the frequency domain filters the image by modifying the Fourier Transform of an image. In this paper, main focus is laid on enhancing an image using frequency domain technique. The objective to show how a digital image is being processed generate a better -quality image.

The content of this paper is organized as follows: Section I gives introduction to the topic and projects fundamental background. Section II describes the types of image enhancement techniques. Section III defines the operations applied for image filtering. Section IV shows results and discussions. Section V concludes the proposed approach and its outcome.

1.1 Digital Image Processing

Digital image processing is a part of signal processing which uses computer algorithms to perform image processing on digital images. It has numerous applications in different studies and researches of science and technology. The fundamental steps in Digital Image processing are image acquisition, image enhancement, image analysis, image reconstruction, image restoration, image compression, image segmentation, image recognition, and visualization of image.

The main sources of noise in digital image processing come under image acquisition and image transmission. Image Enhancement basically improves the visual quality of the image by providing clear images for human observer and for machine in automatic image processing techniques. Digital image processing has fundamental classes depending on their operations:

A. Image enhancement

Image enhancement deals with contrast enhancement, spatial filtering, frequency domain filtering, edge enhancement and noise reduction. This project briefly shows the theoretical and practical approaches in frequency domain.

B. Image analysis

It deals with the statistical details of an image. It is possible to examine the information of an image in detail. This information helps in image restoration and enhancement. One of the representations of the information is the histogram representation. During image analysis, the main tasks include image segmentation, feature extraction and object classification.

C. Image restoration

In this class, the image is corrected using different correction methods like inverse filtering and feature extraction in order to restore an image to its original form.

D. Image compression

It deals with the compression of the size of the image so that it can easily be stored electronically. The compressed images are then decompressed to their original forms. The image compression and decompression can either lose their size by maintaining high quality or preserves the original data size without losing size.

E. Image synthesis

This class of digital image processing is well known now-a-days in the film and game industry and is very advanced in 3-dimensional and 4-dimensional productions. In both cases the images and videos scenes are constructed using certain techniques of visualization.

1.2 Image Enhancement

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 process a given image so that the result is more suitable than the original image for a specific application.

Image enhancement simply means, transforming an image f into image g using a transformation function T . Let the values of pixels in images f and g are denoted by r and s respectively. Then the pixel values r and s are related by the expression,

$$s = T(r)$$

Where, T is a transformation that maps a pixel value r into a pixel value s .

2. IMAGE ENHANCEMENT TECHNIQUES

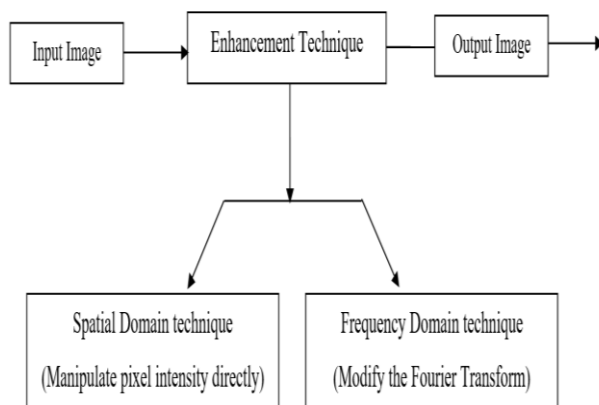


Fig. 1. Types of Enhancement Technique

The enhancement technique differs from one field to another according to its objective. Advancement in the technology brings the development in the digital image processing techniques in both domains:

A. Spatial domain.

The term spatial domain refers to the image plane itself, and approaches in this category are based on direct manipulation of pixel values of an image. It enhances the whole image in a uniform manner. The value of the pixels with coordinates (x, y) in an enhanced image 'F' is the result of performing some operation on the pixels with the neighbourhood of (x, y) in the input image 'f'. This method is straightforward and are chiefly utilized in real time applications. But it lags in producing adequate robustness and imperceptibility requirement.

B. Frequency domain.

The frequency domain processing techniques are based on modifying the Fourier transform of an image. The basic idea in using this technique is to enhance the image by manipulating the transform coefficient of the image, such as Discrete Fourier Transform (DFT), Discrete Wavelet Transform (DWT), and Discrete Cosine Transform (DCT). This methods advantages includes low complexity of computations, ease of viewing and manipulating the frequency composition of the image and the easy applicability of special transformed domain properties.

3. IMAGE ENHANCEMENT USING FREQUENCY DOMAIN TECHNIQUE

In frequency domain methods, the image is first transferred into frequency domain. All the enhancement operations are performed on the Fourier transform of the. Image enhancement function in the frequency domain is denoted by the expression:

$$g(x, y) = T[f(x, y)]$$

where $f(x, y)$ is the input image, $g(x, y)$ is an enhanced image formed by the result of performing some operation, T on the frequency component of the transformed image.

3.1 Filtering in the Frequency Domain

The procedures required to enhance an image using frequency domain technique are:

- i. Transform the input image into the Fourier domain.
- ii. Multiply the Fourier transformed image by a filter.
- iii. Take the inverse Fourier transform of the image to get the resulting enhanced image.

3.2 Basic Steps for Filtering in the Frequency Domain:

1. Given an input image $f(x, y)$ of size $M \times N$.
2. Compute $F(u, v)$, the DFT of the image.

3. Multiply $F(u, v)$ by a filter function $H(u, v)$, i.e., $G(u, v) = H(u, v)F(u, v)$

4. Compute inverse DFT of the $G(u, v)$.

5. Obtain the real part of the result.

Step-1 Input Image

An input image may be defined as a two-dimensional function, $f(x, y)$, where x and y are spatial (plane) coordinates, and the amplitude of f at any pair of coordinates (x, y) is called the intensity or grey level of the image at that point.

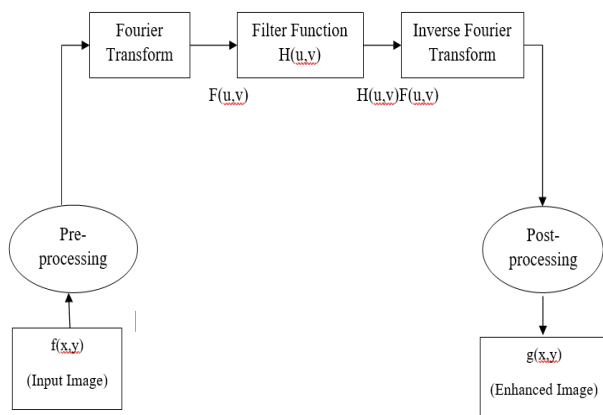


Fig. 2. Frequency Domain Filtering Operations

Step-2 Compute Fourier Transform of the input image.

The image $f(x, y)$ of size $M \times N$ will be represented in the frequency domain $F(u, v)$ using *Discrete Fourier Transform (DFT)*. The concept behind the Fourier transform is that any waveform that can be constructed using a sum of sine and cosine waves of different frequencies. The Discrete Fourier Transform (DFT) of an image takes a discrete signal and transforms it into its discrete frequency domain representation. The Fourier transform $F(u)$, of a single variable continuous function $f(x)$, is defined by:

$$F(u) = \frac{1}{M} \sum_{x=0}^{M-1} f(x) e^{-j2\pi ux/M}$$

where, u represents the frequency and x represents time/space. The exponential in the above formula can be expanded into sines and cosines with the variables u and v determining these frequencies.

Step-3 Filtering of the Fourier Transformed image.

A filter is a tool designed to suppress certain frequency components of an input image and return the image in a modified format. They are used to compensate for image imperfections such as noise, and insufficient sharpness. By filter design we can create filters that pass signals with frequency components in some bands, and attenuate signals

with content in other frequency bands. The general formula for filtering is given as:

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

where the $H(u, v)$ is the transfer function, and $F(u, v)$ is the Fourier transform of the image function. The $G(u, v)$ is the filtered final function.

In all the filters, it is important to find the right filter function $H(u, v)$ as it amplifies some frequencies and suppresses certain frequency components in an image. There are many filters that are used for blurring/smoothing, sharpening and edge detection in an image. Based on the property of using the frequency domain the image filters are broadly classified into two categories:

1. Low-pass filters / Smoothing filters.
2. High-pass filters / Sharpening filters.

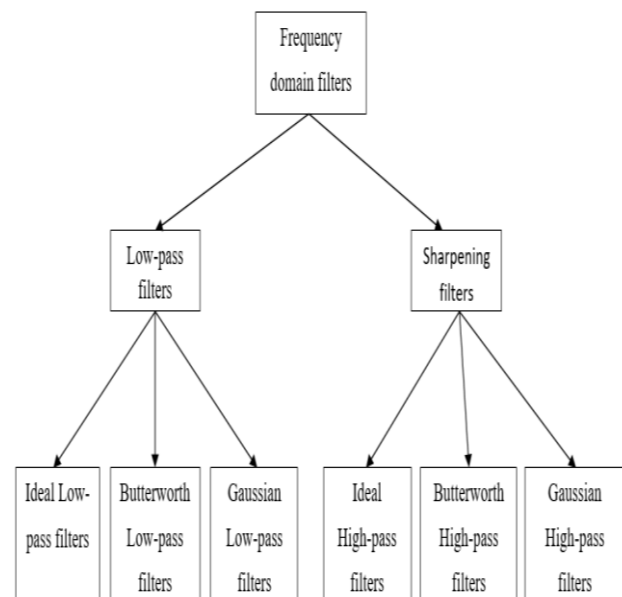


Fig. 3. Types of Frequency Domain Filters

A. Image Smoothing (Low-pass Frequency Domain Filters)

A low-pass filter that attenuates (suppresses) high frequencies while passing the low frequencies which results in creating a blurred (smoothed) image. It leaves the low frequencies of the Fourier transform relatively unchanged and ignores the high frequency noise components. Three main low-pass filters are:

i. Ideal low-pass filter (ILPF)

An ideal low pass filter deals with the removal of all high frequency values of the Fourier transform that are at a distance greater than a specified distance from the origin of the transformed image. The filter transfer function for the Ideal low-pass filter is given by:

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

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

ii. Butterworth low-pass filter (BLPF)

The filter transfer function for the Butterworth low-pass filter is given by:

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

iii. Gaussian low-pass filter (GLPF)

The filter transfer function for the Gaussian low-pass filter is given by:

$$H(u, v) = e^{-D^2(u, v) / 2D_0^2}$$

B. Image Sharpening (High-pass Frequency Domain Filters)

Sharpening of an image in the frequency domain can be achieved by high pass filtering process which attenuates (suppress) low frequency components without disturbing high frequency information in the Fourier transform of the image. The high-pass filter H_{hp} is often represented by its relationship to the low-pass filter (H_{lp}) as:

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

i. Ideal High-Pass Filter (IHPF)

The ideal high pass filter simply cuts off all the low frequencies lower than the specified cut-off frequency. The filter transfer function is given as:

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

ii. Butterworth High-pass Filter

The transfer function of Butterworth high-pass filter of order n and with a specified cut-off frequency is given by:

$$H(u, v) = 1 - e^{-D^2(u, v) / 2D_0^2}$$

iii. Gaussian High Pass Filters

The transfer function of the Gaussian high-pass filter with cut-off frequency locus at a distance $0 D$ from the origin given by:

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

In the above formulas, D_0 is cut-off frequency, a specified nonnegative number. $D(u, v)$ is the distance from point (u, v) to the center of the filter.

Step-4 Compute Inverse Fourier Transform to get the enhanced image.

We then need to convert data back to real image to use in any applications. After the needed frequencies removed it is easy to return back to the spatial domain. Function represented by Fourier transform can be completely reconstructed by an inverse transform with no loss of information

For this the Inverse Fourier Transform of the filtered image is calculated by the following equation:

$$f(x, y) = \frac{1}{MN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u, v) e^{j2\pi(ux/M + vy/N)}$$

4. RESULTS AND DISCUSSIONS



Fig. 4. Original Input Image

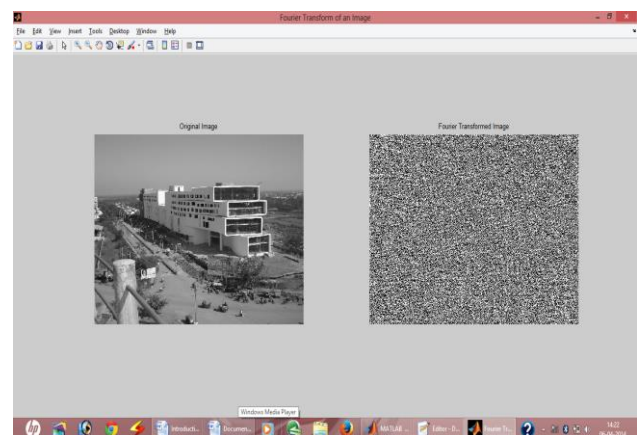


Fig. 5. Fourier Transform of an Image



Fig. 6. Ideal Low-Pass Filtered Image

In Fig. 6., filtering center component is responsible for blurring. The circular components are responsible for the ringing effects. The severe ringing effect in the blurred images is a characteristic of ideal filters.



Fig. 7. Butterworth Low-Pass Filtered Image

In Fig. 7., the BLPF with less number of orders does not have any ringing effect. As the order increases BLPF results in increasing ringing effects. Less ringing effect is due to the filter's smooth transition between low and high frequencies.



Fig. 8. Gaussian Low-Pass Filtered Image

In Fig. 8., there is no ringing effect of the GLPF. Ringing artifacts are not acceptable in fields like medical imaging.

Hence Gaussian low-pass filter is used more instead of the ILPF/BLPF.

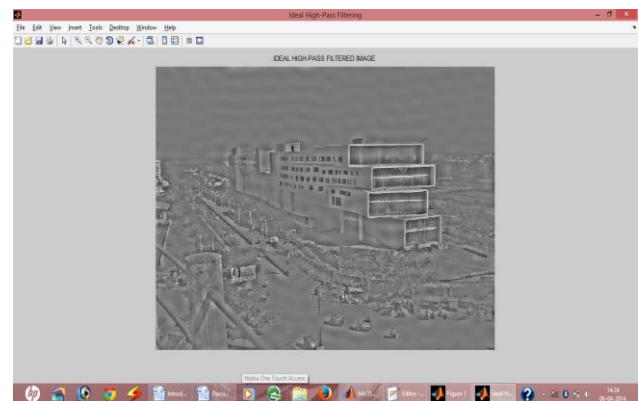


Fig. 9. Ideal High-Pass Filtered Image

The severe ringing effect in Fig. 9. is a characteristic of ideal filters. It is due to the discontinuity in the filter transfer function. Ringing effect in this filter is so severe that it produces distorted and thickened object boundaries.

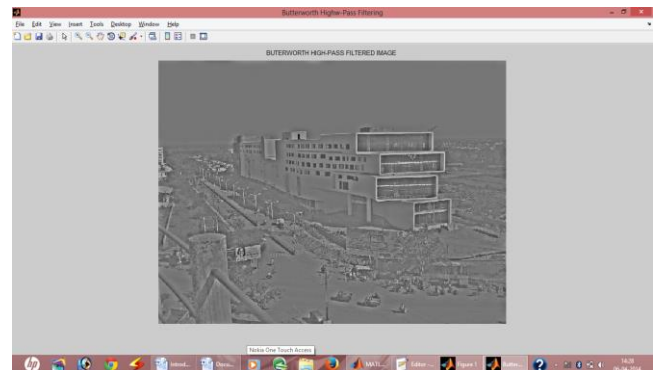


Fig. 10. Butterworth High-Pass Filtered Image

Boundaries in Fig. 10. are much less distorted compared to IHPF. This is more appropriate for image sharpening than the ideal HPF, since this not introduce ringing.



Fig. 11. Gaussian High-Pass Filtered Image

The results obtained in Fig. 11. are smoother than with the previous to filters Even the filtering of the smaller objects and thin bars is cleaner with Gaussian filter.

5. CONCLUSION AND FUTURE SCOPE

In this project, we focus on existing frequency domain based image enhancement techniques that includes filters that are useful in many application areas as medical diagnosis, army and industrial areas. Program is developed to compute and display the image after applying various low pass and high pass filters on it.

In this project frequency domain filters are implemented in MATLAB. It is found that low-pass filters smoothen the input image by removing noise and results in blurring of the image and high-pass filters sharpens the inside details of an image. Ideal filters results in the ringing effect in the enhanced image. Using the Butterworth filters the ringing effect gets reduced since there are no sharp frequency transitions, whereas the use of Gaussian filters completely gives the filtered image without any ringing effect.

The future scope can be the development of adaptive algorithms for effective image enhancement using Fuzzy Logic and Neural Network. Many more filters can be added into functionality. The same work can be extended for further digital image processing applications such as image restoration, image data compression etc.

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