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Comparison Between Spatial and Frequency Domain Methods

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Abstract—

The purpose of this research is to present a proper comparison between image filters in spatial domain and frequency domain, on the basis of various parameters of a grayscale image. This paper explores results of filtering techniques from both domains, presenting a detailed comparative analysis on the efficiency and effectiveness of filtering in both domains.

Keywords— Spatial Domain; Frequency Domain; Image Enhancement; Image Filtering, Entropy ,Image Entropy, Standard Deviation.

I. INTRODUCTION

In this research we shall be comparing different techniques for image filtering in spatial and frequency domains. The basic idea behind image enhancement is to transform the whole or part of the image, to achieve desired result. Most of the time this enhancement pertains to enhancing the visual appearance of image. It is a problem-oriented process; meaning the output is obtained according to need of the application. Image Enhancement transforms are used for providing better representations of otherwise un-obvious details. The two kinds of image enhancements mainly used are smoothing and sharpening. Smoothing refers to the blurring of edges in image intensity levels. Sharpening refers to highlighting image edges. These two enhancements can be achieved using image filtering .Image Filtering is referred to as the mathematical transformation of the image matrix to achieve enhancement of image .Image filtering is done in two domains; One is the spatial domain, which refers to the 2-D x-y plane and the other domain is the frequency domain, which is mathematically the Fourier domain, (u-v plane) which is used to deal with frequency values. Image Filters which are nothing but mathematically generated masks which are used to work with image intensity values, therefore enhancing the image. The Spatial domain filtering methods modify pixel intensity directly. The Frequency domain filtering methods modify the Fourier transform of the input image. Both work on different principles, and they both provide different images as output. So based on the parameters of those discrete images as output, A quantized comparison and analysis is obtained.

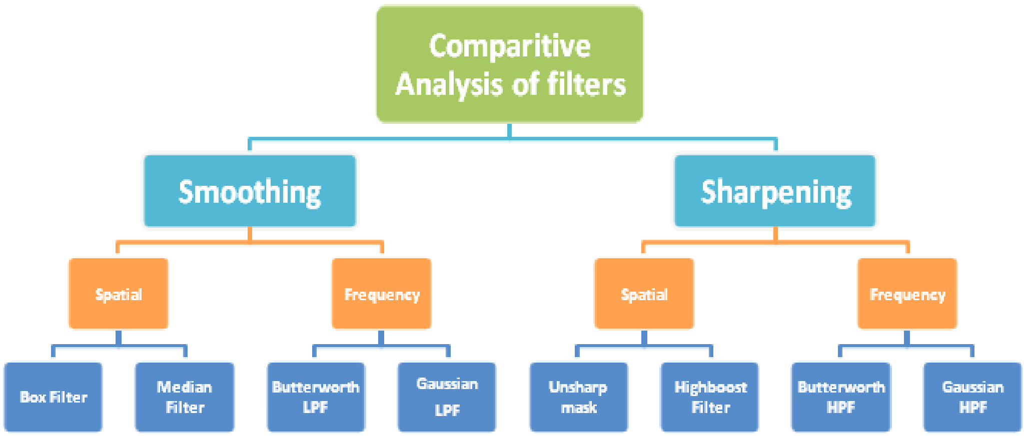

Figure 1: A graphic representation of the comparison presented in this research before we begin, we specify the parameters of original Image:

Figure 2: Original Image (cameraman.tiff, entropy: 7.009, Standard Deviation: 62.3417)
Figure 2 shows a generic grayscale image, cameraman.tiff

II. SMOOTHING

Smoothing refers to averaging out the edges present in the image. An edge in an image is a boundary or curve at which a significant intensity change occurs in some physical component or region of an image [7].

A. Smoothing in Spatial Domain

1) Box Filter(Linear):

Figure 3: After Box Filter (entropy: 7.0271, Standard Deviation: 57.9969)

This figure 3 shows image presents a box filtered representation of the original image. A box filter is a kind of a smoothing filter in which each pixel of the resulting image has a value of its neighbouring pixels in the input image. This filter was implemented on the original image, by creating a matrix where each cell value was = 1/25 for a 5X5 filter. Dividing the image pixels with the following filter value, achieves a box blur like above

2) Median Filter:

Figure 4: After Median Filter (entropy: 6.9680, Standard Deviation:62.0752)

This figure 4 shows result of median filter, applied on the original image. The median filter replaces pixel values entry by entry with the median value of the neighborhood [5]. The pattern of neighbours' is the referred as the window through which the filter slides. This image shows a median filtered representation of the original image, Here the median filter is implemented, in the same manner.

B. Smoothing in Frequency Domain

1) Butterworth Low Pass Filter:

Figure 5 After Butterworth LPF (entropy: 5.3874, Standard Deviation:21.4869)

This figure 6 represents result of butter worth low pass filter on original image. Butterworth high pass filter is a type of signal processing filter, which attenuates low frequency elements of the image producing a flat frequency response. A second order Butterworth filter is applied to the following image which passes all frequencies lower than 0.10.

2) Gaussian Low Pass Filter:

Figure 6 After Gaussian Filtering (entropy: 7.0260, Standard Deviation: 59.6999)

This figure 5 shows result of Gaussian LPF, applied on original image. Gaussian filtering is applied by convolving the 2D Gaussian distribution function with the input image, And a Fourier transform of the Gaussian function is multiplied with the image signal (which has also been Fourier transformed) to yield a Gaussian blur, which attenuates high frequency signals. Here a smoothing Gaussian filter is applied, which averages out the image with a Standard Deviation value of 2 and uses filter size of 2 as well.

III. SHARPENING

Image sharpening refers to any enhancement technique that highlights edges in an image (Refer definition of edges in II) [8] .Image sharpening is widely used to increase the contrast in images and also to recover blurred portions of an image.

A. Sharpening in Spatial Domain:

1) Unsharp Mask:

Figure 7 After Unsharp (entropy: 7.1471, Standard Deviation:74.0242)

This figure7 illustrates result of unsharp filtering on the original image.
This technique uses a blurred, or "unsharp", negative image to create a mask of the original image. The unsharp mask is then combined with the positive (original) image, creating an image that is less blurry than the original. Here the filter is implemented such that it mathematically subtracts the smoothness of the image; as a result blurred information is cancelled out in this procedure.

2) Highboost Filter:

Figure 8 After High Boost (entropy: 2.5061, Standard Deviation:83.0416)

This figure 8 shows result of high boost filtering on original image
The high-boost filter is used to enhance high frequency components while still keeping the low frequency components. It is composed of an all pass filter and an edge detection filter; it is a simple sharpening operator. It is used for amplifying high frequency components of signals and images .Implementation is achieved by subtracting a smoothed version of the picture and boosting edge information of the resultant image [6].

B. Sharpening in Frequency Domain

1) Butterworth Low Pass Filter:

Figure 9 After Butterworth HPF (entropy: 5.0866, Standard Deviation:27.1428)

This figure 9 represents result of butter worth high pass filter, on original image. Butterworth high pass filter is a type of signal processing filter, which attenuates low frequency elements of the image while producing a flat frequency response. Implementation is similar to BLPF, to achieve a more precise comparison.

A second order Butterworth high pass filter is applied to the following image which passes all frequencies higher than 0.10.

2) Gaussian High Pass Filter:

Figure 10 After Gaussian HPF (entropy: 2.5807, Standard Deviation: 26.4227)

This figure 10 shows effect of Gaussian HPF, applied on the original image. Gaussian High Pass filtering is achieved by multiplying the 2D Gaussian distribution function with the image, which highlights the step intensity variations such as edges. This filter attenuates signals which are nearer to the image center. [4].Here a smoothing Gaussian High Pass filter is implemented by subtraction of low frequency elements, leaving the high frequency elements in the filtered image.

IV. COMPARITIVE ANALYSIS

A. Prologue

To obtain a detailed analysis of both filtering domains, we use entropy and standard deviation of an image. We measure the information entropy of the images to determine variance in information content, with each filter applied .Entropy of an image determines the information content of that image[1] A more numerical definition of entropy states that Entropy for a gray scale image refers to the number of gray levels covered in that image , by this convention, ,the entropy of a binary image is considered minimum at grayscale as only 2 possible levels are reached if all 256 levels are reached the image is histogram equalized and entropy is maximum [2].Entropy of original image considered here is found out to be 7.009. This implies that maximum number of grey levels covered with respect to image matrix elements amounts to 7.009.

Now considering Standard Deviation value of the images, this shows the mathematical distance between the average value of the image matrix and all other elements of that image matrix. A high standard deviation implies that the image data is widely spread with respect to the average or expected value of image matrix, and conversely a lower Standard Deviation value signifies that the values of matrix elements are similar to average value of image matrix. Standard Deviation of the original image is found to be 62.3417, so the variance between matrix elements and average of original image is 62.3417.

B. Smoothing

1) Entropy Analysis:

TABLE I ENTROPY COMPARISON TABLE FOR SMOOTHING FILTERS

Entropy values in spatial domain		Entropy values in frequency domain	
Box Filter	**6.9680**	**BLPF**	**5.3874**
Median Filter	**7.0271**	**GLPF**	**7.0260**

The Table 1 shows entropy analysis for smoothing filters in the spatial domain (Box Filter & Median Filter) versus the smoothing filters in the frequency domain (Butterworth LPF & Gaussian LPF).

Entropy by this table seems totally filter dependent, but on taking a closer look, comparing the instances of Gaussian low pass filter, and Box filter, we can observe effective smoothing, though in case of box filtering even if entropy is more, which suggests a more equalized image representing more information, we observe, that essential information is blurred. On the contrary, in the frequency domain, the Gaussian filter achieves a lesser entropy value than the box filter, but achieves a more apparent smoothing than blurring of image information.

Butterworth low pass filter applies second order filter which, results to a loss of most of image information decreasing to a value of 5.3.Therefore we can conclude that for effective image smoothing Gaussian LPF and box filter produce a better entropy value and smoothen the image .The only difference being that Gaussian filter still retains vital image information better.

2) Standard Deviation Analysis:

Table II Standard Deviation Comparison Table For Smoothing Filters

Standard Deviation values in spatial domain		Standard Deviation values in frequency domain	
Box Filter	**57.9969**	**Butterworth LPF**	**21.4869**
Median Filter	**62.0752**	**Gaussian LPF**	**59.6999**

The Table 2 shows standard deviation analysis for smoothing filters in the spatial domain (Box Filter & Median Filter) versus the smoothing filters in the frequency domain (Butterworth LPF & Gaussian LPF).

Smoothing is an averaging operation , So the lower sigma value shall imply more smoothing .By observing median filter's standard deviation we can see that not a lot of smoothing is achieved .The standard deviation value for BLPF is very less , which implies most averaging ; yet the smoothing achieved is not visually appealing ,and is very dissimilar to original image. Therefore Butterworth LPF may not be suitable for many applications.

On having a look at results from Box filter and Gaussian filter, a lot of smoothing is performed. The variance between image elements and average value of image has decreased sizeably. Gaussian Filter has lesser smoothing than Box Filter, yet it can be said that both these filters have achieved effective and efficient smoothing, as both results are coherent with the original image.

C. Sharpening

1) Entropy Analysis:

Table III Entropy Comparison Table For Sharpening Filters

Entropy values in spatial domain		Entropy values in frequency domain	
Unsharp	**7.1471**	**BHPF**	**5.0866**
Highboost	**2.5061**	**GHPF**	**2.587**

The Table 3 shows entropy analysis for sharpening filters in the spatial domain (high boost & unsharp) versus the sharpening filters in the frequency domain (Butterworth HPF & Gaussian HPF).

The following entropy values suggest a high loss in gray level information, except in the unsharp mask instance, which sharpens the edges of the image without increasing the noise or blemish [3], leading to effective sharpening of image elements; with a gain in entropy value. In other filters such as the Gaussian high pass filter or High boost filter the focus was on thresholding greyscale values, which when applied made the more apparent elements darker and the less apparent elements lighter resulting in loss in entropy information

In Butterworth high pass filter, lower frequency values were eliminated, resulting in loss of image information, leading to decrease in entropy value. Therefore we can conclude that unsharp mask is the most likely choice, if one wants to sharpen the image while preserving entropy values

2) Standard Deviation Analysis:

Table IV Standard Deviation Comparison Table For Sharpening Filters

Standard Deviation values in spatial domain		Standard Deviation values in frequency domain	
Unsharp	**74.0242**	**Butterworth HPF**	**27.1248**
Highboost	**83.01416**	**Gaussian HPF**	**26.4227**

The Table 4 shows standard deviation analysis for sharpening filters in the spatial domain (high boost & unsharp) versus the sharpening filters in the frequency domain (Butterworth HPF & Gaussian HPF).

Sharpening highlights the edges of the image, which results in high contrast between image elements. This variance can be seen noticeably in the spatial domain sharpening filters.Unsharp mask is a highly efficient sharpening mask , which has added to variance between image elements and average value of an image. And High boost Filter using High boost function has added a large amount of contrast to the image, while preserving a lot of image elements.

On the contrary , result in frequency domain have achieved a lower standard deviation ,because of the function of high pass frequency transform function , which acts as thresholding function ,eliminating lower frequencies ,by only allowing higher level frequency values .Therefore only a image intensity values of values remained , and many of the image elements have the same intensity value out of small set of intensity values present in the image. Therefore standard deviation might be calculated less than standard deviation of original image .As an instance, observing the Gaussian HPF result, a thresholding effect is achieved where lighter elements are white and darker image elements are blackened out. As most image elements are white, standard deviation is found out to be of a lesser value.

Therefore it can be concluded that spatial sharpening methods are better suited to obtain a high contrast image.

V. CONCLUSIONS

We derive a comparison between filters in spatial and frequency domain, gaining further insight in the filter results

We also gain a conscious understanding of how entropy and standard deviation value of the image play an important role when comparing frequency and spatial domain. Furthermore we gain insight into the working of various (smoothing and sharpening) filters, in both the aforementioned domains.

A. Further Work

This research can be used in applications for Grayscale filtering, and as a reference for further comparison between both domains. It also can be used for study related to filtering domains and filtering techniques.

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