Comparison between Butterworth and Gaussian High-pass Filters using an Enhanced Method

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Abstract
Filtering is aimed to preprocess image in order to make it more adaptive for a specific application. Several types of filters are available, involving low-pass filters, which prevent higher frequencies from passage and high-pass filters, which cut low frequencies. The purpose of this paper is to compare between Butterworth High Pass Filter (BHPF) and Gaussian High Pass Filter (GHPF) within the frequency domain to enhance these two filters and to obtain sharper images. The proposed enhanced models were applied on standard pictures and simulated using MATLAB. Experimental results comparing the old and new filters design showed that GHPF outperformed BHPF. Moreover, the new designed filters outperformed the original ones.
Keywords:
Gaussian High-Pass Filter, Butterworth High-Pass Filter, Image Sharpening, Fast Fourier.

1. Introduction

The development of image processing began in the early of 1970s. After that and with the appearance of necessary elements like computers, memories and cameras in recent market, the image processing technology has been strongly growth within. Image enhancement and pattern recognition are considered as the two major applications for the image processing. Where, image is considered as the major tool for communication between humans. It also represents the global mean of communication due to its rich content, which enables the humans from different cultures and all ages to understand it. In addition, the image is the most effective communication way, where the human can analyze the image in its preferred way through identifying the text and then extract the required information. Therefore, image processing represents a set of techniques and methods that operate to enhance the visual appearance of images and extract relevant information [1] [2]. The processing of images using software allows integrating an impressive catalog of filters. Where, these filters can be modified and loaded in the form of plug-ins to be ready for downloading on the Web. On the other hand, filters can be classified into three types based on the area of use: special effect filters, retouching filters (aesthetic sense) and correction filters (sharpening, smoothing and reduction of noise are the main functions of the correction filters) [3].

The purpose of this paper is to perform a comparison between BHPF and GHPF to enhance the image sharpness. This paper is composed of seven sections, where several related works have been reviewed in the second section. Fourier Transform (FT) has been illustrated in the third section, while the performance of filters in the frequency domain has been described in the fourth section. The suggested methodology has been explained in the fifth section, while the results obtained from the conducted experiments have been reviewed and discussed in the sixth section. A summary of the paper is shown in the last section.

2. Related work

Ayush and Manjeet [4] analyzed the performance of BHPF and GHPF in frequency domain. The qualitative and quantitative methods had been applied to analyze the performance of those two filters for image sharpening. Magnetic Resonance (MR) images and Computed Tomography (CT) images were used within experiments, also a Butterworth filter with 4th order and cut-off frequency (Do=100) was also used. The obtained results showed that the performance of BHPF is better than the performance of GHPF. On the other hand, Prasad [5] presented a method to sharpen noisy images using Homomorphic filter. Where, the filter sharpens the details and edges of images by reducing the illumination variation. Also, Aziz and Bhagirathi [6] demonstrate the performance of low-pass and high-pass filtering techniques based on Wavelet Transform (WT) and FT. The performance of Butterworh, Ideal and Gaussian filters within high-pass and low-pass techniques were compared. The obtained results showed that the Gaussian filter within both low-pass and high-pass techniques had the best performance and was the most suitable one for transformation, because it had maximum Signal to Noise Ratio (SNR) and minimum Root Mean Square Error (RMSE) values. Further, Anuradha [7] presented the effectiveness of filtering process within frequency domain based on different parameters of grayscale images. The author utilized different parameters

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in order to gain more insight into filtering results, and a conscious understanding of the role of entropy and standard deviation value in comparison between spatial and frequency domains.

3. Fourier Transform (FT)

In General, FT is utilized to represent the image in frequency domain, where it is easy to implement and has many advantages with regard to the image processing.
The Fourier Transform is defined as:

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

While, the inverse of Fourier Transform is defined as:

$$f(x,y)=\sum_{u=0}^{n}\sum_{v=0}^{n} F(u,v)e^{j2\pi(u\frac{x}{M}+\frac{vy}{N})} \quad (2)$$

In a 2D image, the first dimension transform is performed for the first line of image F (u, y) and then it is kept in the memory. After that, the same calculation is performed column by column on the computed image.
On the other hand, Fast Fourier Transform (FFT) is utilized instead of the Discrete Fourier Transform (DFT) because it is faster. However, FFT can only be used on images with second order width and height [8].

4. Filtering

Based on the figure below, FT can be calculated to process the image by multiplying F (u, v) term, which represents the original image with H (u, v) term, which represents the FT function of filter. G (u, v) is the output of filtering process and it represents the enhanced image in frequency domain. Therefore, Inverse Fourier Transform (IFT) can then be performed to recover the enhanced image in time domain.

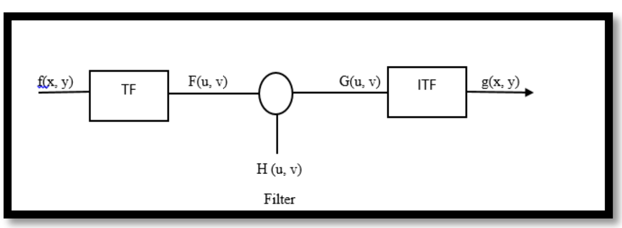

Fig. 1 filtering principle

4.1 Filters

The main purpose of filtering is to improve the visual quality of image (e.g. mitigate and / or eliminate the noise) or extract image attributes (e.g. contours) [8][9]. Where, the process of filtering can be performed by changing the level value of gray pixel within image according to the value of its neighbors. Filtering process should obtain an image with optimal visibility by keeping the significant elements of image [10]. Where, the neighborhoods of the processed pixel represent the function of mask shape, which selected by the filter.
Moreover, various filtering methods have been developed according to the type and the intensity of noise, while others have been developed based on the applications of which image is intended. The first and the simplest developed method is based on the stationary linear filtering (invariant transitions). However, the limitations of these techniques, especially their poor conservations led to the development of nonlinear filtering.

- **High-pass Filters (Sharpening)**

The major function of high-pass filter is to mitigate and eliminate energy of low frequencies within the spectrum as well as accentuate edges and details of the image. However, the noise within the image is amplified by this type of filters. On the other hand, the high-pass filter promotes high spatial frequencies and enhances contrast within the image. Also, the high-pass filter is characterized by the presence of a core that surrounded the central pixel of image with negative values. The function of the high-pass filter H_{hp} is represented by [6]:

$$H_{hp} = 1 - H_{lp} \quad (3)$$

Where;
H_{lp} : represents the low-pass filter.

- **Butterworth High-pass Filter**

The Butterworth high-pass filter can control the sharpness of the filter based on its order. The function of the Butterworth high-pass filter is given by:

$$H(x,y) = \frac{1}{1+\left[\frac{D0}{\left[(x-\frac{M}{2})^2+(y-\frac{N}{2})^2\right]^{1/2}}\right]^{2n}} \quad (4)$$

Where; $D0$: represents the cut-off frequency and n: is the order of the filter.

- **Gaussian Filter**

Gaussian filter is considered as an isotropic filter with specific mathematical properties. Further, it is very common in nature and it is used within different applications involving the image processing. The Gaussian function of two dimensional images is given by:

$$H(x,y)= e^{-\left(\left(\left[(x-\frac{M}{2})^2+(y-\frac{N}{2})^2\right]^{1/2}\right)^2/2D_0^2\right.} \quad (5)$$

Where; $D0$ is called by sigma and it represents the standard deviation of the function. The value of sigma is generally used to determine the width of Gaussian filter. Typically, Gaussian filter with a sigma less than one is applied to reduce the noise within images. On the other hand, Gaussian filter with a sigma higher than one is utilized for images that used to make the “unsharp mask”.

5. Methodology

Different images have been processed to attain the objective of this paper. Where, MATLAB Software has been used to process the images. The function of the suggested high-pass filter H_{hp} is given by:

$$H_{hp} = 1 - H_{lp}/s \qquad (6)$$

Where, s parameter is the responsible about the filter sharpness controlling. The filter in (6) is constructed in a frequency domain and it has been used to construct New Butterworth High Pass Filter (NBHPF) and New Gaussian High Pass Filter (NGHPF) based on the Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE) quality parameters. Also, the behavior of Older Butterworth High Pass Filter (OBHPF) in (3) has been compared with the behavior of NBHPF in (6).

5.1 Mean Square Error (MSE)

MSE has been calculated to evaluate the performance of the suggested algorithm. Where, a statistical treatment has been applied throughout the image to get the demanded “metric”, which required for quality assessment. Hence, MSE can be calculated by (7):

$$MSE = \frac{1}{M*N}\sum_i^N \sum_j^M \left|X_{i,j} - Y_{i,j}\right|^2 \qquad (7)$$

Also, the quality assessment is performed between the source image, which is given by $X_{i,j}$ and the resultant image$Y_{i,j}$.

5.2 Peak Signal-to-Noise Ratio (PSNR)

PSNR represents the expression for the ratio between the maximum power value of image signal and the power value of distorting noise, which impacts on the image representation quality. The value of PSNR can be calculated by:

$$PSNR_{dB} = 10log_{10}(\frac{L^2}{MSE}) \qquad (8)$$

Where; L represents the number of luminance levels and its equal to 255 for the 8 bits in colored image.

Also, PSNR is commonly used to evaluate the signal quality based on its power. Thus, when the value of PSNR is less than 30 dB, a noticeable damage will appear in the image.

6. Discussion and Results

The values of MSN and PSNR have been used to perform a comparison between the two filters. The computed values of MSE and PSNR for both filters are shown in Table 1 and Table 2. The comparison between New Butterworth High Pass Filter (NBHPF) and New Gaussian High Pass Filter (NGHPS) is shown in Table 1, while the comparison between NBHPF and Older Butterworth High Pass Filter (OBHPF) is shown in Table 2. The figures below illustrate the output of BHPS and GHPF in all cases.

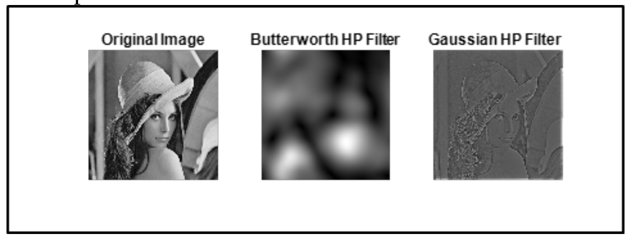

Fig. 2 output of OBHPF and OGHPF for image 1 with Do =10 and n=2.

Fig. 3 output of NBHPF and NGHPF for image 1 with Do =10 and n=2.

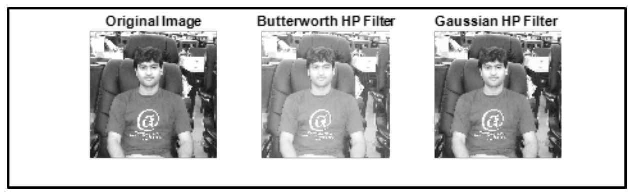

Fig. 4 output of NBHPF and NGHPF for image 2 with Do =10 and n=2.

Fig. 5 output of NBHPF and NGHPF for image 3 with Do =10 and n=2.

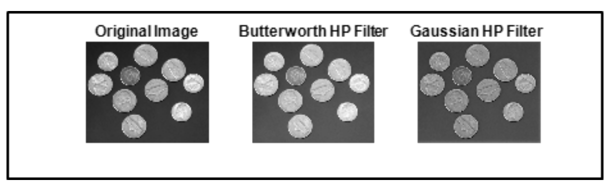

Fig. 6 output of NBHPF and NGHPF for image 3 with Do =10 and n=2.

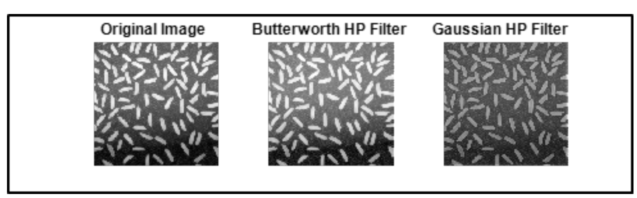

Fig. 7 output of NBHPF and NGHPF for image 4 with Do =10 and n=2.

As shown from the figures above, the outcomes of the NBHPS are better than the output of the NGHPF in the term of sharpness in all tested images. In addition, the images with lower value of MSE and higher value of PSNR are more clearly visible than the others. Table 1 shows the values of PSNR and MSE parameters for all images. In addition, the experiments show that the optimal value of s parameter to reach the demanded enhancement is 1.5. This value improves high frequencies and suppresses low frequencies.

Table 1: Values of MSE and PSNR for various images using NBHPF and NGHPF.

Image 1			Comments
Parameters	NBHPF Quality value	NGHPF Quality value	All images processed by NBHPF are more visible and sharper than images processed by NGHPF (Figure 2 to Figure 6) The visibility of image increased with higher value of PSNR and lower value of MSE.
MSE	26.465	4.14E-05	
PSNR	33.904	91.965	
Image 2			
Parameters	NBHPF Quality value	NGHPF Quality value	
MSE	13.089	2.54E-05	
PSNR	36.962	94.09	
Image 3			
Parameters	NBHPF Quality value	NGHPF Quality value	
MSE	18.163	5.83E-05	
PSNR	35.539	90.478	
Image 4			
Parameters	NBHPF Quality value	NGHPF Quality value	
MSE	15.718	4.77E-05	
PSNR	36.167	91.342	
Image 5			
Parameters	NBHPF Quality value	NGHPF Quality value	
MSE	27.124	1.71E-05	
PSNR	33.797	95.797	

Further, the outcomes of the experiments confirm that the BHPF has better performance than the GHPF. Also, the new suggested method confirms that BHPF behaves better than GHPF in all cases. The contribution of the current work can be shown by the sharpness of filters, where the BHPF and the GHPF are sharper than the other types of filters.

Table 2: the values of MSE and PSNR of various images using NBHPF and OBHPF

Image 1			Comments
Parameters	NBHPF Quality value	OBHPF Quality value	Values of PSNR parameter for NBHPF are higher than values of OBHPF and values of MSE for NBHPF are lower than values of OBHPF.
MSE	26.465	30.617	
PSNR	33.904	33.271	
Image 2			
Parameters	NBHPF Quality value	OBHPF Quality value	
MSE	13.089	15.471	
PSNR	36.962	36.236	
Image 3			
Parameters	NBHPF Quality value	OBHPF Quality value	
MSE	18.163	22.144	
PSNR	35.539	34.678	
Image 4			
Parameters	NBHPF Quality value	OBHPF Quality value	
MSE	15.718	18.981	
PSNR	36.167	35.348	
Image 5			
Parameters	NBHPF Quality value	OBHPF Quality value	
MSE	27.124	30.575	
PSNR	33.797	33.277	

In addition, the above table shows that the parameters help to enhance the sharpness of the images. Also, the value of PSNR in the new filter is higher than that in the old filter, while the value of MSE in the new filter is lower than that in the old filter and this enhances the visibility of image.

7. Conclusion

The measurement of image quality plays a significant role in various applications of image processing. Where, different images have been processed to perform the comparison between the BHPF and the GHPF. In this paper, a new design has been suggested to enhance the performance of the BHPF and the GHPF. The suggested values of filter's parameters made the performance of BHPF better than the performance of GHPF. Also, the higher values of PSNR and the lower values of MSE enhance the visibility and the sharpness of the images. The outcomes show that the sharpness of image by NBHPF is better than that by NGHPF.

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