

Effect of Frequency Domain Filters on Bio-Medical Images

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Abstract

This study tries to find out the most effective frequency domain filter used for enhancing biomedical images. Five different biomedical images have been taken and they are filtered with different low and high pass filters at different cut off frequencies. As far as enhancement method is concerned, the method is very simple because the motive here is to find the most effective filter not a good enhancement technique. To assess the enhancement the metric MSE is used. The experiments are done on MATLAB.

Keywords: Butterworth, frequency domain, Gaussian, Ideal, MSE.

INTRODUCTION

In late 1960s, space applications emerged as the first application of digital image processing and in early 1970s emerged the medical applications. The invention of Computerized Axial Tomography (CAT) in the early 1970s is considered to be a major breakthrough in image processing for medical diagnosis. CAT is also called as simply Computerized Tomography (CT). Then by the increasing use of direct digital imaging systems for medical diagnostics, digital image processing became more and more important in the area of medicine. As the digital imaging advanced it also reflected on biomedical imaging systems. In addition to CT or other originally digital methods like Magnetic Resonance Imaging (MRI), the other then analogue imaging modalities like endoscopy or radiography now incorporates digital sensors. The entire digital image processing techniques or algorithms can be implemented in biomedical image processing. Therefore, biomedical image processing is nothing but using digital image processing techniques in biomedical sciences.

BIOMEDICAL IMAGING MODALITIES

Ever since the discovery of X-rays, the medical images have been of great help in

medical diagnostics and treatments. Medical images have been used in education and research representing morphology and biological functions in terms of 1D, 2D, 3D and in some cases 4D image data. One example of 4D is cardiac MRI.

Nowadays, we have several imaging modalities based on transmission, refraction or reflection of light, temperature, radiation, spin or sound. Fig.1[1] shows the image characteristics with different imaging modalities. Evidently, the delineation algorithm of an individual vertebra shape that is suitable for an image of one modality cannot be directly implemented on images of other modalities. Earlier the major imaging sources like CT-scanner and MRI were used for the purpose of segmentation and 3D visualization such as surface detection and shading to obtain the 3D shape and slice interpolation to tackle the low spatial resolution.

With the advancement in physics and electronics, we started having greatly improved detectors in CT, coils in MRI, transducers in ultrasound etc. Chemistry also contributed through contrast agents which greatly helped and have been helping in

the diagnostics. Combining these with more efficient computers helped in taking up the image processing tasks of higher

level which could have been difficult otherwise.

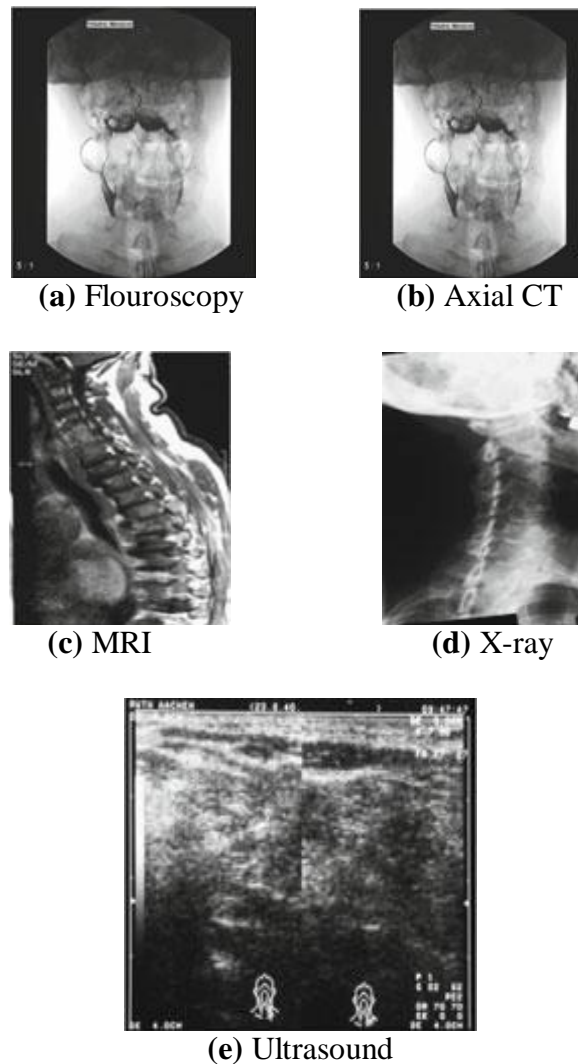


Figure 1: Images (cervical vertebra) from different modalities.

IMAGE RESTORATION AND ENHANCEMENT

Image restoration attempts to restore images that have been degraded. It identifies the degradation process/model and attempts to reverse it. Often distinguished from enhancement, because it is more objective in its goal. Enhancement endeavors mostly to improve from appearance or application point of view. It is largely subjective[2].

Enhancement methods are *ad hoc* usually assuming no model for the degradation. Previously when we highlighted certain

features of the image using any image enhancement technique, it was assumed that the initial image displayed a fairly accurate representation of the objects of interest. But it is not so, the image has to be restored so that the objects of interest are accurately represented before implementing any enhancement technique. So, image restoration takes care of the degradations that occur prior to enter the image processing system. The goal of an image restoration algorithm is to generate an estimate of the original picture, prior to the degradation.

There is a little commonality between image restoration and image enhancement. Over and over again image enhancement algorithms, like median filtering, can be utilized to restore deteriorated images. However, the term image restoration is typically linked with minimizing, or even eliminating, image artifacts owing to blurring and noise. Restoration methods are generally centered on explicit models and assessed quantitatively (e.g., MSE). There are numerous causes of blurring: temporal aliasing, camera motion, out of focus lens, etc. Overall the procedures used to decrease the effects of blurring are in accordance with the cause of blurring. There are multiple sources of noise: additive Johnson noise, bit loss in communication, multiplicative noise (e.g., speckle), etc. Again, the sources of noise usually dictate the type of processing performed.

FREQUENCY DOMAIN

Frequency domain is basically a space defined by a French mathematician Jean Baptiste Joseph Fourier [3]. Functions can be transformed to this domain by using Fourier transform equations as mentioned ahead. Frequency domain is of great utilization as far as image processing applications like image analysis, image filtering, image reconstruction, etc. [4]. The best part is that the functions can be brought back to the original form by the inverse process.

An image may be deteriorated due to various reasons like optics, electronics or environment but may also be enhanced to restore to a great extent if not entirely. Enhancement helps in restoring several features of an image. The image may also be corrupted by noises like Additive noise, Gaussian noise, Poisson noise, Impulse noise etc. To tackle these types of noises, we have various types of filters [4], [5]. The basic operations performed in spatial domain with corrupted image is smoothing and

sharpening. Smoothing or blurring in spatial domain is same as low pass filtering in frequency domain and sharpening in spatial domain is same as high pass filtering in frequency domain [3], [6]. The word frequency in images is very enthralling. Low intensity transitions in an image point to low frequency contents and sharp intensity transitions point to high frequency contents of the image. Cutoff frequency in image filter is nothing but the pixel distance from the center of the image, and is commonly represented by D_0 [3], [6].

In frequency domain, it can be identified how the signal is distributed over various ranges of frequencies. The basic concept of frequency domain image filtering comprises calculation of 2-D Discrete Fourier transform (DFT) of the image, with the help of a filter function and then finally obtaining the inverse Discrete Fourier Transform [4], [6].

Discrete Fourier Transforms

2-D Fast Fourier transform (2D- DFT) given as

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

Where $x, u = 0, 1, 2, \dots, M-1$

$y, v = 0, 1, 2, \dots, N-1$

In (1), $f(x, y)$ is the spatial domain 2D-function, which represents spatial domain image of size $M \times N$, while $F(u, v)$ represents its frequency domain representation [3], [7], [8], [6].

2-D Inverse Fast Fourier transform (2D-IDFT) given as

$$f(x, y) = \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u, v) e^{j2\pi(\frac{ux}{M} + \frac{vy}{N})} \quad (2)$$

Where $x, u = 0, 1, 2, \dots, M-1$

$y, v = 0, 1, 2, \dots, N-1$

The Inverse Discrete Fourier Transform (IDFT) is used to go back to the spatial domain so that the processed image can be displayed and viewed in spatial domain.

Steps for filtering in the frequency domain

1. Let $f(x,y)$ be the input discrete image of size $M \times N$.
2. Zero padding is applied to $f(x,y)$ to obtain padded image $f_p(x,y)$ of size $P \times Q$, where $P = 2M$ and $Q = 2N$. Zero padding is actually a process where necessary number of zeros are appended to the original image $f(x,y)$.
3. The padded image $f_p(x,y)$ is multiplied by $(-1)^{(x+y)}$ to center its transform.
4. The 2D-DFT, $f(u,v)$ of image obtained in step 3 is computed.
5. A real symmetric filter, $h(u,v)$ of size $P \times Q$ is developed with center at $(P/2, Q/2)$.
6. $f(u,v)$ is multiplied with the filter function $h(u,v)$.
7. The inverse DFT, $g_p(x,y)$ of the image obtained in step 6 is taken.
8. Crop the top left quadrant of $g_p(x,y)$.
9. Obtain the real part of cropped part to get the final processed image, $g(x,y)$.

Frequency Domain Filters

Low pass filters

An image is smoothed or blurred by Low pass filters. It is accomplished in frequency domain by attenuation of high frequency components in the image. The output of low pass filter contains reduced intensity transitions in the image. Three low pass filters namely, Ideal low pass filter (ILPF), Butterworth low pass filter (BLPF) and Gaussian low pass filter (GLPF) will be implemented on the biomedical images on MATLAB platform and performances based on MSER will be compared.

Ideal low pass filter (ILPF)

ILPF allows to pass all the frequency components within the circle of radius, D_0 which is cutoff frequency, while attenuates all the frequency lying outside this circle. It is given in the form of filter function as in (3).

$$H(u,v) = \begin{cases} 1 & \text{if } D(u,v) \leq D_0 \\ 0 & \text{if } D(u,v) > D_0 \end{cases} \quad (3)$$

$$\text{Where } D(u,v) = \left[\left(u - \frac{P}{2}\right)^2 + \left(v - \frac{Q}{2}\right)^2 \right]^{1/2}$$

is the distance of the point (u,v) from center $(\frac{P}{2}, \frac{Q}{2})$ of the frequency rectangle of size $P \times Q$.

Butterworth low pass filter (BLPF)

Butterworth filter has a varying performance depending on its order. For higher order the Butterworth filter approaches the Ideal filter. For low order values Butterworth filter is more like a Gaussian filter. It is given in the form of filter function as in (4)

$$H(u,v) = \frac{1}{1 + [D(u,v)/D_0]^{2n}} \quad (4)$$

Where n is the filter order. $D(u,v)$ and D_0 are same as defined above [7], [8], [6], [4].

Gaussian low pass filter (GLPF)

This is the generalized filter for digital images. It is given in the form of filter function as in (5)

$$H(u,v) = e^{-D^2(u,v)/2D_0^2} \quad (5)$$

Where $D(u,v)$ and D_0 are same as defined above [7], [8], [6], [4].

High pass filters

High pass filter de-blurs images and makes it look sharp. In frequency domain, the images are sharpened by not allowing the low frequency components and allowing the high frequency components to pass. Three high pass filters namely, Ideal high pass filter (IHPF), Butterworth high pass filter (BHPF) and Gaussian high pass filter (GHPF) will be implemented on the biomedical images on MATLAB platform and performances based on MSER will be compared.

Ideal high pass filter (IHPF)

The IHPF function is given by (6)

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

It is just the opposite of ILPF, it allows to

pass all the frequency outside the radius D_0 which is cutoff frequency of IHPF, while attenuates all the frequency within the radius D_0 . $D(u,v)$ and D_0 are same as defined above [7], [8], [6], [4].

Butterworth high pass filter (BLPF)

The BHPF function is given by (7).

$$H(u, v) = \frac{1}{1 + [D_0/D(u,v)]^{2n}} \quad (7)$$

Where $D(u,v)$ and D_0 are same as defined above and n is the order of filter [7], [8], [6], [4].

Gaussian high pass filter (GHPF)

GLPF function is given by (8). [7], [8], [4].

$$H(u, v) = 1 - e^{-D^2(u,v)/2D_0^2} \quad (8)$$

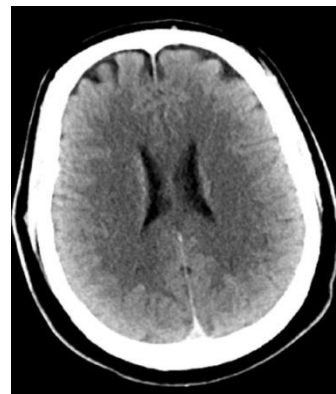
Where $D(u,v)$ and D_0 are same as defined above.

ENHANCING BIOMEDICAL IMAGES WITH FREQUENCY DOMAIN FILTERS

For the purpose of finding best frequency domain filter for enhancing biomedical images five medical images as shown below in Fig. 2 were taken. These images were then corrupted



(a) Foot Xray



(b) Head CT



(c) Brain MRI



(d) Fetal Ultrasound



(e) Abdomen MRI

Figure 2: Different medical images.

by adding blur and noise. Blur was added by filtering with 10 X 10 smoothing filter and the noise added was Gaussian. Both the corrupted images were added to form the final corrupted images as shown in Fig. 3. All the experiments in this manuscript were performed on MATLAB.

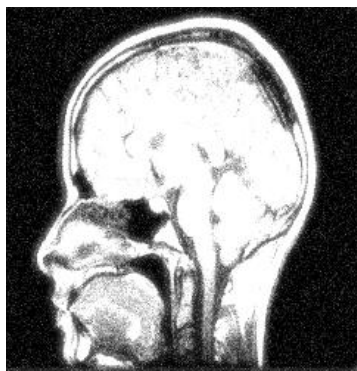
The enhancement method chosen is simple as the emphasis is given on finding out the most effective filter rather than how good the enhancement method is. The flowchart for enhancement method is shown in Fig. 5 and it goes as follows:



(a) Foot Xray



(b) Head CT



(c) Brain MRI



(d) Fetal Ultrasound

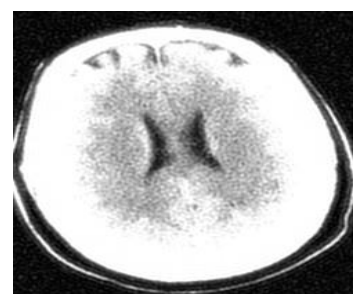


(e) Abdomen MRI

Figure 3: Different corrupted medical images.



(a) Foot Xray



(b) Head CT



(c) Brain MRI



(d) Fetal Ultrasound



(e) Abdomen MRI

Figure 4: Most enhanced medical images.

Table 1: MSE values in thousands (cut off frequency=20).

Image	Ideal	Butterworth(Order 2)	Gaussian
Foot Xray	4.9341	5.0979	5.4902
Head CT	5.7069	5.7082	6.8455
Brain MRI	5.4847	5.5382	6.5802
Fetal Ultrasound	4.0611	4.1853	4.9390
Abdomen MRI	5.1029	5.2185	6.0525

Table 2: MSE values in thousands (cut off Frequency=30).

Image	Ideal	Butterworth(Order 2)	Gaussian
Foot Xray	4.7846	4.9332	5.4146
Head CT	5.4239	5.4879	6.6132
Brain MRI	4.9917	5.1282	6.4459
Fetal Ultrasound	3.9430	4.0033	4.8557
Abdomen MRI	4.6710	4.8632	5.9998

Table 3: MSE values in thousands (cut off frequency=50).

Image	Ideal	Butterworth(Order 2)	Gaussian
Foot Xray	4.7565	4.9056	5.3308
Head CT	5.2323	5.3818	6.4025
Brain MRI	4.6425	4.8317	6.02535
Fetal Ultrasound	3.7711	3.9157	4.7246
Abdomen MRI	4.4460	4.6452	5.8847

Table 4: MSE values in thousands (cut off frequency=75).

Image	Ideal	Butterworth(Order 2)	Gaussian
Foot Xray	4.7639	4.9610	5.2805
Head CT	5.1438	5.3445	6.2029
Brain MRI	4.5008	4.7220	6.1082
Fetal Ultrasound	3.7615	3.9658	4.6247
Abdomen MRI	4.3567	4.5886	5.7388

Table 5: MSE values in thousands (cut off frequency=100).

Image	Ideal	Butterworth(Order 2)	Gaussian
Foot Xray	4.8304	5.0434	5.2643
Head CT	5.1851	5.3924	6.1103
Brain MRI	4.5305	4.7252	5.9993
Fetal Ultrasound	3.8114	4.0288	4.5481
Abdomen MRI	4.3740	4.5923	5.6300

Table 6: MSE values in thousands (cut off frequency=150).

Image	Ideal	Butterworth(Order 2)	Gaussian
Foot Xray	4.9546	5.0866	5.2188
Head CT	5.2757	5.4132	5.9651
Brain MRI	4.6346	4.7392	5.8358
Fetal Ultrasound	3.9231	4.0505	4.4109
Abdomen MRI	4.4821	4.6091	5.5058

Table 7: MSE values in thousands (cut off frequency=200).

Image	Ideal	Butterworth(Order 2)	Gaussian
Foot Xray	4.9828	5.0690	5.2104
Head CT	5.2572	5.3511	5.8616
Brain MRI	4.6073	4.6764	5.6877
Fetal Ultrasound	3.9262	4.0184	4.3469
Abdomen MRI	4.4601	4.5434	5.3890

Step1. Take the input/corrupted image as shown in Fig. 3.

Step2. Filter the image with Ideal low pass filter.

Step3. Take the filtered image as obtained in step 2 and apply Ideal high pass filter on it.

Step4. Add the images obtained in Step2 and Step3 [9].

Step5. Repeat the process with different cutoff frequencies i.e., $D_0=20, 30, 50, 75, 100, 150, 200$.

Step6. Repeat the process with Butterworth(order 2) and Gaussian filters.

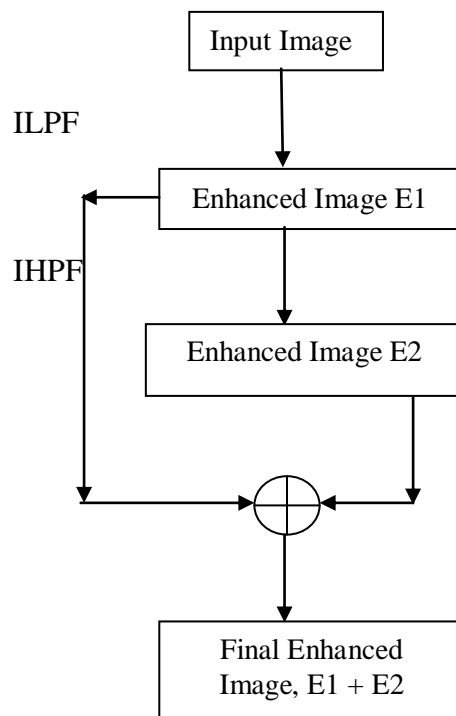


Figure 5: Flowchart of the enhancement method.

RESULTS AND DISCUSSION

Mean square error (MSE) [10] values of the enhanced images when compared with the original images for different filters at different cutoff frequencies were

obtained. The three filters, Ideal low and high pass filters, Butterworth low and high pass filters and Gaussian low and high pass filters were used in the enhancement method. Table 1 to Table 7 shows MSE

values with the three filters at cut off frequencies 20,30,50,75,100,150 and 200 are shown in from Table 1 to Table 7 respectively. By looking at the seven different tables, it can be seen that the lowest MSE values for all the biomedical images were obtained when Ideal filter was implemented. Except for the first image, *Foot Xray*, all the lowest MSE values appear in Table 4, with cut off frequency 75. For the *Foot Xray* image the lowest MSER value appear in Table 3, with cut off frequency 50. The most enhanced images i.e., the ones with least MSER values are shown in Fig. 4.

CONCLUSION

It was seen that best results were obtained by using the ideal filter and the corresponding images are shown in Fig. 4. So, all together we can say that the filter which works most effectively for Bio medical images in frequency domain is Ideal Filter at a cut off frequency of about 75.

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