

Best Frequency Domain Filter for Fetal Ultrasound Images

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Abstract— This paper tries to find out the most effective frequency domain filter used for enhancing Ultrasound images. A fetal ultrasound image has been taken and is filtered with different low and high pass filters at different cut off frequencies. The enhancement method is very simple because our aim 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— Ideal, Butterworth, Gaussian, Frequency Domain, MSE.

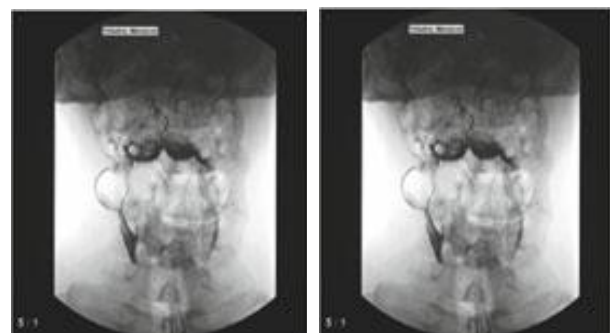
I. INTRODUCTION- BIOMEDICAL IMAGING MODALITIES

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. Now a days 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.

II. MEDICAL ULTRASOUND

Medical ultrasound (also known as diagnostic sonography or ultrasonography) is a diagnostic imaging technique based on the application of ultrasound.

It is used to create an image of internal body structures such as tendons, muscles, joints, blood vessels, and internal organs. Its aim is often to find a source of a disease or to exclude pathology. The practice of examining pregnant women using ultrasound is called obstetric ultrasound, and was an early development and application of clinical ultrasonography. Ultrasound refers to sound waves with frequencies which are higher than those audible to humans (>20,000 Hz). Ultrasonic images, also known as sonograms, are made by sending pulses of ultrasound into tissue using a probe. The ultrasound pulses echo off tissues with different reflection properties and are recorded and displayed as an image. Compared to other dominant methods of medical imaging, ultrasound has several advantages. It provides images in real-time and is portable. It is substantially lower in cost than other imaging modalities and does not use harmful ionizing radiation. Drawbacks include various limits on its field of view, such as the need for patient cooperation, dependence on physique, difficulty imaging structures behind bone and air, and the necessity of a skilled operator, usually a trained professional.



(a) Fluoroscopy

(b) Axial CT

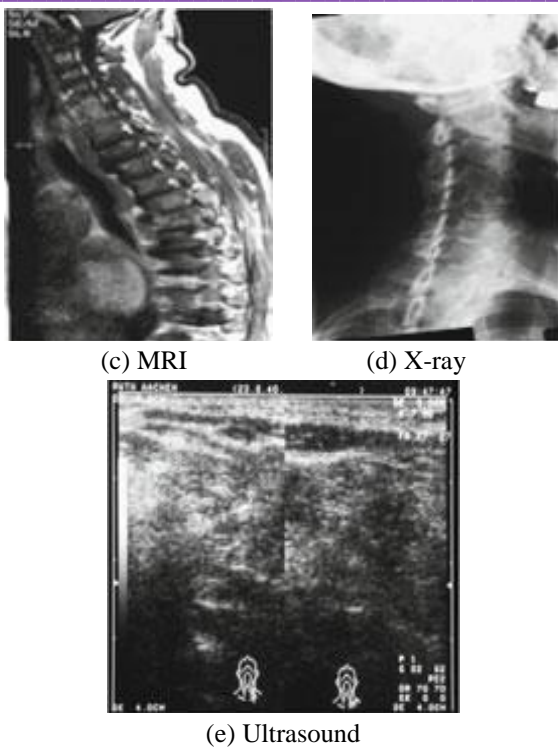


Fig. 1 Images (cervical vertebra) from different modalities

III. 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].

A. 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, $u = 0, 1, 2, \dots, M-1$

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

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

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

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.

B. 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, $g(x,y)$.

C. Frequency Domain Filters

1) 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 MSE 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).

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

(3)

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 $\left(\frac{p}{2}, \frac{q}{2} \right)$ 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)

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

(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)

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

(5)

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

2) 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)

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

(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 (BHPF)

The BHPF function is given by (7).

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

(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].

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

(8)

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

IV. ENHANCING FETAL ULTRASOUND IMAGE WITH FREQUENCY DOMAIN FILTERS

For the purpose of finding best frequency domain filter for enhancing fetal ultrasound images, the image as shown below in Fig. 2 was taken for experimentation. The image is then corrupted by adding blur and noise. Blur was added by



Fig. 2 Fetal Ultrasound

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:



Fig. 3 Corrupted Fetal Ultrasound



Fig. 4 Enhanced Fetal Ultrasound

TABLE 1. MSE VALUES IN THOUSANDS

Ideal	Butterworth (Order 2)		Gaussian
		Cut off frequency	
4.0611	4.1853	20	4.9390
3.9430	4.0033	30	4.8557

3.7711	3.9157	50	4.7246
3.7615	3.9658	75	4.6247
3.8114	4.0288	100	4.5481
3.9231	4.0505	150	4.4109
3.9262	4.0184	200	4.3469

- 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.

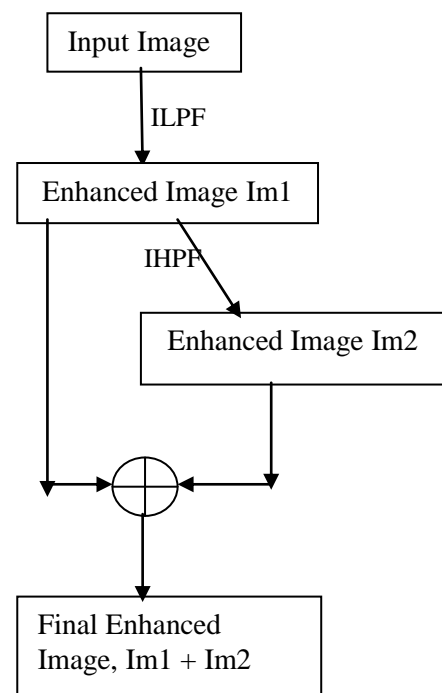


Fig. 5 Flowchart of the Enhancement Method

V. RESULTS AND DISCUSSION

Mean Square Error (MSE)[10] values of the enhanced image when compared with the original image 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 shows MSE values with the three filters at different cut off frequencies. By looking at the table it can be seen that the lowest MSE values was obtained when Ideal filter was implemented with cut off frequency 75. The most enhanced image is shown in Fig. 4.

VI. 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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