Ultrasound Mid-end Processing on Android Platform

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Dedication

To my family and to everyone who has been part of my learning experiences.

Abstract

Commercially-available, portable ultrasound devices are increasingly ubiquitous, but they all utilize ad-hoc processing and display hardware. This inevitably drives up the cost of these devices and usually results in poor user-interface. Many doctors now already carry this hardware around in their pocket on a smartphone, so why not use it to drive down medical device costs and provide a familiar user-interface? This thesis seeks implementation of midend algorithms to develop ultrasound imaging system. Firstly, midend system has been simulated on matlab and then later on android platform for smartphone, to replicate present ultrasound imaging. Later our algorithms related to demodulation, compression and image contrast enhancement are validated by porting them onto android. In order to realize an ultrasound imaging system, several engineering aspects need attention. The signal processing algorithms related to midend design of ultrasound system include envelope detection, compression techniques to fit dynamic range and image enhancement techniques to obtain good quality image.

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Chapter 1

Introduction

Ultrasound is the most popular and inexpensive non-invasive medical imaging technologies. With the introduction of portable and handheld ultrasound systems, ultrasound is being used not only in hospitals, but also in clinics, private practices, and maybe someday in our households. This ever-increasing use of ultrasound drives the need to develop faster, smaller, and more efficient ways to collect ultrasound data and convert it into usable and viewable images. One of the key processes in generating viewable ultrasound images that may be improved is scan conversion [1].

Medical images can be diagnosed through various imaging modalities like Magnetic Resonance Imaging (MRI), Computed Tomography (CT), Ultrasonography (US), Intravenous Urography (IVU), Angiography (AG). Each of this modality has distinct advantages and disadvantages in contrast formation, sensitivity, resolution, level of invasive and cost. MRI gives the same information as CT scan in regards to kidney imaging. However, the contrast material gadolinium present in MRI is associated with Nephrogenic Systemic Fibrosis (NSF) [2], which decreases the kidney functioning. IVU is used to measure kidney size, shape and in the evaluation of pelvis and ureters. The major drawback with IVU technique is, due to radiation and IV contrast administration there may be renal failures [3]. CT uses computer processed X-rays to form tomographic image and gives most of the details similar to ultrasound. But this has disadvantage of radiation exposure and also usage of contrast dye can cause kidney damage. Ultrasound-based diagnostic imaging technique is used for visualizing body structures and is called Ultrasonography. Ultrasonography is an ultrasound based imaging technique for visualizing internal organs structure, at real time. It uses ultrasound spectrum from 1MHz to 50MHz for good resolution and good penetrating ability [4]. These ultrasound signals are generated by converting a Radio Frequency (RF) electrical signal into mechanical vibration via a piezoelectric transducer sensor[5]. Ultrasonography interprets the echoes of high frequency sound waves sent into the biological tissue from the surface and forms the image. It is used for both diagnosis and therapeutic procedures with least invasive as it is radiation free, patient-friendly and less expensive when compared to other procedures [6]. The developing trend in the digital electronics lead to the development in the ultrasound systems particularly in improving the image quality, decreasing the price for implementation and also in its size. Traditional ultrasound machines are not very flexible in implementing new features as they were built using multiple fixed-function circuit boards to meet high data rate requirements [7]. Design of ultrasound machines in the recent years could provide some flexibility in core ultrasound processing on smartphone based platform.

Figure 1.1: Smartphone Ultrasound Device

1.1 Literature Survey

Ultrasonography became an important tool in the field of medical imaging diagnosis. It offers high resolution images with the advantages of real-time, non-invasive and cost-effective imaging [27]. Nowadays, portable ultrasound (US) imaging systems have been widely researched because the importance of rapid action is hihy needed in the urgent situation taking place such as in, the emergency rooms, the scene of the accidents or the battlefields [28]-[30]. A portable ultrasound imaging system includes a handheld scan head coupled by a cable to a portable battery-powered data processor and display unit, preferably in the form of a lap-top computer or mobile phone screen [8]. Fig: 1.1 shows a smartphone based portable ultrasound to find widepread use in medical field across the world. Because of inexpensive, it will lead to even wider use, especially in rural and third-world areas. This device will find widepread use in Emergency Rooms, in the medical wards and as well as in practice sessions. This Smartphone Ultrasound is a great start for diagnosing all types of medical problems, as a screening device such as vascular problems, gallstones, kidney stones, abdominal masses, and other problems. This invention will be brought to areas that could not afford it, or live in inaccessible areas which creates drastic positive change in medical field.

Since 1965s, ultrasound imaging systems in medical field have had the ability that shows a real-time image. However, their size was too big to move somewhere which became their disadvantage and this disadvantage limits its clinical utility in diagnosis on the field [23]. And, current portable ultrasound imaging systems have relatively light in weight and high-end microprocessors for required signal and image processing in ultrasound imaging system. So, it's not only providing a clinically valuable image quality but also support various imaging modes such as, color Doppler, spectral Doppler and power Doppler, which are essential in non-hospital settings, such as developing countries, emergency field and disaster scene [24]-[26].

However, current portable ultrasound imaging systems have some limitations. One of them is portability that utilize a single device for ultrasound signal and image processing. Recently, moblie devices, such as smartphone or tablets ae used which have a built-in application processor and graphics processing unit. Rapid improvements in these application and graphical processing units leads them to become the next generation portable ultrasound systems [22].

To support this point-of-care diagnosis, there are a variety of portable ultrasound imaging systems commercially released. For example, Fig:1 model is a Mobisante, which is the worlds first smartphone-based ultrasound imaging system. This device has been approved by the FDA to reduce healthcare costs and improve diagnosis. In their words, MobiUS fuses the power and wireless connectivity of a smartphone with the Internet into a game-changing diagnostic solution that is personal and accessible. Our patent pending intellectual property makes the system easy to use and to share information with remote providers [9].

GE healthcare released portable ultrasound imaging system, Acuson Freestyle, which employed RF communication technique for having easy-to-use wireless probes in interventional guiding procedures. This system, however, have a difficulty in point-of-care diagnosis due to 4.8kg of weight [31]. Otherwise, VSCAN developed by GE healthcare is the most light US imaging system in the world with 390-g weight for point-of-care diagnosis. However, the display size is only 3.5 inch in diagonal direction and its pixel resolution is limited in 240 x 320 pixels so that the high resolution ultrasound image cannot be provided to users. Also, the probe cannot be replaced so that the various types of ultrasound transducers cannot be supported [32].

Chapter 2

Background Information

2.0.1 Ultrasound System Architecture

The block diagram in Fig. 2.1 illustrates a simple model of an ultrasound probe with a single element transducer. Ultrasound system consists four parts.First one is transducer which transmits ultrasonic waves and wait to receive the echo signals. Second is front-end which uses a high frequency, high voltage pulse to excite the transducer to produce ultrasound waves. The sound waves, or echoes, that bounce back from the tissue excite the transducer to produce an electric signal [10]. The signal is amplified by the front-end and processed to make the data more suitable for human visual consumption. Then, Mid-end Processing which converts raw echo signals into anatomical signal. And last is Scan Conversion for mapping the data to target image display.

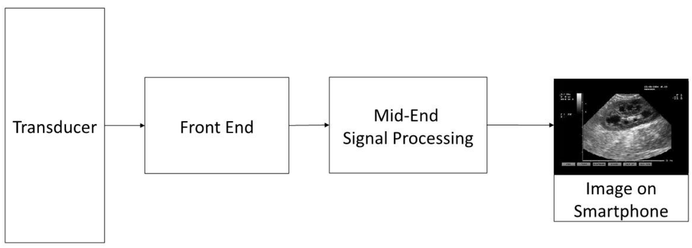

Figure 2.1: Block diagram of a simple ultrasound system

2.0.2 Modes in Ultrasound

3 different types of ultrasound imaging modes are given as, i) B-mode ii) M-mode and, iii) Duplex mode The B-mode is an ultrasound image in 2-dimension, where image is measured across the top and bottom of the of the screen just like a regular image. Whereas, M-mode is a 2-dimensional image which also allows the recording of the motion and Duplex-mode is a combination of B-mode

and color flow doppler, which has mainly used in cardiac and vascular scanning applications. So, the ultrasound imaging system discussed here utilizes the B-mode [33].

2.0.3 B-Mode Processing

B-mode ultrasonography in which the position of a spot on the Cathode Ray Tube(CRT) display corresponds to the time elapsed (and thus to the position of the echogenic surface) and the brightness of the spot to the strength of the echo, movement of the transducer produces a sweep of the ultrasound beam and a tomographic scan of a cross section of the body [33]. B-mode (Brightness mode) is comparatively same as A-mode, as brightness corresponds to the amplitude of the sampled signal. The transducers scans the body plane by sending sound wave to produce a 2D image. Its also known as 2D mode. In B-mode, the beamformed data signal is firstly demodulated with envelope detection to extract the magnitude of received echo signals , later logarithmic compression to logarithmically compress the magnitude ingormation for effiient visualization and scan conversion for removing artificats is used. It consists of 3 main parts: Envelope Detection, Logarithmic Compression and Scan-conversion.

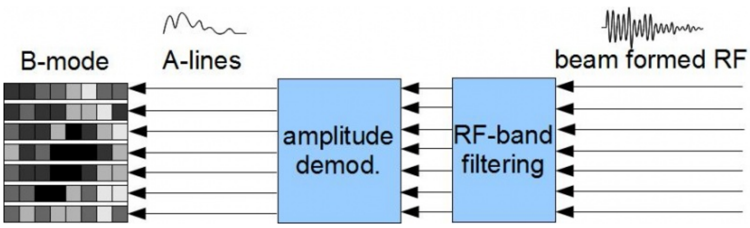

Figure 2.2: Beam-Formed RF data to pre scan converted B-Mode images

Chapter 3

Ultrasound Midend System Architecture

3.1 Ultrasound Midend System Architecture

Before mid-end processing, two more steps needs to be done i.e. i) Time Gain Compensation(TGC) and, ii) Frequency Filtering.

Time Gain Compensation

The acoustic waves generated by the ultrasound transducer loses energy as they travels through the tissue due to the attenuation because of absorption and scattering, and focussing effects. Consequently, reflections from deeper tissue features will appear weak in the recorded signals. To compensate for this, a simple correction is applied assuming the attenuation within tissue follows the relation as,

$$\mathrm{p} = p_0 e^{-\alpha f d} \tag{3.1}$$

where α is the attenuation coefficient in dB/(MHz cm), f is the transmit frequency in MHz, and d is the round-trip distance travelled in cm [34].

Frequency Filtering

The scan lines are then filtered using a gaussian filter centered about the transmit frequency or the second harmonic. This reduces the noise effects outside the transmit frequency range, and also obtains the harmonic signal for tissue harmonic imaging. The filtering is performed using gaussian filter by a specific required filter center frequency and percentage bandwidth [34].

3.1.1 Envelope Detection

Envelope Detection is a demodulation process which is used for removing high frequency variations from the scanline. Block diagram of envelope detector is shown in Fig. 3.1.

The envelope of beamformed data is,

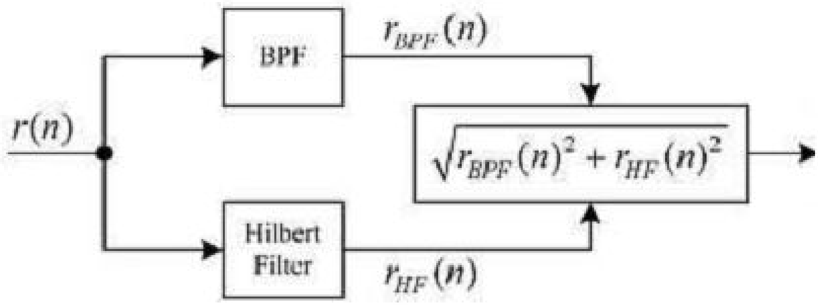

Figure 3.1: Envelope Detection Block Diagram

$$\text{x(n)} = \sqrt[2]{(r_{BPF})^2 + (r_{HF})^2}. \tag{3.2}$$

where,r_{BPF} is In-phase component and r_{HF} is Quadrature component of the data signal r(n).

Traditional approach to generate I/Q data include analog/digital base band demodulation which requires significant extra circuitry on each channel. Hence Hilbert Transform is used to reduce the amount of hardware required and get accurate values of the quadrature components as it provides 90-degree phase shift at all frequencies [12]. The Hilbert transform shifts the phase of a signal by 90 degrees i.e. positive frequency components are shifted by -90 degrees, and negative frequency components are shifted by +90 degrees. The efficient method to calculate the quadrature component is to pass the RF beamformed data via hilbert transform because of providing 90 degree phase shift. For the extraction of analytic signal from the received echo data, Finite Impulse Response(FIR) Hilbert filter method is used. The impulse response of Hilbert Transform h(n) of length N in time domain is

$$h(n) = \begin{cases} \frac{2}{\pi}\frac{sin^2(\frac{\pi(n-\alpha)}{2})}{(n-\alpha)} & \text{for } n \neq \alpha \\ 0 & \text{for } n = \alpha \end{cases} \tag{3.3}$$

where, $\alpha = \frac{N-1}{2}$

The transfer function of the Hilbert transformer in the above expression has discontinuties at zero frequency and at half the sampling frequency, the direct use of the transfer function is impossible in time domain. So in an approximate way, a well designed FIR Hilbert filter is used to generate the hilbeert transformed data of the received echo signal [21].

Digital FIR filter approximations are used to implement the Hilbert transformation. FIR filter for Linear Time Invariant (LTI) systems described as follows [11]

$$\text{y(n)} = b_0x[n] + b_1x[n-1] + b_2x[n-2] + ... + b_Mx[n-M]. \tag{3.4}$$

$$\text{y(n)} = \sum_{i=0}^{M} b_i x[n-i] \tag{3.5}$$

where x is the input signal, y is the output signal and the constants b_i, i = 0; 1; 2; ::::; M , are

Filter Order	RMSE Value
16	0.0109
20	0.0096
24	0.0092
28	0.0091
32	0.0090

Table 3.1: Normalised RMSE value for Hilbert Filter

the coefficients

The magnitude response of 16, 20, 24, 28, 32 tap filters is shown in Fig.3. The RMSE value for each filter is shown in Table-I,

So, for simulation and implementation 24-tap FIR Hilbert filter is used because of medium RMSE value [13]. And the frequency response of a24-tap FIR Hilbert filter used in Fig. 3.2

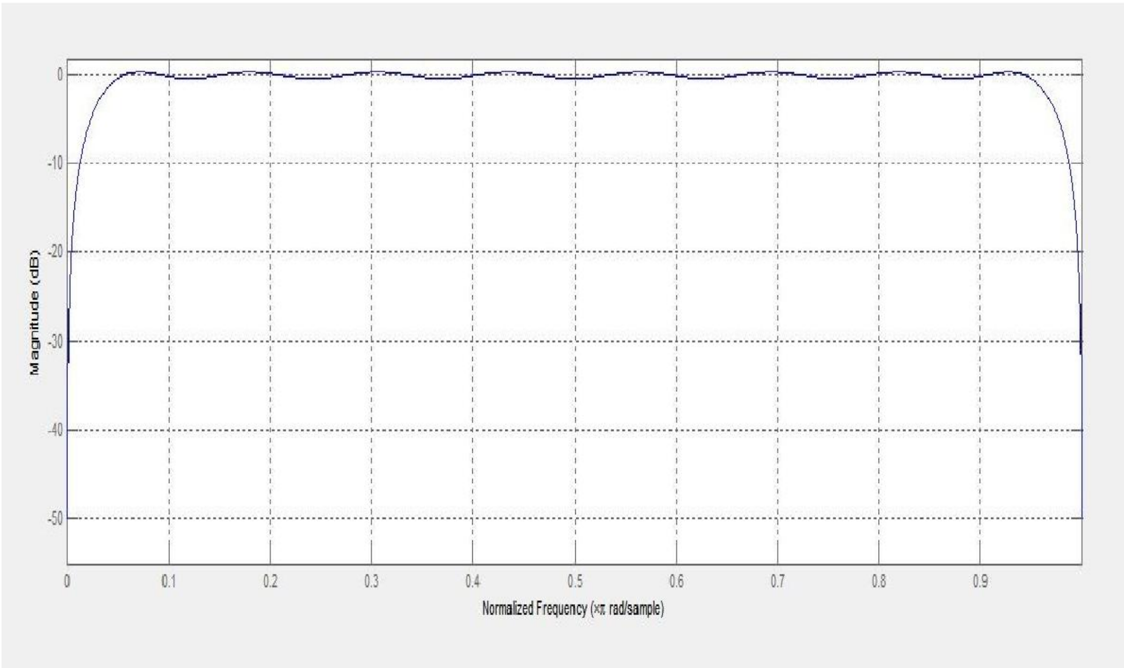

Figure 3.2: Frequency response of 24-tap

Finally, after doing this detection technique, the enveloped rf data signal is shown in Fig:3.3, where blue line corresponds to Input signal and red line to enveloped output signal.

3.1.2 Logarithmic Compression

The amplitude change in the RF data is very high. So, if the same image is mapped linearly to a 0-255 grayscale image, many important image features will only have image values of 0-9. Because of the presence of few very high amplitude points in the image masks everything else [14]. Therefore, in order to achieve a balance in histogram or in image itself, the amplitude values are mapped nonlinearly by a logarithmic function which adjusts the dynamic range.

Dynamic Range is defined as the difference between the highest and lowest signal amplitudes

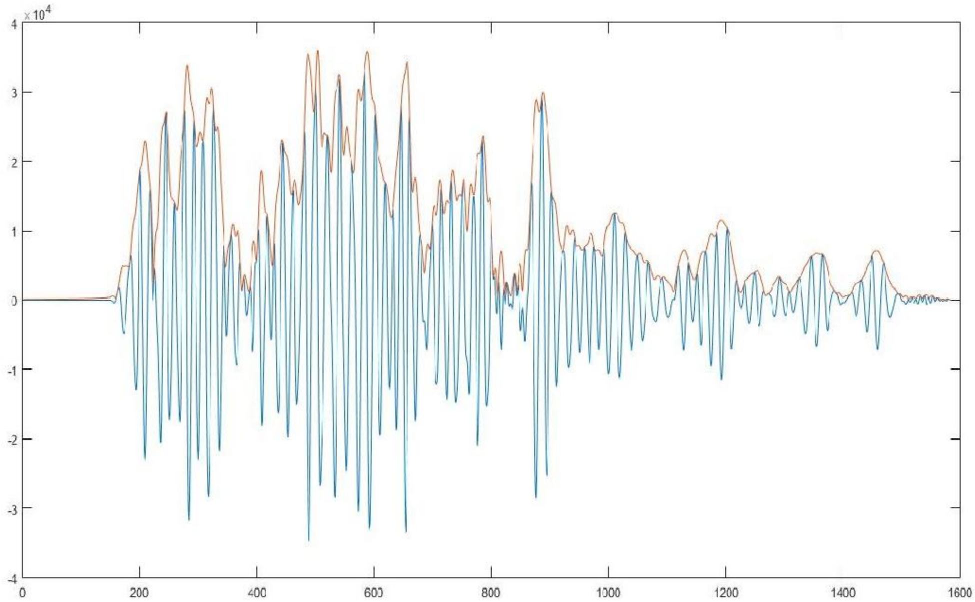

Figure 3.3: RF Enveloped Signal

that can be processed by a particular component of the ultrasound system. Some reflected echoes contains very high amplitude signals which cannot be processed due to their large dynamic range, so we must reduce this range. Dynamic range eliminates the lower echo signals without doing a large effect on the high amplitude signals. So, overall gain reduces the overall picture brightness or echo signals evenly. The maximum dynamic range of the human eye is in the order of 30 dB [15]. The actual dynamic range of the received signal depends on the ADC bits, the TGC amplifier used in the front end, and the depth of penetration. The signal is compressed using logarithmic function to fit the dynamic range used for display. Some parameters in the compression function can be used to adjust brightness. Log Compression compresses the input signal using the expression signal as,

$$\text{y(n)} = \log_{10}(1 + mx * x(n))./\log_{10}(1 + mx) \tag{3.6}$$

where, mx is the compression factor, x(n) is the enveloped signal and y(n) is the log-compressed output signal.

3.1.3 Scan Conversion

The purpose of scan conversion is to interpolate the raw data to be displayed data. The raw data can be in Cartesian coordinate (for linear probe transducer) and in polar coordinates (for curvilinear or phased array probe transducer). Transformation of coordinates is needed to interpolate the data accurately on the display screen depending on the display resolution.Therefore, scan conversion is essentially an interpolation process.The importance of the LCD pixels is that if the pixels are not square in shape, this should be taken into account in the image generation. Otherwise the final image would appear skewed on the screen [16]. Typically, the output data needs to be displayed on a monitor or LCD screen or smartphone screen. To avoid artifacts also, interpolation is needed for unsampled pixels. The resultant image quality is dependent on the interpolation algorithm. Majority of the interpolation improves both smoothness and detailed regions which degrades the image quality.

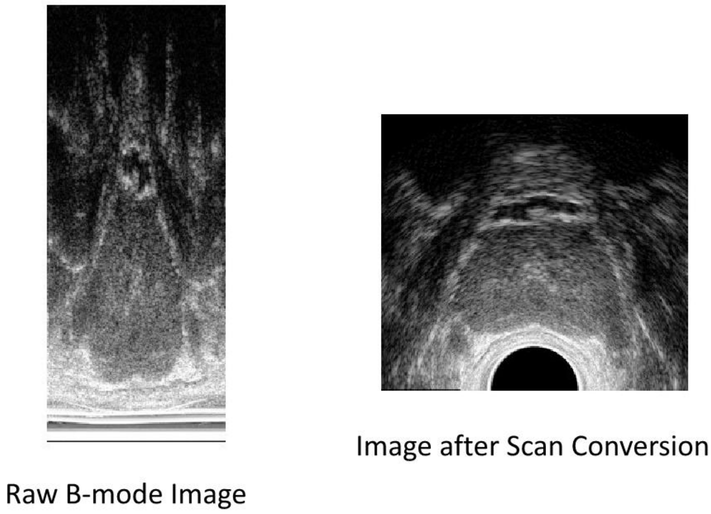

Figure 3.4: Raw Image and Scan Convereted Image

Given that the sampling rate is fixed and there is no over sampling, then there is no one-to-one mapping between the raw B-mode frame and the output image. Thus some form of interpolation is typically performed during the scan conversion process. Three widely used scan conversion algorithms (nearest neighbor, linear interpolation, and bilinear interpolation) can be used. So, for the purpose of scan conversion, we used Bilinear Interpolation algorithm, because of its hiher accuracy in image quality than the remaining two algorithms. Before discussing bilinear interpolation algorithm, lets discuss linear interpolation.

Linear Interpolation

Linear Interpolation is the simplest form of interpolation, connecting two data points with a straight line. Only two consecutive samples of the original sequence are involved in the computation of an interpolated sample [19]. It is a curve fitting method for finding new data points in the range of a set of known data points using linear polynomials. Linear interpolation is often used to fill the gaps in a table [17].

If two known points are given as (x_0, y_0) and (x_1, y_1) , then straight line between these points is the linear interpolant. For a value x in the interval (x_0, x_1) , the value y along the straight line is given by equaling their slopes as,

$$\frac{y - y_0}{x - x_0} = \frac{y_1 - y_0}{x_1 - x_0}[17] \tag{3.7}$$

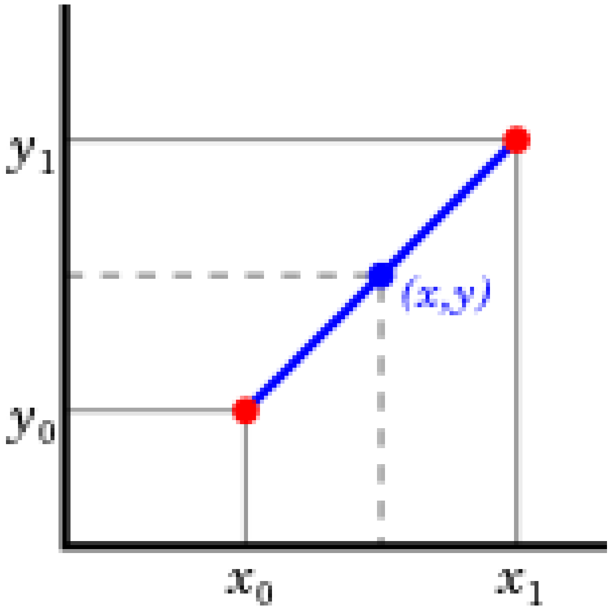

Figure 3.5: Linear Interpolation

By solving the above equation for y, which is the unknown value at x, is given as,

$$y = y_0 + (y_1 - y_0)\frac{x - x_0}{x_1 - x_0} \tag{3.8}$$

From the above equation, y designates that this is a first-order interpolating polynomial. This formula can also be understood as a weighted average [18].

Bilinear Interpolation

Bilinear interpolation is often used to improve image quality after performing spatial transformation operations such as digital zooming or rotation [20]. Bilinear Interpolation is an extension of linear interpolation for interpolating functions of two variables (x and y) . The key idea is to perform linear interpolation first in one direction, and then again in other direction. So, for the image formation and image enhancement, bilinear interpolation is used. Bilinear interpolation is performed using four data points from adjacent vectors to compute the value for the needed pixel. This method achieves more accuracy in image quality than the linear interpolation method. Fig.3.6 below shows the bilinear interpolation as [20],

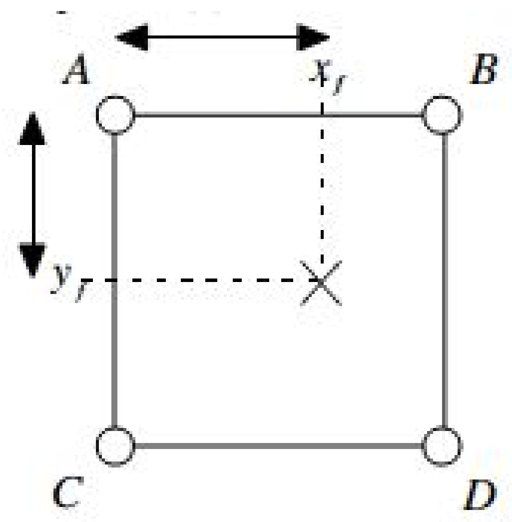

Figure 3.6: Bilinear Interpolation

Chapter 4

Results

4.1 Results

The B-mode ultrasound images from the smartphone based processing are compared and validated with the matlab results on the basis of of image quality i.e. Structural Similarity Index (SSI) parameter. Finally, after getting the image on smartphone, image is being save automatically in sdcard of smatphone itself with specific time and date, so that it can be accessed later for further use.

4.1.1 Smartphone Software

The devices corresponding android application is written in java language using the android 23.0 SDK. All the requirements for the smartphone operating software i.e. android were verified. For the requirement of complete image, image interpolation must be done after the raw b-mode image is saved to the users gallery on the android phone. It is implemented on android 4.1 version, so it can run on approximately 75 percent android based smartphone's. I have tested this application on different android version such as on, android 4.1 jelly bean, android 5.1 lollipop and also on latest version, android 6.0 marshmallow also. But in android version 6.0, due to security reasons , the user has to give permission to all new applications which he wants to install. These security permissions only in marshmallow versions while in lower versions, no need of security permissions like this. While an Iphone or Windows phone application could foreseeably be written for our project, android was chosen for this project because of easy avaliability and also low cost for ultrasound application existed on the platform at the time. The initial view is a list of stored rf data, from which the user can browse and select for further processing. The user can also start a new scanning of different rf data and save ithe image with repsect to date and time and access the saved images. The user for seeing can also zoom the save images upto five times. At the saved images, the user can scroll through saved images, email the currently displayed images, open the currently displayed image in another program, or delete.

Image	SSI Value
Phantom Image	0.8208
Fiel II Image	0.7255
Fetus Image	0.9119

Table 4.1: SSI values of images

4.1.2 Android Application

The beamformed rf data is being browsed and selected and all the signal processing takes place in background of the applicaton while image is loading. The outlook of the smartphone based application is shown in the below figures as,

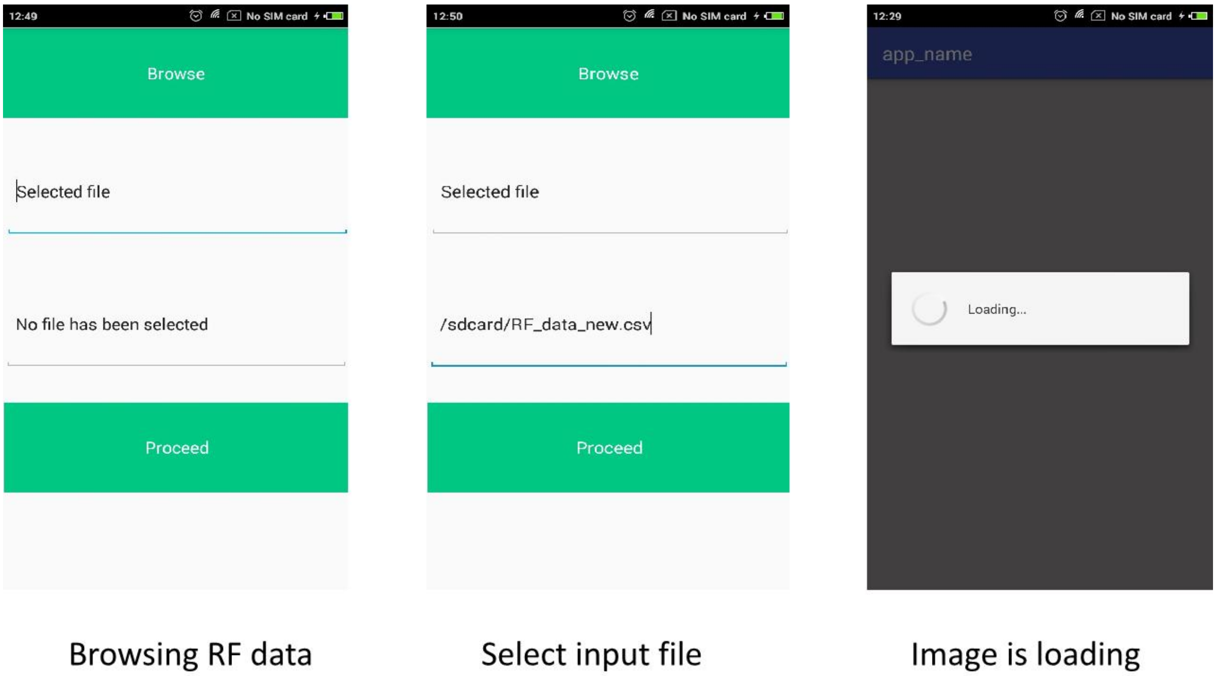

Figure 4.1: Application Outlook

4.1.3 Android Results

Following are the images on android for different beamformed rf data,

4.1.4 Matlab Results

Following are the images simulated in matlab for different beamformed rf data,

The given Table 4.1 shows the structural similarity index of the android images with respect to matlab images as,

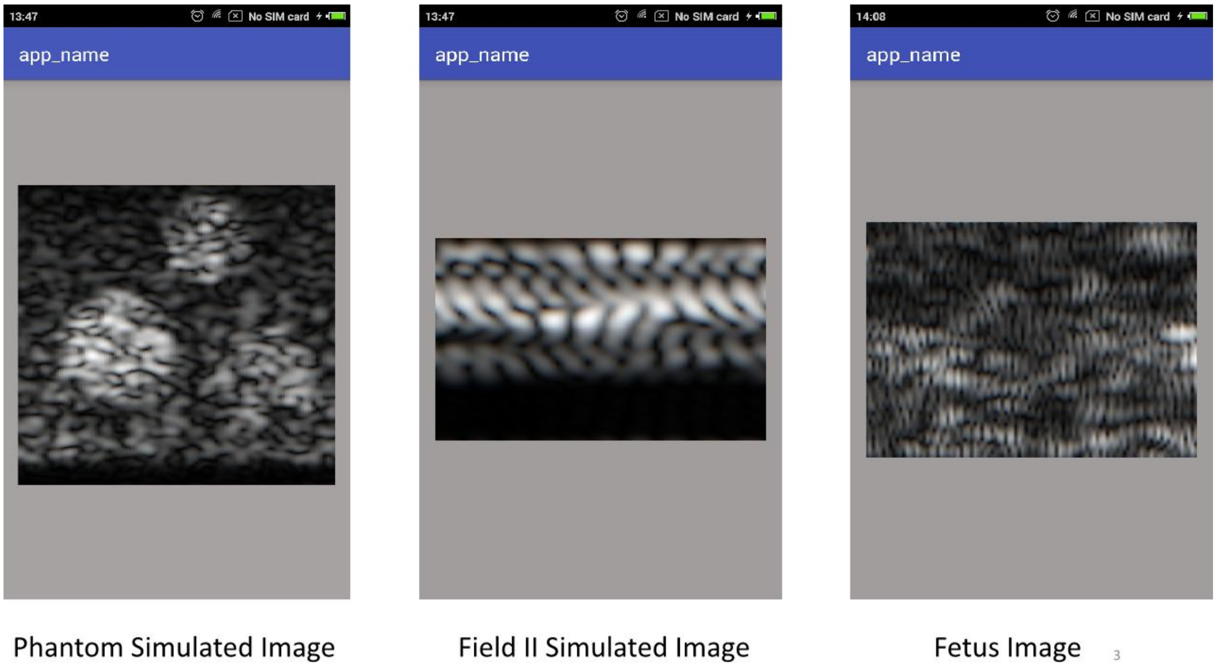

Figure 4.2: Android Images

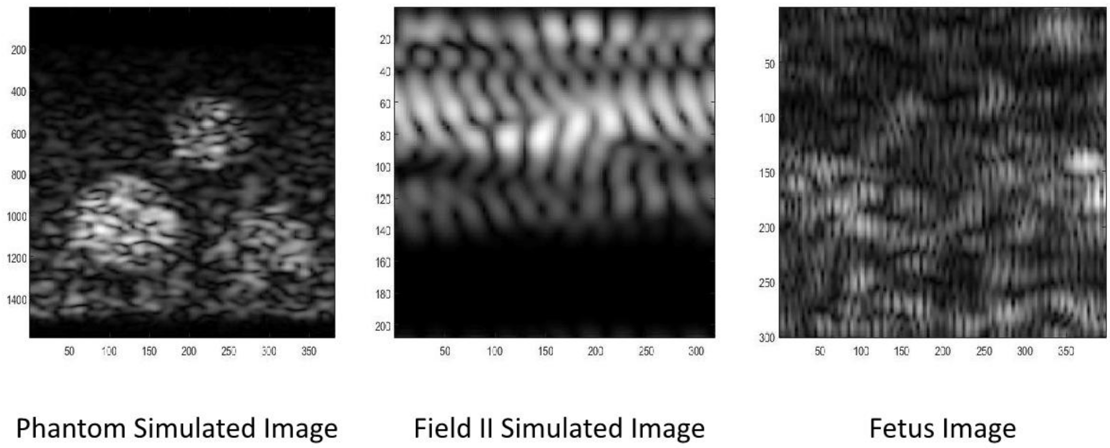

Figure 4.3: Matlab Images

Chapter 5

Summary and Discussion

The main focus areas of this work is Midend implementation on Android platform. In this context, the thesis reports choice of detection , compression techniques that best suite ultrasound imaging system, image enhancement technique to enhance the image clarity so as to not miss any critical information. The algorithms are tested on various platforms and a large database to provide proof of concepts and support the claims made. In the course of these studies, several interesting insights were obtained. This chapter discusses future scope in this direction.

5.0.5 Midend Implementation on Android

We were able to present the smartphone based ultrasound midend system that would process the echo signals received from tissues. While processing we were able to develop envelope detection block using 32-tap FIR Hilbert transform, logarithmic compression block to compress the dynamic range, interpolation to reduce the blocking artifacts and finally image quality is enhanced using full scale contrast stretch to give a better contrast than traditional ultrasound systems. The feasibility to reconstruct an ultrasound B-mode image by utilizing the high-end Android based smartphone was successfully demonstrated [22]. The ultrasound B-mode image reconstructed from the Android smartphone where an 320*300 image is reconstructed and displayed. Implementation on smatphone reduces the cost of development, huge improvement in portability and also provides a platform for the researchers to develop new algorithms and implement them which can lead to a new era of ultrasound imaging.

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