

Color Doppler Ultrasound Volumetric Flow Extraction

EECS 451 Project

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Abstract—Doppler Ultrasound (DUS) is a non-invasive method used to image tissue and obtain information about blood flow. In color frequency (CF) mode, radio-frequency (RF) data are obtained and processed to calculate blood flow rate and velocity of blood flowing through the vessels. In this project, the receive waveform data of a phantom vessel were collected using a transducer. Then, the data were processed to obtain the velocity and flow rate of the scanned vessel.

in the phantom using a machine. Five different flow rates (200 mL/min, 250mL/min, 300mL/min, 350mL/min, and 400mL/min) were collected to produce five datasets. The experimental setup can be seen in Figure 1. The raw data collected from the machine were IQ data, which are RF data that are already demodulated. The datasets were then loaded into Matlab for processing.

I. INTRODUCTION

Many conditions affecting the blood vessels are commonly diagnosed using Doppler Ultrasound (DUS). Such conditions include aneurysms, blood clots, heart valve defects, narrowing of the arteries, health issues of an unborn fetus, and more [1]. DUS is a non-invasive technique to provide information about blood flow including flow rate and velocity. This imaging modality requires signal processing of sound data including RF demodulation into in-phase and quadrature (IQ) data, wall filtering, and spectral analysis to obtain Doppler frequency.

II. BACKGROUND

To obtain RF data for processing, DUS typically transmits sound waves at a certain frequency into tissue, and these sound waves are scattered by moving tissue. The frequency of the scattered waves is shifted in proportion to the velocity of the moving tissue (or blood cells) [2]. From this frequency shift, the velocity of the blood cells can be determined.

III. METHODS

In this project, IQ data of a phantom vessel were collected and processed to calculate the flow rate in Matlab. Various ultrasound principles and digital signal processing methods were used for this calculation.

A. Data Collection

Data were collected using the GE Logiq Ultrasound machine with a 10L (10MHz) transducer. In-phase and quadrature (IQ) data were collected by scanning a phantom of similar composition to tissue which contained a tube with liquid flowing through it to simulate a blood vessel in the human body. The liquid was being pumped through the tube

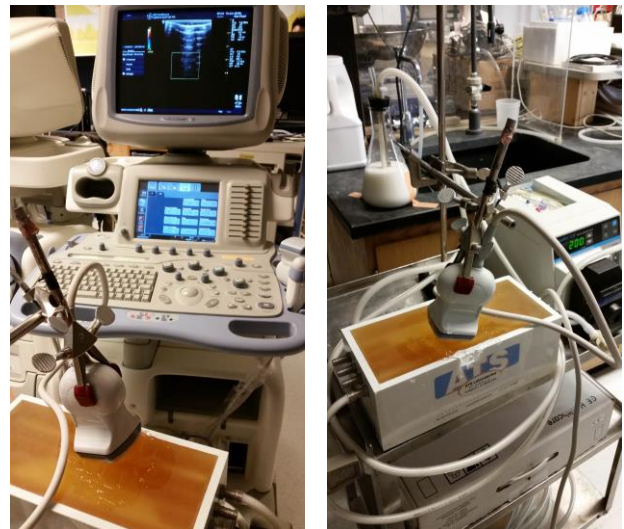


Figure 1. Experimental setup for data collection

B. Raw Data Format

The IQ data collected using the transducer were saved as a 4096x128x10 matrix and the values were 16-bit integers. Other parameters (including those specified in section III.D.) were also saved in the datasets collected by the GE Ultrasound machine.

C. Data Processing and DSP Tools Used

The raw data collected from the machine were IQ data, which are demodulated RF data. The first processing step was to remodulate the IQ data to obtain the RF data, then the RF data were demodulated to obtain the IQ data. The third

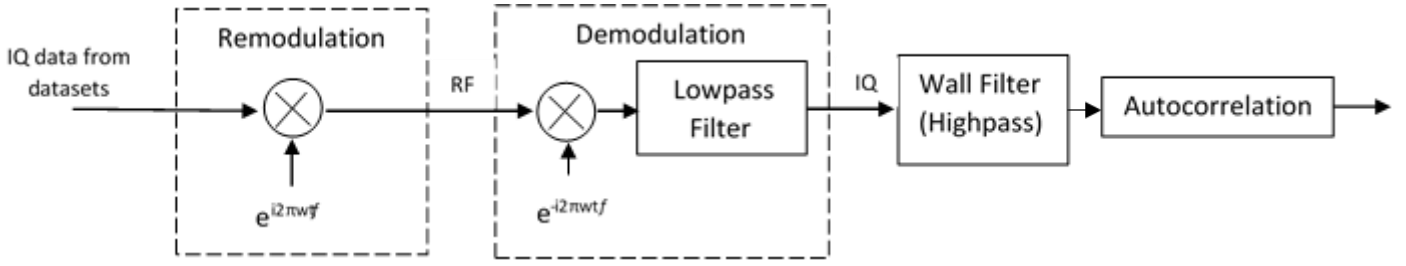


Figure 2. Block diagram of project and processing of IQ data to produce volumetric flow rate (the output of the autocorrelation step). Not shown is the processing of the phased array image to select the blue pixels.

processing step was to filter the IQ data with a high pass filter (lines X in the code) which removed low frequency noise of the vessel wall. This filtered data was then used to construct the autocorrelation factor, which was used to calculate the blood velocity and volumetric flow rate. The last processing step was to use the discrete cosine transform to remove red pixels from the image.

a) *DSP Tool 1: Demodulation* The first DSP tool used in this project was to remodulate then demodulate the IQ data obtained from the raw dataset. This is useful for obtaining data from the raw radiofrequency data which contain information about the frequencies of the waves, but must be converted to IQ data before undergoing doppler processing.

To reconstruct the IQ data from RF data (because the dataset did not contain the original RF data, just the IQ data), a phase was added to the IQ data according to the following relation:

$$x_{IQ}(t) = x_{RF}(t)e^{-i2\pi ft} \quad (1)$$

Where X_{IQ} is the IQ signal, X_{RF} is the RF signal, f is the frequency specified in the dataset, and t is the time.

b) *DSP Tool 2: Remodulation via Lowpass Filter and Downsampling* The next DSP tools used were to demodulate the RF data to obtain the IQ data. First, the equation above was applied to the RF data. A lowpass filter was then used to collect the desired signal. Finally, the signal was downsampled [4].

c) *DSP Tool 3: Wall Filter* A wall filter was implemented to remove low frequency noise due to movement of the vessel walls.

d) *DSP Tool 4: 2-D Discrete Cosine Transform* This DSP was not taught in class and although this does not contribute to the velocity and flow calculations, this tool could be useful to eliminating noise in DUS color images if that noise is known to be an error and is seen in every scan performed by the machine.

D. Equations and Parameters used for Velocity and Volumetric Flow Calculations

To obtain the autocorrelation value, the follow equation was implemented in Matlab:

$$r(nT) = \sum_{i=1}^{m-n} [I_{n+i}I_i + Q_{n+i}Q_i] + i \sum_{i=1}^{m-n} [I_iQ_{n+i} - I_{n+i}Q_i] \quad (2)$$

Where I is the in-phase data, Q is the quadrature data, m is the number of Doppler firings, and n is the firing separation.

The mean frequency used to calculate velocity from the Doppler equation is given as follows:

$$f_{mean} = \frac{\phi(T)}{2\pi T} \quad (3)$$

where T is the pulse repetition period ($T = 1/PRF$) and ϕ is the phase, given by,

$$\phi(T) = \tan^{-1} \left[\frac{N}{D} \right] \quad (4)$$

where N is the second term and D is the first term of the autocorrelation equation (equation 2).

Then the velocity of the blood flow was calculated by rearranging the following equation to solve for v:

$$f_D = \frac{2v \cos(\theta) f_c}{c} \quad (5)$$

where v is the velocity of moving blood cells, θ is the angle between the transducer and the phantom vessel, c is the speed of sound in tissue (approximately 1540m/s), f_D is the shifted frequency, and f_c is the center frequency (given by equation 3) [2],[3].

In this project's code, the power Doppler, which uses the signal level to determine the amount of flowing tissue, was not implemented since I could not fully comprehend the concept of it. Not accounting for the power of the signal and some phase rotations was most likely the source of error in my code.

IV. RESULTS

A. Calculated Velocities and Flow Rates

Using the equations specified in the previous section, the velocities and flow rates were obtained and the flow rates are seen in Table 1. The calculated flow rates are not even close to the actual flow rates. This is due to phase corrections that were not accounted for in my code as well as numerous other factors that require a much deeper understanding of Doppler processing that I did not implement.

Table 1. Flow rates calculated from Doppler processed data

Image #	Actual Flow Rate (mL/min)	Calculated Flow Rate (mL/min)
1	200	.0218
2	250	.0291
3	300	.0547
4	350	.0499
5	400	.0796

There does not seem to be any correlation between the actual flow rate and the calculated flow rate, indicating that not enough factors were considered in the calculation of the flow rate.

B. Removing the Red flow from the Doppler Images

The 2-D discrete cosine transform was used on a color-flow image (Figure 3) to eliminate the red pixels. The resulting image is seen in Figure 4 and is essentially the original image except that the blue (and not the red) pixels were turned black. This is useful because then the black pixels can be selected and turned blue. Thus, the resulting image would be the original image, except without the red pixels. This tool was mostly used as means to learn a new DSP concept, however, it could be useful in selecting a particular color (or sign of blood flow) from an image or for eliminating noise of a particular color.

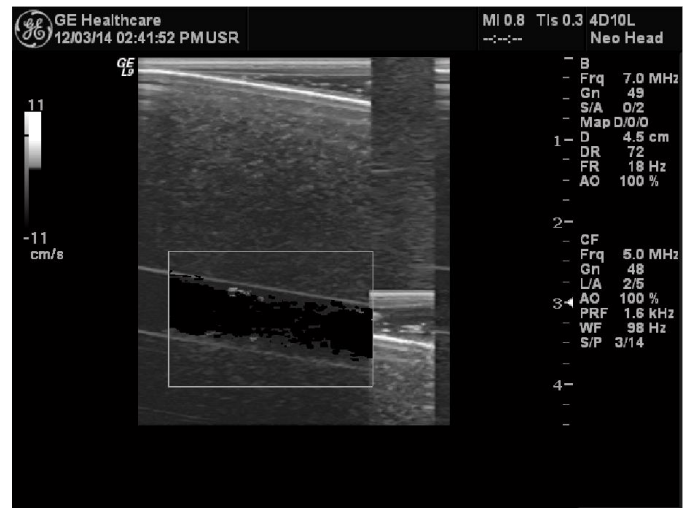


Figure 4. Same image as Figure 2, but with processing to change only the blue (and not the red) pixels to black so that they can be selected.

C. GE Logiq's Processing Result (Real-time Image Reconstruction)

GE's machine could process the blood flow and velocity in real-time. Just to prove the value of this project and to demonstrate its versatility, I also collected an image of a human Carotid artery using a phased array (Figure 5). A phased array was used because it more accurately displays the geometry of the imaged tissue than the linear array used in this project. Blood flow calculations would have to be modified to produce the correct blood flow value for this different type of transducer.

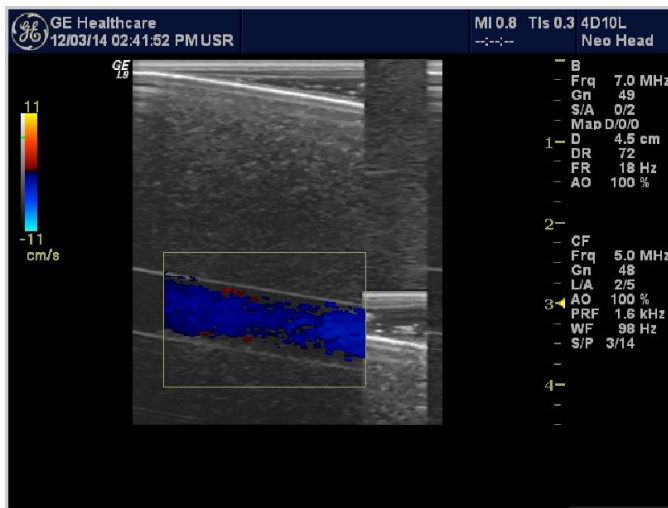


Figure 3. Original image of phantom vessel with volumetric flow of 300 mL/min

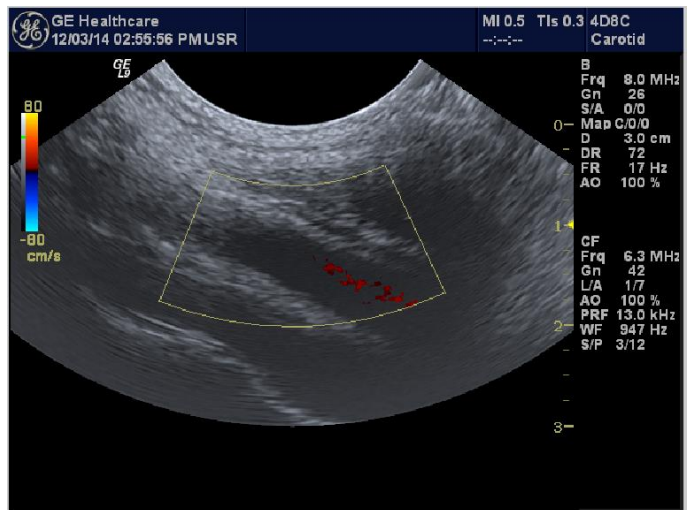


Figure 5. Image of human Carotid artery which was scanned using a phased array.

V. CONCLUSIONS

Doppler processing techniques can provide valuable information from raw pressure and frequency data. This processing requires many digital signal processing tools and an in-depth knowledge of Doppler ultrasound. Ultimately, the code written for this project was not sufficient in determining the correct volumetric blood flow of the phantom vessels since

a few factors were not accounted for in the calculations. This was due to a lack of understanding on my part since it was difficult to teach myself the concepts of Doppler processing mostly through internet resources.

There are other techniques for calculating volumetric flow rate which may have been more effective including creating a spectrum of the filtered IQ data by windowing it and performing the Fast Fourier Transform (FFT) of it to obtain the Doppler shift. The Power Doppler technique may also have been more effective.

VI. ACKNOWLEDGMENTS

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