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Biomedical Image Acquisition

Lab 3 – Ultrasound

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1 Introduction

An ultrasound allows us to see images inside our bodies. For this lab we looked inside a person's neck and took ultrasound images of the carotid artery. Our goal is to use what we have learned to in class to measure the dimensions and flow in the carotid artery from the ultrasound data acquired. The goal of the last part of this lab is to reconstruct the B-mode image of a liver by extracting the appropriate information from the acquired RF data of a liver.

2 Methods

2.1 Carotid Artery Data Collection

After a simple demonstration of a real ultrasound imaging system, we were shown how to align the transducer to get a proper ultrasound image. Before pressing the transducer to the tissue, an ultrasound gel was used on the transducer. This gel allows the sound waves to travel from the transducer to the tissue with reduced reflection which increases the diagnostic imaging [3].

The Ultrasonix machine we are using for this lab scans in real time. So, to find the carotid artery the transducer was pressed on the right side of the neck horizontally at first. When the ultrasound image showed a circular object it means we have located the carotid artery. The transducer was then twisted to scan the neck tissue vertically. This resulting ultrasound image and data was then captured and saved.

2.1.1 Diameter of the carotid artery

To calculate the diameter of the carotid artery, we observe the M-scan image. We found the number of pixels when the artery is relaxed in the diastole stage and when the artery is contracted in the systole case.

To find the conversion factor from pixels to centimeters, we take the given depth of the image of 3.5 cm and divide by the total vertical pixels of the image as shown in equation 1.

$$Pixels\ to\ Centimeters = \frac{3.5\ cm}{Y\ pixels} \tag{1}$$

2.1.2 Percentage Change of the Diameter for Systole and Diastole

To calculate the percentage of the diameter for systole and diastole. We utilize the diameter during and diastole and systole and use equation (2)

$$\%\ Change\ of\ Diameter = \frac{d_{diastole} - d_{systole}}{d_{diastole}} \times 100\% \tag{2}$$

2.1.3 Average Volume Flow Rate

To find the average volume flow rate, Q, assuming a parabolic flow profile, we use equation (3) [2]

$$Q = \frac{v_{max}}{2} \times \pi r^2 \tag{3}$$

where v_{max} is the maximum blood flow over time. Since the maximum blood rate changes over time, we take the average of maximum blood flow over one repetition to be the v_{max} by integration over time using equation (4). This calculation can be seen in Section 3.1.3.

$$f_{avg} = \frac{1}{b-a}\int_a^b f(x)dx \tag{4}$$

2.2 Liver Ultrasound Data

To begin investigating a representative ultrasound data we refer to a radio-frequency data of a liver. We first plot the A-scan image as seen in Section 3.2.1.

We took the 2076 data points for an A-scan image of the liver and used the function 'Hilbert' to create a complex set of data in order to obtain the imaginary part. To obtain the envelope we took the complex data and took the absolute value. These plots can be seen in Section 3.2.1.

Then we calculated the image depth of penetration. We know that the data of the liver was digitized at 40 MHz or at 25 ns. Since we have 2076 samples we can calculate the pulse repetition rate, T_R. We can then multiply T_R with the speed of sound to find the distance travelled and divide by two because of round trip.

$$d_p = \frac{T_R \times c}{2} \tag{5}$$

The c in equation (5) is for the speed of sound so $c = 1561\ m/s$. These calculation results can be found in Section 3.3.

We then processed the entire B-scan by obtaining the envelope of all 360 A-scans. We took the log of all the values of the envelope to compress the dynamic range. We used the depth calculated by equation (5) to obtain the correct y-axis. Each A-scan has a lateral step of 1 mm, which can be used to find the x-axis range.

We adjusted the contrast and brightness of the reconstructed image by using the command 'imcontrast' to open the Adjust Contrast tool found in MATLAB until the features in the image were brighter and easier to analyze. The result of this adjustment can be found in Section 3.4.

By taking the intensity at the blood vessel to be our targeted contrast and the intensity beside the vessel to be the background contrast, we can calculate the local contrast as seen in equation (6).

$$local\ contrast = (I_t - I_b)/\ I_b \tag{6}$$

3 Results

3.1 Carotid artery

3.1.1 Diameter of Carotid artery

Figure 1 shows the M-scan of the carotid artery, the cursors indicate the range of pixel locations during systole and diastole.

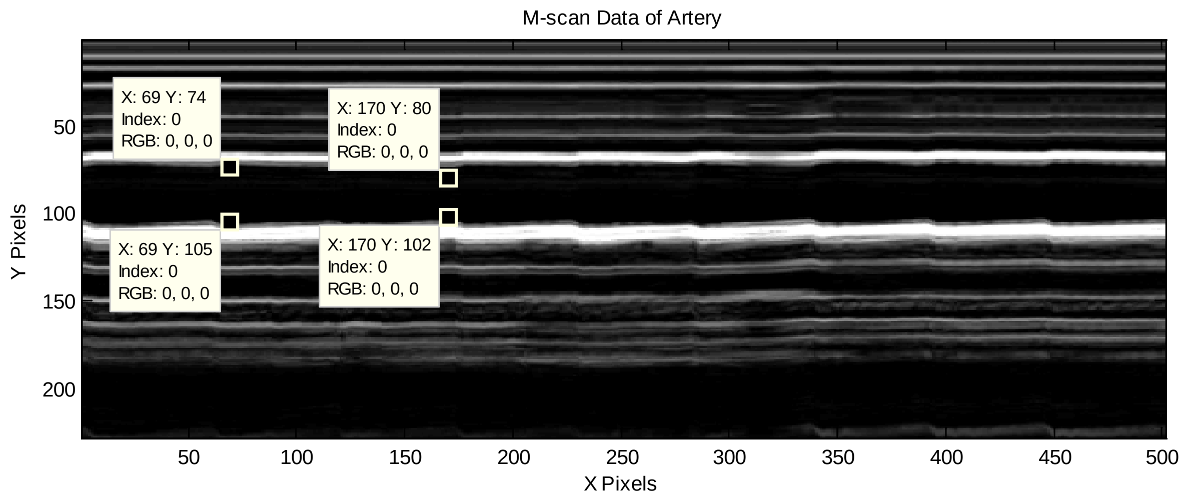

Figure 1: M-scan of Artery

From Figure 1, we count the number of pixels during systole to be 22 pixels. With a total of 228 Y-pixels we use equation (1) to convert to centimeters, the diameter of the carotid artery when contracted is 0.338 cm.

Similarly, we count the number of pixels during diastole to be 31 pixels. Using equation (1), the diameter of the carotid artery when relaxed is around 0.476 cm or 4.76 mm.

3.1.2 Percentage Change of the Diameter

Using equation (2) and the diameter during diastole of 0.476 cm and during systole of 0.338 cm, the percentage change of the diameter during systole and diastole is

$$\%\ Change\ of\ Diameter = 29\% \tag{7}$$

3.1.3 Average Volume Flow Rate

By assuming that the time between two white dots is half a second, then one repetition takes roughly 1 second. We can do a simple integration over time by using equation (4) to find the average value over the triangle in order to find the average maximum blood flow over one repetition as seen in Figure 2. Over one repetition we calculated that the average maximum blood flow rate is around 70 cm/s.

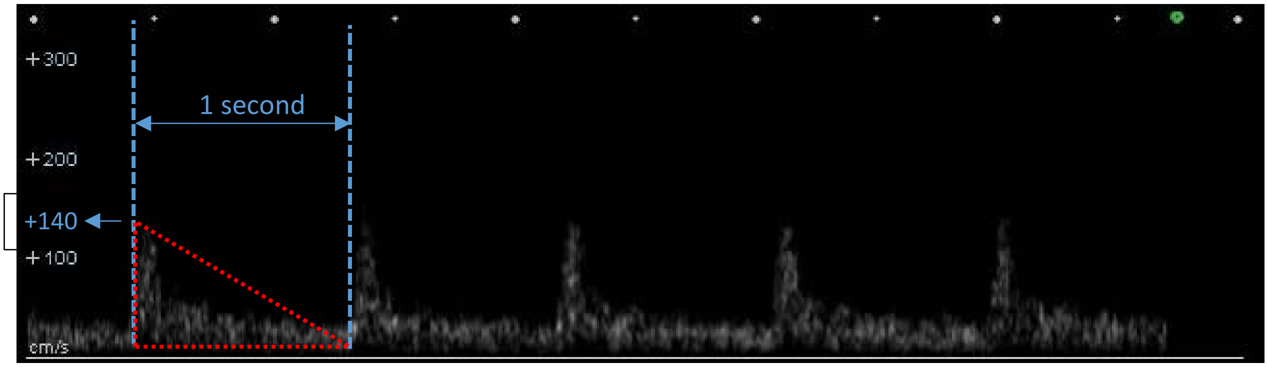

Figure 2: Blood Flow Rate through Artery

Taking the average diameter during diastole and systole, the average radius is 0.2035 cm. Using equation (3) the average volume flow rate is

$$Q = 4.55\ cm^3/s \tag{8}$$

3.2 Liver Ultrasound Data

3.2.1 A-scan Image

The plots for the real part, imaginary part of the RF data can be seen in Figure 3 and Figure 4. Figure 5 is a plot of the imaginary part, real part and the envelope of the data.

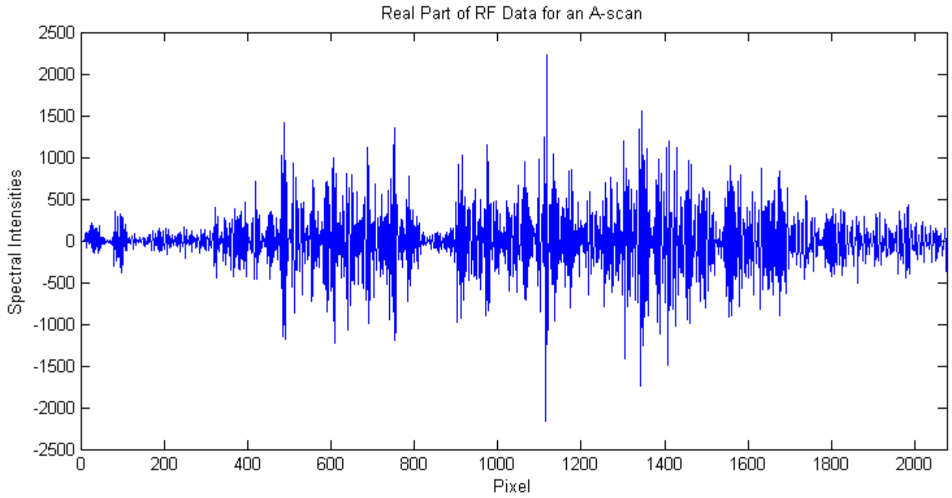

Figure 3: Real part of A-scan Data

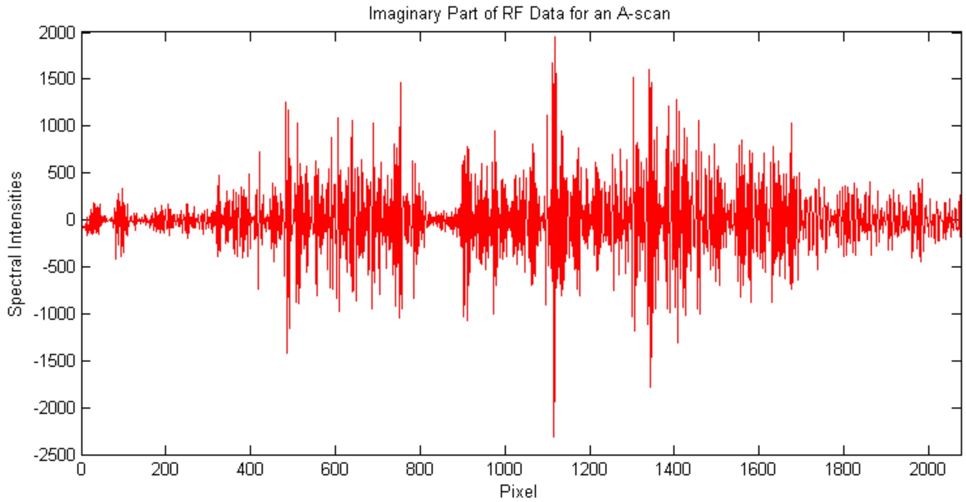

Figure 4: Imaginary part of A-scan data

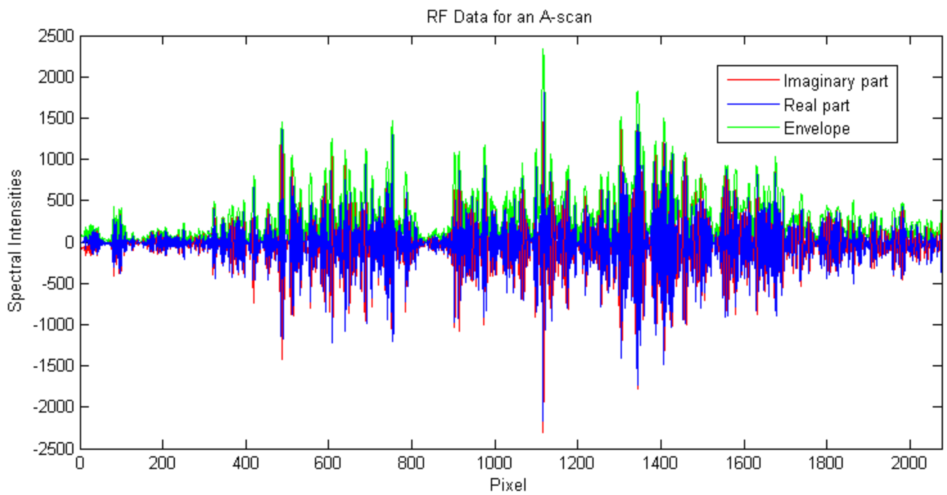

Figure 5: A-Scan Image of Liver, imaginary part, real part and the envelope of the data is plotted

3.3 Depth Calculation Result

Using the equations and values in Section 2.2, the pulse repetition rate is

$$T_R = 25\ ns \times 2076\ samples = 5.19 \times 10^{-5} s \quad (9)$$

Using equation (5), the depth of penetration is 4.048 cm.

3.4 Image Reconstruction

The image reconstruction of the liver and the image after adjusting the contrast and brightness can be seen in Figure 6 and Figure 7 respectively.

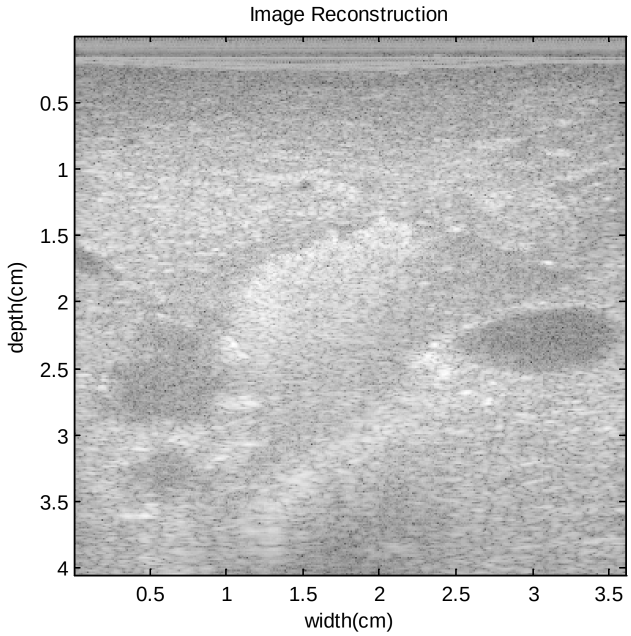

Figure 6: The image reconstruction of the liver

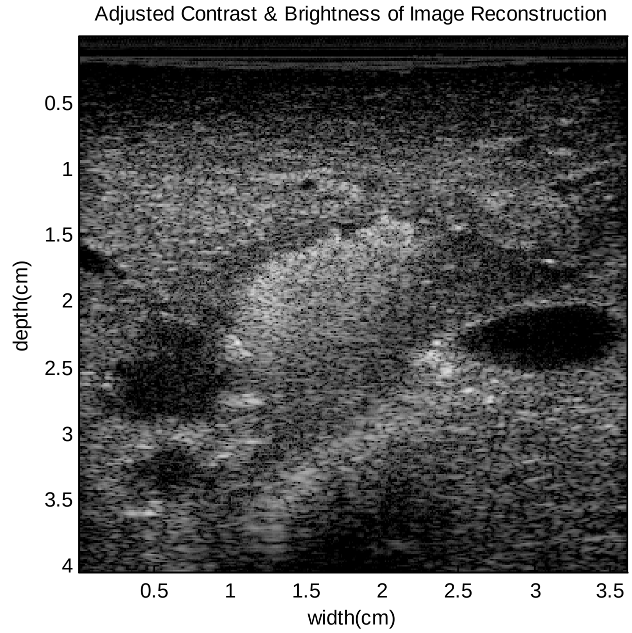

Figure 7: Adjusted contrast and brightness of image

The intensity locations used for local contrast of the vessel is seen Figure 8.

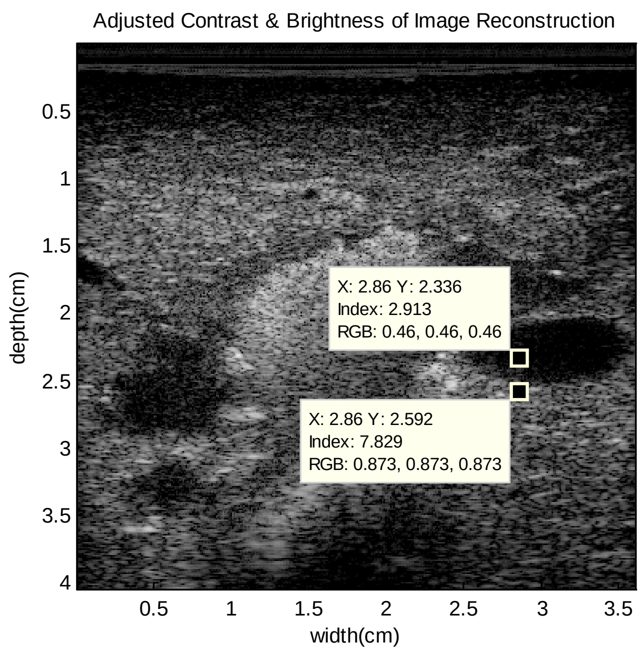

Figure 8: The intensity locations for local contrast of the vessel

Using equation (6) and Figure 8, we see that the targeted intensity is 2.913 and the background intensity is 7.829 and thus the local contrast of the vessel is 0.6279.

4 Discussion

4.1 Comparison of Carotid Artery with Published Values

4.1.1 Diameter Values

A published medical paper tested 500 patients and found the mean diameters of all their common carotid artery and internal carotid artery. The mean diameter values for an internal carotid artery for men and women are 5.11 mm and 4.66 mm respectively [5]. Here we focus on the 5.11 mm value because our data came from a male.

Since our ultrasound data came from a male our estimated diameter of 4.76 mm was not close to the expected value of 5.11 mm. Instead it was closer to the expected diameter value for a female, 4.66 mm. This unexpected difference could be because of how we used point estimation of the top and bottom of the carotid artery data as shown in Section 3.1.1 and Figure 1.

4.1.2 Volume Blood Flow Rate

Another published medical paper is used for the comparison of the volume blood flow rate. This paper uses data from only 28 volunteers. According to this paper the published value for the average volume blood flow rate is 277 ± 25 mL/min or 4.62 ± 0.42 cm^3/s. Our estimated calculated value from our data was 273 mL/min or 4.55 cm^3/s. This is very similar to the published value, however there is a big difference when adding in the error compensation. The published average volume blood flow rate ranges from 239-338 mL/min or 3.98-5.63 cm^3/s. So our result of 4.55 cm^3/s which lies in the middle of that range is an acceptable estimation. [1]

Looking at Section 3.1.3, Figure 2, and equation (3) we can see that even just a small change in our estimation of the maximum blood flow over time would change the average volume flow rate drastically. Our results matches with the range of the published average volume flow rate because if our estimation for the maximum blood flow rate was slightly lower or slightly higher than our estimated average volume flow rate would still fall into the lower or maximum range of the published value.

4.2 Liver Ultrasound Data

From Section 3.3, we calculated the depth of penetration to be around 4.048 cm. This seems around the correct order of magnitude since if we viewed the videos for the artery the depth penetration is around 3.5 cm.

It is the coherent nature of ultrasound that creates speckle. A speckle is not considered noise and it can even provide information on the tissue being scanned [4]. From Figure 6 and Figure 7, we can observe that there are indeed speckles in this image which are tiny bright and dark dots that create a grainy looking background. These grainy parts in our image are actually speckles and not noise. As sound waves travel away from a piezoelectric transducer through a random medium or structure, there is some interference which causes the waves to be scattered constructively or destructively. When the waves travel back to the transducer, they sum up and form a speckle pattern [6]. The random intensity fluctuation distribution contains many random bright and dark dots which forms the grainy parts we see in our reconstructed image.

5 Conclusion

We were able to measure the dimensions and flow in the carotid artery. Through the B-scan image of the carotid artery we were able to approximate the diameter of the carotid artery for diastole and systole as 0.476 cm and 0.338 cm respectively. We were able to find the percent change of the artery during systole and diastole and the difference 29%. Using a captured image of the M-mode scan we were able to estimate the average volume flow rate of the carotid artery to be 4.55 cm^3/s.

After comparing our carotid artery diameter with an online published value for males, we found that our estimated result of 4.76 mm was lower than the average expected 5.11 mm. Our estimated average volume flow rate 4.55 cm^3/s was very similar to the published value of 4.62 ± 0.42 cm^3/s, but that is only without the error compensation. Our estimated result still makes sense because if we consider the slight increase or decrease of the maximum blood flow rate then then our estimated average volume flow rate would also increase or decrease, but still be in range of the published value even with error compensation.

Also, we were able to reconstruct the B-mode image of a liver from the acquired RF liver data. We calculated an approximate image depth of 4.048 cm. We processed the representative ultrasound data by taking the logarithmic value of the data. The image was very dark and hard to observe when looking at the data before taking the logarithmic value. After adjusting the contrast to improve the image quality, we were able to clearly see the liver, vessels, and speckle. Lastly, we calculated the local contrast between the darkest blood vessel and the background which is 0.6279.

6 Reference

[1] J.F. Soustiel, E. Levy, Menashe Zaaroor, R. Bibi, S. Lukaschuk, D. Manor, (2002). "A New Angle-Independent Doppler Ultrasonic Device for Assessment of Blood Flow Volume in the Extracranial Internal Carotid Artery," in American Institute of Ultrasound Medicine. J Ultrasound Med 21:1405-1412. [Online]. Available: www.jultrasoundmed.org/content/21/12/1405

[2] S.W. Atlas, "Fundamentals of Flow and Hemodynamics" in *Magnetic Resonance Imaging of the Brain and Spine, Volume 1*. Lippincott Williams & Wilkins, 2009.

[3] (2016, April 28). *Why is Ultrasound gel used?*. [Online]. Available: https://healdove.com/health-care-industry/aquasonic_ultrasound_gel

[4] M.V. Sarunic, "Ultrasound part II – US System," BME 477 - Lecture 14 and 15, 2016.

[5] J. Krejza, M. Arkuszewski, S. Kasner, J. Weigele, A. Ustymowicz, R. Hurst, B. Cucchiara, S. Messe (April 2006). "Carotid Artery Diameter in Men and Women and the Relation to Body and Neck Size." Stroke. 37 (4): 1103–1105. [Online]. Available: http://stroke.ahajournals.org/content/37/4/1103

[6] P. J.H., "Waves In Complex Media," July 2012. [Online]. Available: http://www.physics.umanitoba.ca/~jhpage/

7 Appendix

```matlab
clc;
clear all;
close all;
load('F:\Users\Daniel\Documents\ENSC477\Lab3\LabData_part1\rfliver.mat')
load('F:\Users\Daniel\Documents\ENSC477\Lab3\LabData_part1\13-18-40.mat')
load('F:\Users\Daniel\Documents\ENSC477\Lab3\LabData_part1\13-23-46.mat')

imagesc(M)
colormap('gray')
title('M-scan Data of Artery');
figure
imagesc(log(D))

%Ascan real part of RF data
for i = 1:2076
    xaxis(1,i)=i;
end;
plot(xaxis,RfDataFilt(:,1));
xlim([ 0 2076])
title('Real Part of A-scan Data');
xlabel('X-Pixel');
ylabel('Spectral Intensities');
figure

%imaginary part of RF data
RfData_complex=hilbert(RfDataFilt(:,1))
plot(xaxis,imag(RfData_complex),'r');
xlim([ 0 2076])
title('Imaginary Part of A-scan Data');
xlabel('Pixel');
ylabel('Spectral Intensities');

%Extract Envelope
envelope=abs(RfData_complex);
figure
%Plot, real, im and envelope
plot(xaxis,imag(RfData_complex),'r', xaxis,real(RfData_complex),'b', xaxis, envelope, 'g');
xlim([ 0 2076])
title('A-scan Data');
xlabel('Pixel');
ylabel(' Spectral Intensities');
legend('Imaginary part', 'Real part', 'Envelope')

%Envelope of entire b-scan, log to compress dynamic range
for i=1:360
```

```
    rf_complex=hilbert(RfDataFilt(:,i));
    env=abs(rf_complex);
    rf_env(:,i)=log(env);
    width(i)=i*0.01;
end;

%depth of each sample
for i=1:2076
    depth(i)= i*(25e-9*1560*0.5*100);
end

figure
image=imagesc(width,depth,rf_env);
colormap('gray');
title('Image Reconstruction');
ylabel('depth(cm)');
xlabel('width(cm)');
imcontrast(image)
```