Lab Report

ENSC 477 - Biomedical Image Acquisition

Lab 3

Group 9

Group Member	Student ID
Benjamin Martin	301347720
Daria Zhevachevska	301326410

School of Engineering

Faculty of Applied Sciences

Simon Fraser University

Fall 2020

Introduction:

Ultrasound is an imaging method that uses high-frequency sound waves to produce images of body structures. It is a very popular imagining modality and since it uses acoustic radiation, which does not ionize, so there is no risk of introducing cancer during the image diagnostics. This is very important when imaging fetus in utero and human heart.

Ultrasound uses acoustic waves produced by a transducer which converts electrical signals into acoustic pulses that travel as longitudinal pressure waves. This acoustic wave reflects at the boundary of two media with amplitudes proportional to the difference in acoustic impedance between two media. This backscattered wave is received by the transducer, which detects the acoustic signal using a piezoelectric material which converts the ultrasound wave to an electric signal described by its varying voltage over time.

RF-Mode allows to save the digitized radio-frequency (RF) data from the analog high frequency ultrasound signal. The collected RF data is then passed through typical RF signal processing steps, which are used in the B-Scan image creation.

This lab introduces the use of ultrasound in echocardiography for heart imaging, where the cross-sectional images of the heart give a lot of diagnostic and functional information about the health of the heart, such as the dimensions of the carotid artery. In addition, the Doppler imaging technique can provide a quantitative measurement of the blood flow within the vessels.

Furthermore, ultrasound is used as guidance for real-time surgical procedures, such as preparation for liver biopsy, where the clinician images the liver to verify the position of the target tissue which is to be extracted for further diagnostics.

Part 1: Measuring the Dimensions of the Carotid Artery and the Rate of Blood Flow

Method

In this part we examined the B-Scans, Doppler Spectrum and M-Mode of the carotid artery to obtain the quantitative measurements of the carotid artery such as 1) diameter of the artery, 2) % change of the diameter during systole and diastole, 3) average blow flow and compared the measurements to published values.

The diameter of the artery is measured manually by drawing a straight line from the top to bottom wall of the artery. The B-Scan “at rest” is selected to perform such measurement. To get the correct scale the image depth (3 cm, taken from the provided .avi file) is divided by the number of vertical pixels of the image.

Same steps are performed to measure the percent change of the diameter during systole and diastole. The systolic frame is chosen to be the B-Scan with expanded artery, because systole occurs when the heart pushes blood and the pressure placed on the vessels increases. The diastolic frame is chosen to be the B-scan with contracted vessel, because diastole occurs when the heart relaxes, and the blood pressure drops. The percent change in diameter is calculated:

$$\text{The \% change of the diameter } = \frac{\text{Systole Diameter} - \text{Diastole Diameter}}{Diastole\ Diameter} * 100\%$$

The average blood volume flow rate with a parabolic flow rate is calculated with the equation below:

$$Flow\ Rate = \frac{\pi r^2 V_{measured}}{\mathrm{P}\cos\,(\theta)}$$

Where the gate diameter and θ, the angle between the direction of the blood flow and the doppler angle, are taken from the doppler.avi. The average velocity is estimated from the Doppler Spectrum plot, constant P is the fraction of a paraboloid blood flow covered by the gate, and r is the measured radius of the artery.

Results

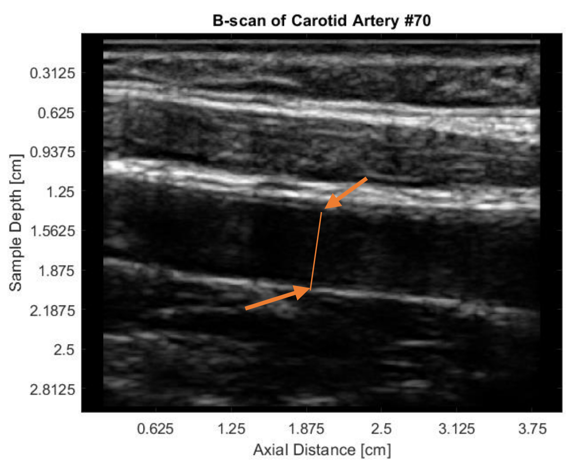


Figure 1. *Diameter of the Carotid Artery*

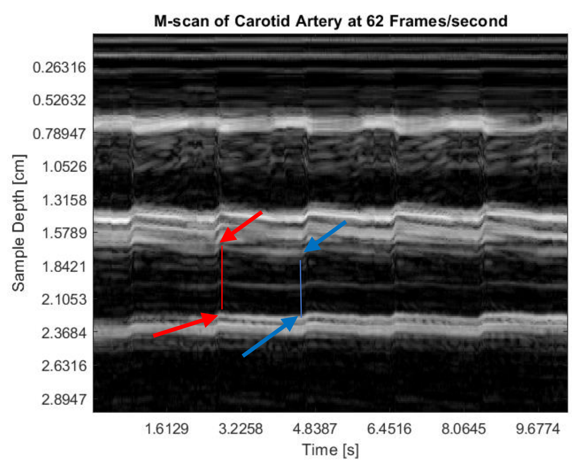


Figure 2. *Systole (red) and Diastole (blue) Diameter*

The length of the line indicated with orange arrows in Figure 2 is measured to be 80 pxl. At 3cm/480pxl, the diameter of the Carotid Artery is measured to be 5mm.

Using the M-scan of the Carotid Artery the percent change in diameter between Diastole and Systole is measured to be 28.7 pxl and 24 pxl respectively in Figure 2. The calculated percent change in diameter using the formula presented in method is 19.5%.

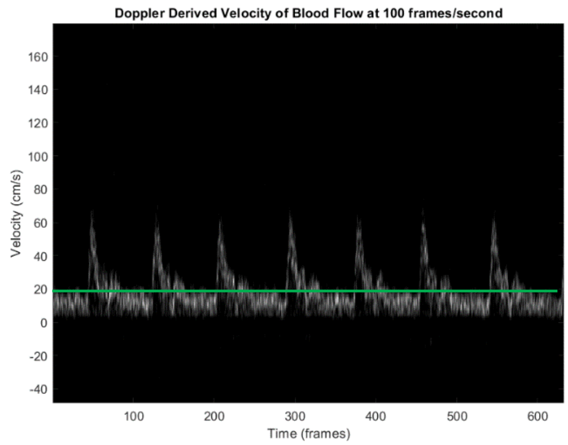


Figure 4. *Velocity of Blood Flow in the Direction of the doppler scan (Average Estimated Velocity of 20cm/s in green)*

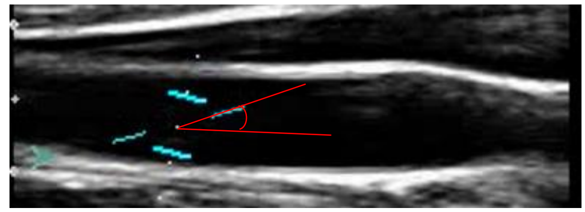


Figure 5. *Doppler B-scan measuring the angle between the ultrasound receiver and the angle of motion (ɵ = 35°)*

P, the fraction of a parabolic blood flow covered by the gate is calculated:

$$\frac{3.5mm\ gate}{5mm\ artery\ diameter} = inner\ 70\%\ of\ the\ paraboliod\ metered$$

$$\int_0^1 1 - x^2 dx = 0.667 \quad \int_0^{0.7} 1 - x^2 dx = 0.586$$

$$P = \frac{0.586}{0.667} = 0.878\ of\ the\ total\ blood\ flow$$

The average volumetric flow rate is calculated:

$Flow\ Rate = \frac{\pi r^2 V_{measured}}{\mathrm{P}\cos(\theta)} = \frac{\pi(0.25cm)^2 20cm/s}{(0.878)\cos(35°)}$ = 5.46cm^3/s = 5.46ml/s = 327.6 ml/min

The three calculated measurements are compared to published value in the table below where the ± indicates standard deviation values.

Measurement	Published Value	Calculated Value
Diameter	Mean diameters in women: ICA (4.66±0.78 mm) and CCA (6.10±0.80 mm) Mean diameters in men: ICA (5.11±0.87 mm) and CCA (6.52±0.98 mm)[1]	5 mm
% Change	Diastolic diameter: 6.33 mm, Systolic diameter 7.13mm[2] -> 13% change	19.5%

[1] https://www.ahajournals.org/doi/full/10.1161/01.str.0000206440.48756.f7#:~:text=Mean%20diameters%20of%20ICA%20(4.66,%2C%20age%2C%20and%20blood%20pressure

[2] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2343041/#:~:text=At%20the%20same%20time%2C%20both,of%20the%20end%2Ddiastolic%20diameter

Avg. Flow Rate	395 ± 79 ml/min[3]	327.6 ml/min

Table 1. *Published and Calculated Values of the Carotid Artery*

Discussion

Comparing our measured value of 5mm for Carotid Artery Diameter to published values gives confidence in our measurements as our values fall with the diameters published for women. Our average volumetric flow rate is also closely corresponded with the published value.

The M-scan, a single A-scan location where the changes are measured over time, reveals the periodic nature of blood flow. As time passes the distinct sections, which are biological features such as artery walls, contract and expand. The cycle repeats several times across the duration of the M-scan.

Our calculated value for percent change in diameter between Diastolic and Systolic periods is larger than predicted by published values. This error could be variance in the patient, or due to measurement error caused by a lack of contrast on the edge of upper artery wall in the M-mode image. The lower wall in the image is clearly defined and easy measures accurately. This difference in contrast could be explained an effect of a separate boundary close to the artery wall for which the spatial pulse length used is too wide to resolve both boundaries distinctly.

Part 2: Investigating Representative Ultrasound Data

Method

The radio-frequency data acquired by a 6.67MHz ultrasound transducer, digitized at 40MHz is used to construct an image of the liver. The entire B-scan is processed by detecting the envelope of all A-scans. This is done by taking the magnitude of the complex representation of the RF data which consists of 360 A-scans, each acquired for $2076\ frames \times \frac{1\ s}{40e6\ frames} = 5.1900e-5\text{ s}$ long. The given RF data represents only the real part of a complex wave, therefore the inbuilt MATLAB function *hilbert()* is used to generate the missing imaginary component. Next, the dynamic range is compressed by taking the logarithm and the brightness/contrast is adjusted using *imadjust()*.

Local contrast around the vessel area is found by selecting two rectangular regions: dark pixels from the elliptical features in the image and lighter background pixels around the chosen feature. The target and background mean intensities are computed by averaging all pixels within the selected regions and used for the local contrast calculation, both for the initial B-Scan and the contrast enhanced B-scan.

$$C_{local} = \frac{I_{target} - I_{background}}{I_{background}}$$

[3] https://www.jvascsurg.org/article/0741-5214(86)90148-5/fulltext

Results

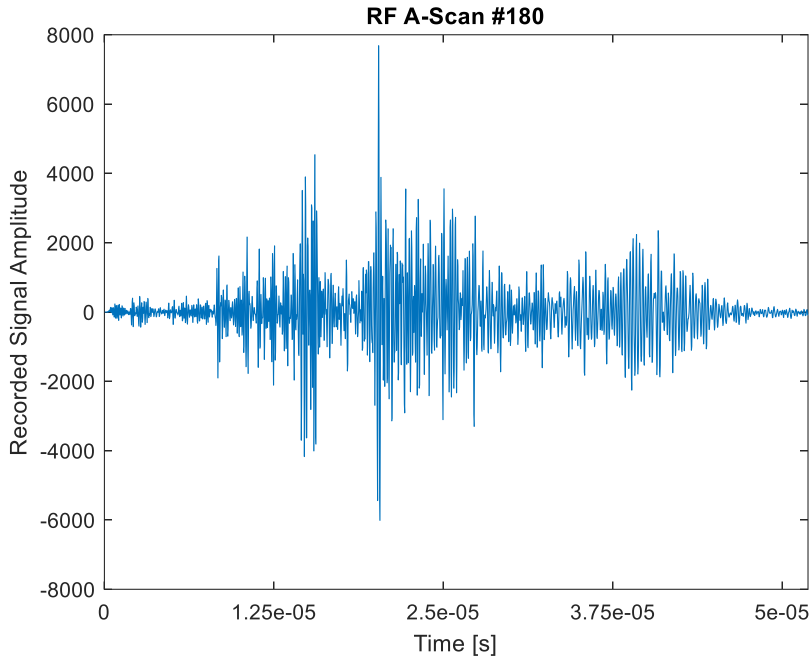


Figure 6. *FR A-Scan #180*

To compute the image depth, we use the known constant that the speed of sound in liver is c_{liver}= 1570 m/s. The factor of a half accounts for the wave's round-trip travel.

$$Image\ depth = 2076\ frames \times \frac{1\ second}{40e6\ frames} \times \frac{1570\ m}{1\ second} \times \frac{1}{2} = 4.074cm$$

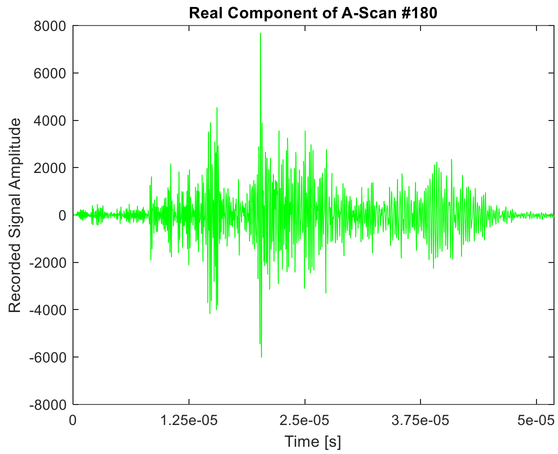


__Figure 7.__ The Real Component of A-Scan #180

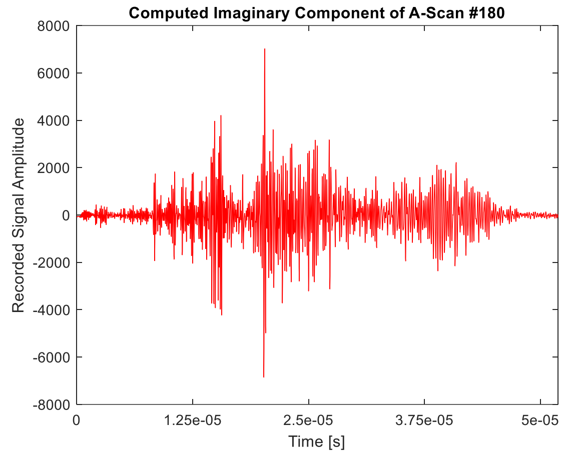


__Figure 8.__ The Computed Imaginary Component of A-Scan #180

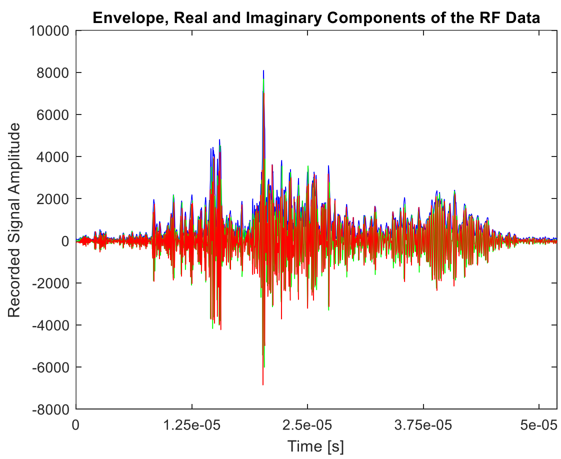


__Figure 9.__ Envelope (blue), real (green), and imaginary (red) components of A-Scan #180

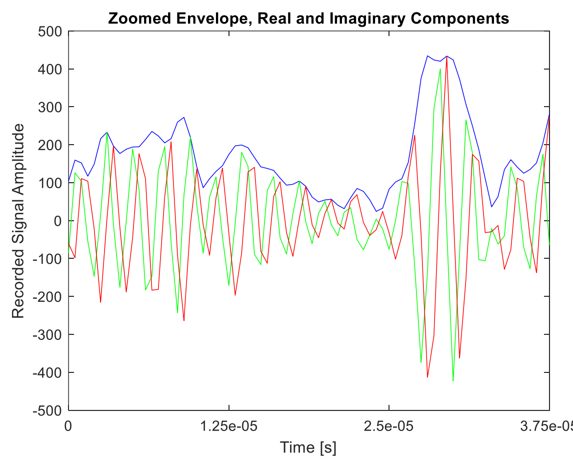
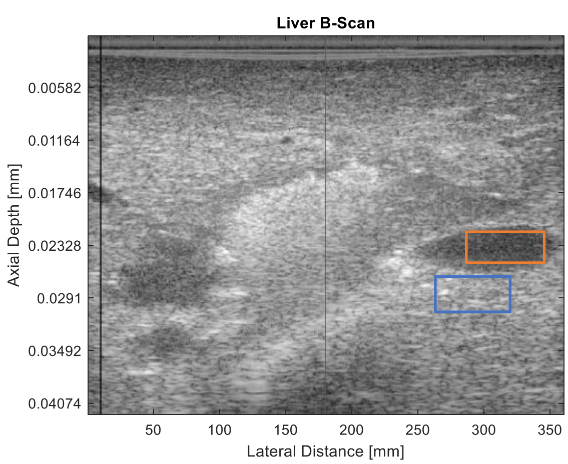


__Figure 10.__ A zoom on the Envelope (blue), real (green), and imaginary (red) components of a portion of A-Scan #180



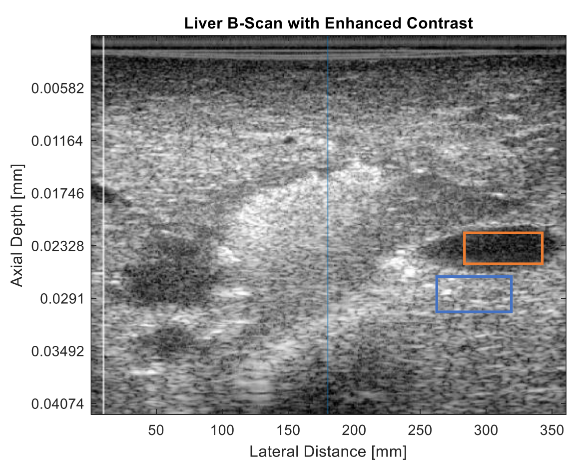


__Figure 11.__ The Liver B-scan reconstructed from the recorded RF ultrasound signal. The area within the coloured squares were used to determine the intensity of a vessel (orange) and the background (blue) by computed the mean intensity in each area. The blue vertical line indicates the A-scan #180, which is used for the previous steps. Image on the right is the same image with enhanced contrast.

$$C_{local} = \frac{I_{target} - I_{background}}{I_{background}} = \frac{0.337 - 0.604}{0.604} = -0.441$$

$$C_{local\ with\ contrast} = \frac{0.198 - 0.576}{0.576} = -0.657$$

“Lowering” the contrast makes the elliptical vessels stand out more, the negative sign indicates that the intensity of the target is lower than its surroundings.

Discussion

Doppler Ultrasound was used to detect the velocity of blood flow. This utilizes the Doppler effect by comparing the initial frequency to the perceived frequency detected. If an object is moving away from the source, the perceived wavelength is lower, and the frequency is higher. If an object is moving away from the source, the perceived wavelength is higher, and the frequency is lower. This change in frequency is measure on an axis which need not be parallel to the axis of the objects velocity since the recorded velocity will be the projection of the object’s velocity on that axis.

The RF signal digitized by the transducer records only the real part of an ultrasound wave which is a complex function. To detect the envelope of the wave, the imaginary part is computed using the Hilbert transform. Summing the real and imaginary parts of the ultrasound wave, we form a complete representation of the wave as a complex exponential and detect the envelope as the modulus of the function.

After reconstructing the complex wave from its detected real components, he real and imaginary components can be seen to have extremely similar shapes except for the changes in magnitude of the envelope over time. This is because the RF signals are carried by sinusoidal signals and the Hilbert transform of a sine function is a negative cosine function, and the Hilbert transform of a cosine function is a sine function. Since sines and cosines are phase shifted versions of each other, the imaginary component follows the shape of the real component but is phase shifted to lag the real component by 90 degrees as a sine function lags a cosine function.

Speckle, an artifact of coherent imaging, appears as a spotted texture across the B-scan image. The pattern negatively affects contrast but also provides sub resolution information which is trackable over time. If only the speckle is changing in multiple B-scans taken across time, the information reveals movement such as low flow blood. Speckle tracking has diagnostic value in both angiography and elastography.

Appendix

```
%%%%%%%%%%%%%%%%%% Part 1 %%%%%%%%%%%%%%%%%%%%%%%%%%
%% Load the data
addpath('C:\Users\Dasha\Desktop\Fall 2020\ENSC
477\Labs\Lab3-US\MatLab\');
addpath('C:\Users\Dasha\Desktop\Fall 2020\ENSC
477\Labs\Lab3-US\Data\');
bScan = RPread('bscans.b32'); %b-scans of carotid artery
mMode = RPread('mmode.b32'); %m-mode of carotid artery
dopplerBscan = RPread('DopplerBscan.b32'); %doppler b-scan
dopplerSig = RPread('DopplerSignal.pw'); %doppler spectrum

%% Display B-scans
%display all b-scans of carotid artery in a loop
figure(1);  colormap('gray');
for i = 1:132
title(['B-scan of Carotid Artery #',num2str(i)]);
imagesc(squeeze(bScan(:,:,i)));
pause(0.2);
end

%display the mid b-scan for estimating the diameter of the
carotid artery
figure(2)
imagesc(squeeze(bScan(:,:,70))); colormap('gray');
title('B-scan of Carotid Artery #70');
xlabel('[pxl]'); ylabel('[pxl]');
[x, y, temp] = improfile();
distance = abs(y(1) - y(end));
sprintf('The distance = %.1f pixels.', distance);

%% Display M-Mode
%display the m-Mode for estimating % change of the diameter
during systole
%and diastole
figure(3)
imagesc(mMode); colormap('gray');
[x, y2, temp] = improfile();
distance2 = abs(y2(1) - y2(end));
sprintf('The systole distance = %.1f pixels.', distance2);
[x, y3, temp] = improfile();
distance3 = abs(y3(1) - y3(end));
sprintf('The diastole distance = %.1f pixels.', distance3);
```

```
pch = (distance3 - distance2) / distance3 *100; %calculte %
change

%% Display the Doppler B-scans
figure(4); colormap('gray');
for i = 1:27
title(['Doppler B-scan #',num2str(i)]);
imagesc(squeeze(dopplerBscan(:,:,i)));
pause(0.2);
end
[x, y4, temp] = improfile();
distance4 = abs(y4(1) - y4(end));

%%%%%%%%%%%%%%%% Part 2 %%%%%%%%%%%%%%%%%%%%%%%
%% Load the data
liverData = load('C:\Users\Dasha\Desktop\Fall 2020\ENSC
477\Labs\Lab3-US\Data\rf-liver.mat');
RFDataFilt = liverData.RfDataFilt;

%% Display RF data A-scan
figure(1)
plot(RFDataFilt(:, 180));  colormap('gray');
title('RF A-Scan #180');
val = [0 500 1000 1500 2000]/40e6;
charVal = strsplit(num2str(val)); %create char values for
x-axis
xticks([0 500 1000 1500 2000]); xlim([0,2076]);
set(gca,'XTickLabel', charVal);
ylabel('Recorded Signal Amplitude'); xlabel('Time [s]');

%% R and Im of RF data A-scan
HTIm = hilbert(RFDataFilt(:, 180)); %HT
figure(2)
plot(real(HTIm), 'g');
title('Real Component of A-Scan #180');
ylabel('Recorded Signal Amplitude'); xlabel('Time [s]');
xticks([0 500 1000 1500 2000]); xlim([0,2076]);
set(gca,'XTickLabel', charVal);
figure(3)
plot(imag(HTIm), 'r');
title('Computed Imaginary Component of A-Scan #180');
ylabel('Recorded Signal Amplitude'); xlabel('Time [s]');
xticks([0 500 1000 1500 2000]); xlim([0,2076]);
```

```
set(gca,'XTickLabel', charVal);

%% Envelope & R & Im of RF data A-scan
figure(4)
plot(abs(HTIm), 'b'); %envelope plot
hold on
plot(real(HTIm), 'g'); %real part plot
hold on
plot(imag(HTIm), 'r'); %imaginary part plot
hold off
title('Envelope, Real and Imaginary Components of the RF
Data');
ylabel('Recorded Signal Amplitude'); xlabel('Time [s]');
xticks([0 500 1000 1500 2000]); xlim([0,2076]);
set(gca,'XTickLabel', charVal);

figure(5)
plot(abs(HTIm(1:140)),'b');
hold on
plot(real(HTIm(1:140)),'g');
plot(imag(HTIm(1:140)),'r');
hold off
title('Zoomed Envelope, Real and Imaginary Components');
ylabel('Recorded Signal Amplitude'); xlabel('Time [s]');
val2 = [25 50 75 100]/40e6;
charVal2 = strsplit(num2str(val)); %create char values for
x-axis
xticks([25 50 75 100]); xlim([25,100]);
set(gca,'XTickLabel', charVal2);


%% Process the B-scan
%detect the envelope of each RF A-scan
HT = zeros(size(RFDataFilt));
for i = 1:360
HT(:, i) = abs(hilbert(RFDataFilt(:, i)));
end

figure(6)
J = mat2gray(imresize(log(HT), [360 360])); %log and resize
the image depth
imagesc(J); colormap('gray');
hold on
plot([180,180], [0,360]);
```

```
hold off
title('Liver B-Scan');
xlabel('Lateral Distance [mm]'); ylabel('Axial Depth
[mm]');
val = [50 100 150 200 250 300 350]/350 *4.074e-2; %mm
charVal = strsplit(num2str(val)); %create char values for
x-axis
set(gca,'YTickLabel', charVal);

%For display purpose adjust brightness and contrast of the
image
% imcontrast
J2 = imadjust(J,[0.2 0.9]);
figure(7)
imagesc(J2); colormap('gray');
hold on
plot([180,180], [0,360]);
hold off
title('Liver B-Scan with Enhanced Contrast');
xlabel('Lateral Distance [mm]'); ylabel('Axial Depth
[mm]');
val = [50 100 150 200 250 300 350]/350 *4.074e-2; %mm
charVal = strsplit(num2str(val)); %create char values for
x-axis
set(gca,'YTickLabel', charVal);

%% Calculate the local contrast of one of the vessels
obj = mean(J(193:218, 273:339), 'all');
background = mean(J(230:300, 254:350), 'all');
Cloc1 = (obj - background)/background;
obj = mean(J2(193:218, 273:339), 'all');
background = mean(J2(230:300, 254:350), 'all');
Cloc2 = (obj - background)/background;
```