Introduction

Greyscale imaging in ultrasound, often known as B (brightness) mode, produces a two-dimensional picture in which the organs and tissues of interest are represented as spots of varied brightness. The formation of a B-mode image relies on the pulse-echo principle; assuming the speed of sound remains constant, the position of a target of interest may be inferred by the time taken from emission to its return to the transducer.

A moving picture is created by successively summing in real-time the pulse-echo sequences from many nearby scan lines to create a cross-sectional image. Each echo shown in the image at a point corresponds to the relative location of its origin inside the body cross-section, creating a scaled map of echo-producing objects. The transducer's footprint contains piezoelectric crystals that generate ultrasonic waves by deforming when a voltage is placed across them, converting electrical energy to mechanical energy. The transducer "listens" for returning vibrations after the ultrasonic waves are emitted. These vibrations will deform the piezoelectric crystals, converting mechanical energy to electrical energy. The brightness of the image at each point is related to the strength or amplitude of the echo, giving rise to the term B-mode (brightness mode).

For displaying each echo in a position corresponding to that of the interface or feature (known as a target) that caused it, the B-mode system needs two pieces of information. These are

(1) the range (distance) of the target from the transducer and
(2) the direction of the target from the active part of the transducer, i.e., the position and orientation of the ultrasound beam.

The objective of this experiment was to become familiar with a portable clinical ultrasound scanner, and to determine its axial and lateral spatial resolutions, and contrast in B-mode imaging at two different frequencies.

Method

In this experiment, we find the spatial resolution and contrast in the images, we took using a portable ultrasound scanner from A calibrated tissue-mimicking phantom.

Spatial resolution is related to image coordinates, meaning the higher the number of coordinates, the higher the number of pixels is, which leads to a higher number of sampling and division resulting in higher spatial resolution.

The Contrast is the difference in luminance or the color that makes an object distinguishable. To calculate the contrast, we use the difference between the highest and lowest intensity value.

At the beginning of this experiment, we turned the machine on by pressing ON the button, and then we changed the probe setting of the machine to the C5-2Fs probe. In the next step, we set the transducer central frequency to 2 MHz and 4Mhz, then we applied the coupling gel on the curved surface of the phantom and positioned it perpendicularly on the phantom. We altered the depth, gain, TGC, and dynamic range settings a couple of times and we made sure to align the probe on the desired area with the grayscale targets and the vertical wire targets.

After we saw the desired image on the display, we captured the image by pressing the capture button and saved the B-Mode image on the device. To observe the images that we captured and check to see if it has the desired quality that we are after, we selected the freeze mode on the device and we toggled between different images using the integrated mouse on the device, then we selected the desired images and imported them into the USB drive. Lastly, we downloaded those images from the USB drive into MATLAB, to measure and report the contrast of all the grayscale cysts targets as well as the axial and lateral spatial resolution as a function of depth using wire point targets.

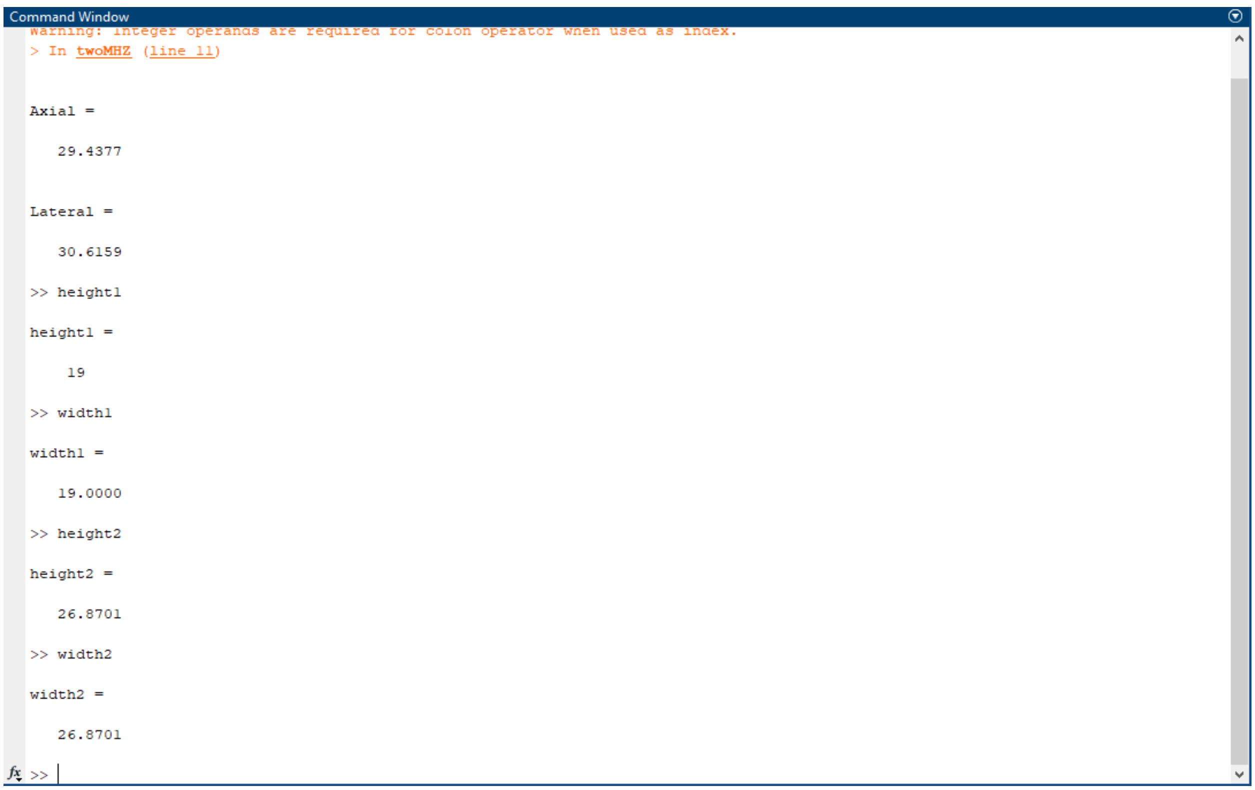
Materials

Materials, which we used in this experiment are as follows:

- A portable ultrasound scanner
- A multi-frequency convex array probe
- A calibrated tissue-mimicking phantom
- An external USB

Results

Spatial resolution results for the 2MHz image:



```
Command Window
Warning: Integer operands are required for colon operator when used as index.
> In twoMHZ (line 11)

Axial =

   29.4377

Lateral =

   30.6159

>> height1

height1 =

    19

>> width1

width1 =

   19.0000

>> height2

height2 =

   26.8701

>> width2

width2 =

   26.8701

>>
```

Spatial Resolution for the 4MHz Image

```
Command Window
    85.9520

>> fourMHZ

axial =

   61.0667


lateral =

   60.4266

>> height1

height1 =

    15

>> width1

width1 =

    22

>> height2

height2 =

   21.2132

>> width2

width2 =

   31.1127

fx >>
```

When we look at the axial and lateral values for 2MHz and 4Mhz images and compare those values, the result indicates that spatial resolution is dependent of axial and lateral resolution and both these values are dependent on the frequency of the ultrasound and based on our values the spatial resolution is higher for 4MHz image. The axial and lateral resolution for the same spot in 4MHz image is 61.0667 and 60.4266, for 2MHz image are 29.4377 and 30.6159.

Contrast

Contrast values for every single pixel in 4MHz Image

I1 | I | I10 | I3 | I4 | I2

3000x4000 uint8

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	54	54	55	56	58	60	62	62	61	59	57	55	53	
2	53	53	54	55	57	60	61	62	61	59	57	55	53	
3	52	52	53	55	57	59	61	62	61	59	57	55	53	
4	50	50	51	53	55	58	60	61	60	59	57	55	53	
5	46	47	48	50	53	57	59	61	61	59	57	55	54	
6	43	44	45	47	51	55	58	60	60	59	58	56	55	
7	39	40	41	44	48	53	57	59	60	59	58	56	55	
8	36	36	38	41	46	51	55	58	59	59	58	57	56	
9	31	32	34	37	43	48	54	57	59	59	58	58	57	
10	27	28	30	34	40	46	52	56	58	58	58	58	57	
11	23	24	26	30	36	43	49	54	56	58	58	58	58	
12	18	20	22	27	33	41	48	53	56	58	59	59	59	
13	15	16	19	24	31	39	47	52	55	57	58	59	59	
14	12	13	16	21	29	37	45	51	55	57	58	59	59	
15	9	10	13	18	26	35	44	50	54	56	58	59	59	
16	6	8	11	17	25	34	43	49	53	56	57	58	59	
17	4	6	9	15	24	33	42	49	53	56	58	58	59	
18	2	4	7	13	22	32	41	48	52	55	57	58	59	
19	1	3	6	12	21	31	41	48	52	55	57	58	59	
20	0	2	5	11	20	30	40	47	52	55	57	58	59	
21	0	1	4	10	20	30	40	47	52	54	56	57	58	
22	0	1	4	10	20	30	40	47	52	54	56	57	58	
23	0	1	4	10	20	30	40	47	52	54	56	57	58	
24	0	1	4	10	20	30	40	47	52	54	56	57	58	

Contrast values for every single pixel in 2MHz Image

I1

600x800 uint8

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	53	62	53	51	57	55	54	53	55	56	56	56	56	5
2	38	58	56	52	56	54	55	55	56	56	56	56	57	5
3	19	52	59	54	56	54	56	57	54	54	54	55	55	5
4	7	48	59	54	57	56	55	54	56	57	58	59	58	5
5	4	47	58	53	58	57	54	51	56	57	57	57	58	5
6	5	48	58	52	59	56	52	53	50	49	48	47	48	5
7	5	50	59	53	57	53	52	60	68	67	66	63	59	5
8	6	51	61	53	56	49	52	66	105	106	107	102	92	7
9	4	52	58	53	57	55	45	71	111	106	104	109	114	11
10	4	52	58	53	57	55	45	71	108	105	102	103	105	10
11	4	52	58	53	57	55	45	71	106	105	103	101	100	10
12	4	52	58	53	57	55	45	71	105	106	106	104	103	10
13	4	52	58	53	57	55	45	71	106	105	105	106	106	10
14	4	52	58	53	57	55	45	71	107	104	102	102	105	10
15	4	52	58	53	57	55	45	71	107	105	102	101	102	10
16	4	52	58	53	57	55	45	71	106	107	106	104	102	10
17	4	52	58	53	57	55	45	71	106	105	104	103	103	10
18	4	52	58	53	57	55	45	71	106	105	104	103	103	10
19	4	52	58	53	57	55	45	71	106	105	104	103	103	10
20	4	52	58	53	57	55	45	71	106	105	104	103	103	10
21	4	52	58	53	57	55	45	71	106	105	104	103	103	10
22	4	52	58	53	57	55	45	71	106	105	104	103	103	10
23	4	52	58	53	57	55	45	71	106	105	104	103	103	10
24	4	52	58	53	57	55	45	71	106	105	104	103	103	10
25	8	45	61	52	56	54	48	68	105	104	103	102	102	10
26	22	51	61	51	56	54	48	69	108	107	106	105	104	10
27	41	57	60	51	57	53	48	71	106	105	103	102	102	10
28	54	59	57	52	58	53	48	71	106	106	104	103	103	10
29	57	57	55	52	59	53	48	70	105	104	103	102	102	10
30	56	55	54	53	59	53	48	69	108	107	106	105	105	10
31	54	54	56	54	57	53	50	69	111	111	109	108	108	10
32	54	55	58	55	56	52	51	70	98	97	96	95	95	9
33	55	55	55	55	55	55	55	55	52	52	52	52	52	5

Contrast

Regarding contrast, based on our obtained values, we can argue that the contrast is higher in the 2MHz image compared to 4Mhz image.

Discussion

In the images there are 6 shallow cyst targets, 5 deep cyst targets and point scatterers which are used for image processing. We used the Field II simulation tool in MATLAB to measure the spatial resolution and contrast, the functions, which were used in this experiment are as followed: field. init.m, field. end.m, calc.h.m. For higher frequency the contrast values seem to be higher as it can be seen from the matlab results and the resolution of the image is higher also for the higher frequency.

Spatial resolution is the smallest discernable change in gray (intensity) level. Mathematically one can say that spatial resolution can be stated with pixels per unit distance, which is being the most common measure of a meaningful measure of spatial resolution. For measuring spatial resolution, we use axial and lateral resolutions.

Axial resolution described as the smallest distance used to differentiate between two reflectors in parallel with the direction of the ultrasound beam, and axial resolution has inverse relationship with the spatial pulse length. It can be calculated this way:

AR = ½ × (spatial pulse length)

Spatial pulse length = (the number of cycles in a pulse of ultrasound) * (the wavelength)

Lateral resolution can be described as the smallest distance that can be distinguished between two reflectors placed perpendicularly to the direction of the ultrasound beam. Lateral resolution can be calculated as shown below:

$(LR) = 0.4 \times \lambda \times F/L$

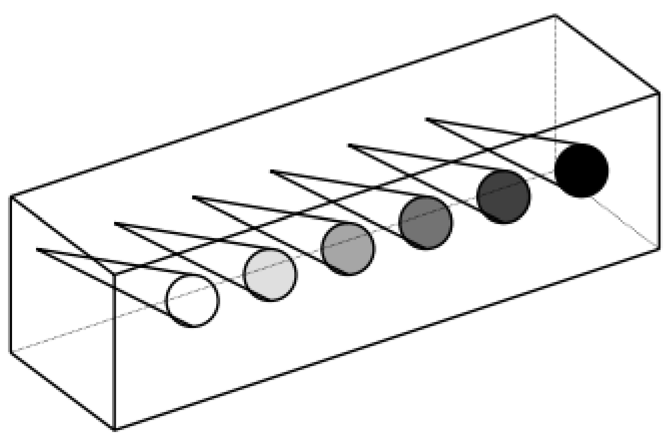
LR (Lateral resolution)

λ (Ultrasound wavelength)

F (Focal depth)

L (Aperture length)

Contrast resolution is the ability to identify the differences in echo amplitudes of nearby structures. To calculate the contrast resolution, we use the difference between the highest and lowest intensity value.



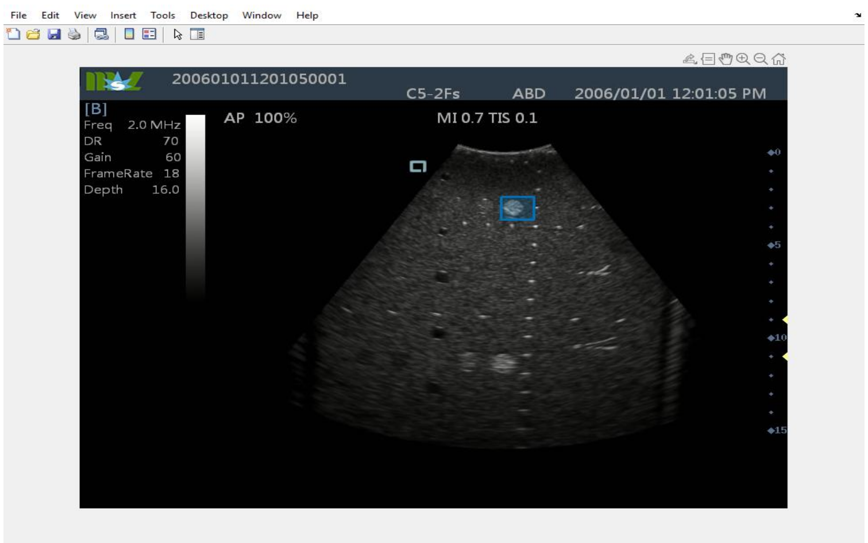
(Contrast Detail Phantom)

References

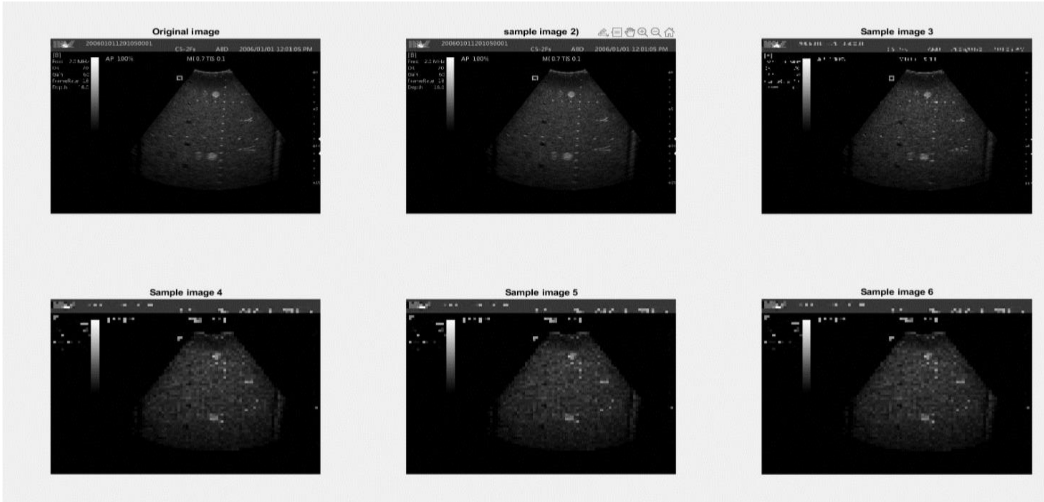
1. Peter R. Hoskins, Kevin Martin, Abigail Thrush. Diagnostic Ultrasound. (2010) ISBN: 9781139488907
2. Bob Jarman. Emergency Point-of-Care Ultrasound. (2017) ISBN: 9780470657577

2MHz Image

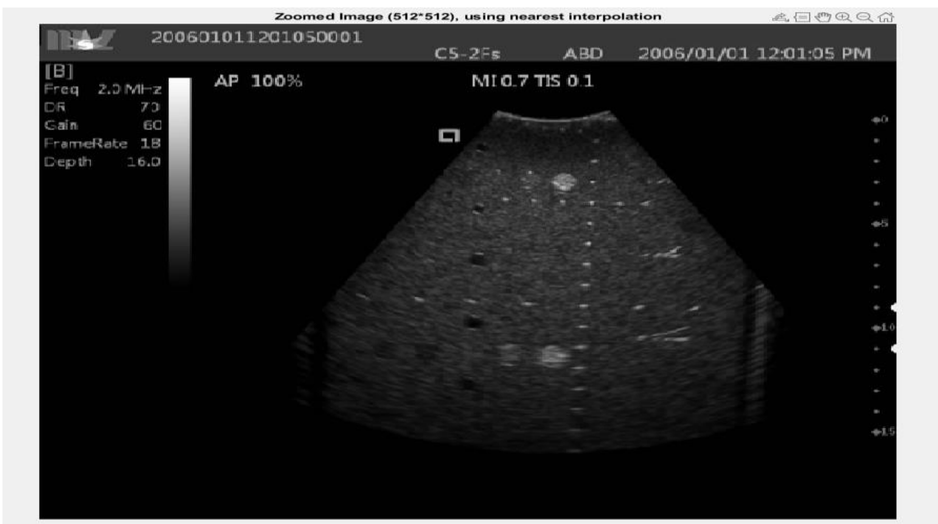
MATLAB RESULTS for 2MHz



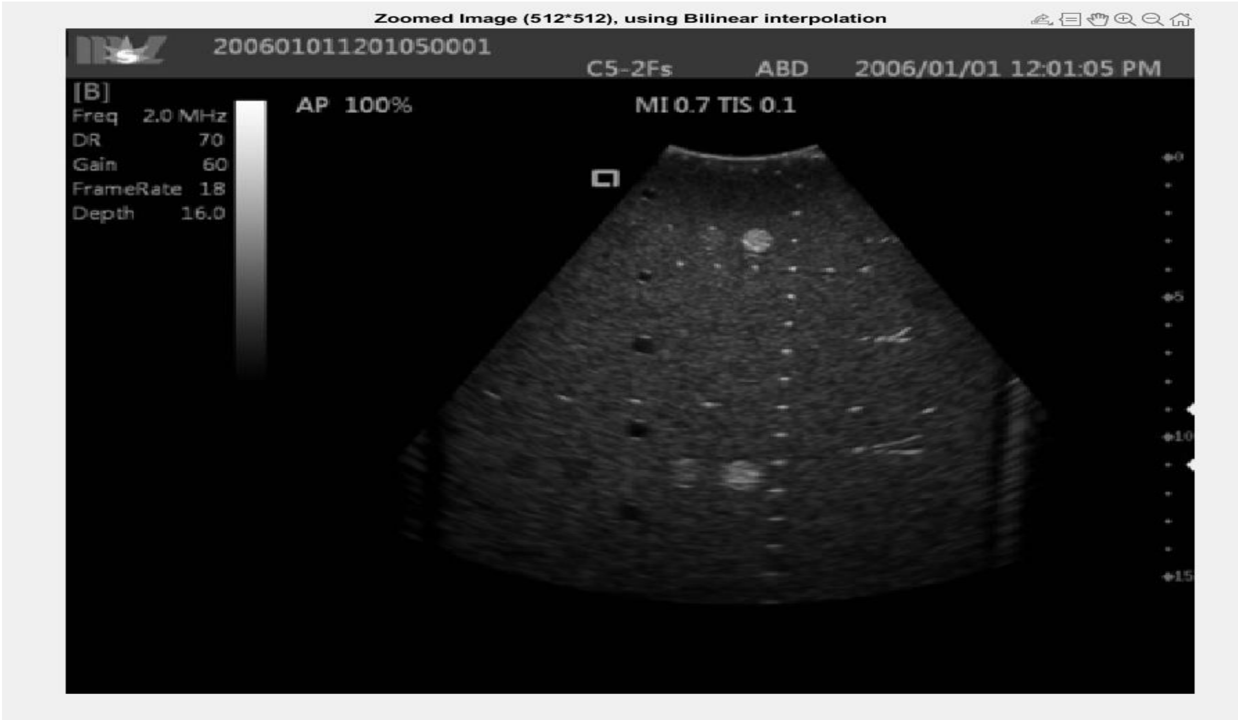
(Selecting a specific part of the Original Image for spatial and contrast measurements)



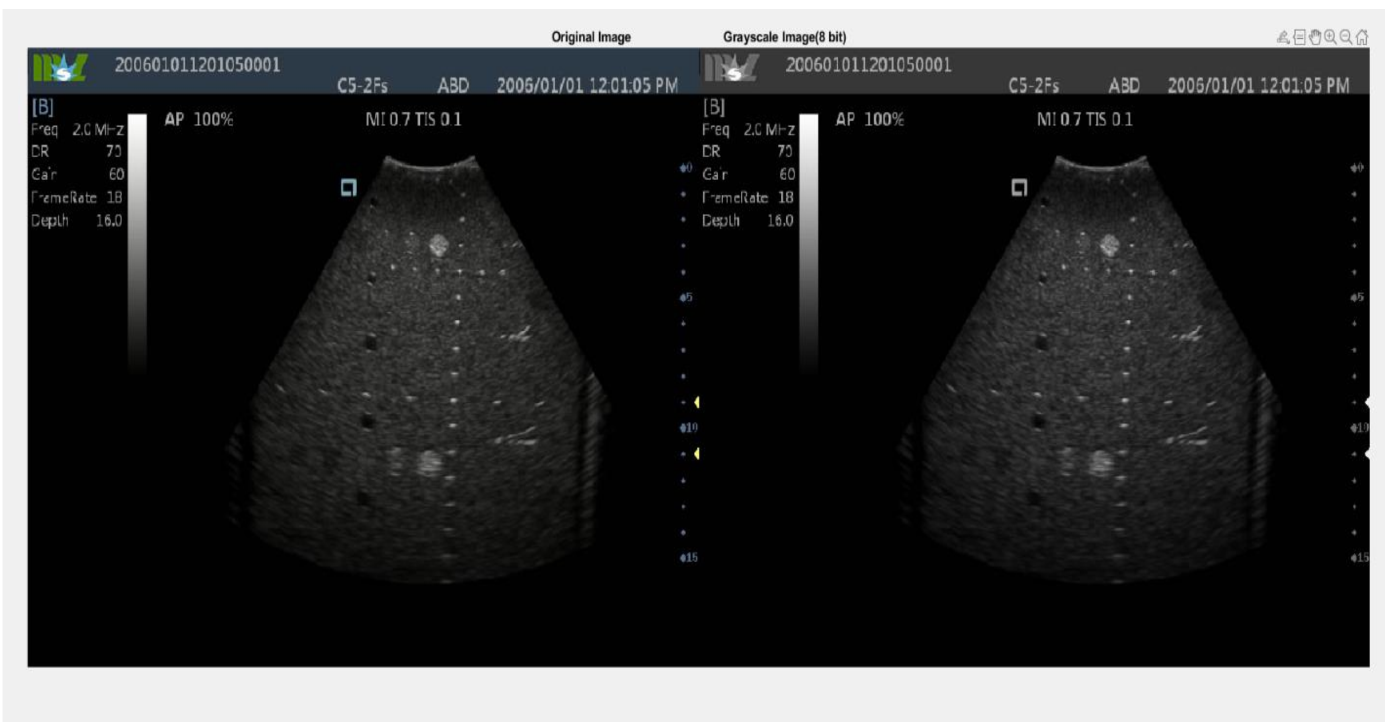
(Running Image processing on 2MHz Image)



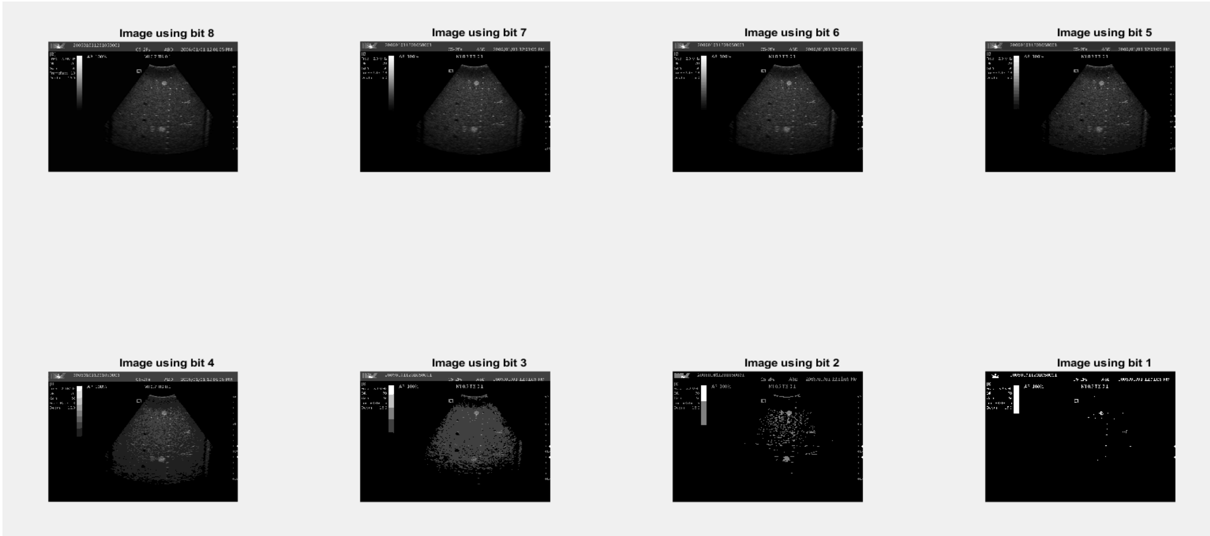
(Using Nearest Interpolation)



(Using Bilinear Interpolation)

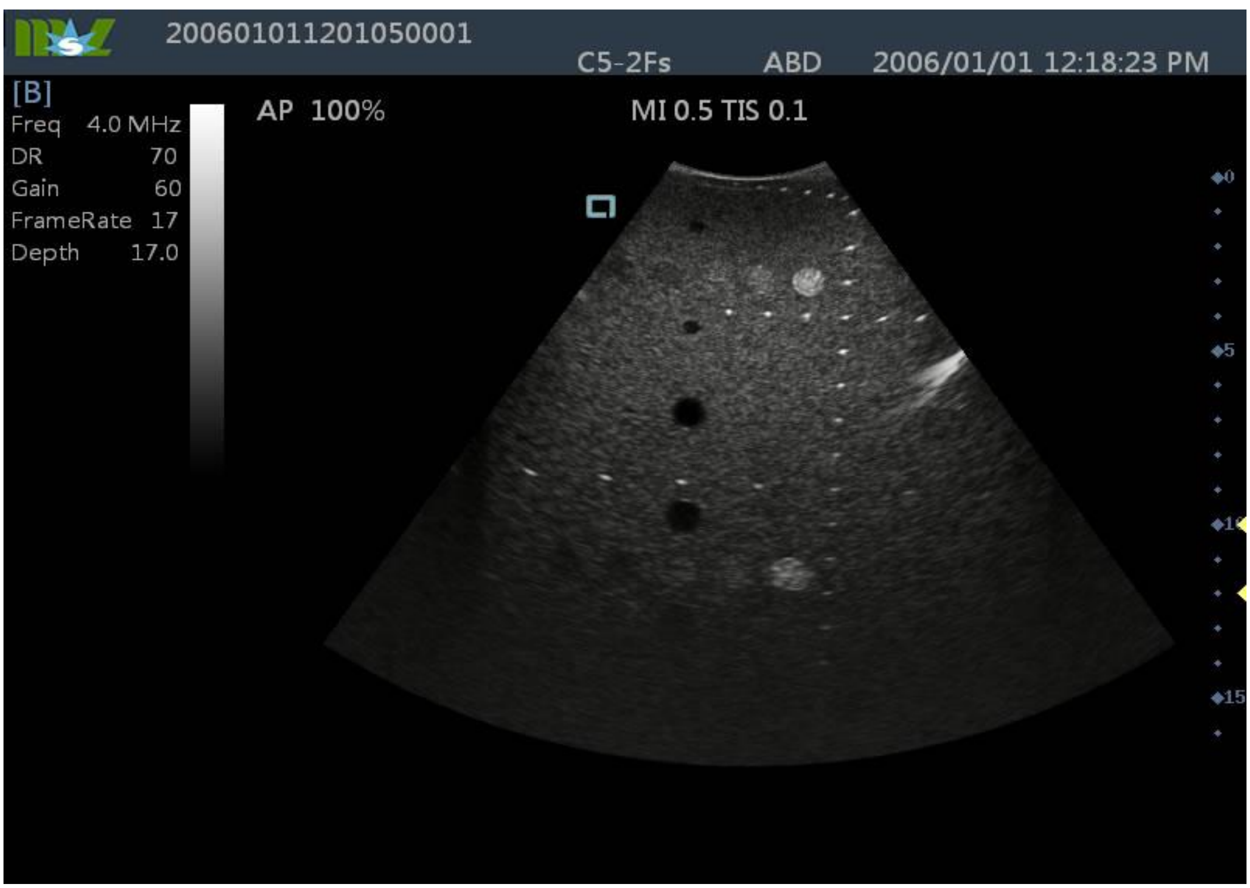


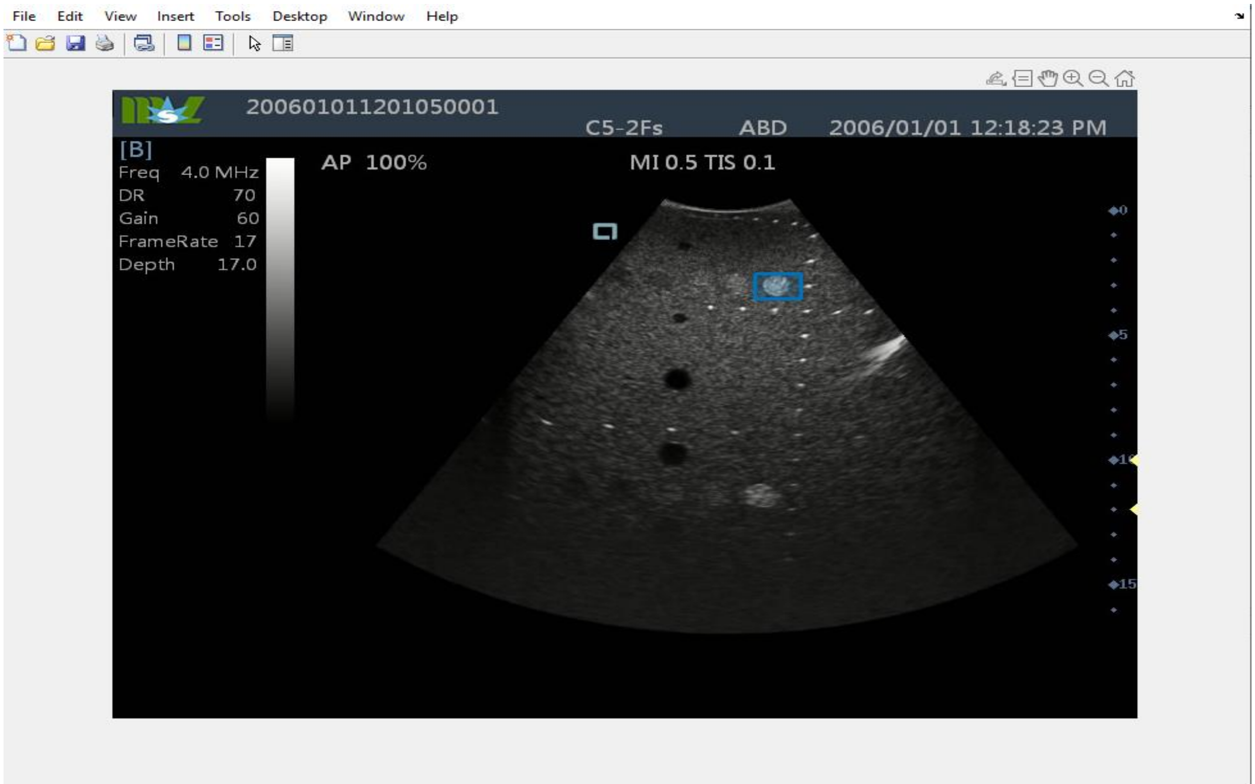
(Comparison of the original Image and the Grayscale Image (8bit))



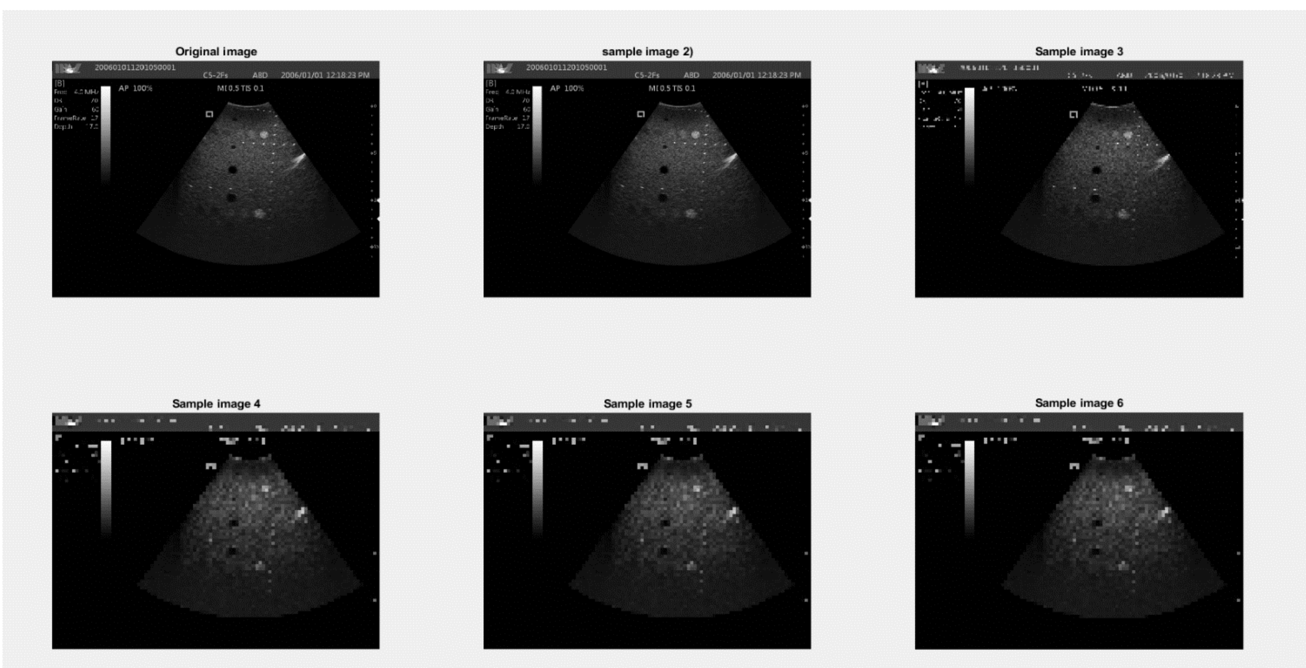
(Running Image Processing to increase the resolution based on the spatial resolution and contrast)

4MHz Image

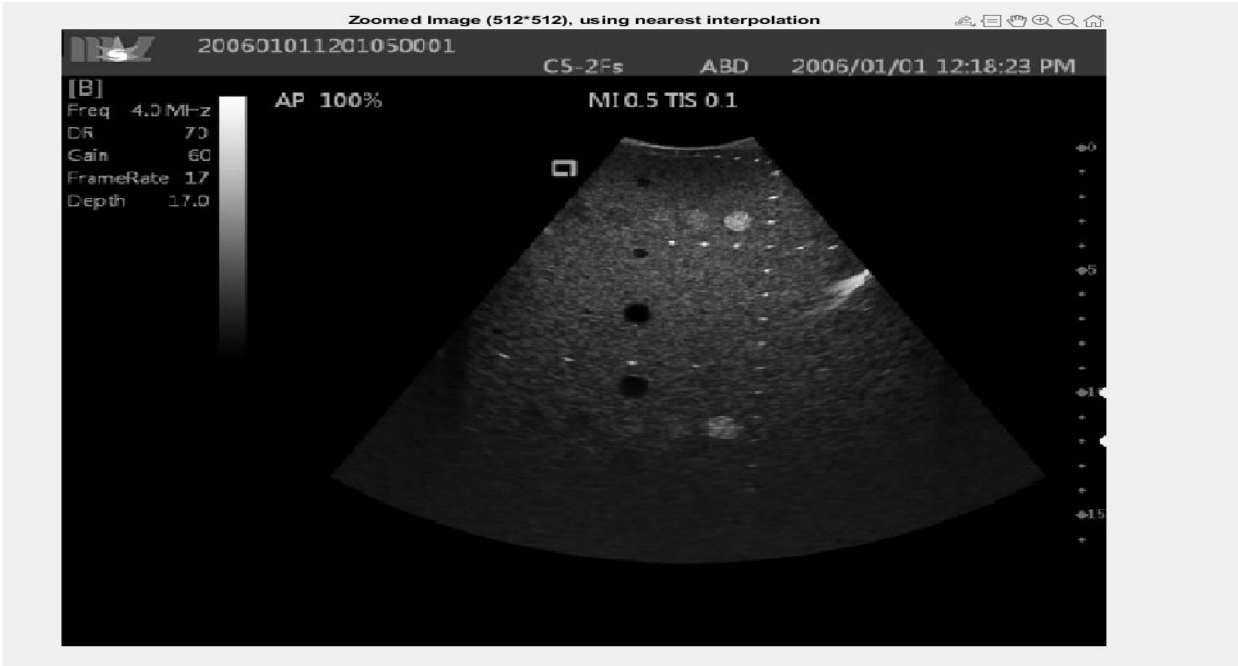




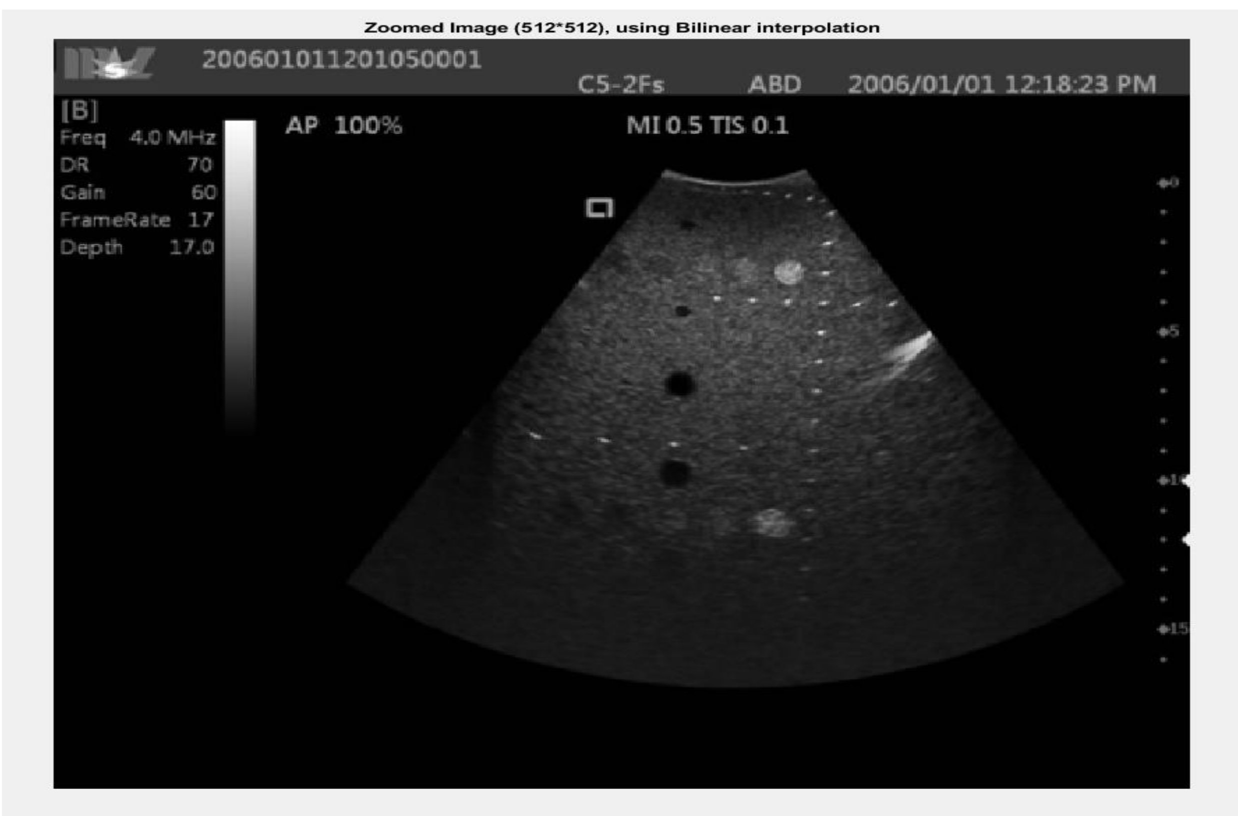
(Selecting a specific part of the Original Image for spatial and contrast measurements)



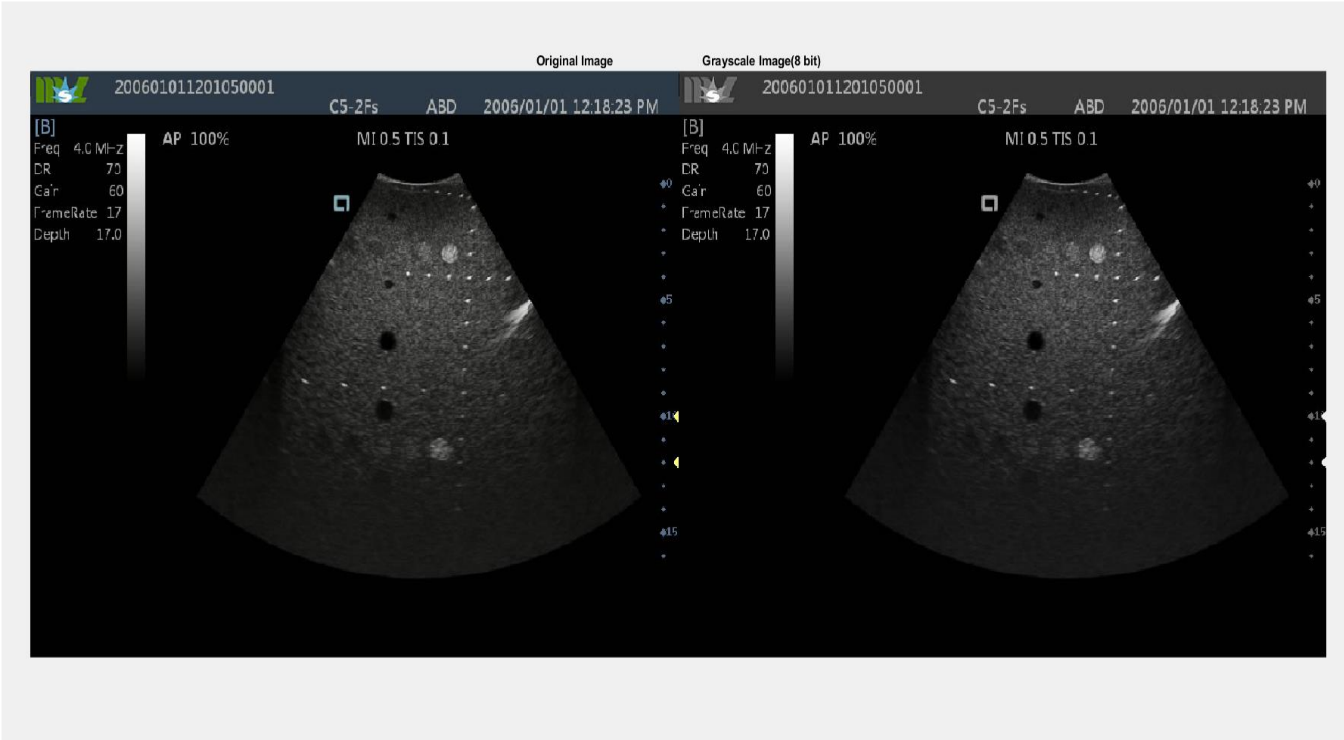
(Running Image processing on 4MHz Image)



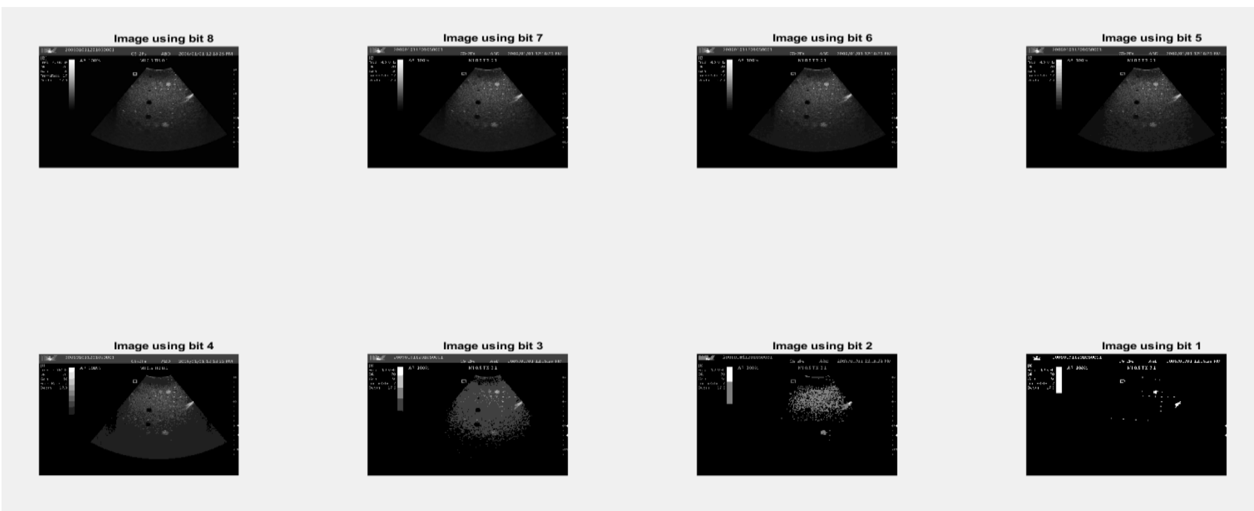
(Using Nearest Interpolation)



(Using Bilinear Interpolation)



(Comparison of the 4MHz original Image and the Grayscale Image (8bit))



(Running Image Processing to increase the resolution based on the spatial resolution and contrast)

MATLAB CODE for 2MHZ Image

```
info = imfinfo('200601011201050001.JPG');
% contrast the contrast of all the grayscale cysts targets relative to the background
grayImage = imread('200601011201050001.JPG');
imshow(grayImage);
roi = drawrectangle;
row1 = roi.Position(2);
row2 = roi.Position(2) + roi.Position(4);
col1 = roi.Position(1);
col2 = roi.Position(1) + roi.Position(3);
% Get the mean in that box
meanGL2 = mean2(grayImage(row1:row2, col1:col2))
% Compute area
height1 = (row2-row1 + 1);
width1 = (col2 - col1 + 1);
area = height1 * width1;
% Make a box twice as big.
height2 = sqrt(2) * height1;
width2 = sqrt(2) * width1;
% Get the midpoint
middleRow = mean([row1, row2]);
middleCol = mean([col1, col2]);
xline(middleCol, 'Color', 'r', 'LineWidth', 2);
yline(middleRow, 'Color', 'r', 'LineWidth', 2);
row1 = round(middleRow - height2/2);
row2 = round(middleRow + height2/2);
col1 = round(middleCol - width2/2);
col2 = round(middleCol + width2/2);
hold on
rectangle('Position', [col1, row1, width2, height2], 'EdgeColor', 'y', 'LineWidth', 2);
% Get the mean in that box
meanGL2 = mean2(grayImage(row1:row2, col1:col2))

%M  MATLAB program on Spatial Resolution

I = imread('200601011201050001.JPG'); %Read image information
subplot(231);
I1 = rgb2gray(I);%convert Color Image to Grayscale Image
imshow(I1);
title('Original image'); %Output this image
I2 = imresize(I1,05); %for resizing this fuctioncan be used

%I2 = I1(1:2:end,1:2:end); % The row and column directions are sampled
subplot(232);
imshow(I2);
title('sample image 2)');

I3 = I1(1:4:end,1:4:end);
subplot(233);
imshow(I3);
title('Sample image 3');

I4 = I1(1:8:end,1:8:end);
subplot(234);
imshow(I4);
title('Sample image 4');
```

```
I5 = I1(1:8:end,1:8:end);
subplot(235);
imshow(I5);
title('Sample image 5');

I6 = I1(1:8:end,1:8:end);
subplot(236);
imshow(I6);
title('Sample image 6');

z = imread('200601011201050001.JPG');
z=im2gray(z);
z2=imresize(z,0.75);
figure
imshow(z2);
title('Original Image 7');

I7=imresize(z2,[512,512],"nearest");
figure(2)
imshow(I7);
title('Zoomed Image (512*512), using nearest interpolation');

I8=imresize(z2,[512,512],'bilinear');
figure(3)
imshow(I8);
title('Zoomed Image (512*512), using Bilinear interpolation');

I9=imresize(z2,[512,512],'bicubic');
figure(4)
imshow(I9);
title('Zoomed Image (512*512), using Bicubic interpolation');

% Intensity Resolution
% MATLAB program on Intensity Resolution (Quantization Levels)

I = imread('200601011201050001.JPG');
Igray = rgb2gray(I);
montage({I, Igray});
title('Original Image                             Grayscale Image(8 bit)');
[r, c, s] = size(Igray); %% Get Rows, Columns and Plane Number
m = max(max(max(Igray))); %% Get maximum value of pixel in Image
b = [ 1 2 3 4 5 6 7 8 ]; %% divide 8 bit image by different levels
                         %%e.g. for 8, it is 2^8 = 256 hence will give 1 bit image
figure
for dd = 1 : length(b)
    d = 2^dd; %% since total number of bits is equal to 2^dd
    z = round(Igray/d); %% divide each pixel by 2^dd
    subplot(2, 4, dd) ;
    title(['Image using bit ',num2str(abs(dd-9))]);
    hold  on
    imshow ( z * d );
end

 %calculating contrast ratio of an grayscale image
 I = imread('200601011201050001.JPG');
 I10 = rgb2gray(I);%convert Color Image to Grayscale Image
```

```
image_contrast = max(I(:)) - min(I(:));
```

MATLAB CODE for 4MHz Image

```
info = imfinfo('200601011218230012.JPG');
% contrast the contrast of all the grayscale cysts targets relative to the background
grayImage = imread('200601011218230012.JPG');
imshow(grayImage);
roi = drawrectangle;
row1 = roi.Position(2);
row2 = roi.Position(2) + roi.Position(4);
col1 = roi.Position(1);
col2 = roi.Position(1) + roi.Position(3);
% Get the mean in that box
meanGL4 = mean2(grayImage(row1:row2, col1:col2))
% Compute area
height1 = (row2-row1 + 1);
width1 = (col2 - col1 + 1);
area = height1 * width1;
% Make a box twice as big.
height2 = sqrt(2) * height1;
width2 = sqrt(2) * width1;
% Get the midpoint
middleRow = mean([row1, row2]);
middleCol = mean([col1, col2]);
xline(middleCol, 'Color', 'r', 'LineWidth', 2);
yline(middleRow, 'Color', 'r', 'LineWidth', 2);
row1 = round(middleRow - height2/2);
row2 = round(middleRow + height2/2);
col1 = round(middleCol - width2/2);
col2 = round(middleCol + width2/2);
hold on
rectangle('Position', [col1, row1, width2, height2], 'EdgeColor', 'y', 'LineWidth', 2);
% Get the mean in that box
meanGL4 = mean2(grayImage(row1:row2, col1:col2))

%M  MATLAB program on Spatial Resolution

I = imread('200601011218230012.JPG'); %Read image information
subplot(231);
I1 = rgb2gray(I);%convert Color Image to Grayscale Image
imshow(I1);
title('Original image'); %Output this image
I2 = imresize(I1,05); %for resizing this fuctioncan be used

%I2 = I1(1:2:end,1:2:end); % The row and column directions are sampled
subplot(232);
imshow(I2);
title('sample image 2)');

I3 = I1(1:4:end,1:4:end);
subplot(233);
imshow(I3);
title('Sample image 3');
```

```
I4 = I1(1:8:end,1:8:end);
subplot(234);
imshow(I4);
title('Sample image 4');


I5 = I1(1:8:end,1:8:end);
subplot(235);
imshow(I5);
title('Sample image 5');

I6 = I1(1:8:end,1:8:end);
subplot(236);
imshow(I6);
title('Sample image 6');

z = imread('200601011218230012.JPG');
z=im2gray(z);
z2=imresize(z,0.75);
figure
imshow(z2);
title('Original Image 7');

I7=imresize(z2,[512,512],"nearest");
figure(2)
imshow(I7);
title('Zoomed Image (512*512), using nearest interpolation');

I8=imresize(z2,[512,512],'bilinear');
figure(3)
imshow(I8);
title('Zoomed Image (512*512), using Bilinear interpolation');

I9=imresize(z2,[512,512],'bicubic');
figure(4)
imshow(I9);
title('Zoomed Image (512*512), using Bicubic interpolation');

% Intensity Resolution
% MATLAB program on Intensity Resolution (Quantization Levels)

I = imread('200601011218230012.JPG');
Igray = rgb2gray(I);
montage({I, Igray});
title('Original Image                             Grayscale Image(8 bit)');
[r, c, s] = size(Igray); %% Get Rows, Columns and Plane Number
m = max(max(max(Igray))); %% Get maximum value of pixel in Image
b = [ 1 2 3 4 5 6 7 8 ]; %% divide 8 bit image by different levels
                         %%e.g. for 8, it is 2^8 = 256 hence will give 1 bit image
figure
for dd = 1 : length(b)
    d = 2^dd; %% since total number of bits is equal to 2^dd
    z = round(Igray/d); %% divide each pixel by 2^dd
    subplot(2, 4, dd) ;
    title(['Image using bit ',num2str(abs(dd-9))]);
    hold  on
    imshow ( z * d );
end
```

```
%calculating contrast ratio of an grayscale image
I = imread('200601011218230012.JPG');
I10 = rgb2gray(I);%convert Color Image to Grayscale Image
image_contrast = max(I(:)) - min(I(:));
```