[RT516: Medical Imaging]

Project #2: Ultrasound Imaging

DESCRIPTIONS

In Part I of this project, you will design several array transducers for operation in the far field using the Fourier Transform relationship discussed in class.

In Part II of this project, you will use some provided code and write some additional code of your own in order to "reconstruct" (i.e. beamform) some ultrasound data acquired in an imaging phantom. You will then vary different parameters in the code to determine the effect on the resulting image. As a reference, an example reconstructed image from the phantom data is enclosed below. This example image is not perfect, and this does not mean that your image must be exactly equivalent to this image, however, if your image is very different or if you cannot see the hyperechoic (dark) targets in the bright background, then there could be a problem.

Part I. As discussed in class, the spatial distribution of pressure in the far field or at the focus for a given transducer can be approximated by taking the Fourier transform of the aperture of the transducer. The two-way beam (lateral point spread function) simply applies this concept twice. In this part of the project, you will use Matlab to take Fourier transforms of different apertures and to design your own aperture using this relationship.

Please read through all parts before starting.

Assume a 64 element linear array transducer with no weighting / apodization (that is, all enabled elements have a value of 1 in Matlab). Inter-element separation is 200 μm. Center frequency is 3 MHz. Depth z = 3 cm. For now, assume that you have some enabled elements in the center of a Matlab vector (equal to 1) and some zeros on the edges of this vector. (It is suggested to make the total length of the vector in Matlab ≈ 1000. Only 64 values in the center will be non-zero.) You can also neglect the effects of kerf and element discretization (i.e. comb function) for now. For each section of Part I, state any assumptions you made. Show the following:

Figure 1: Subplot 1: Show the plot of the aperture. Label both axes.

Subplot 2: Show the plot of the approximation of the 2-way far field beam pattern (PSF) in the lateral direction for this aperture. The y-axis should be in dB scale. The x axis should be lateral distance (m, cm, mm, you decide what is best), linear scale.

1. Assume a Gaussian apodization function across the same 64 elements. Start with standard deviation $\sigma = 1$ for the Gaussian function. You can then change this value if you would like, but please explain why. Show the following:

Figure 2: Subplot 1: Show the plot of the aperture. Label both axes.

Subplot 2: Show the plot of the approximation of the 2-way far field beam pattern (PSF) in the lateral direction for this aperture. The y-axis should be in dB scale. The x axis should be lateral distance.

Describe in 2-3 sentences any differences you see between the lateral point spread funcions in Figures 1 and 2. Quantify: What is the peak level of the first side lobe in dB? What is the -6 dB beam width of the main lobe?

2. Maintain a 64 element array but spread the elements apart by 2x relative to the current spacing so that there is now a gap of 1 element between adjacent elements (the position in the vector associated with the gap is equal to 0 in Matlab). Show the following:

Figure 3: Subplot 1: Show the plot of the aperture. Label both axes.

Subplot 2: Show the plot of the approximation of the 2-way far field beam pattern (PSF) in the lateral direction for this aperture. The y-axis should be in dB scale. The x axis should be lateral distance.

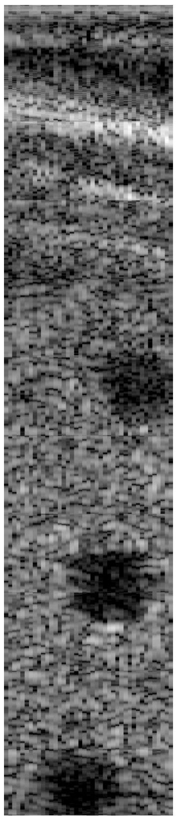
Describe in 2-3 sentences any differences you see between the lateral point spread functions in Figures 1 and 3. Quantify: What is the peak level of the first side lobe in dB? What is the -6 dB beam width of the main lobe?

3. Design your own aperture of 64 elements by repositioning elements and varying weighting (weighting does not have to equal 1 or follow a given equation, 64 elements do not have to be consecutive or follow any specific pattern, Tx and Rx apertures can be different). For the aperture you designed, show the following:

Figure 4: Subplot 1: Show the plot of the aperture. Label both axes.

Subplot 2: Show the plot of the approximation of the 2-way far field beam pattern (PSF) for this aperture. The y-axis should be in dB scale. The x axis should be lateral distance.

Describe in 2-3 sentences any differences you see between the lateral point spread functions in Figures 1-3 and the lateral PSF for your aperture in Figure 4. Quantify if possible, i.e. what is the side lobe level, -6 dB beam width? Explain why these differences occur.



Part II. An ultrasound RF channel data set was acquired using a tissue-mimicking phantom with several hypoechoic targets in depth (as in the figure). This data was acquired for 41 focused transmit beams. Other acquisition parameters are already included in the provided Matlab code, which will read in the data. Your goal is to reconstruct this raw RF data into an image with 1 receive line for each of the 41 transmit beams (that is, your final image will have n rows by m columns, where n = number of samples in depth and m = 41).

1. Complete the code to reconstruct the image. Comments indicate where you should enter code. You do not have to follow this if you prefer to make additional modifications to the code in order to make your image in a different way.

2. Using your completed code, vary the assumed speed of sound. Which speed of sound provides the highest image contrast? (Show images for each speed you tested, show a plot of contrast vs. speed of sound, and describe your procedure/equation for quantifying contrast.) Does the contrast depend on assumed speed of sound? Why or why not?

3. Using your completed code, apply different window functions as in Part I above. For this part, you can either use the "best" speed of sound you found in question 2 or you can use the initial speed of sound you were given. Apply the following windows (i.e. apodization, weighting) to the data:

A. Rect (this is what you have already been doing)

B. Gaussian

C. Cosine (i.e. only the positive half cycle).

For each case, ensure that the values in the window function are sufficiently high to avoid a noisy image. State any assumptions you made or any other parameters you chose for developing the windows in B and C. As long as your final images are displayed in dB scale (normalized), you should be able to directly compare the images. For each case, provide the following: Image with labeled units, color bar and title explaining which case it is (i.e. "Rect"). Contrast value for that particular window.

For all images, plot the horizontal cross section through the dark target centered at a depth of approximately z=25 mm. This should be 1 figure containing 3 lines (rect, Gaussian, Cosine) where the x axis is lateral distance and the y axis is image intensity (i.e. pixel value).

Considering the figure you just made with the 3 lines and the contrast values you found, does changing the windowing function affect the contrast or any other characteristic of the image? Explain why or why not.

4. Design your own window function that is different from any of those in question 3. Describe why you chose this function, show an image, provide a contrast value measured using this window function, and plot the same cross section as in 3. Describe the differences between this image and the other images and any improvements that you see.

[RULES]

A MATLAB code (RT516_US_NAME.m) is provided for the known object. When you turn in the project, rename this file to
RT516_US_part1_[YourLastName].m / RT516_US_part2_[YourLastName].m

You will work on the project **independently** (yes, you can do it). Your report will have graphs and images and will be submitted via E-mail. In addition, you will also submit a copy of your final ".m" file. In the report, name your plots and images, and label the axes (unlike on figures here), and write a few sentences commenting on what you did, which equation you utilized, and the appearance of the images. You can choose preferable languages (English or Korean).

Working with other students is generally OK if the intent is to provide you with environment where you can discuss questions, etc. **Please do not split up the problems and then share solutions**. You are expected to do your own work, but when you get stuck, you may ask anyone in the class or the instructor for help. Copying solutions from anyone will be considered a violation of the rules.

Submit via E-mail at jaesok.yu@dgist.ac.kr, **DUE DATE: 2021/06/04 (Fri), 11:59PM.**